Alternative policy measures and farmers' participation to improve rural landscapes and water quality: A conceptual framework

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1. INTRODUCTION

Globalization, sustainability and multifunctionality are keywords that dominate the debate on agricultural policy reform in many countries. On one hand, national governments face the challenge to make further reductions in trade distortions, which countries agreed to limit in the Uruguay Round Agreement on Agriculture. For the agricultural sector, this will imply reductions in product and production oriented support and income losses. On the other hand, there are increasing environmental concerns and unresolved environmental problems associated with agriculture. In particular, the use of pesticides and chemical fertilizers and the disposal of animal wastes are major sources of water pollution in areas with intensive agriculture, while the growth of urban population, income and leisure have enhanced the demand for the multiple benefits of rural landscapes.

Altogether, this constitutes a challenge for agricultural and environmental policy reform toward more market orientation of agricultural production, and better integration of environmental and social concerns. Correspondingly, agricultural and environmental policies have to jointly address issues of efficiency, equity and environmental protection. The external costs and benefits of agricultural activities must be internalized to achieve an optimal resource allocation. Yet, this is complicated by the mutual interaction of policy instruments and management practices that aim at improving rural water quality and landscapes, respectively, and by the joint determination of agricultural input and land use in a watershed. Moreover, policy reforms may involve a reassignment of environmental property rights. For instance, a shift of policy towards the use of instruments that aim at internalizing external costs of agricultural water pollution would entail a transformation of the farmers' implicit right to pollute the water into an explicit right of

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society to enjoy the benefits of clean water. As a consequence, the establishment of the polluter pays principle may induce a decline of farmers' income, and, for equity reasons, call for adequate compensation.

Thus, the evaluation of policies that aim at improving rural landscapes and water quality cannot be restricted to criteria of economic efficiency. Rather, following BROMLEY (2000), two more dimensions require consideration. These entail the assignment of environmental property rights and incentive structures to alter the current policy climate. Alternative policy measures must be considered. In particular, voluntary agreements between regulators and farmers deserve attention as a policy tool for improving rural landscapes and water quality.

The aim of this article is to provide a theoretical analysis of alternative policy measures and present a conceptual framework of a voluntary agreement with farmers' participation to improve rural landscapes and water quality. To this end, a static allocation model of optimal resource allocation in a rural watershed is introduced in Section 2. This model is used to determine the conditions for an optimal resource allocation from a social planner's point of view, and to compare this with the privately optimal allocation from a farmer's perspective. Furthermore, the model provides the reference for the investigation of alternative measures to improve rural water and landscape benefits in Section 3. This involves considerations about the influence of different environmental taxes and subsidies on the assignment of environmental property rights among farmers and the public. Based on this background, a charge-subsidy scheme is proposed in Section 4 as a cost-effective instrument for pollution control and as conceptual framework of a voluntary environmental agreement between farmers and a government agency. Finally, Section 5 concludes.

2. OPTIMAL ALLOCATION OF AGRICULTURAL RESOURCES

Agriculture is an activity that modifies the natural environment for the purpose of enhancing the flow of goods and services from agricultural land. On one hand, farmers produce food and fiber and cultivate the rural landscape, which provides both amenity and functional benefits to society. On the other hand, agriculture is a major source of water pollution in many areas with high animal density and intensive crop production, respectively. Runoff and leaching from agricultural land carries salts, fertilizers, pesticides, pathogens and other pollutants into surface and ground waters, damaging aquatic ecosystems and wildlife, degrading drinking water supplies, posing risks to human and animal wealth, and impairing water for commercial and recreational uses (SHORTLE, ABLER and RIBAUDO, 2001).

As with other types of pollution, significant reductions in surface and ground water pollution in rural areas requires the application of either enforceable regulatory approaches or changes in the economic conditions, so that farmers adopt more environmental-friendly production practices. This is difficult because of the nonpoint-source characteristics of agricultural water pollution, which cannot be monitored on a continuous and widespread basis with reasonable accuracy or at reasonable cost, and which is inherently stochastic.[1] Moreover, any incentive-based control of agricultural water pollution is complicated by the fact that diversion of marginal agricultural land and the establishment of buffer strips along watercourses are at the same time measures of pollution control and a source for improved landscape benefits, such as enhanced biodiversity and rural amenities. These aspects are integrated in the analytical framework of an economic allocation model for a watershed, which combines the farmers' decisions about optimal input use and crop selection at the field level with the social costs and benefits of water pollution and agricultural land use. Using this framework, alternative measures for improving rural landscapes and water quality are examined. These measures include different policy instruments and assignments of environmental property rights, as well as a voluntary agreement with farmers' participation in an environmental contract.

