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Abstract

This paper presents an incentive scheme to control agricultural non-point-source pollution. The analysis is based on a nested agent framework with three parties; farmers, a country's government, and the governments of all countries that affect each other's environmental quality. Unlike previous analysis of incentive schemes to control agricultural pollution, we suggest non-individual contracts between farmers and a regulating authority as a solution to the domestic pollution problem. Our incentive scheme proposes collective penalties as a way to control pollution. To solve the international problem of pollution management of a common (water) resource, we propose an international agency with authority to write and enforce contracts in each of its member countries. We show that the information requirement on a country's government can be substantially reduced if contracts can be made non-individual.

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Introduction

Non-point source (NPS) pollution has during the last decade received substantial attention, both in policy and in terms of identifying feasible and cost-effective solutions to abatement problems. Griffin&Bromley (1982) show that NPS pollution can be effectively monitored even though pollution can not be traced to its source. By taxing inputs rather than outputs they show that an equally efficient solution can be obtained as when emissions can be directly monitored. This work was continued by Shortle&Dunn (1986) who included uncertainty in the problem and showed that an efficient solution can be obtained even under these conditions

Controlling inputs can certainly help to control NPS pollution, since the main source of agricultural pollution is surface runoff and ground water leaching of nutrients and pesticides. Focusing on the use of inputs only, does however mean that potentially important abatement measures are ignored. Management oriented measures, such as different cropping patterns or land use have also been suggested to reduce agricultural pollution (Drake 1993, Fleischer et al 1989). An input-focused policy will thus ignore the potential for these measures.

Incentive schemes that allow for a more flexible approach to agricultural pollution problems have been suggested by Segerson (1988), Meran&Schwalbe (1987), and Xepapadeas (1992). Policies are based on collective rewards and penalties. Under these incentive schemes, farmers are free to choose the method to reduce pollution, as long as the aggregated pollution does not exceed a certain level. One shortcoming of the incentive schemes is that they are based on individual contracting between firms and a regulating authority. This requires that the regulating authority has substantial information in order for it to be able to formulate optimal contracts for each firm.

The purpose of this paper is to formulate a policy that allows and encourages cost-effective solutions to NPS pollution problems. We describe and discuss the problem of agricultural pollution in the context of uncertainty and internationally distributed pollutants. We also provide a suggested solution to an agricultural NPS pollution problem on both a national and an international level.

We use a nested agent framework with farmers, governments, and a ”Super-State-Authority” as the parties in the pollution-abatement process. The incentive scheme that we propose is based on collective penalties for farmers. It is shown that individual contracts with each farmer are not necessary to achieve cost-effective abatement of NPS pollution. In the suggested incentive scheme, we also show that international NPS pollution can be effectively monitored by the notion of an international agency with authority to act as a law-enforcer in its member-countries.

Parties in a water quality policy

In defining policies for NPS water pollution we have parties acting on three levels: First, there are farmers who produce goods, but also affect water quality by their actions. Second, we have a country’s government which has an interest to increase and maintain welfare in the country. Third, we have the governments of all the countries that affect each other’s water quality. This means that the government of each country plays two roles which may be in conflict with each other; in one role it acts as a law-enforcer of environmental legislation to make sure that polluters comply with environmental laws. In the other role the government acts as a representative for its consumers and polluters to advance the country's interests from an international agreement.

Farmers and water quality

Farmers provide food for consumption but their production also affects water quality. We assume that farmers produce two goods; crops (*y*) and water quality *(e)*. Water quality production is defined to be measures that a farmer can take to reduce leaching of nutrients from arable land.

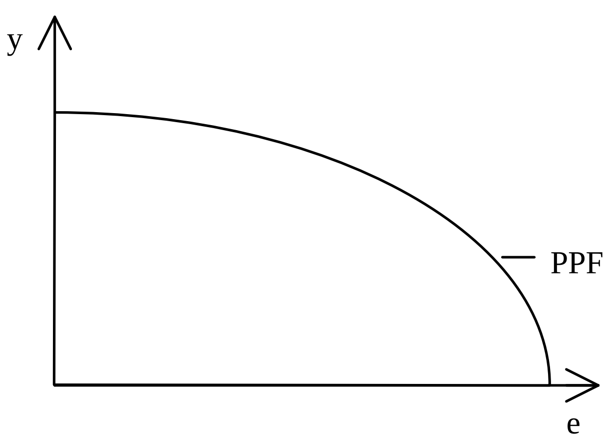
Farmers use several inputs in their crop production. Labor, capital, land, and fertilizer are some examples. These factors are not specific for crop production, some of them could equally well be used for production of water quality. We will make the simplifying assumption that both crop production and water quality production are functions of the factors capital (K), labor (L), and land (A). The factor land is not homogenous, we may have several different kinds of land uses each with different effects on farmers profits and water quality.

Production of crops is associated with uncertainty. Harvest is affected by stochastic factors, such as precipitation and temperature. Therefore farmers can not know exactly what will be the profits associated with a certain input. As we in this paper do not analyze the effects of uncertainties in crop production, we will make the simplifying assumption that crop yield is not stochastic. We can now write the production functions for crops as $y = y(K, L, A)$.

If we assume that all other sources of pollution are held constant, we can write water quality as a function of farmers' factor use. Factor use alone however does not capture the full effects of farmers' impact on water quality. Stochastic events such as storms and temperature affect how much of the nutrients applied to arable land will finally reach the sea, and thus also determine agricultural impact on water quality. Let the uncertainty be captured in the stochastic variable δ. We can thus write the stochastic production function for water quality as $e = e(K, L, A, \delta)$. Let the production functions be such that both production of y and e is increasing in factor use. In reality it might be difficult to distinguish among what measures increase water quality and crop yield respectively, especially since some of the measures might increase both.

