Green auctions versus uniform agri-environmental payments under heterogeneous conditions

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Contributed Paper prepared for presentation at the International Association of Agricultural Economists Conference, Beijing, China, August 16-22, 2009.

Abstract.

This paper examines how jointness of environmental benefits and environmental heterogeneity affect auction designs and the potential benefits of green auctions over conventional flat-rate agri-environmental policies. A sealed bid green auction is used to promote an agri-environmental program with two environmental targets, nutrient runoff reduction and biodiversity provision. A score index comprising of environmental performance and the monetary size of bid is developed to rank the farmers' applications. The green auction is analyzed analytically and then empirically by using Finnish data.

An auction that screens according to the environmental score and another one with an additional cost-saving component are simulated in the context of two different conservation options based on whether enlarged field edges are located in whichever edge of a parcel, providing only biodiversity benefits or are located on the waterfront (buffer strip) providing joint benefits in terms of promoting biodiversity and reducing nitrogen runoff. Empirical results show that independently of whether the auction program supports simple enlargement of field edges or buffer strips, the green auction with the cost saving component has the highest social welfare performance, followed by the flat rate payment, followed in turn by the green auction ranking by environmental score. When environmental benefits are jointly produced by a practice the dominance, in welfare terms, of the green auction with cost-saving is further enhanced.

Keywords: bid, joint environmental benefits, score index value

1. Introduction

Most agri-environmental programs in Europe are based on fixed flat rate payments provided to farmers who comply with a predetermined set of management practices/criteria, such as reduced tillage or limits on the intensity and timing of fertilizer, manure and pesticide applications. The obvious problem with this type of flat rate payment approach is that heterogeneity in neither farmers' compliance costs nor site-productivity of environmental goods supplied are taken into account in policy design and implementation. Designing and implementing more efficient agri-environmental policies is difficult because of asymmetric information between a farmer and a policy maker.

Informational asymmetries are due to the inability of policy maker to produce exact knowledge for policy designs or to carry out effective monitoring activities. Principal–agent models are typically used to address the adverse selection problem in agriculture.

Auction theory provides an interesting way to extend the principal-agent approach by incorporating competition between agents for winning a contract with the principal. Auctions have been recently applied to environmental conservation on agriculture (Latacz-Lohmann and Hamsvoort 1997, Stoneham et al. 2003, Vukina et al. 2006). In conservation auctions, farmers bid competitively for a limited amount of environmental conservation contracts. When making a bid a farmer faces a trade-off between net payoffs and acceptance probability so that a higher bid increases the net payoff but reduces the probability of getting a bid accepted. Thus, competitive bidding will push farmers to reveal their compliance costs and as a result it will reduce farmers' information rents and improve the cost-effectiveness of an agri-environmental program.

Previous auction theory applications have not been very explicit in two important features affecting agri-environmental programs. First, environmental sensitiveness may greatly differ across the fields. Second, agri-environmental programs provide benefits in multiple environmental dimensions. For instance, if the goal is to promote biodiversity by increasing the width of field margins also nutrient and pesticide runoff to waterways may be reduced jointly. The implications of jointness between multiple environmental outputs on auction design and outcomes have not been examined so far.

In this paper we examine to what extent jointness and environmental heterogeneity affect the performance of different auction designs vis-à-vis conventional flat rate policies. We investigate auctions both analytically and empirically by using Finnish data. We compare a flat rate policy with two alternative auction designs, a green auction without and with a cost saving component. The rest of the paper is organized as follows. Section 2 develops a theoretical frame of the green auction design. Section 3 presents the empirical model used to simulate the auctions. Section 4 is devoted to presentation and discussion of results and, finally, a concluding section 5 ends the paper.

2. Theoretical framework

Suppose the government announces an agri-environmental program to promote nutrient runoff reduction and biodiversity provision. Farmers are asked to present a combination of environmental management actions and related bids. To guide the bids, the government indicates the weights given to the environmental performance and the size of the bid. Moreover, farmers promising to reduce fertilizer application are required to make a costly soil nutrient test and to report the actually applied amounts of fertilizer to prevent moral hazard associated with non-point pollution. Drawing on the farmers' bids, a single score value (*I*) will be computed for each application. The applications will be accepted according to the score value in so far as the scores exceed a cutoff value (I^c), which is defined endogenously after the bids have been submitted.