2.1. A disaggregated allocation model

Following the argumentation of JUST and ANTLE (1990), our allocation problem is usefully defined in relation to an environmentally meaningful geographical unit, such as a watershed or aquifer. It involves farmers' decisions about the use of land and other agricultural inputs at the level of individual fields, and environmental characteristics that determine the productivity of the land and influence the level of pollution generated by agricultural activities on each field. Moreover, the model includes the spatial accumulation of water pollution at the watershed level, and the effect of individual land-use decisions on the rural landscape that is defined by the allocation of land among different uses. Altogether, this must be integrated in an economic allocation model which maximizes for the entire watershed the total of agricultural income plus the social benefits and disutilities of the rural landscape and water pollution, respectively.

With respect to land use, the focus of this article is on the allocation of heterogeneous agricultural land among different activities. These activities include permanent pastures, different farm management practices or farming systems that are defined by specific crop rotations and cultivation techniques (cf. LINTNER and WEERSINK, 1999; QIU and PRATO, 1999), as well as set-aside areas for pollution control and improving semi-natural habitats, respectively (cf. RIBAUDO, OSBORN and KONYAR, 1994; BABCOCK, LAKSHMINARAYAN, WU and ZILBERMAN, 1996; SUMPSI, IGLESIA and GARRIDO, 1998; WOSSINK, VAN WENUM, JURGENS and DE SNOO, 1999; BYSTRÖM, ANDERSSON and GREN, 2000; MA, TARMI and HELENIUS, 2002). The area of agricultural land is fixed in the subsequent analyses, but the individual fields are differentiated according to their environ-

1. There is a large body of literature on the economics of nonpoint-source pollution, analyzing various aspects of the problem and proposing a variety of policy measures to manage agricultural water pollution. An excellent overview and bibliography is provided in a volume edited by SHORTLE and ABLER (2001).

mental characteristics, like soil type and topography. In other words, we shall concentrate on land-use decisions at the field level and additional environmental benefits from the retirement of cropland and improvement of rural water quality. In contrast, the question of optimal land allocation between agricultural and non-agricultural uses, which is addressed in other articles (cf. McCONNELL, 1989; LOPEZ, SHAH and ALTOBELLO, 1994; BRUNSTAD, GAASLAND and VÅRDAL, 1999; HEDIGER and LEHMANN, 2003), is not the issue of this article. Rather, it determines the reference framework of our analysis.

As mentioned above, the spatial context of our allocation problem is defined with respect to the environmental unit of a watershed or aquifer, and the individual fields as production units. Correspondingly, our analysis comprehends an environmental problem (the sink problem) and a set of site-specific production problems (the sources).

2.1.1. The production problem

On each field i ($i = 1, \ldots, I$) with a given set of given environmental attributes z_i, a farmer's decision problem involves the selection of a farming system j ($j = 1, \ldots, J$), as well as the intensity of fertilizer application m_{ij} and other variable inputs v_{ij} per hectare. These intensities can be different for each site and farming system. Formally, this is depicted by the site-specific per-hectare production function $y_{ij} = f(m_{ij}, v_{ij}, z_i)$ for each farming system, which describes yield per hectare as a concave function of input intensities and environmental attributes:[2]

$$\frac{\partial f}{\partial m_{ij}} \begin{cases} > 0 & \text{for} \quad m_{ij} < \hat{m}_{ij} \\ \leq 0 & \text{for} \quad m_{ij} \geq \hat{m}_{ij} \end{cases} , \quad \frac{\partial f}{\partial v_{ij}} > 0 \quad , \quad \frac{\partial f}{\partial z_i} \geq 0 \tag{1}$$

$$\frac{\partial^2 f}{\partial m_{ij}^2} < 0 \quad , \quad \frac{\partial^2 f}{\partial v_{ij}^2} < 0 \quad , \quad \frac{\partial^2 f}{\partial z_i^2} \leq 0 \quad , \quad \frac{\partial^2 f}{\partial m_{ij} \partial v_{ij}}, \quad \frac{\partial^2 f}{\partial m_{ij} \partial z_i}, \quad \frac{\partial^2 f}{\partial v_{ij} \partial z_i} \gtreqless 0$$

This reflects the general observation that yield per hectare increases with additional factor inputs, and that plant growth is limited for biophysical reasons. This saturation effect is represented by the maximum amount of fertilizer input per hectare $\hat{m}_{ij}$ beyond which yield would not further increase with additional factor inputs.[3]

2. Notice that for a comprehensive activity analysis the set of farming systems must be defined such as to comprehend all feasible combinations of crop rotations and cultivation techniques that can be applied in a given geographical area. Hence, the allocation problem is to choose on each field the activity (farming system) that that would generate the highest return (cf. KEUSCH, 2000).
3. Theoretical descriptions and empirical estimations of agricultural production functions have been provided by various authors, including the classic book of HEXEM and HEADY (1978) and the recent work of SCHMID (2001).

