Environmental good production in the optimum activities portfolio of a risk averse-farmer

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Summary – *An analytical framework is proposed for analysis of environmental good production by farmers in the case of price uncertainty. Environmental good production contracted by means of agri-environmental agreements is treated as a riskless option in the farmer's production activities portfolio. It is shown that agri-environmental agreements aiming at biodiversity competing with beef production are likely to increase management intensity on the non-enrolled land, and that the effect of the payments for these agreements on the number of hectares enrolled is ambiguous. It is also demonstrated that an increase in the output price variability and/or a decrease in the level of decoupled subsidies will induce an increase (decrease) in the area enrolled in agreements aiming at biodiversity competing with (complementary to) beef production. The obtained results are illustrated by means of efficient frontiers generated using mathematical programming farm level models of suckler cow farms in* Monts du Cantal*, in France.*

Keywords: *uncertainty, portfolio optimisation, biodiversity, agricultural policy, mathematical programming*

Production de biens environnementaux dans une gestion optimale d'un portefeuille d'activités d'un agriculteur avec aversion au risque

Résumé – Cet article propose un cadre d'analyse de la production de biens environnementaux par des agriculteurs en situation d'incertitude sur les prix. La production de biens environnementaux contractée par des mesures agri-environnementales est considérée comme une activité sans risque dans le portefeuille d'activités d'un agriculteur. Nous montrons que l'adoption d'une mesure agri-environnementale favorable à la biodiversité au détriment de la production bovine favorise l'intensification de cette dernière production, tandis que l'effet du niveau des paiements pour ce type de contrat sur le nombre d'hectares souscrits est ambigu. Nous montrons aussi qu'une augmentation de la variabilité de prix des outputs, et/ou une baisse du niveau d'une aide découplée, aura un effet positif (négatif) sur le nombre d'hectares dédié à la production de biodiversité en concurrence (complémentaire) avec la production bovine. Ces résultats sont illustrés à l'aide de frontières d'efficacité en mobilisant un modèle de programmation mathématique appliqué aux élevages allaitants des Monts du Cantal, en France.

Mots-clés : incertitude, optimisation de portefeuille, biodiversité, politique agricole, programmation mathématique

Descripteurs JEL : Q12, Q18, Q28

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1. Introduction

The Common Agricultural Policy (CAP) reform of June 2003 follows the trend of decoupling agricultural subsidies from production activities with the aim to fulfil the World Trade Organization (WTO) commitments requiring application of less trade distorting agricultural policy instruments. Progressive reduction of the price support and of coupled subsidies, which accompanies this reform, is likely to increase the price volatility of agricultural outputs. As Hennessy (1998) demonstrated, under uncertainty even decoupled subsidies influence behaviour of a risk-averse farmer. Thus it seems meaningful to apply models which enable to account for uncertainty and for farmers' risk aversion if evaluating agricultural policies. In this paper, we propose such a framework for analysis of environmental good production by farmers when contracted by means of agri-environmental agreements.

Uncertainty is an important issue concerning the joint production of agricultural and environmental goods. Vermersch (2001) considers uncertainty as a special source of jointness. Hanley and Oglethorpe (1999) support indirectly this concept when they state that the guaranteed nature of agri-environmental payments offered to UK farmers represented for them an important incentive to adopt these agreements 'as a risk-reducing management tool'. In our paper, we do not consider uncertainty as an independent source of jointness. We investigate rather how the volatility of output prices changes the willingness of farmers to comply with agri-environmental agreements if one or another of the main sources of jointness as defined by the Organization for Economic Co-operation and Development (OECD, 2001) is present: allocable fixed inputs (competing production) and non-allocable inputs (complementary production).

Joint production of agricultural commodities, beef, and an environmental good, grassland biodiversity, is investigated here. The quantity of biodiversity produced depends on the grassland management intensity. Usually some special level of farming activity is required and the quantity of biodiversity produced falls both if this level is not attained and if it is exceeded. For example Balent *et al.* (1998) found that in the Pyrenees the species richness of pastures slightly increases when the dry mass consumption increases from 0.5 tonnes per hectare per year to something more than 1 tonne per hectare per year, but above this value it starts to fall. The optimal level of beef production is not unique for all biotopes. Thus some fragile biotopes require only very low levels of farming intensity and the beef and biodiversity production is generally **competing** there. The competition is caused by the presence of an allocable fixed input: the grassland. It can be considered as allocable because it should be partially or completely diverted from beef production in order to secure biodiversity production. On the other hand, there are regions where biodiversity is permanently jeopardised by invasive species and it would be lost without sufficiently high management intensity. There the beef and biodiversity production are generally **complementary**. The source of complementarity is the presence of a non-allocable input: the cattle herd. An increase in the number of livestock units enables to produce at the same time more beef and more biodiversity. We chose to deal with grassland biodiversity production by suckler cow farms precisely for this opportunity to analyse both complementary and competing agricultural and environmental good production.

This paper complements the work presented by Havlík *et al.* (2005) by transposing the analysis of environmental good production under uncertainty from the expected utility framework to the mean-variance framework. Generally, if a risk-averse farmer has the possibility to produce several outputs, he will not only adjust the overall supply but also its structure in the search for the optimum portfolio of activities. We consider the application of the separation theorem described by Tobin (1958) in the financial theory context, in order to simplify the portfolio optimisation problem and to make its solution more tractable. Tobin demonstrated that if both risky and riskless assets are available, the optimisation proceeds in two steps. First, the optimum portfolio of risky assets is assembled, whose composition does not depend on the risk aversion of the investor. Second, the investor decides depending on his risk aversion which share of money he invests in the risky portfolio and which share should be held in the riskless asset. Thus as long as the riskless asset is present in the optimum portfolio, the relative composition of risky assets remains constant, and we can deal with the multitude of risky assets as with a single composite one.

The Tobin's separation theorem was applied to analyse the farm diversification problem already by Johnson (1967) who considered as a riskless option the land leasing in or out. He concluded that a strongly risk-averse farmer will tend to lease out a share of his land in order to ensure a higher stability of returns, while a risk-neutral farmer will rather tend to lease in some additional land in order to increase his expected returns even if this will increase their variability. Roche and McQuinn (2004) applied the same separation theorem to the analysis of the European Union's CAP reform of the June 2003. They found that a complete decoupling of agricultural subsidies will encourage farmers who choose to produce, to introduce in their portfolio of activities riskier outputs than before the reform.

Our model is based on the assumption that the agricultural commodities represent risky activities due to stochastic output prices – the unique source of uncertainty in the model. The agricultural commodities are throughout the paper designed by a general term – beef. But this general term covers different combinations of animal categories produced on the farm (animals sold at various ages, fattened or lean, etc.). To each animal category correspond a specific expected price and specific price variability. Environmental good production remunerated by means of agri-environmental agreements is considered as a riskless activity. This is justified by the fact that agri-environmental agreements propose a guaranteed annual payment to the farmer during several years (5, 10 or 20) in exchange for his compliance with requirements involved in the contract. These requirements include some restrictions on the farming activity and/or they demand additional tasks to be carried out. The farmer is remunerated for compliance with the requirements and not for the result of his compliance. Thus not only the amount of the payment is guaranteed but also the farmer controls entirely the respect of conditions implying the attribution of the payment. The assumption of the riskless character of agri-environmental agreements enables a straightforward comparative statics analysis of the impact of economic and policy parameters, like the output price variability or the amount of decoupled subsidies, on environmental good production by risk-averse farmers. These results can be more or less directly derived from those known in the finance literature. Our major aim is to draw attention to the potential usefulness of this analytical framework in the domain of agricultural and agri-environmental policy analysis.

The analytical framework is illustrated by implementing a mathematical programming farm level model of a representative suckler cow farm in the *Monts du Cantal*, France. In this region, zones representing both complementary and competing beef and biodiversity production can be found in formally designated 'Environmentally Sensitive Areas' (ESAs), where agri-environmental agreements were proposed to farmers with the aim to enhance the biodiversity production. A simplified version of these agreements from two selected ESAs is incorporated into the programming model in order to represent both competing and complementary biodiversity production.