To formalize this bidding procedure, we first define how the environmental performance of each bid is assessed. We assume that environmental performance includes two components: an improvement in agricultural biodiversity (BD) and in water quality by reducing nutrient runoff (BZ). In working lands (cultivated lands), biodiversity is mostly promoted by field margins, which provide semi-natural habitat for wildlife. Reducing nutrient runoff can be made by many means. The most obvious way is to reduce fertilizer application, another is provided by establishing buffer strips between fields and waterways. We denote fertilizer application by *l* and buffer strips by *m*. Then, we can express biodiversity and water quality improvement benefits relative to the maximum improvement obtainable in a given parcel as $BD(m)$ and $BZ(l,m)$, respectively. Assumption 1 characterizes the environmental performance in the program,

Assumption 1. *Environmental performance, E*
Environmental performance is a linear combination of biodiversity and water quality improvement benefits, $E(l,m) = \alpha BD(m) + \beta BZ(l,m)$ with $0 < \alpha, \beta < 1$ and $\alpha + \beta = 1$ and $0 < E(m,l) \leq 1$. Moreover,

A.1 $$\frac{dE}{dl} \equiv E_l = \beta BZ_l < 0;$$

A.2 $$\frac{dE}{dm} \equiv E_m = \alpha BD_m + \beta BZ_m > 0$$

From assumptions A.1 and A.2 we see that decreasing fertilizer application and increasing buffer strip size reduce nutrient runoff. Moreover, there is a tradeoff between them: by increasing the size of the buffer strips one can allow for higher fertilizer application in the bid for obtaining the same score. This substitution possibility plays a crucial role in the model.

We next define the score value *I*. By assumption, it depends on the environmental performance E and the payment *r* required by the farmer relative to the maximum payment as a function of environmental benefit provided, $R(E)$. Moreover, the score value is defined as a share of the maximum obtainable score value, denoted by $\bar{I}$. Let ω_e and ω_r denote the weights given to the environmental performance and the payment required, respectively. Like above, we have $0 < \omega_e, \omega_r < 1$ and $\omega_e + \omega_r = 1$. Now, the score value can be expressed as,

$$I = \left[\omega_e E + \omega_r (1 - \frac{r}{R(E)}) \right] \bar{I} \; . \tag{1}$$

Thus, equation (1) says that the score value of each bid is a share ($0 < I \leq \bar{I}$) of the maximum obtainable score value. Clearly, it depends positively on the weight given to the environmental performance and negatively on the payment required for the bid.

Farmers form their bids following the above rules. To become accepted into the program a farmer's application's index score must be above the endogenously determined cutoff value. Obviously, the farmer's bidding strategy will be guided by expectations about this cutoff value. We assume that the farmers are risk-neutral, so that they focus on expected values only. Thus, the farmer will submit a bid if the expected profit from participating exceeds the profits under the private optimum. The expected profits depend on the probability of being accepted in the program. Let $\underline{I}$ denote the minimum index value to have a chance at entering the program. Then the probability of being accepted to the program is defined by

$$P(I > I^c) = \int_{\underline{I}}^{I} f(I)dI = F(I) \ . \qquad (2)$$

Let $\pi_0^* = pf(l^*) - cl^*$ denote the farmer’s restricted profits under the privately optimal solution, with l^* the optimal fertilizer application, *p* crop price and *c* fertilizer price. Furthermore, we express the profits under the agri-environmental payment program conditional on the choices of actual fertilizer rate *l,* buffer strip *m* and soil nutrient test (*NC)* as $\pi_1 = (1-m)[pf(l) - cl] - NC$.