Assuming given crop prices p_j, constant marginal costs of cultivation c_m and c_v, as well as fixed costs c_{ij} that are site and crop specific, the net revenue that can be earned per hectare with the farming system j on site i is:

$$\pi_{ij} = p_j y_{ij} - c_m m_{ij} - c_v v_{ij} - c_{ij} \tag{2}$$

while each plot that is taken out of production generates a uniform revenue π_0. Correspondingly, the total agricultural income at the watershed level is

$$\Pi = \sum_{i=1}^{I} \left(\sum_{j=1}^{J} \pi_{ij} x_{ij} + \pi_0 x_{i0} \right) A_i \tag{3}$$

Here, A_i denotes the size of plot i, and x_{ij} and x_{i0} represent the shares of plot that are allocated to farming system j and land retired from production, respectively:

$$\sum_{j=1}^{J} x_{ij} + x_{i0} = 1 \tag{4}$$

Thus, the farmers' private allocation problem is to maximize on each site the net revenue per hectare by choosing the optimal allocation of the agricultural land among the different options, and the optimal intensity of fertilizer and other inputs. Formally, this is to maximize

$$\pi_i = \sum_{j=1}^{J} \left(p_j f(m_{ij}, v_{ij}, z_i) - c_m m_{ij} - c_v v_{ij} - c_{ij}\right) x_{ij} + \pi_0 x_{i0} + \lambda_i \left[1 - \sum_{j=1}^{J} x_{ij} - x_{i0} \right] \tag{5}$$

with the Lagrange multiplier λ_i representing the site-specific land rent.

The private optimum on each site requires that the variable inputs are engaged according to their marginal value products:

$$p \frac{\partial f}{\partial m_{ij}} - c_m = 0 \quad \text{and} \quad p \frac{\partial f}{\partial v_{ij}} - c_v = 0 \tag{6}$$

and that the entire plot is allocated to the activity (farming system or land retirement) which generates the highest possible land rent under the given conditions:

$$\lambda_i = \max\{\pi_{ij}, \pi_0 \mid j = 1, \ldots, J\} \tag{7}$$

Yet, this abstracts from environmental impacts of agricultural activities and on-farm decisions.

2.1.2. The environmental problem

From a social point of view, the optimal allocation requires that the external benefits and costs of agricultural activities are suitably taken into consideration by the farmers. In our model, these are functions of the total set-aside area Q and the degree of water pollution E, respectively:

$$B(Q) \quad \text{and} \quad D(E) \tag{8}$$

$$B'(Q) > 0\ ,\ B''(Q) \leq 0 \quad \text{and} \quad D'(E) > 0\ ,\ D''(E) \geq 0$$

with

$$Q = \sum_{i=1}^{I} x_{i0} A_i \quad \text{and} \quad E = \sum_{i=1}^{I} \sum_{j=1}^{J} \varepsilon_{ij} x_{ij} A_i \tag{9}$$

The latter is the consequence of spatial accumulation of emissions from each site that is under production.

For each site and farming system, the potential emission per hectare is a function of factor inputs, environmental characteristics of the land, and a stochastic variable θ which reflects the influence of weather conditions on the transport and fate of pollution:

$$\varepsilon_{ij} = g(m_{ij}, v_{ij}, z_i, \theta) \tag{10}$$

$$\text{with} \quad \frac{\partial g}{\partial m_{ij}} > 0\ ,\ \frac{\partial g}{\partial v_{ij}} \gtreqless 0\ ,\ \frac{\partial g}{\partial z_i} \gtreqless 0$$

$$\frac{\partial^2 g}{\partial m_{ij}^2} > 0\ ,\ \frac{\partial^2 g}{\partial v_{ij}^2} \geq 0\ ,\ \frac{\partial^2 g}{\partial z_i^2} \geq 0\ ,\ \frac{\partial^2 g}{\partial m_{ij} \partial v_{ij}}, \frac{\partial^2 g}{\partial m_{ij} \partial z_i}, \frac{\partial^2 g}{\partial v_{ij} \partial z_i} \gtreqless 0$$

The shape of this convex function reflects the observation that the runoff and leaching of nutrients (nitrogen and phosphorus) from a given field increase with the rate of fertilizer application, and the ambiguity that can be related to changes in environmental attributes and other factor inputs (such as labor).[4]

2.2. The social optimum

Altogether, a social planner's optimization problem is to maximize the farmers' total income, Π, plus the social benefit of retiring agricultural land, $B(Q)$, minus the social cost (disutility) of rural water pollution, $D(E)$. This social objective function must be maxi-

4. The functional and parametric specification of such functions is an empirical question (cf. SCHMID, 2001).

mized subject to equations (4) and (9). This is formally represented by the subsequent Lagrange function with λ_Q, λ_E and λ_i denoting the shadow prices of the rural landscape and water pollution, and site-specific value of agricultural land (the land rents):

$$\begin{aligned} L = & \sum_{i=1}^{I}\left(\sum_{j=1}^{J}\pi_{ij}x_{ij} + \pi_0 x_{i0}\right)A_i + B(Q) - D(E) \\ & - \lambda_Q\left[Q - \sum_{i=1}^{I} x_{i0}A_i\right] + \lambda_E\left[E - \sum_{i=1}^{I}\sum_{j=1}^{J}\varepsilon_{ij}x_{ij}A_i\right] \\ & + \sum_{i=1}^{I}\lambda_i\left[1 - \sum_{j=1}^{J} x_{ij} - x_{i0}\right]A_i \qquad \max! \end{aligned} \tag{11}$$