The paper is structured as follows: In the next section, the analytical model is introduced both in a formal and a graphical way, and the comparative statics results are presented. In section 3, the programming model is briefly described, then its basic results are discussed, and finally, graphical illustration based on the model simulations is provided for some of the comparative statics results from section 2. Section 4 concludes the paper by a summary of obtained results and by a short discussion of their policy implications and of their limits.

2. Analytical framework: Portfolio optimisation

To introduce this section, we briefly present the general problem without agri-environmental agreements, when only risky agricultural commodities can be produced. In this case, the farmer's stochastic profit $\tilde{\pi}$ can be expressed as follows:

$$\tilde{\pi} = A_c \sum x_i \tilde{r}_i + L - FC, \text{ with } 0 \le A_c \le A \qquad (1a)$$

A_c is the area cultivated before agreements are proposed, and A is the total available area. The total available area is throughout the paper considered fixed. A_c is a decision variable in this model without agri-environmental agreements, but it is not allowed to exceed A. For notational convenience, A_c and A are in what follows normalised so that $A_c = 1$ [1]. x_i is the level of activity i per hectare. We will often refer to the vector of per hectare levels of activities x_i (i = 1,…,n), as to the structure of the portfolio of risky activities, or of agricultural commodities. Activities i represent both different animal categories (lean heifers, fattened bulls,…), and different techniques of production of the same animal category (grain-fed heifers, grass-fed heifers,…). This differentiation enables adjustments in the portfolio of risky activities both in terms of diversification, by changing the herd structure, and in terms of intensification or extensification, by changing the per hectare production within a constant herd structure. $\tilde{r}_i$ is the stochastic gross margin per unit of activity i – its stochastic

[1] In the models with agri-environmental agreements, A_c cannot be changed because it represents the area cultivated **before** implementation of the agreements; it is a fixed parameter. Therefore it is convenient to set it equal to 1.

character stems from the output price variability, L is a decoupled subsidy awarded to the farmer as a lump sum payment without any linkage with the agricultural activity, and FC is the fixed cost.

The expected value of the profit μ is

$$\mu = \mu_R + L - FC \text{, with } \mu_R = \sum x_i \overline{r_i}, \tag{2a}$$

where $\overline{r_i}$ is the expected gross margin of activity i, and μ_R represents the expected gross margin of the portfolio of risky activities.

The standard deviation of the profit σ is

$$\sigma = \sigma_R \text{, with } \sigma_R = \sqrt{\sum_i \sum_J x_i x_j \sigma_{ij}}, \tag{3a}$$

where σ_{ii} is the variance of the gross margin of activity i and σ_{ij} is the covariance between gross margins of activities i and j. Since only risky activities are present in the portfolio, the standard deviation of the global profit is equal to the standard deviation of the gross margin from risky activities σ_R.

The set of portfolios of risky activities which provide the minimum standard deviation for particular levels of expected profit, constitutes the efficient frontier. (For a formal specification, see the programme defined by equations (P.1-8) in section 3 designed to generate efficient frontiers and other relevant information). We make a common assumption that the efficient frontier is concave, which means that initially, the expected profit can be increased without much increase in its variability, but beyond a certain range, additional profit cannot be obtained without considerably increasing the variability. This form is determined by the fact that some production factors are fixed. Thus, in order to obtain additional expected profit, either more profitable and more risky activities are to be introduced into the portfolio, like animal categories with higher volatility of sale prices, or more intensive activities, which enable to increase the per hectare production. Intensification beyond the initially optimal level leads to a more than proportionate increase in production costs therefore the resulting increase in profit variability is not compensated by an adequate increase in its expected value.

The risk-averse farmer is supposed to constitute his portfolio of activities so that it maximises his utility expressed as a function of the first two moments of the profit distribution – mean and standard deviation. Utility function $U(\mu, \sigma)$ is assumed increasing in the expected profit, $U_\mu \geq 0$, decreasing in its standard deviation, $U_\sigma \leq 0$, and concave [2]. Meyer (1987) formally derived some important characteristics of indifference curves associated with the utility function $U(\mu, \sigma)$: The slope of

[2] Meyer (1987) demonstrated that under the 'location and scale parameter condition', maximisation of $U(\mu,\sigma)$ leads to results consistent with those obtained by maximisation of the expected utility of profit $EW(\tilde{\pi})$, with $W'(\tilde{\pi}) > 0$ and $W''(\tilde{\pi}) < 0$. In the case studied here, this condition is fulfilled; the profit $\tilde{\pi}$ depends linearly on the stochastic gross margins $\tilde{r}_i$, hence the profit distributions differ from one another only by location and scale parameters.

indifference curves $S(\mu, \sigma)$ is non-negative, $S(\mu,\sigma) = -U_\sigma / U_\mu \geq 0$, the indifference curves are convex, and for farmers who exhibit decreasing absolute risk aversion (DARA), the slope of indifference curves decreases as the expected profit increases, $S_\mu = \dfrac{U_{\mu\mu} U_\sigma - U_{\sigma\mu} U_\mu}{U_\mu^2} \leq 0$ [3]. These characteristics will be in what follows extensively used both for the formal and graphical comparative statics analysis.

The solution to the farmer's maximisation problem corresponds to the tangency point between the efficient frontier (EF) and an indifference curve (IC). In figure 1, if no agri-environmental agreement were proposed, the optimum production portfolio of agricultural commodities would correspond to the point R.

2.1. Competing beef and biodiversity production

Agri-environmental agreements concerning biodiversity production demand from the farmer a decrease of the farming intensity if biodiversity production is competing for resources with beef production. An illustrative example are the environmental set-asides where the farmer receives a payment for not using a part of his land for agricultural production. Thus he exchanges a part of the risky income from agricultural commodities production for a guaranteed income from environmental good production. The profit function can be in this case written as follows:

$$\tilde{\pi} = zt + (1-z)\sum x_i \tilde{r}_i + L - FC\,,\;\; A = 1\,,\;\; 0 \leq z \leq 1, \tag{1b}$$

where z represents the share of land withdrawn from agricultural production to be enrolled in the agri-environmental agreement, and t represents the transfer payment per hectare of land enrolled. Here we assume that the farmer was cultivating all the available land A before the agreement has been proposed, and that he can enroll all his previously cultivated land in the agreement. In reality, only a part of the farm is often eligible for agri-environmental agreements; this constraint is explicitly accounted for in the applied analysis in section 3.

The expected value of the profit involving production of competing environmental goods is

$$\mu = zt + (1-z)\mu_R + L - FC\,, \tag{2b}$$

and its standard deviation is

$$\sigma = \left(1-z\right)\sigma_R \tag{3b}$$

The possibility to enroll some land in the riskless agreement aiming at competing biodiversity production is presented graphically in figure 1. The farmer can gain the

[3] For expositional reasons, we consider all through the paper that farmers exhibit decreasing absolute risk aversion. DARA preference assumption is well supported by empirical studies carried out by *e.g.* Lins *et al.* (1981), Saha *et al.* (1994) or Chavas and Holt (1996). However, the present analysis is readily transposable to the cases of increasing (IARA) or constant (CARA) absolute risk aversion as well.

sum T, $T = t + L - FC$, without facing any risk if he enrolls all his land in the agreement (z = 1). T represents for him a certainty equivalent. Tobin's separation theorem implies that as long as z is strictly positive, the farmer first determines the structure of the portfolio of risky activities x_i, and only then, depending on his preference structure, he decides about its extent by determining the share of land $(1 - z)$ on which this portfolio should be produced. The optimum portfolio of risky activities is determined as a tangency point between the efficient frontier without environmental good production and a straight line emanating from the point T, the point A. The overall efficient frontier, containing both risky and riskless activities, is now composed of two segments: a linear segment, in finance literature called sometimes a market opportunity line, which represents linear combinations of the certainty equivalent and the optimum portfolio of risky activities corresponding to the point A, and a concave segment, the part of the original – before the agri-environmental agreement – efficient frontier situated rightwards to the tangency point A, where only risky activities enter the efficient portfolios.