Farmer’s information rent (see Latacz-Lohmann and Van der Hamsvoort 1998) is reflected in the size of the bid for the payment of providing environmental benefits to the program. We denoted above the bid by *r*. In the presence of hidden information, $r \geq \pi_0^* - \pi_1$. Recall, the environmental benefits are produced by a combination of fertilizer application and buffer strips. Therefore, we assume that the farmer reflects their relative impact on the bid when producing the environmental benefits by choosing *l* and *m*. More specifically, we make the following assumption.

Assumption 2. *The farmer’s bid, r*

The farmer’s bid *r*, depends on the size of the buffer strip and fertilizer application:

A.3 $r = r(l,m)$ with $\dfrac{dr(l,m)}{dl} = r_l < 0$ and $\dfrac{dr(l,m)}{dm} = r_m > 0$

Assumption A.3 follows from the fact that a higher fertilizer application rate reduces, but a larger buffer strip increases the difference $\pi_0^* - \pi_1^*$ and thereby the payment required as compensation to participate in the program. Hence, unlike previous studies, *r* reflects the inherent trade-off between buffer strips and fertilizer application.

Now, the farmer's expected profits can be expressed as,

$$E\pi \equiv \Pi = \left[\pi_1(l,m) - \pi_0^* + r(l,m)\right]F(I). \qquad (3)$$

The economic problem of the farmer is to choose *l* and *m* (and thereby the bid *r*) so as to maximize the expected profits (3) from the bid subject to (1) and the obvious constraints $E(l,m) \leq 1$ and $r \leq R$. The Lagrangean for the problem reads as,

$$L = \left[\pi_1(l,m) - \pi_0^* + r(l,m)\right]F(I) + \lambda_r(R - r) + \lambda_E(1 - E) \qquad (4)$$

At an interior solution the Lagrange multipliers are zero and the first-order conditions can be expressed as,

$$l^0: \quad (1-m)\left[pf_l - c\right] + r_l = -\left[\omega_e E_l + \omega_r \frac{rR_l}{R^2}\right]\frac{F'(I)}{F(I)}\Phi\bar{I} \qquad (5a)$$

$$m^0: \quad -\left[pf(l) - cl\right] + r_m = -\left[\omega_e E_m + \omega_r \frac{rR_m}{R^2}\right]\frac{F'(I)}{F(I)}\Phi\bar{I}\,, \qquad (5b)$$

where $\Phi = (1-m)\left[pf(l) - cl\right] - NC + r(l,m) - \pi_0^*$.

In both necessary conditions for the optimum, the LHS term indicates the economic costs of providing environmental goods to the program and the RHS term indicates the expected return, that is, the effects of *l* and *m* on the score index and on the acceptance probability. Note that in (5a), RHS bracket term is positive, so that that the LHS bracket term must be positive, too, and greater than r_l, which is negative. This is intuitive. The farmer reduces fertilizer application and, due to the concave response function, the value of marginal product pf_l exceeds the net costs of fertilizer use. In (5b), the RHS bracket term is negative, so that the negative LHS bracket term is greater than r_m**.** Recall, finally, from

Assumptions A.1 and A.2 that $\frac{dE}{dm} \equiv E_m = \alpha BD_m + \beta BZ_m > 0$, which indicates that buffer strips really perform in equation (5b) the double function of promoting biodiversity and water quality improvement at the same time.

To develop further the interpretation, suppose first that the maximum rental payment by the program is a priori fixed and independent of $E(l,m)$, $R = \overline{R}$. Re-arranging and dividing (5a) by (5b) yields then the following optimality condition for the interior solution,

$$\frac{E_l}{E_m} - \frac{r_l}{r_m} = -\frac{\pi_l^1}{\pi_m^1}. \tag{6}$$

Thus, at the optimum the difference in the ratio of marginal contributions of fertilizer application and buffer strips on environmental score and the bid equals the ratio of their impacts on the profits.