From this concave maximization problem, we get the first-order optimality conditions of the land allocation problem on each site ($i = 1, \ldots, I$):

$$\pi_{ij} - \lambda_E\varepsilon_{ij} - \lambda_i \leq 0 \quad , \quad [\pi_{ij} - \lambda_E\varepsilon_{ij} - \lambda_i]x_{ij} = 0 \quad , \quad x_{ij} \geq 0 \tag{12}$$

$$\pi_0 + \lambda_Q + \lambda_i \leq 0 \quad , \quad [\pi_0 + \lambda_Q - \lambda_i]x_{i0} = 0 \quad , \quad x_{i0} \geq 0 \tag{13}$$

$$\sum_{j=1}^{J} x_{ij} + x_{i0} = 1 \quad , \quad \lambda_i \geq 0 \tag{14}$$

and those of the intensity problem for each site and farming system ($i = 1, \ldots, I$ and $j = 1, \ldots, J$):

$$p\frac{\partial f}{\partial m_{ij}} - c_m - \lambda_E\frac{\partial g}{\partial m_{ij}} = 0 \tag{15}$$

$$p\frac{\partial f}{\partial v_{ij}} - c_v = 0 \tag{16}$$

Moreover, we find the usual optimality conditions for the shadow prices of the environment:

$$\lambda_Q = B'(Q) \tag{17}$$

$$\lambda_E = D'(E) \tag{18}$$

and for the related environmental conditions:

$$Q = \sum_{i=1}^{I} x_{i0}A_i \tag{19}$$

$$E = \sum_{i=1}^{I} \sum_{j=1}^{J} \varepsilon_{ij} x_{ij} A_i \tag{20}$$

This set of conditions must be satisfied in order to achieve a socially optimal resource allocation. Correspondingly, the marginal social benefit of the rural landscape, $B'(Q)$, and the marginal social costs of water pollution, $D'(E)$, must be taken into account when choosing the intensity of fertilizer use and deciding about the optimal land allocation.

Given the shape of the production and emission functions, the first-order condition in equation (15) shows that from a social point of view the marginal value product of fertilizer application is larger than from a purely private perspective (cf. equation 6). Correspondingly, for each site and farming system, the fertilizer input per hectare must be reduced with respect to the private optimum. As a consequence, yield y_{ij} and income π_{ij} per hectare are lower in the social than private optimum, while the impact on other inputs depends on the sign of the mixed derivation $\partial^2 f/\partial m_{ij}\partial v_{ij}$. Moreover, as shown in equation (12), the potential land rent for each farming system is reduced in comparison to the private situation due to the external cost of pollution, $\lambda_E \varepsilon_{ij}$, while the external benefit of improving the rural landscape, $\lambda_Q = B'(Q)$, increases the value of land which is taken out of production:

$$\lambda_i = \max\{\pi_{ij} - \lambda_E \varepsilon_{ij}, \pi_0 + \lambda_Q \mid j = 1, \ldots, J\} \tag{21}$$

In other words, there must be more land retired in the social optimum than from a private point of view, and the intensity of fertilizer use must be lower on the remaining land of production.

This socially optimal situation cannot be achieved without adequate incentives or regulations. Thus, there is a argument in favor of government intervention. However, it is difficult to achieve the socially optimal levels of rural landscape and water quality because of (a) the nonpoint-source characteristics of agricultural water pollution, (b) the joint determination of fertilizer input and land use, (c) the mutual interactions of different policy instruments, and (d) the income effect of changing environmental property rights. These issues are analyzed in the next section.

3. TAXES AND SUBSIDIES TO IMPROVE WATER QUALITY AND LANDSCAPE BENEFITS

3.1. *Effluent charge and landscape subsidy*

Using the above results, the formulation of an efficient policy for internalizing the external costs and benefits of agriculture seems straightforward. It would require that emissions from each site should be charged at a rate equal to the marginal damage cost of pollution, $\tau = D'(E)$, and subsidies for land retirement at a rate equal to the marginal social benefit of additional landscape elements, such as extensive meadows, buffer strips and hedges, $\sigma = B'(Q)$. In this case, the total agricultural income in the watershed would be:

$$\Pi^* = \sum_{i=1}^{I}\left(\sum_{j=1}^{J}(\pi_{ij} - \tau\varepsilon_{ij} - \lambda_i)x_{ij} + (\pi_0 + \sigma - \lambda_i)x_{i0}\right)A_i + \sum_{i=1}^{I}\lambda_i A_i \tag{22}$$

The last term on the right-hand side represents the aggregate land rent.