The equation of the market opportunity line follows from equations (2b) and (3b)

$$\mu = t + \frac{\mu_R - t}{\sigma_R}\sigma + L - FC \tag{4b}$$

It can be deduced directly from equation (4b) that an increase in the agri-environmental payment t will, by decreasing the slope of the opportunity line, shift the structure of the portfolio of agricultural commodities towards higher expected profits with higher variability. In figure 1, this is depicted by the shift from the portfolio of risky activities corresponding to the point A, to the portfolio corresponding to the point C, as the result of an increase in the agri-environmental payment from t to t', which shifts the point T to the point T'. Higher expected profits from risky activities can be obtained either by incorporating new activities with higher profitability and higher variability, or by increasing the per hectare production of activities present in the portfolio A. Thus risk aversion can partially explain, at least for zones where diversification possibilities are limited, the perverse effects of some environmental agreements which aiming at extensification of agricultural production on a part of the farm, induce its intensification on the land non-enrolled in the agreement.

The structure of the optimum portfolio of risky agricultural commodities, if production of the riskless environmental good is strictly positive, can be determined without caring about the farmers' preference structure. However, in order to determine the share of land a farmer will enroll in the agreement, we have to consider his utility function. We follow the procedure proposed by Ormiston and Schlee (2001), who suggest to reformulate the two-moment utility function into a function V of a single variable. In our case, it is appropriate to define V as a function of the share of land z enrolled in the agreement

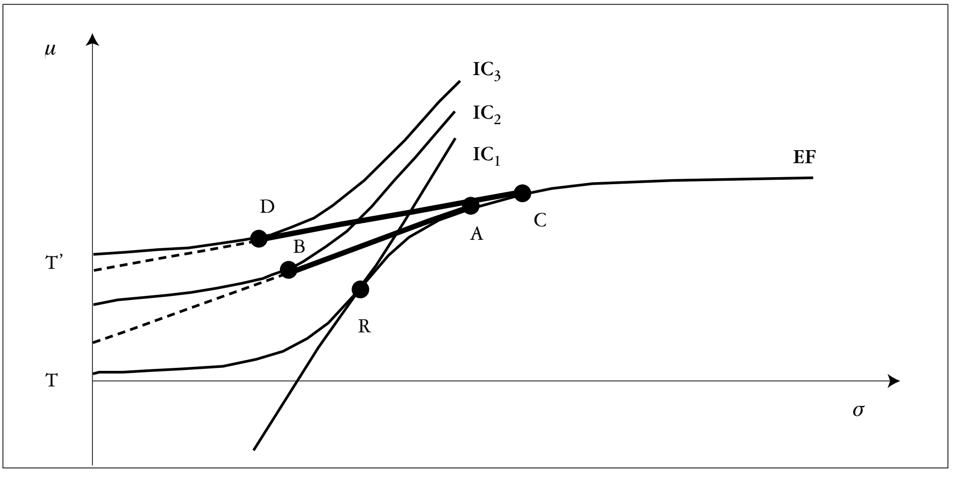
$$V(z) = U(\mu, \sigma) = U\left(zt + (1 - z)\mu_R + L - FC, (1 - z)\sigma_R\right) \tag{5b}$$

The necessary condition for an interior solution to the farmer's maximization problem is

$$V_z = (t - \mu_R)U_\mu - \sigma_R U_\sigma = 0 \tag{6b}$$

and if the function $V(z)$ is concave, which follows directly from the concavity of $U(\mu,\sigma)$, then equation (6b) is also a sufficient condition. According to Milgrom and Shannon (1994, Theorem 4), the comparative statics results for the optimal share of land enrolled in the agreement can in this case be derived by differentiating V_z with respect to the studied parameters. The obtained results are summarised in proposition 1.

Figure 1. **Tobin's separation theorem and the competing beef and biodiversity production**



Proposition 1.

If $U(\mu,\sigma)$ is concave, $U_\mu > 0$ and $U_\sigma < 0$, and the farmer's preferences exhibit DARA, then the share of land z enrolled in an agri-environmental agreement aiming at biodiversity production competing with beef production

(a) increases if the expected value of the gross margin from beef production, μ_R, decreases;
(b) increases if the standard deviation of the gross margin from beef production, σ_R, increases;
(c) increases (decreases) if the lump sum payment, L, (the fixed cost, FC) decreases, and
(d) may increase or decrease if the agri-environmental payment, t, increases.

The proof of proposition 1 is provided in the appendix.

Generally speaking, the comparative statics results depend on two effects: a direct effect [4] and an indirect, wealth, effect. The direct effect corresponds to a rotation of the efficient frontier around the initial indifference curve. The wealth effect is due to a change in the level of expected profit and generates a vertical shift of the new efficient frontier. The wealth effect arises because the absolute risk aversion of DARA farmers

[4] The direct effect is often called also the substitution effect. This terminology is not appropriate for our paper because it postulates competition between the riskless and risky activities, and we deal also with complementary activities.

decreases as the level of expected profit increases. We will turn back to the particular comparative statics results when discussing the illustrative application in section 3.3., here only the point (d) is shortly exposed.

The derivative of W_Z, with respect to t is

$$V_{zt} = U_\mu + z\left(\frac{\sigma_R}{U_\mu}\right)\left(U_\sigma U_{\mu\mu} - U_\mu U_{\sigma\mu}\right) \tag{7b}$$

The sign of the first term, U_μ, gives the sign of the direct effect; it is always positive. The type of the farmer's absolute risk aversion gives the sign of the second term, which is the indirect effect. For DARA farmers, the indirect effect is negative. Hence, the overall effect of an increase in the agri-environmental payment on the area enrolled in the agreement is ambiguous. The two effects can be interpreted as follows: An increase in the agri-environmental payment makes biodiversity production relatively more attractive but at the same time, it increases the farmer's income, and a farmer exhibiting decreasing absolute risk aversion will be less motivated to stabilise his income by production of riskless environmental goods. Only if the direct effect is stronger than the wealth effect, an increase in the transfer payment will produce an increase in the area enrolled in the agreement [5].

The case where the direct effect gains over the wealth effect is depicted in figure 1. The optimum portfolio containing both biodiversity and agricultural commodities production corresponds to the tangency point between the market opportunity line and an indifference curve; for the initial agreement payment t, it corresponds to the point B. This portfolio is composed of environmental good production on the share of land $z = |AB|/|AT|$, and of agricultural commodities production in the structure determined by the point A, on the share of land $(1 - z)$. In this figure, the share of land enrolled in the agreement under the initial payment is lower than the share of land $z' = |CD|/|CT'|$ enrolled in the agreement under an increased payment t'.

2.2. Complementary beef and biodiversity production

Often the most valuable grasslands from the biodiversity point of view are being abandoned because their management is not profitable. Their re-utilisation induces some cost due to the necessary shrub clearing, renewal of the grassland or shrub prevention, and some benefits in the form of supplementary forage. An agri-environmental payment covers usually only a part of this cost, the rest is supposed being covered by the benefits from increased agricultural commodities production. The stochastic profit function can be in this case specified as follows

$$\tilde{\pi} = z(t - s) + (1 + z)\sum x_i \tilde{r}_i + L - FC,\ \ A > 1,\ \ 0 \le z \le A - 1, \tag{1c}$$

[5] Similarly, in an analytical framework based on the mean-standard deviation utility function, Leathers and Quiggin (1991) derived that the effect of a tax on pesticides on their use by DARA farmers is ambiguous. Their result relies on the assumption that pesticides are a sort of risk decreasing input.

where all the terms maintain their meaning presented above, except of z which still indicates the area to be enrolled in the agri-environmental agreement, but because of the nature of this agreement, it should be interpreted as a coefficient with respect to the area (A_c) cultivated before the agreement has been proposed rather than its share. The new parameter s represents the unit cost of shrub clearing, $s > t$. We assume that the area cultivated before the agri-environmental agreement has been proposed, was lower than the total available area, A, and that the farmer can enroll in the agreement any share of the abandoned land. In this analytical part, we do not impose any limit on A, thus z is virtually unconstrained from above. A reasonable upper limit will be explicitly accounted for in the illustrative application presented in the next section [6].