Allowing *l* and *m* to affect the maximum rental payment by the program complicates condition (6) and yields,

$$\frac{w_e E_l + w_r \frac{R_l r}{R^2}}{w_e E_m + w_r \frac{R_m r}{R^2}} - \frac{r_l}{r_m} = -\frac{\pi_l^1}{\pi_m^1}. \tag{7}$$

The economic interpretation of (7) is the same as above. Now the marginal score value return in turn is defined by the ratio of their marginal impact on environmental benefits and on the maximum rental rate. Note, finally, that the ratio is negative indicating that the trade-off in choosing *m* and *l* carries over to the determination of the bid.

3. Empirical model

The empirical model contains 160 parcels with differential land productivities. Environmental heterogeneity is introduced by letting each land productivity to have four different field slopes towards a watercourse. The size of each parcel is normalized to be one hectare; the total land area is 160 hectares distributed equally in the four slope categories. Land can be allocated to three alternative uses: forestry, crop 1 (rape) and crop 2 (spring wheat).

The empirical model has three equations describing the crop production and environmental aspects. It uses private profits and social welfare as two objective functions. The first three equations are

$$y_i = a_i + \alpha_i l_i + \beta_i l_i^2 \qquad \text{(nitrogen response function)} \qquad (11)$$

$$z_i = [1 - \gamma m_i^{0.3}]\phi_j e^{-0.7[1-0.01(1-m_i)l_i]} \qquad \text{(nitrogen runoff function)} \qquad (12)$$

$$S = \psi \Lambda^{\varphi_\alpha} W^{\varphi_\beta} \qquad \text{(floral species richness)} \qquad (13)$$

Following Lankoski and Ollikainen (2003) we employ a quadratic nitrogen response function (11), which incorporates land quality through the intercept parameter a_i and slope parameter α_i.. Per parcel nitrogen runoff function (12) combines the nitrogen uptake by buffer strips (the bracket term) with the conventional runoff function. Parameter ϕ_j calibrates runoff function to runoff generated by a nitrogen application rate of 100 kilos per hectare in the absence of buffers strips (Simmelsgaard 1991). We adjust parameter ϕ_j to reflect the effect of field slope on the propensity for nitrogen runoff on the basis of Finnish evidence. We link buffer strip areas to species diversity with the help of modified species-area relationship (13), which is sensitive to the width (*W)* and length (Λ) of the buffer strip. All parameter values are defined in Appendix 2, Table 1.

The objective functions of the private farmer and the social planner are,

$$\pi^i = (1-m_i)\left[p_i\left(a_i + \alpha_i l_i + \beta_i l_i^2\right) - cl_i - wn_i\right] - rk_i . \tag{14}$$

$$SW = \int_0^1 \sum \pi^i - 3.57Z + 54M^{0.0977} \tag{15}$$

Private profits in (14) are similar as in the theoretical part except that they also account for the fact that cultivation requires employing per parcel a constant amount of labor, n_i (measured in working hours) and capital, k_i. Wage rate per hour is *w*, and *r* refers to the cost of capital. The welfare function is a sum of private profits, runoff damages and biodiversity benefits. The total nitrogen runoff is denoted by *Z* and the overall buffer strip area by *M*. We postulate linear runoff damage and biodiversity benefit and use estimates of € 3.57/kg and € 54/ha, respectively (both are produced from Yrjölä and Kola 2004).

Finally, recall the non-agricultural land use is forestry. We assume that if a parcel of forest is converted to agriculture, there is a lump sum conversion cost but the yields obtained from this converted land will reflect typical agricultural yields. If a previously cultivated land is forested, it will take a long time for this parcel to produce regular forest income**.** Forest income, nitrogen runoff from forests and biodiversity benefits of forestry are reported in Table A1, Appendix 1. All prices and costs are from the year 2002.