For profit maximizing farmers, the optimality conditions would formally be the same as given in equations (12) to (20), with $\lambda_E \equiv \tau$ and $\lambda_Q \equiv \sigma$. With respect to the individual farmer's decisions at the intensive and extensive margins, this implies:

$$\tau = \left(p\frac{\partial f}{\partial m_{ij}} - c_m\right)\Big/\frac{\partial g}{\partial m_{ij}} = D'(E) \quad , \quad \forall\, i,j \tag{23}$$

and

$$\lambda_i = \max\{\pi_{ij} - \tau\varepsilon_{ij} \ , \ \pi_0 + \sigma \mid j = 1,\ldots,J\} \quad , \quad \forall\, i \tag{24}$$

Thus, a policy making use of the artificial prices τ and σ to charge farmers for negative and compensate them for positive externalities, respectively, would theoretically give an incentive to farmers for taking marginal land out of production and reducing the intensity of fertilizer use on each production site, such as to achieve the socially optimal rural landscape and water quality. This would require to charge each farmer for the effective emissions ε_{ij} from each site. However, this is not, in general, a feasible policy option because agricultural water pollution is a nonpoint-source problem.

Given spatial differences in biophysical conditions and processes and the stochastic nature of weather which plays a causal role in the process, flows of pollutant from nonpoint sources cannot be monitored on a continuous and widespread basis with reasonable accuracy or at reasonable cost.

3.2. *A system of input taxes*

An alternative is to individually charge every factor on which the nonpoint externality generation depends (GRIFFIN and BROMLEY, 1982). In the context of our model, this implies a land use tax τ_{ij} which accounts for site and crop specific characteristics, and a uniform fertilizer tax τ_m levied on each unit of fertilizer input. Under consideration of this two-part pollution tax, the total agricultural income in the watershed is:

$$\Pi = \sum_{i=1}^{I}\left(\sum_{j=1}^{J}(\pi_{ij} - \tau_{ij} - \tau_m m_{ij} - \lambda_i)x_{ij} + (\pi_0 + \sigma - \lambda_i)x_{i0}\right)A_i + \sum_{i=1}^{I}\lambda_i A_i \tag{25}$$

whereas the following equalities must hold in order to realize the same outcome (social optimum) as with the Paretean effluent charge $\tau = D'(E)$ in the previous case.

The conditions for a socially optimal allocation with a land use and fertilizer tax are $(\forall\, i, j)$:

$$\tau_{ij} + \tau_m m_{ij} = \tau \varepsilon_{ij} \quad \text{and} \quad \tau_m = p\frac{\partial f}{\partial m_{ij}} - c_m = \tau\frac{\partial g}{\partial m_{ij}} \tag{26}$$

For each site and farming system, the charge per hectare must be exactly the same as in the previous case with a single tax, and the fertilizer tax must be set such as to induce the same conditional intensities of fertilizer application. Apparently, this cannot be determined without adequate information about individual emission functions and about pollution accumulation at the watershed scale. To this end, biophysical models are required that link farming practices to pollution loads, and to chemical and biological indicators of water quality (RIBAUDO and SHORTLE, 2001). In addition, valuation studies are needed for the assessment of the benefits of both rural landscape and water quality improvement.

Altogether, if suitably designed, a combined approach with land use and fertilizer taxes can induce farmers to choose an allocation of production factors which is socially optimal. However, in areas with intensive agriculture and serious water pollution problems, farmers may oppose such policy because they loose the total amount τE of tax payment. The core problem is that any tax system, imposed to price the emission of pollutants, induces a reallocation of environmental property rights in comparison to the situation without such instruments, where farmers had the implicit right to pollute without being charged.

3.3. Subsidies for land retirement

An obvious alternative to taxing a negative externality is to subsidize farmers for the reduction of this externality. In this case, the farmers keep the right to pollute and receive a compensation for their marginal incremental cost of compliance with some specified environmental target.

One form of compensation is the provision of a land retirement subsidy which aims at improving rural water quality to the desired level. Yet, this is not, in general, the socially optimal level of pollution, since the land retirement subsidy does not give an incentive to reduce intensities of fertilizer application, but it provides an additional incentive for land retirement. As a consequence, aggregate pollution remains above the social optimum despite the fact that too much land is taken out of production. In contrast, if exclusively based on motives for increasing ecological and amenity benefits, a uniform subsidy for land retirement will not be sufficient to achieve the socially optimal levels of landscape and water quality benefits.

A more general difficulty is that the proper assessment of a socially optimal policy requires information about landscape benefits and pollution-induced damage costs. This can be resolved in two different ways. On one hand, the assessment can be completed with environmental valuation studies (cf. RIBAUDO and SHORTLE, 2001). On the other hand, one may use predetermined environmental standards as an instrument of environmental policy, such as originally proposed by BAUMOL and OATES (1971) as an alternative to setting Pigovian taxes and subsidies. Their basic idea of using prices and standards has also received attention in the economic literature on nonpoint-source pollution, including the early articles by GRIFFIN and BROMLEY (1982) and SEGERSON (1988), as well as in the more recent literature on ambient-based instruments (cf. CABE and HERRIGES, 1992; XEPAPADEAS, 1995; QIU and PRATO, 1999).