The expected value of the profit involving production of complementary environmental goods is

$$\mu = z\left(t - s\right) + (1 + z)\mu_R + L - FC, \tag{2c}$$

and its standard deviation is

$$\sigma = \left(1 + z\right)\sigma_R . \tag{3c}$$

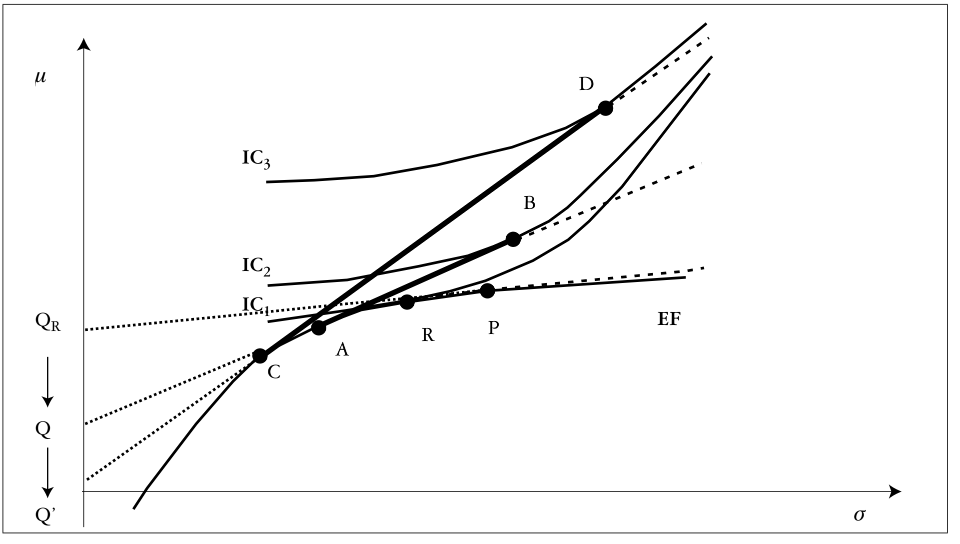
The complementary beef and biodiversity production is depicted in figure 2. As in figure 1, the optimum portfolio of risky activities if no agri-environmental agreements are proposed corresponds to the point R. But the farmer can re-utilise his previously abandoned grassland even without agreements if the cost of its clearing is covered by returns from beef production. We can draw a line which is tangent to the concave efficiency set and which emanates from the point Q_R on the y-axis, $Q_R = s + L - FC$. Q_R resembles to the certainty equivalent point T in figure 1 but it is not. Because while it is possible to re-gain abandoned grassland for the unit cost s, we do not suppose that the farmer will be paid s if he stops the beef production. The market opportunity line [7] without agreements must be tangent to the efficient frontier at the point R, or rightwards to it, because we suppose that the farmer already re-gained the grassland he needed and the cost of regaining any supplementary grassland would not be covered by the stochastic returns. In the case of complementarity, the efficient frontier is composed of two segments – a concave one and a linear one – independently from the existence of an agri-environmental programme. The efficient frontier is concave up to the tangency point with the opportunity line, the point P in figure 2. Up to this point, efficient portfolios are constituted by adjustments in the structure of

[6] This problem is not completely symmetric to the one presented in section 2.1. The symmetric problem would have to be set as follows: 'The Government aims at competing biodiversity production therefore it puts a tax on re-utilisation of the previously abandoned grassland.' Hence, the payment t in section 2.1. is in the present section symmetric rather to the cost of shrub clearing s than to the agreement payment t.

[7] We maintain the terminology, however inappropriate, in order to save correspondence with the competing production case. The market opportunity line is drawn starting from the y-axis only to show its relationship with the point Q_R. Since the farmer cannot obtain any compensation for diverting his land from agricultural production, only the part of the market opportunity line situated to the right to the tangency point with the efficient frontier of risky activities enters the efficient frontier.

agricultural commodities production on the non-degraded land. Beyond the point P, the efficient frontier becomes linear; the farmer expands agricultural production on the progressively regained grassland without changing the commodities structure. If a positive agri-environmental payment is proposed to the farmer, the origin of the market opportunity line shifts downwards from the point Q_R to the point Q, $Q = -(t-s) + L - FC$.

Figure 2. **Tobin's separation theorem and the complementary beef and biodiversity production**



The equation of the market opportunity line with an agri-environmental agreement aiming at complementary biodiversity production follows from equations (2c) and (3c)

$$\mu = -\left(t-s\right) + \frac{\mu_R + \left(t-s\right)}{\sigma_R}\sigma + L - FC \tag{4c}$$

Without considering the farmer's preference structure, equation (4c) implies that an increase in the agri-environmental payment from *t* to *t'*, will shift the origin of the market opportunity line further downwards, from the point Q to the point Q', and will increase the slope of the market opportunity line. Together with the concavity of the efficient frontier, this will encourage a change in the composition of the production bundle of agricultural commodities in direction of lower expected profits, the shift from the point A to the point C in figure 2. This implies that in situations where an agri-environmental payment aiming at biodiversity production competing with beef production is likely to enhance the farming intensity on the non-enrolled parcels, an agri-environmental payment aiming at biodiversity production complementary to beef production will lead to reduction of the farming intensity.

The utility function expressed as a function of the share of land *z* enrolled in the agri-environmental agreement can be written in the complementary case as

$$V\left(z\right) = U\left(\mu,\sigma\right) = U\left(z\left(t-s\right) + \left(1+z\right)\mu_R + L - FC, \left(1+z\right)\sigma_R\right) \tag{5c}$$

The necessary and sufficient condition for an interior solution to the farmer's maximization problem is

$$V_z = \left(t - s + \mu_R\right) U_\mu + \sigma_R U_\sigma = 0 \qquad (6c)$$

The comparative statics results concerning the optimal share of land z enrolled in the agreement can be obtained in the case of complementarity by the same procedure as in the case of competition. These results are summarised in proposition 2.

Proposition 2.

If $U(\mu,\sigma)$ is concave, $U_\mu > 0$ and $U_\sigma < 0$, and the farmer's preferences exhibit DARA, then the share of land z enrolled in an agri-environmental agreement aiming at biodiversity production complementary to beef production

(a) increases if the expected value of the gross margin from beef production, μ_R, increases;
(b) increases if the standard deviation of the gross margin from beef production, σ_R, decreases;
(c) increases (decreases) if the lump-sum payment, L, (the fixed cost, FC) increases, and
(d) increases (decreases) if the agri-environmental payment, t, (the unit cost of shrub clearing, s) increases.

The proof of proposition 2 is provided in the appendix.

The comparative statics results are symmetric to those obtained for the competing biodiversity production, except of the point (d). Unlike in the case of competition, we are able to sign unambiguously the effect of a change in the agri-environmental payment on the area enrolled in the agreement in the case of complementarity. The derivative of V_z with respect to t is as follows

$$V_{zt} = U_\mu - z\left(\frac{\sigma_R}{U_\mu}\right)\left(U_\sigma U_{\mu\mu} - U_\mu U_{\sigma\mu}\right) \qquad (7c)$$

The first term, representing the direct effect, is positive as in equation (7b), but here, also the indirect effect is positive. An increase in the agri-environmental payment makes biodiversity production not only relatively more attractive but it also increases the farmer's income and thus makes for him the risky income from supplementary beef production on the cleared grassland more acceptable as partial compensation for the shrub clearing. This is represented graphically in figure 2. An increase in the agri-environmental payment makes the opportunity line steeper therefore the tangency point with a convex indifference curve must shift towards a higher expected profit with higher variability. But this increase enables also to attain higher indifference curves. Since the slope of indifference curves decreases for a DARA farmer as the level of utility increases, the indirect effect induces further shift of the tangency point towards more variable portfolios. Hence, the share of land enrolled in the agri-environmental agreement when payment t' is proposed, $z' = |CD|/|CQ'|$, will always be higher than the share of land enrolled in the agreement for the initial payment t, $z = |AB|/|AQ|$.