In the green auctions, the planner maximizes the environmental goal of the agri-environmental program subject to the requirement that payments for the accepted bids do not exceed the budget constraint ($\overline{G}$) of the program, defined by $\sum R = a * I \leq \overline{G}$, where *a* indicates how the maximum payment increases with environmental performance. As for the target function, recall the environmental performance index is a weighted linear average of nitrogen runoff reduction and biodiversity promotion. The weights are estimated using the actual social valuation of nitrogen runoff damages and biodiversity benefits in Finland. Estimation yields the weight 0.43 for biodiversity and 0.57 for runoff reduction. Thus, the environmental index, *E,* and the target function of the green auction ranking the bids according to their environmental performance (EnvMax), is given by,

$$E = 0.43BD + 0.57BZ \qquad \text{(EnvMax)} \tag{16}$$

When the cost saving component is added then the relative share of weights for biodiversity and runoff reduction is kept constant. We assign values in equation (1) by setting weights $\omega_e = 0.6$ and $\omega_r = 0.4$ to environmental performance and the cost-saving component to be associated with the bid, respectively. Thus, the target function with the cost saving component (CostSave), is

$$I = \left[0.6E + 0.4(1 - \frac{r}{R(E)}) \right] \bar{I} \qquad \text{(CostSave)} \qquad (17)$$

4. Policy simulations and results

The empirical model is now used to estimate the outcome of our EnvMax and CostSave green auction designs, which are compared with a current flat-rate payment approach. To examine the role of jointness in a sharp focus we assume in both auctions that the enlarged field edges provide (a) biodiversity benefits only (disjoint benefits), or (b) biodiversity benefits and nitrogen runoff reduction (joint benefits). The agronomic requirement for joint benefits in field edges is that they are established between the fields and the water ways, and thereby called buffer strips.

Green auctions are compared with the current Finnish agri-environmental payment program that provides a flat-rate payment to participating farmers as a compensation for the forgone profits of establishing 3 meter wide buffer strips. All policy options are compared with benchmark cases of the private (entailing no enlarged field edges), and the social optimum (with the full set of conservation options). Thus, the alternative policies are defined as follows:

1. Current flat-rate agri-environmental payment (Flat-Rate): *A uniform 3-meter wide enlarged field edge is required. The uniform agri-environmental payment as a compensation for forgone profits amounts to € 21/ha. "Flat-rate disjoint" and "Flat-rate joint" refer to the disjoint and joint benefits, respectively.*

2. Green auction ranking by environmental score (EnvMax): *The bids are selected according to their environmental score. The private optimum is used as a reference to calculate the benefits from nitrogen use reduction. The budget is assumed to be restricted* *to the amount of the current flat-rate payment approach described above. EnvMax_disj and EnvMax_joint refer to the auction disjoint and joint benefits, respectively.*

3. Green auction ranking by environmental score and cost-saving component (CostSave): *The bids are selected according to their environmental score and cost-saving component, which is given a weight 0.4. The private optimum is used as a reference to calculate the benefits from nitrogen use reduction. The budget is assumed to be restricted to the amount of the current flat-rate payment approach. CostSave_disj and CostSave_joint refer to the disjoint and joint benefits, respectively.*

4.1. Flat rate payment versus green auctions under disjoint benefits

We start by reporting the results from the case where environmental benefits are disjoint. Input use and land allocation results are allocated to Tables A2 and A3 in appendix 2. The social welfare under alternative policies and under the private and social optima is given in Table 1.

Table 1. *Disjoint benefits: social welfare performance of alternative policies.*

Policy	Profits, €	Budget outlays, €	Accepted /rejected bids, #	Runoff damage, €	Biodiversity benefits, €	Social welfare, €
Private optimum	11 422	-	-	5695	1288	7617
Social optimum	10 216	-	-	2622	3348	11 615
Flat-rate disjoint	13 001	2482	-	6893	4223	8203
Green auction: **EnvMax_disj**	11 458	955	13 / 13	5297	1649	7458
Green auction: **CostSave_disj**	11 578	874	92 / 92	5083	2927	9151

Table 1 represents the overall social welfare, its components and accepted/rejected bids in the auctions. Social welfare includes the social cost of public funds and we use 15% as the estimate for that cost. In the flat-rate payment program, the environmental payment is set at level € 21 per ha and the overall agri-environmental budget for green auctions is defined by the budget in the flat-rate payment (€ 2482).