With respect to agricultural water pollution, the pricing-and-standards approach requires that a water quality standard has either been politically or bureaucratically determined, and that this target is achieved at least cost to the region. Apparently, this implies a normative shift which gives farmers the right to pollute the water body up to the maximum level of the ambient standard. On the other hand, it shifts the financial burden to the public which has to make funds available to compensate farmers who give up production on selected sites.

Without an effluent charge, but with a subsidy for land retirement consisting of two parts, the total agricultural income in the watershed is:

$$\Pi^\circ = \sum_{i=1}^{I}\left(\sum_{j=1}^{J}(\pi_{ij} - \lambda_i)x_{ij} + (\pi_0 + \sigma + \sigma_i - \lambda_i)x_{i0}\right)A_i + \sum_{i=1}^{I}\lambda_i A_i \qquad (27)$$

In this case, $\sigma = B'(Q)$ represents the rate of the landscape-improvement subsidy, and σ_i denotes the rate of the site-specific pollution-control subsidy. The latter is required to lease land away from production. This must be carefully targeted to meet the least-cost requirement of pollution control. Correspondingly, the pollution-control subsidy is determined by the additional cost of land retirement that is required for achieving the water quality target. For those plots that are to be retired ($x_{i0} = 1$) in order to satisfy the water quality target, the minimum rate of subsidy is:

$$\sigma_i = \max_{\{j\}}\{\pi_{ij}\} - \pi_0 - \sigma \qquad (28)$$

For plots that, for achieving the optimal outcome, shall remain under crop production ($x_{i0} = 0$), no additional subsidy is required; $\sigma_i = 0$ is sufficient.

In sum, this suggests that, using spatial information about land rents and costs of land retirement, a differentiated policy with site-specific subsidies could help to achieve the water quality target at minimum cost for the environmental authority. However, the information acquisition could be expensive, and farmers may oppose for equity reasons against a differentiated subsidy scheme. In this case, the government may grant one single subsidy

$$\hat{\sigma} = B'(Q) + \max_i[\sigma_i x_{i0}] \tag{29}$$

This would be sufficient to achieve the water quality target. But, it would be more costly for the public hand, and it would be in contradiction with the famous conclusion of TINBERGEN (1952) that there should be at least one policy measure for each policy objective.

4. A BALANCED CHARGE-SUBSIDY SCHEME FOR POLLUTION CONTROL

The combination of taxes and subsidies for pollution control constitutes another alternative to taxing negative externalities without altering the assignment of environmental property rights. It requires that some effluent charge is collected and that the revenues are fully earmarked to farmers as a subsidy for the retirement of agricultural land and conversion into extensive grassland, buffer strips and forest land (HEDIGER, 2003). In the following, this budget-balancing charge-subsidy scheme is extended to include both benefits of water quality and landscape improvement. It involves the assumption of a predetermined water quality standard.

For the subsequent analysis this standard is translated into a regional limit on total emissions, $E_§$, that should not be exceeded. On the contrary, landscape quality Q is free, as in the original model in Section 2, and farmers receive a subsidy equal to the marginal external benefit of improving the rural landscape: $\sigma = B'(Q)$. Correspondingly, the aggregate farmers' income in the watershed is:

$$\begin{aligned}\tilde{\Pi} = &\sum_{i=1}^{I}\left(\sum_{j=1}^{J}\pi_{ij}x_{ij} + (\pi_0 + \sigma)x_{i0}\right)A_i + \sum_{i=1}^{I}\lambda_i\left[1 - \sum_{j=1}^{J}x_{ij} - x_{i0}\right]A_i \\ &+ \tilde{\lambda}_E\left[E_§ - \sum_{i=1}^{I}\sum_{j=1}^{J}\varepsilon_{ij}x_{ij}A_i\right]\end{aligned} \tag{30}$$

In contrast to the previous section, the charge-subsidy scheme gives, on one side, farmers the right to pollute the affected water body up to the environmental standard. It implies the assignment of a partial property right on a natural resource and of the related rent, $\tilde{\lambda}_E E_§$, with $\tilde{\lambda}_E$ denoting the shadow price of the water quality constraint. On the other side, this policy scheme implies that consumers have the right to enjoy water quality at the predetermined level. In addition, the budget of this charge-subsidy scheme shall be balanced.

Given these conditions, incentives are required that are designed to achieve the environmental quality goal at minimum cost. As shown in the previous section, the combination of a land use tax with a fertilizer tax is such a policy measure. In this case, equation (30) becomes:

$$\tilde{\Pi} = \sum_{i=1}^{I}\left(\sum_{j=1}^{J}(\pi_{ij} - \tilde{\tau}_{ij} - \tilde{\tau}_m m_{ij} - \lambda_i)x_{ij} + (\pi_0 + \sigma - \lambda_i)x_{i0}\right)A_i + \sum_{i=1}^{I}\lambda_i A_i + \tilde{\lambda}_E E_§ \tag{31}$$