3. An illustrative application

How the above presented analytical framework applies in practice is demonstrated on a case study of beef and biodiversity production by suckler cow farms in *Monts du Cantal* in *Massif Central*, France. The *Monts du Cantal* is a humid volcanic region with an altitude reaching from 900 to 1 300 meters where the cattle rearing plays a crucial role in the preservation of an open countryside and of the species richness of omnipresent meadows. Several zones were designated as Environmentally Sensitive Areas (ESAs), (in French: *opérations locales agri-environnementales, OLAE)* in order to enhance both the complementary and competing beef and grassland biodiversity production.

A representative of the competing beef and biodiversity production is the *Tourbières du Nord Cantal* (Northern Cantal Peatlands) ESA. It is constituted around valuable peatlands where the danger of over intensification is predominant because of the fragility of these biotopes. Several agri-environmental agreements were proposed to farmers containing basically restrictions on fertilisation and on the animal density. The eligibility of parcels for a particular agreement depends on their distance from the peatland; the constraints become more severe when approaching the peatland.

The *Haute Vallée du Mars* (Upper Valley of the Mars River) ESA concerns a valley, where on the contrary, grassland biodiversity is jeopardised by abandonment or by very low intensity of agricultural activity. The beef and biodiversity production are complementary there. The agri-environmental agreements impose in this case minimum stocking density requirements and demand renovation of already degraded grasslands. A good representative is the agreement aiming at regaining heavily degraded pastures (pastures covered by more than 35 per cent by bushes), which asks the farmers for mechanical clearing in the first year and for maintenance by pasture in the following years. Agreements are signed for 5 years.

3.1. Model description

Efficient frontiers and other relevant results are obtained by solving the following programme of minimisation of the standard deviation of profit σ, equation (P.1), for progressively higher levels λ of expected profit μ, equation (P.2):

$$\min_{X_j, Z} \sigma, \text{ where } \sigma = \sqrt{\sum_k w_k(\pi_k - \mu)^2} \quad \text{(P.1)}$$

such that

$$\mu \geq \lambda \quad \text{(P.2)}$$

$$\pi_k = \sum_i r_{ik} X_i + (t - s)Z + L - FC, \quad \forall k \quad \text{(P.3)}$$

$$\mu = \sum_k w_k \pi_k \quad \text{(P.4)}$$

$$\sum_i c_{im} X_i \leq d_m, \quad \forall m \quad \text{(P.5)}$$

$$\sum_i c_{iLand} X_i \leq d_{Land} - Z \qquad \text{Tourbières ESA} \qquad (\text{P.5b } \textit{Land})$$

or

$$\sum_i c_{iLand} X_i \leq d_{Land} + Z \qquad \text{Mars ESA} \qquad (\text{P.5c } \textit{Land})$$

$$Z \leq ZE \qquad (\text{P.6})$$

$$\sum_k w_k = 1, \qquad (\text{P.7})$$

$$X_i \geq 0, \quad \forall i, \text{ and } Z \geq 0, \qquad (\text{P.8})$$

where w_k is the probability of the state k, π_k is the net income in the state of nature k, X_i is the total (not 'per hectare' as in the analytical model) level of different activities, r_{ik} is the gross margin of activity i if the state of nature k occurs, Z is the area enrolled in the agri-environmental agreement (in hectares), and t, s, L, and FC remain as defined above (s = 0 for the Tourbières ESA). c_{im} is the input requirement coefficient of activity i for input m (all inputs except land), and d_m is the available quantity of input m, c_{iLand} is the land requirement coefficient of activity i, and d_{Land} is the available non-degraded land. ZE is the area eligible for the agri-environmental agreement. The optimisation is carried out over decision variables X_i and Z. (Z would correspond to zA_c from section 2 if A_c were expressed in hectares and not normalised to 1).

For these simulations, we applied a simplified version of the Opt'INRA Salers. Opt'INRA Salers [8] is a linear programming model constructed on the basis of the Opt'INRA model [9] and adapted for analysis of suckler cow farms breeding the Salers cow in the studied region. INRA has an experimental farm in *Marcenat*, on the *Cézallier plateau* in the Cantal region of France, which is home to a herd of suckler cows of the hardy Salers breed. It is an experimental site for the EU project FORBIOBEN [10] and has reliable technical references on forage and animals at one's service. Complementary data sources used for the parameterisation of the Opt'INRA Salers were: historical cases from regional farm networks (Réseaux d'élevage Auvergne et Lozère, 2003), the opinions of experts from the Chamber of Agriculture of the Cantal and technical references obtained by INRA's proper research on the types of Salers animals and the mountain forage areas. The basic model structure is as follows:

– Animal production determines breeding activities (different stages of the life of an animal in relation to its diet and the production goal) and sales. The central element is the Salers suckler cow. It calves on 15 February, can be fertilised by a bull of the Salers or Charolais breed and may or may not be 'premium-eligible'. The herd is restocked with heifers from stock in the case of pure-breed farms and with the purchase of heifers of different ages for mixed-breed farms. All of the sales categories of males and females (young, old, lean, fat, premium, non-premium) encountered at this time in the studied area, in total 32 animal

[8] For more details about this model see Havlík *et al.*, 2005.
[9] See a detailed description of this model in Veysset *et al.*, 2005.
[10] FORBIOBEN: Foraging for Biodiversity and Benefits, QLK-2001-00130

categories, were introduced into the model and represent now the risky activities which may enter the production portfolio.

– Animal feed is based on conserved forage (hay, bales or regrowth) in the winter and on pasture alone in the summer because the entire utilisable agricultural area (UAA) is constituted by grassland. All of the forage is produced on the farm and can be supplemented by purchased concentrate when necessary. Rations for each animal were calculated according to its weight, its needs (production, growth) and the quality of the forage dispensed, maximising the quantity of forage ingested. Each animal can choose between different types of rations but with the same nutritional value. Opt'INRA Salers arbitrates between the number, the type of animal and the types of rations provided in order to balance needs and resources.
– The grassland management system is relatively complex. Different types of grasslands were defined according to the farmers' practices (early mowing + grazing, late mowing + grazing, topping + mowing + grazing, etc.). A grassland management schedule was established and the growth and grass farming season was thus divided into six periods. For the purpose of this study, we considered that all of the hay meadows received organic fertilisation corresponding to the herd maintained during winter. Each type of grassland produces a specific quantity and quality of forage for each period.

Two simplifications were applied to the original model in order to make the results more transparent. First, in the original version, the model accounts for the heterogeneity in parcels; distinction is made for example between areas that can be used as hay meadows and those that cannot, or between fertilisable and non-fertilisable areas. This heterogeneity was removed from the model which is applied here. All the parcels are homogeneous and the model is entirely free to decide about the number of hectares managed in a particular way. The second simplification concerns the administrative framework. In the original model the pertinent CAP premiums are depicted and the model can choose whether or not to claim each premium, with the constraints that this implies. These constraints were likely to deteriorate the comparability with the theoretical framework exposed above, which does not account for them. We aggregated all the premiums in a single payment attributed per livestock unit. (The amount of this payment was calculated from results obtained with the original model for the CAP 2002 payment scheme).

Uncertainty stems from the volatility of output prices. Five sets of prices were used corresponding to annual average output prices of the years 1998-2002. Not having at hand any more suitable estimation of subjective probabilities the farmers accord to these prices, we assume that any of these sets of prices can occur with the same probability, 20 per cent. In order to analyse the impact of different degrees of price variability on biodiversity production, the output prices were in the model defined in the following form

$$p_{ik} = \bar{p}_i(1+\varepsilon_{ik}h), \ \varepsilon_{ik} = \frac{p_{ik} - \bar{p}_i}{\bar{p}_i} \qquad \text{(P.9)}$$

where p_{ik} is the price of the output i in the state of nature k, $\bar{p}_i$ is the expected value of the price of output i, and ε_{ik} is the deviation from the expected price in the state k. The parameter h serves to model a change in the price variability without affecting the price level.