By definition, welfare in all policies remains below the socially optimal solution. The green auction with cost saving performs best and is followed by the flat rate policy and then the auction ranking the bids by their environmental score (EnvMax_disj). The budget outlays for both auction designs are considerably lower than the budget constraint imposed by the equivalency with the flat-rate payment program, because all applicants are accepted without exhausting the funds. The fact that the budget is not exhausted highlights two potential problems when designing an auction mechanism: either there are too few applicants or if there are many, the majority of bids can be characterized as “low-cost-low-quality”.

When the cost-saving component is included in the ranking it becomes considerably easier to attain what is perceived as an acceptable score, as is highlighted by 100% participation. The farmers’ strategy in this case is to provide relatively small environmental improvements and requesting low payments. Despite these shortcomings the social welfare outcome for the green auction with the cost-saving component is significantly higher than both the private optimum and flat-rate payment policy.

4.2. Flat rate payment versus green auctions under joint benefits

We next analyze the case where the environmental benefits provided by enlarged field edges (now buffer strips) are joint. Table 2 compares the social welfare performance of alternative policies relative to the private and social optima.

All three policies are welfare-enhancing relative to the private optimum; however, their performance differs substantially in terms of aggregate welfare and environmental performance. The green auction with the cost-saving component (CostSave_joint) dominates other policy designs. It induces the highest welfare and brings runoff damages and biodiversity benefits close to the social optimum. As in the previous section, the flat rate payment policy outperforms the auction that maximizes the environmental score (EnvMax_joint).

Table 2. *Joint benefits: social welfare performance of alternative policies.*

Policy	**Profits, €**	**Budget outlays, €**	**Accepted /rejected bids, #**	**Runoff damage, €**	**Biodiversity benefits, €**	**Social welfare, €**
Private optimum	11 422	-	-	5695	1288	7617
Social optimum	10 216	-	-	2622	3348	11 615

Flat-rate joint	13 001	2482	-	5234	4223	9861
Green auction: **EnvMax_joint**	12 448	2515	24 / 68	4215	2051	8370
Green auction: **CostSave_joint**	12 369	2484	58 / 34	3292	2932	10 127

The presence of jointness in environmental benefits changes the number of bids submitted and accepted in the two auctions. Jointness implies that the environmental benefits from a unit of buffer are higher and it is easier for the farmer to construct a bid with an acceptable score. Whilst previously all bids were accepted, in the joint benefit case only ¼ of submitted bids are accepted.

Relative to the environmental ranking with joint benefits, the ratio of accepted bids improves when the cost-saving component is incorporated in the ranking, going up to 63%. It is interesting to note that, relative to the case with disjoint benefits, fewer bids are accepted when benefits are joint. This is because on the demand side, since jointness implies higher environmental benefits from a unit of buffer, the agency will be willing to "retire" more productive land into buffer, and farmers are happy to bid that land into the program up to their opportunity cost. Therefore, the cost of bids is higher when benefits are joint. Welfare is enhanced because the greater reduction in runoff damage and improvement in biodiversity compensate for higher unit costs of conservation. Cost saving clearly matters, as acceptance rate is much higher under the cost-saving auction than the case without factoring in costs, leading to a better outcome in social welfare terms.

5. Conclusions

This paper analyzed to what extent jointness and environmental heterogeneity affect the performance of different auction designs vis-à-vis conventional flat rate policies. Both joint and disjoint benefits result in the same ranking of policies. The green auction with the cost saving component outperforms others. For joint benefits the outcome is quite close to the social optimum. In contrast, the green auction ranking by environmental score performed worse, and was even less welfare-enhancing than the flat-rate payment. This demonstrates the importance of the cost-saving component in environmental policy design.

Jointness of environmental benefits plays an important role for the performance of the green auctions. Allowing for joint benefits made both auctions (also the flat rate policy) more successful, because the costs of providing environmental benefits were reduced. When maximizing the environmental score too few bids are submitted, whereas when cost-saving is incorporated there are many applicants but the majority of bids are “low-cost-low-quality”.