It consists of three parts: the farmers' profits, the land rents, and the environmental resource rent. So far we have not specified the use of the latter, which is equal to the total tax revenue:

$$\tilde{\lambda}_E E_{\S} = \sum_{i=1}^{I}\sum_{j=1}^{J}(\tilde{\tau}_{ij} + \tilde{\tau}_m m_{ij})x_{ij}A_i \tag{32}$$

It can be reimbursed to the farmers on either a per-capita or per-hectare basis. Both variants are allocation neutral with respect to the given allocation of agricultural and non-agricultural land. Yet, the idea of the charge-subsidy scheme is to use this revenue for subsidizing the land retirement as a tool of pollution control. In our model, this can be introduced as an additional subsidy $\tilde{\psi}$ per hectare of land that is retired. The requirement for a balanced budget is then:

$$\tilde{\psi} \cdot \sum_{i=1}^{I} x_{i0}A_i = \tilde{\lambda}_E E_{\S} = \sum_{i=1}^{I}\sum_{j=1}^{J}(\tilde{\tau}_{ij} + \tilde{\tau}_m m_{ij})x_{ij}A_i \tag{33}$$

Hence, equation (31) changes to

$$\tilde{\Pi} = \sum_{i=1}^{I}\left(\sum_{j=1}^{J}(\pi_{ij} - \tilde{\tau}_{ij} - \tilde{\tau}_m m_{ij} - \lambda_i)x_{ij} + (\pi_0 + \sigma + \tilde{\psi} - \lambda_i)x_{i0}\right)A_i + \sum_{i=1}^{I}\lambda_i A_i \tag{34}$$

and the resulting land rents are

$$\lambda_i = \max\{\pi_{ij} - \tilde{\tau}_{ij} - \tilde{\tau}_m m_{ij}, \pi_0 + \sigma + \tilde{\psi} \mid j = 1, \ldots, J\}, \quad \forall\, i \tag{35}$$

With respect to the influence of the additional subsidy $\tilde{\psi}$, equation (35) indicates that the amount of land retired and thus the landscape quality increase. As a consequence, there is less pressure to reduce the flow of pollution from the remaining sources. This implies a higher rate of fertilizer application per hectare, a lower shadow price, and lower tax rates to control pollution than in the reference case without the subsidy $\tilde{\psi}$. Moreover, the charge-subsidy scheme leaves the full property right on the land and landscape benefits, as well as a certain right to pollute with the farmers. This should result in a higher aggregate farm income than under a tax-based policy, and a lower burden for the public hand than under a policy with pure subsidies. Altogether, this suggests that the proposed charge-subsidy scheme could be an appealing policy instrument for rural landscape and water quality improvements, to both farmers and the public. Moreover, it could provide the conceptual basis for a voluntary environmental agreement between farmers and a government agency.

The idea of voluntary agreements has gained much attention as an alternative to mandatory approaches based on regulation or legislation (CARRARO and LÉVÊQUE, 1999;

OECD, 1998; WU and BABCOCK, 1999). A voluntary agreement is the equilibrium outcome of the interaction between a polluter and a regulatory agency (SEGERSON and MICELI, 1998). It involves agreement upon an ambient quality standard that is binding to the signatories of the contract, and requires regulatory threats and reliable monitoring to involve sufficient participation. These threats call for the imposition of regulatory instruments if and when the voluntary approach fails to meet the environmental targets (ALBERINI and SEGERSON, 2002).

Given the fact that farmers usually have more information than government authorities about on-farm inputs in production but less information about biophysical processes that influence yield and pollution, cooperative approaches are the most suitable to improve rural landscapes and water quality at the watershed level. Voluntary agreements constitute an institutional framework for such cooperation. A balanced charge-subsidy scheme offers the least-cost instrument for achieving environmental targets, and implies a minimum change of environmental property rights in comparison to the situation without internalizing external costs and benefits of agriculture.

Building on this background, we can conceptualize a voluntary agreement for improving rural landscape and water quality as follows. Once the parties have agreed upon the water quality target and the signatories have accepted to take the responsibility to achieve this target, the charge-subsidy scheme is used as a cost-effective price mechanism among the participating farmers. They could form a club which collects a land use tax and distributes the revenue to subsidize land retirement for achieving the water quality target. If this target is met, the signatories of the contract also receive a government subsidy according to the marginal social benefit of the landscape. Non-signatories are neither charged nor do they receive any subsidy. The regulatory agency monitors water quality, and, if the environmental target is not met, this authority can impose taxes on land use and fertilizer inputs upon all farmers. However, the regulator must take into account that extreme weather events can have a strong influence on rural water quality, and that, dependent on the initial policy regime, a period of adjustment is required to find the cost-effective solution and compliance with the ambient target.

5. CONCLUSION

The results show that, to attain an efficient resource allocation, farmers must be compensated for the provision of environmental benefits (positive externalities) of agricultural land use (landscape), and charged for the negative externalities of water pollution. However, this is complicated by the nonpoint-source character of agricultural water pollution, by the joint determination of agricultural inputs and land allocation, and by the impact on environmental property rights which different policy instruments have.