The agreement representing the Tourbières ESA, where the aim is to reduce the intensity of farming in the neighbourhood of the peatlands, is modelled by the possibility not to utilise up to 25 hectares of the total UAA, which is 100 hectares, in exchange for a per hectare agreement payment (450 euros per ha per year). The agreement applying to the Mars ESA is represented by the possibility to acquire up to 25 hectares of additional grassland to the initial 100 hectares. There is a unit cost attributed to the shrub clearing of the parcel (750 euros per ha per year during 5 years) and a payment for each hectare cleared (300 euros per ha per year). The number of hectares eligible for both agreements is limited to cover only a part of the farm, and land eligible just for one of the two agreements can be found on one farm as they concern distinct ESAs.

3.2. Basic simulation results

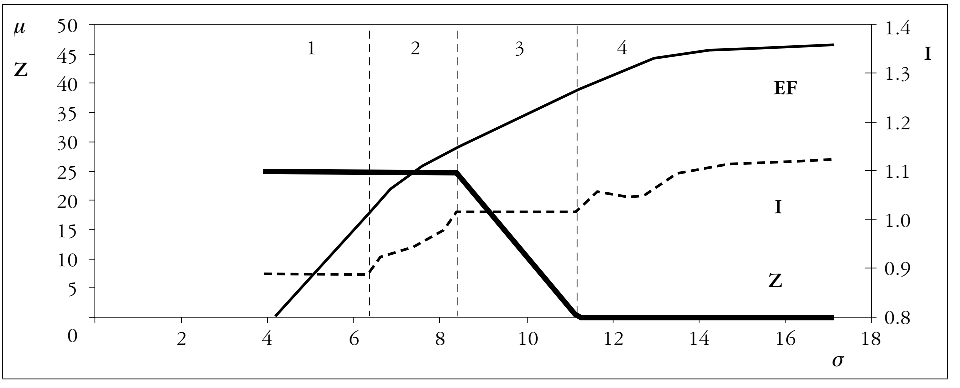
In this section the results of simulations obtained by applying the programme (P.1-8) are presented graphically – in the terms of efficient frontiers (EF), biodiversity production, approximated by the number of hectares enrolled in one or another agreement (Z), and farming intensity (I), approximated by the number of livestock units per hectare.

Figure 3 contains results for competing beef and biodiversity production. The efficient frontier consists of four segments, two linear ones and two concave ones. The segment n° 1 is linear and it emanates from the value of expected profit where the standard deviation is equal to zero. This point generally corresponds to the negative value of fixed cost and to zero agricultural activity. But in the modelled case, the farmer has the possibility to enroll a part of his land in an agreement which remunerates him for not utilising it. So the highest expected profit attainable is equal to the negative value of fixed cost plus the number of hectares eligible for the agreement (25 hectares) multiplied by the agreement payment. (This point is not depicted in the picture).

The first segment is linear because the farmer determines once the optimal structure of his activities and than he only increases the share of land in production before the limit of a fixed factor, here only land is considered as such, is hit. This is confirmed by the shape of the dashed curve which represents the farming intensity and whose value is in the first segment constant. (The value can be read on the secondary y-axis). The number of hectares enrolled in the agreement is measured by the crank-shaped biodiversity production curve. Its value can be read on the principal y-axis similarly as the expected profit which is expressed in 1 000 euros. In the first segment, all the eligible grassland is enrolled in the agreement.

When the grassland becomes a limiting factor for further increase of the expected profit, adjustments in the production structure occur in order to use the land more efficiently and to save the agri-environmental payment. This leads to an increase in the farming intensity on land in production, and to a more than proportionate increase in the profit variability compared to its expected value. Thus the efficient frontier is concave in segment n° 2. Also in this segment, all the eligible land remains enrolled in the agreement.

Figure 3. **Portfolio optimisation with an agri-environmental agreement for competing beef and biodiversity production**



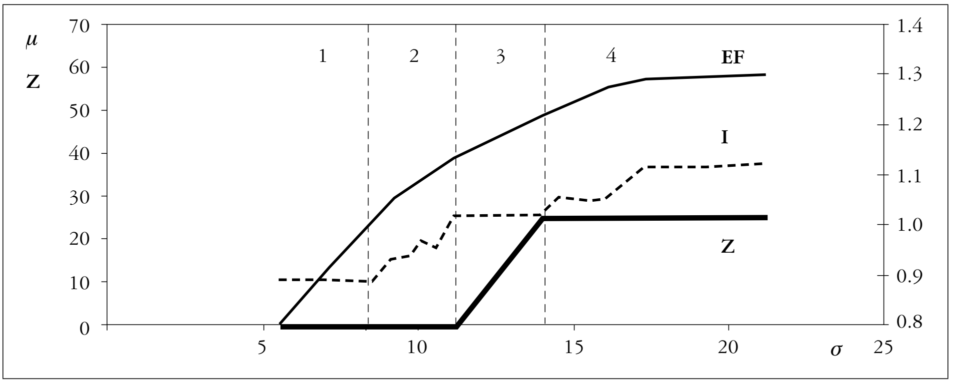
The linear segment n° 3 corresponds to a progressive reduction of the grassland enrolled in the agreement with a constant structure of beef production activities and a constant farming intensity on the non-enrolled grassland. It represents a fragment of the market opportunity line from figure 1. Since only a part of the grassland is considered as eligible for the agreement, not the whole opportunity line can be integrated in the efficient frontier but only its fragment. The fact that Tobin's separation theorem applies exclusively to this part of the efficient frontier, does not harm the comparative statics analysis because the biodiversity production changes just along this segment.

The last concave segment, n° 4, corresponds to the situation where no grassland is enrolled in the agreement. At this stage, additional expected profit can be obtained only by adjusting the farming system, which also actually happens as can be seen regarding the evolution of the farming intensity. This segment is identical to the corresponding part of an efficient frontier when no agri-environmental agreement is proposed.

The case of complementary beef and biodiversity production is depicted in figure 4. The efficient frontier is once again composed of two linear and two concave segments but their meaning is different from the case above. The linear segment n° 1 emanates from the point where the standard deviation is equal to zero and the expected profit is equal to the negative value of fixed costs. (This point is not depicted in the picture). The reason of the linearity is the same as in the competing beef and biodiversity case. The linear development lasts as long as there is some free non-degraded grassland. In this segment no land is enrolled in the agreement aiming at regaining the degraded grassland.

Adjustments in the farming system, which are behind the concavity of the segment n° 2, are motivated by the aim to use the non-degraded grassland as efficiently as possible before proceeding to clearing some additional land. Farming intensity increases in this segment and still no degraded grassland is being regained.

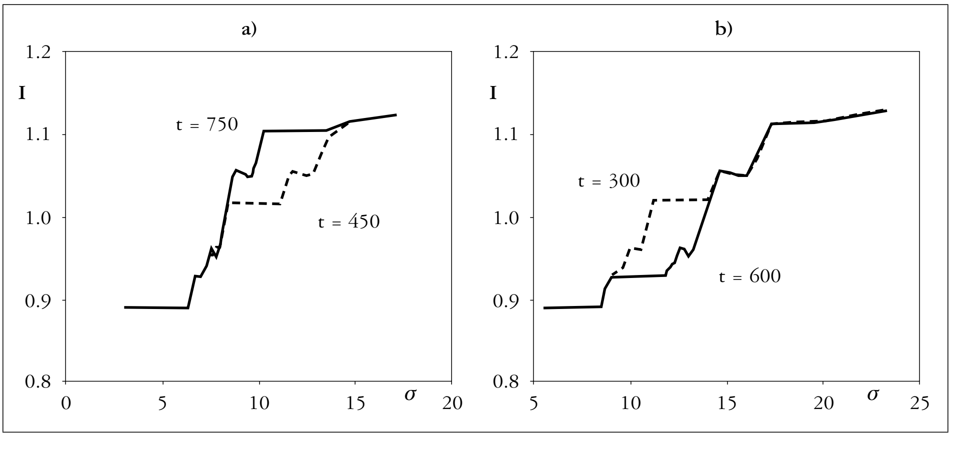
Figure 4. **Portfolio optimisation with an agri-environmental agreement for complementary beef and biodiversity production**



The segment n° 3 is linear and it corresponds to a fragment of the market opportunity line from figure 2. Only to a fragment because the amount of degraded grassland is limited. In accord with the Tobin's separation theorem, the structure of beef production and farming intensity are constant and the adjustment concerns just the extent of the beef and biodiversity production. The area enrolled in the agreement linearly increases. In the last segment, n° 4, all the eligible land is already enrolled. This segment is concave because there is no further possibility to acquire additional grassland and the expected profit can be increased only by changing the farming system.