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Appendix 1. Parameter values in the numerical application

Table A1. Parameter values.

Parameter	*Symbol*	*Value*
Agriculture		
Prices		
price of rape	p_1	€ 0.255/kg
price of wheat	p_2	€ 0.13/kg
price of nitrogen fertilizer	c	€ 1.2/kg
Land quality		
$a_1 = e_0 + e_1 q$; $\alpha_1 = \mu_0 + \mu_1 q$ $a_2 = h_0 + h_1 q$; $\alpha_2 = \eta_0 + \eta_1 q$		
where		
basic level of response for rape	μ_0	9.72
basic level of response for wheat	η_0	30.8
slope of the response change for rape	μ_1	0.01
slope of the response change for wheat	η_1	0.05
parameter of quadratic nitrogen response function	β	-0.0324 for rape -0.094 for wheat
initial level of productivity for rape	e_0	700
initial level of productivity for wheat	h_0	680
slope of the productivity change for rape	e_1	10
slope of the productivity change for wheat	h_1	23
Nitrogen runoff		
nitrogen leakage at average nitrogen use under 4 different field slope	ϕ_j	11.4; 13.3; 16.7; 20.0 kg/ha
share of surface runoff from total runoff	γ	90%
Labor and capital inputs		
farmer's wage rate per hour	w	€ 11.35/h
farmer's labor input per hectare	n	6.57 h/ha
capital cost	rk	€ 144/ha
Forestry		
Annual forest income		€ 47.8/ha
Nitrogen runoff		N 2 kg/ha
Nitrogen runoff damage		€ 7.15/ha
Biodiversity benefits		€ 16/ha
Exogenous social rent		€ 56.65/ha

Appendix 2. Input use and land allocation results

Table A2. Disjoint benefits: input use and land allocation results. Average input use is reported in bold and the range is given below the average.

Policy	**Nitrogen intensity, kg/ha**		**Width of enlarged field edge, meters**		**Land allocation, # of parcels allocated to**		
	Rape	*Wheat*	*Rape*	*Wheat*	*Forest*	*Rape*	*Wheat*
Private optimum	**80.3** 80.2-80.5	**122.8** 120.3-125.4	**0.5**	**0.5**	68	12	80
Social optimum	**70.0** 67.3-72.5	**114.2** 111.5-117.1	**9.2** 7.3-11.8	**9.9** 7.2-13.7	76	40	44
Flat-rate disjoint	**79.8** 79.1-80.5	**122.8** 120.3-125.4	**3.0**	**3.0**	40	40	80
Green auction: **EnvMax_disj**	**65.0** 47.7-80.5	**123.2** 120.6-125.4	**8.2** 0.5-19.6	**0.5**	68	25	67
Green auction: **CostSave_disj**	**70.0** 65.5-74.0	**120.9** 118.8-123.1	**3.1** 1.8-4.6	**0.9** 0.8-1.1	68	36	56

Table A3. Joint benefits: input use and land allocation results. Average input use is reported in bold and the range is given the average.

Policy	**Nitrogen intensity, kg/ha**		**Width of buffer strip, meters**		**Land allocation, # of parcels allocated to**		
	Rape	*Wheat*	*Rape*	*Wheat*	*Forest*	*Rape*	*Wheat*
Private optimum	**80.3** 80.2-80.5	**122.8** 120.3-125.4	**0.5**	**0.5**	68	12	80
Social optimum	**70.0** 67.3-72.5	**114.2** 111.5-117.1	**9.2** 7.3-11.8	**9.9** 7.2-13.7	76	40	44
Flat-rate joint	**79.8** 79.1-80.5	**122.8** 120.3-125.4	**3.0**	**3.0**	40	40	80
Green auction: **EnvMax_joint**	**66.9** 60.6-80.5	**123.1** 120.3-125.4	**25.8** 0.5-42.7	**0.5**	68	35	57
Green auction: **CostSave_joint**	**67.7** 64.3-80.5	**121.7** 110.5-125.4	**15.7** 0.5-24.0	**4.2** 0.5-21.6	68	56	36