A policy which combines a land use tax with a fertilizer tax and a subsidy for land retirement can give incentives to farmers, such that the aggregate outcome is a social optimum. However, it implies a reassignment of the implicit property right on water bodies from farmers to consumers. On the contrary, a subsidy for pollution control leaves this right with the farmers. It results in a suboptimal allocation of agricultural land and an increased intensity of fertilizer inputs, while subsidies for buffer zones and land retirement will not in general be sufficient to meet water quality targets if they are exclusively based on motives for increasing ecological and amenity benefits. Nonetheless, some form of subsidy or transfer payment to farmers will be required to compensate them, at least partially, for their income losses due to the reassignment of environmental property rights that accrues under the regime of an effluent-based charge on either inputs or emissions.

One option is the use of the "effluent charge" revenue to compensate farmers for the cost of compliance with a socially determined and agreed upon water quality standard. This could provide a basis for a voluntary agreement with farmers' participation in an environmental contract in the watershed. Additional incentives for participation can come from a cross-compliance scheme which gives farmers a subsidy for their provision of external landscape benefits, as long as the agreed water quality targets are met. Moreover the existence of two types of asymmetric information can provide an incentive for participation in an environmental agreement. On one hand, farmers have knowledge about their effective management practices and input use. On the other hand, they do not in general have sufficient information about the biophysical characteristics of their soils to determine the socially optimal input of pesticides and fertilizers. Some monitoring and model-based information will be required, along with consulting services provided by agricultural and environmental authorities.

All in all, the problems of agricultural water pollution and the provision of rural landscapes can be jointly addressed with an adequate mix of policy instruments, with a charge-subsidy scheme for pollution control and compensation for the provision of rural amenities, and farmers' participation in a local environmental agreement. This must be designed at the local scale to adequately reflect local environmental conditions.

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SUMMARY

The challenge of rural landscape and water quality improvement is investigated as a problem of positive and negative externalities. Based on this analytical background, alternative policy measures are evaluated, and a charge-subsidy scheme with balanced budget is proposed as a cost-effective instrument of pollution control. It earmarks the revenue of

a combined land use and fertilizer tax to subsidize farmers for land retirement. In combination with a subsidy for the social benefits of the rural landscape, the charge-subsidy scheme provides a conceptual framework for the design of a voluntary environmental agreement between farmers and the regulator. Moreover, while contributing to an environmental quality improvement in rural areas, it leaves the property right on the land resources with the farmers, gives consumers the right to enjoy water quality at a sufficient and socially agreed level and farmers the right to pollute up to this level.

ZUSAMMENFASSUNG

Die Verbesserung der Landschafts- und Gewässerqualität im ländlichen Raum wird dargestellt als ein Problem von positiven und negativen Externalitäten. Auf dieser analytischen Grundlage, werden alternative Politikmassnahmen beurteilt, und es wird eine Lenkungsabgaben-Subventions-Lösung mit ausgeglichenem Budget als kosten-effektives Instrument für die Kontrolle landwirtschaftlicher Gewässerverschmutzung vorgeschlagen, welches die Einnahmen aus einer kombinierten Landnutzungs- und Dünger-Steuer für die Subventionierung von Flächenstilllegungen verwendet. Zusammen mit einer Abgeltung für die sozialen Nutzen der Kulturlandschaft stellt dies den konzeptionellen Rahmen dar für die Ausgestaltung einer freiwilligen Vereinbarung zwischen Landwirten und der zuständigen Umweltbehörde. Dadurch kann insgesamt ein Beitrag geleistet werden zur Verbesserung der Umweltqualität im ländlichen Raum. Zudem werden die Eigentumsrechte an den Landressourcen bei den Landwirten belassen, während die Konsumenten implizit das Recht erhalten, sich an einer ausreichend guten Gewässerqualität zu erfreuen, und die Landwirte dasjenige, die Gewässer bis zu einem gesellschaftlich vereinbarten, maximalen Grad der Verschmutzung zu belasten.

RÉSUMÉ

L'amélioration des paysages et de la qualité de l'eau en milieu rural est représentée par un problème d'externalités positives et négatives. A partir de cette base analytique, des mesures politiques alternatives sont évaluées. En tant qu'instrument efficace et minimisant les frais, une système de taxes et subventions à budget équilibré est proposée pour le contrôle de la pollution agricole des eaux. Le revenu de taxes imposées aux engrais et à l'utilisation des terres est redistribué en tant que subventions pour l'abandon de terres agricoles. Avec les subventions pour le bénéfice social de paysages cultivés, cette approche représente un cadre conceptuel pour la création d'accords volontaires entre agriculteurs et institutions environnementales. En améliorant ainsi la qualité de l'environnement en milieu rural, les droits de propriété des ressources des terres restent chez les agriculteurs. En plus, les consommateurs peuvent jouir d'une qualité de l'eau améliorée et les agriculteurs peuvent continuer à polluer l'eau jusqu'à une limite maximale déterminée par un consensus social.