In section 2, before having introduced into the model the indifference curves, we derived that an increase of the payment for biodiversity competing with agricultural commodities will encourage the farmer to engage in a more profitable but also more risky structure of beef production. We argued that in production systems with limited diversification possibilities, like beef cattle farms in less favoured areas, this is likely to

Figure 5. **Effects of different levels of agri-environmental payments on farming intensity in the a) competing and b) complementary beef and biodiversity production case**



result in an increase in the farming intensity on land not enrolled in the agreement. Figure 5 provides a comparison of farming intensities under the base value of agri-environmental payments, represented by the dashed lines, and farming intensities under agri-environmental payments increased by 300 euros per hectare, represented by the solid lines. Figure 5a represents the case of the Tourbières ESA with competing beef and biodiversity production. It shows that with the increased agri-environmental agreement, the farming intensity is above the farming intensity corresponding to the base payment, all over the range where the area enrolled in the agreement is different – higher – from the area enrolled with the base payment. These results confirm that agri-environmental agreements aiming at extensification on a part of the farm may encourage intensification on the rest of the land if uncertainty is present and the farmers are risk-averse. Figure 5b shows that this effect is opposite in the Mars ESA, where beef and biodiversity production is complementary; the farming intensity with an increased agreement payment is, over the range where the enrolled areas differ, always lower than the farming intensity with the base payment.

3.3. Uncertainty and decoupled direct payments

Some comparative statics results concerning the effects of different economic and policy parameters on environmental good production were analytically derived in section 2. In what follows, these results are illustrated graphically for the parameters of special interest with respect to the recent CAP reform: The output price variability and the amount of decoupled subsidies. The presented figures contain efficient frontiers and corresponding biodiversity production curves generated by the above presented models. The simulation results are complemented by theoretical indifference curve maps representing a farmer with decreasing absolute risk aversion.

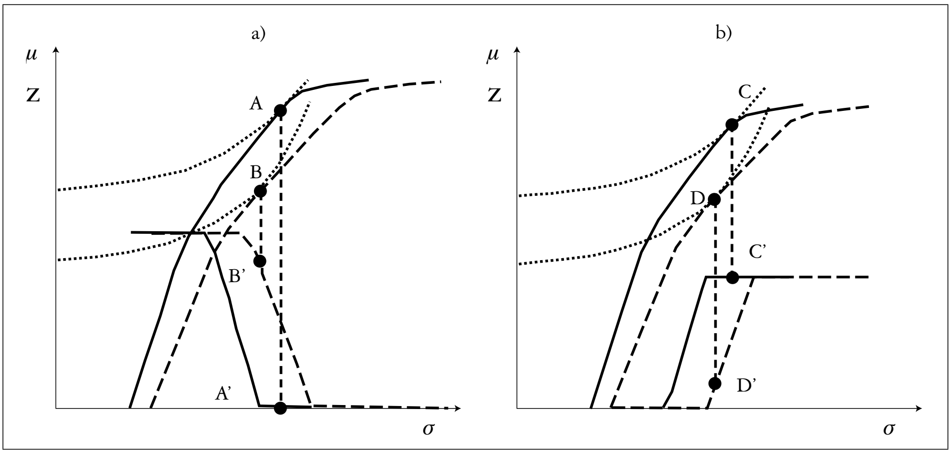
3.3.1. Uncertainty

For the analysis of a change in the level of uncertainty, we consider an increase in the beef price variability. It is modelled by an increase of the value of the parameter h presented in equation (P.9), from 4 to 5 [11]. The results are presented in figures 6a and 6b for competing biodiversity production in the Tourbières ESA and for complementary biodiversity production in the Mars ESA, respectively. The solid lines correspond to the initial level of output price variability, the dashed lines correspond to its increased level. An increase in the variability of beef prices rotates the efficient frontiers clockwise downwards and reduces thus the slope of efficient frontiers. The resulting direct effect encourages farmers to shift towards portfolios with lower expected profits. The wealth effect reinforces the direct effect because the indifference curves of DARA farmers become steeper at lower levels of utility. In the case of competition, the optimum portfolio shifts from the point A to the point B, and consequently, the biodiversity production increases from level A' to level B'. In the case of complementarity, the initial portfolio corresponding to the point C shifts to the

[11] Simulations were carried out for higher than observed levels of the output price variability in order to enhance readability of the schemes.

point D, and in this case, biodiversity production decreases from the initial level corresponding to the point C' to a lower level corresponding to the point D'.

Figure 6. **Effects of different levels of output price variability on a) competing and b) complementary beef and biodiversity production**

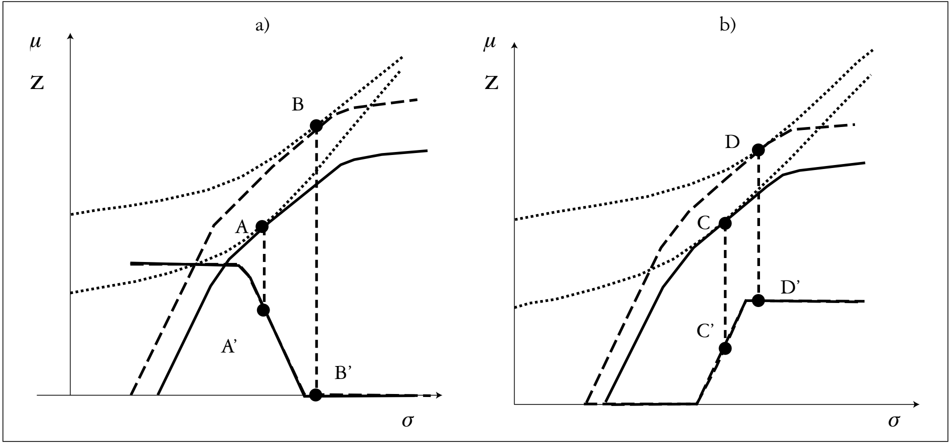


The direct and wealth effects can be interpreted as follows: In the case of competition, the more variable income from agricultural production is for a risk-averse farmer less attractive therefore he is more inclined to exchange a part of it for the lower but riskless income from the agri-environmental agreement. This lower income makes a DARA farmer even more risk-averse and encourages him further to exchange the variable income for the sure one by increasing the area diverted from beef production to biodiversity production. If complementary biodiversity is at stake, the reasoning is similar. The utility resulting from the highly variable income is no longer sufficient to cover the part of the shrub clearing cost which is not covered by the agreement payment. (We recall that it is supposed that the cost of regaining the abandoned grassland is never completely covered by the agreement payment and it should be partially compensated by supplementary gains from beef production). The utility of the supplementary income from additional beef production is not only lower because the income variability increased but also because the DARA farmer is at the new utility level more risk-averse.

3.3.2. Decoupled subsidies

Effects of the introduction of a decoupled subsidy in the form of a lump sum payment are presented in figure 7, where a lump sum payment of 5000 euros is accorded to the farmers; solid and dashed lines represent the situations without and with the decoupled subsidy, respectively. The decoupled subsidy does not influence either the variability of the income from agricultural production nor its relative profitability compared to biodiversity production therefore the efficient frontier just shifts upwards and remains perfectly parallel to the original one. Introduction of a decoupled subsidy has no direct effect on the choice of optimum production portfolio. Its only effect, in our simplified

Figure 7. **Effects of different levels of decoupled subsidies on a) competing and b) complementary beef and biodiversity production**



model, is the wealth effect. DARA indifference curves become flatter, the farmers become less risk averse, as the level of the expected profit increases, so the tangency point with the new efficient frontier moves northeast, corresponding to the shifts from the point A to the point B in figure 7a, and from the point C to the point D in figure 7b. These shifts in optimum portfolios bring about a decrease in competing biodiversity production and an increase in complementary biodiversity production.

The economic rational behind the adjustments of biodiversity production after introduction of a decoupled subsidy can be interpreted as follows: The wealth effect makes the variable income more attractive both for farmers producing competing biodiversity in the Tourbières ESA, and for farmers producing complementary biodiversity in the Mars ESA. The farmers in the Tourbières ESA are thus less motivated to stabilise their incomes by entering in the agri-environmental agreement, and competing biodiversity declines. On the other hand, complementary biodiversity in the Mars ESA increases because the variability of the income from supplementary beef production becomes less a problem for the Mars ESA farmers so that they are ready to clear the previously abandoned grassland.

4. Conclusion

An analytical framework was proposed which enables to analyse the willingness of a DARA risk-averse farmer to enroll in an agri-environmental agreement when facing uncertainty in output prices. In this framework, the agri-environmental payments are considered as a riskless income. Both competing as well as complementary beef and biodiversity production was analysed applying mathematical programming farm level models of a representative suckler cow farm in the *Monts du Cantal*. However, the modelled agri-environmental agreements represent just the extreme cases where in the competing case, some grassland should be completely diverted from beef production, and in the complementary one, some abandoned grassland is to be re-utilised. In reality, many agreements only limit, do not exclude, farming activity, or demand clearing of only partially degraded pastures. Since we dealt with the extreme cases in order to make more visible the principles of the proposed framework, the obtained results remain qualitative.

As mentioned in the introduction, this paper is closely related to the one by Havlík *et al.* (2005). Both papers analyse the effects of parameters like the amount of decoupled subsidies or the output price variability on competing and complementary grassland biodiversity production, and they are applied to the same case studies. The papers differ mainly by the analytical framework; Havlík *et al.* (2005) carried out their analysis within an expected utility model, while this paper adopted the mean-standard deviation model and applied the Tobin's separation theorem. The comparative statics results obtained by the two models are equivalent: An increase in the output price variability and/or a decrease in the level of decoupled subsidies will have positive effects on competing biodiversity production and negative effects on complementary biodiversity production. These results are in line with those derived by Hennessy (1998) who was reasoning in terms of input use. Although not surprising, these results can be considered as a sort of validation of the analytical model presented in this paper.

More interesting, and without equivalents in Havlík *et al.* (2005), are the comparative statics with respect to agri-environmental payments. We demonstrated that parcels not enrolled in an agreement aiming at low-intensity grassland management are likely to be managed more intensively after an increase of the agreement payment. As such agri-environmental agreements often request 'low' farming intensity and not 'lowering' of the farming intensity, the farmer usually enrolls parcels where the intensity is already sufficiently low for whatever reason, *e.g.* poor land quality, and not the others. While the environmental effect of such an agreement is zero if the farmer is risk-neutral, the environmental effect is negative if the farmer is risk-averse. This result favours whole farm agri-environmental programs which require that also the grassland not enrolled in specific agreements should be managed in an environment friendly way. Whole farm agri-environmental programmes are currently applied for example in Austria or in the Czech Republic. If a farmer wants to enter the Czech Sound Grassland Management programme, he has to enroll all his grassland in a general management agreement. If his grassland is eligible, he can enroll a part of it also in supplementary, more restrictive, agreements but he still has to hold all the rest enrolled in the general agreement. Havlík *et al.* (2006) analysed whole farm programmes within a principal-agent model with special attention to adverse selection issues. Their results suggest that whole farm programmes can help to reduce overcompensation of farmers which typically results from asymmetric information between farmers and the Government, and thus to make the agri-environmental policy more cost-effective.

Alternatively, the whole farm framework for more focused agri-environmental agreements could be provided by decoupled payments linked to properly designed cross-compliance conditions. On the basis of our results concerning the impact of decoupled payments on biodiversity production, we would recommend to introduce environmental regionalisation of decoupled payments. Higher than average direct payments should be awarded to farmers in regions where biodiversity and agricultural commodities are complementary, and lower than average payments to farmers in regions where biodiversity competes with agricultural commodities. To a certain degree, this differentiation already applies within the less favoured area payments, which can be considered as decoupled payments accorded to farmers in regions where environmental good production is supposed being complementary to agricultural commodities production. However, this suggestion is to be taken with precaution. Our analysis was carried out only for beef cattle grassland based farms; the adaptation strategies to a change in the amount of decoupled subsidies in other sectors and regions could lead to disappointing results. For example, Leathers and Quiggin (1991), or recently, Serra *et al*. (2006) showed that the effect of a change in the decoupled payment on use of risk decreasing inputs by DARA farmers is indeterminate. Hence, theoretically, lower decoupled payments for highly productive regions could induce increased pesticide application there. More empirical studies are necessary to determine not only the sign but also the magnitude of these sometimes contradictory effects, so that informed policy decision can be taken.

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APPENDIX

The comparative statics results rely on the following assumptions about the utility function: increasing in the expected profit, $U_\mu \geq 0$, decreasing in its standard deviation, $U_\sigma \leq 0$, and concave; with indifference curves whose slope $S(\mu,\sigma)$ corresponds to the DARA preference structure:

$$S_\mu = \frac{U_{\mu\mu}U_\sigma - U_{\sigma\mu}U_\mu}{U_\mu^2} \leq 0 \text{ and } S_\sigma = \frac{U_{\mu\sigma}U_\sigma - U_{\sigma\sigma}U_\mu}{U_\mu^2} \geq 0.$$

Proof of Proposition 1

We first notice that equation (6b) $V_z = \left(t - \mu_R\right)U_\mu - \sigma_R U_\sigma = 0$ is equivalent to

$$\frac{t-\mu_R}{\sigma_R} = \frac{U_\sigma}{U_\mu} \equiv -S(\mu,\sigma) \qquad \text{(A.1b)}$$

The calculus will be detailed only for comparative statics on z with respect to μ_R, the point (a). The other results exposed in Proposition 1 are obtained in the same way.

$$V_{z\mu_R} = -U_\mu + \left(1-z\right)\left(t-\mu_R\right)U_{\mu\mu} - \left(1-z\right)\sigma_R U_{\sigma\mu}$$

$$= -U_\mu + \left(1-z\right)\left(\frac{\sigma_R}{U_\mu}\right)\left(\frac{t-\mu_R}{\sigma_R}U_\mu U_{\mu\mu} - U_\mu U_{\sigma\mu}\right) \qquad \text{(A.2b)}$$

Recalling the content of equation (A.1b), equation (A.2b) is equivalent to

$$V_{z\mu_R} = -U_\mu + \left(1-z\right)\left(\frac{\sigma_R}{U_\mu}\right)\left(U_\sigma U_{\mu\mu} - U_\mu U_{\sigma\mu}\right) < 0 \qquad \text{(A.3b)}$$

According to the assumptions about the utility function, equation (A.3b) is strictly negative. This proofs the point (a).

Proof of Proposition 2

We first notice that equation (6c) $V_z = \left(t - s + \mu_R\right)U_\mu + \sigma_R U_\sigma = 0$ is equivalent to

$$\frac{t-s+\mu_R}{\sigma_R} = -\frac{U_\sigma}{U_\mu} \equiv S(\mu,\sigma) \qquad \text{(A.1c)}$$

The calculus will be detailed only for comparative statics on z with respect to μ_R, the point (a). The other results exposed in Proposition 2 are obtained in the same way.

$$V_{z\mu_R} = U_\mu + \left(1+z\right)\left(t-s+\mu_R\right)U_{\mu\mu} + \left(1+z\right)\sigma_R U_{\sigma\mu}$$

$$= U_\mu + \left(1+z\right)\left(\frac{\sigma_R}{U_\mu}\right)\left(\frac{t-s+\mu_R}{\sigma_R}U_\mu U_{\mu\mu} - U_\mu U_{\sigma\mu}\right) \qquad \text{(A.2c)}$$

Recalling the content of equation (A.1c), equation (A.2c) is equivalent to

$$V_{z\mu_R} = U_\mu - \left(1+z\right)\left(\frac{\sigma_R}{U_\mu}\right)\left(U_\sigma U_{\mu\mu} - U_\mu U_{\sigma\mu}\right) > 0 \qquad \text{(A.3c)}$$

According to the assumptions about the utility function, equation (A.3c) is strictly positive. This proofs the point (a).