Each farmer has a potential trade-off between y and e. We can picture this trade-off as a production possibility frontier (PPF), where farmers, depending on their endowments, have possibilities to produce certain amounts of crops and water quality.

Figure 1. A Farmer's production possibilities in terms of crop and water quality production



As a regulating authority, the government wants to minimize its costs for obtaining sufficient information about the farmers. It is therefore in the interest of the government to find a control measure that requires a minimum of information. We will make the assumption that the government does not have sufficient information to regulate in detail farmers' use of factors. We also assume that the government does not have information whether a particular farm is efficient or not. Indeed not even the farmer has this information. It is therefore unnecessary to write production functions for *y* and *e* as functions of the factor use. Instead we can write crop production and water quality as functions of expenditure.

If we denote the expenditure level by '*c*', and let '*a*' be the fraction of '*c*' that is used for water quality production, we can redefine the production functions for *y* and *e*. Let also the factor input in crop production be denoted by $d=c-a$. In terms of figure 1 the expenditure level, *c*, is represented by a PPF-curve. The expenditure levels, *a* and *d*, are linear combinations of *c*, yielding different levels of crops and water quality. It is now possible to write the production functions for *y* and *e* as functions of the expenditure in each production:

$$y^i=y^i(d^i) \qquad e^i=e^i(a^i,\delta)$$

The Government

In order to gain influence over farmers' production of *y* and *e,* the government would want to find a feasible way to affect farmers' factor use; the composition of *c*. In the case of perfect information, the objective of the government is to maximize welfare with respect to agricultural factor use. But are the choices of farmers observable? A plausible assumption is that the government can not obtain farm-specific information about factor use, and thus not be able to observe the level of *a* and *d* directly. In this setting farmers have an informational advantage over the government. This asymmetry of information motivates a principal-agent approach. In order to maximize welfare the government needs an incentive system that makes farmers improve water quality. However, there exists some common knowledge. The government can costlessly observe the outcome of farmers' factor use. Output and water quality is observable ex-post, but despite this information the government can not observe factor use directly, and hence will have less information than farmers.

Individual farm yield of crops, and individual farm impact on pollution, depend on details such as management of the local farm, soil type, and local climate. It is therefore desirable to find a system of payments that is flexible enough to allow farmers to make their own decisions on whether to allocate factors to improve water quality. Indeed, a system that corresponds to a regime of ”marketable permits” would take care of inefficiencies. The problem here is however that it is difficult, or associated with large costs, to trace pollution back to the polluter, and thus there are limited opportunities to control compliance with any direct regulation of emissions.

The impossible ”n”

Policies for reducing non-point source (NPS) pollution have been suggested by a number of authors. A crucial part of a NPS policy must be its flexibility and ability to encourage cost-effective abatement of NPS pollution. Therefore direct regulation or direct taxation of factors seems to be a less desirable way of achieving NPS pollution abatement.

Griffin&Bromley (1982), Shortle&Dunn (1986), and other authors suggest that when actual emissions can not be measured, pollution should be monitored by controlling the use of inputs. Even though this method will reduce water pollution, it fails to include potentially important and cost-effective abatement measures, such as improved management practices.

Incentive schemes to ensure cost-effective abatement of NPS pollution have been suggested by authors such as Segerson (1988), Xepapadeas (1992), and Meran&Schwalbe (1987). We will briefly summarize and discus some of the properties of these approaches, especially from the point of view of information requirement and efficiency. The general outline of the incentive systems that are proposed by the authors, is given in Holmström (1982). He designs a system that enables the principal to obtain a first best solution, even though the actions of agents can not be observed. He also shows that the proposed system eliminates moral hazard.

Segerson (1988) presents an incentive scheme that builds on collective payments with individual contracts for all polluters. She assumes that the emissions from individual polluters can not be measured but that it is possible to measure ambient concentrations of the pollutants. In her suggested incentive scheme an ambient pollution standard is set. If the aggregate pollution is less than that dictated by the ambient standard, then firms receive a positive payment. If pollution levels exceed the standard, each polluter has to pay a fee that is linear in ambient pollution level, plus a penalty for exceeding the ambient pollution level. In the latter case, each polluter must pay the penalty, no matter whether they have undertaken any pollution abatement measures. The fact that the system relies on individual contracts and does not allow for ”pollution trade” among farmers, makes the system look more like a system of Pigouvian taxes than a ”bubble”, as was proposed by Segerson.

Meran&Schwalbe (1987) show that it is possible to design incentive schemes based on effluent taxes or effluent standards even though the effluent emission level can not be observed. They suggest a system, based on the ambient concentration of pollutants, where every polluter is liable if the ambient pollution level is exceeded. They suggest two types of individually designed contracts where the polluter must pay a fee if the aggregate level of pollution exceeds the ambient standard. The polluter pays nothing if the ambient pollution standard is not violated. By this incentive scheme they show that both effluent taxes and ambient standards can be used effectively, despite the fact that effluent levels of pollution are not observable.

Xepapadeas (1992) suggests a scheme where contracts are not individual, but each firm pays the same fine if deviations from the ambient standard are detected. While the analysis is presented in a dynamic framework, Xepapadeas shows that the conclusions are equally valid under a static incentive scheme.

The incentive schemes suggested by Segerson and by Meran&Schwalbe build on individual contracting. This means that the policy-maker must design ”n” different contracts requiring unique information about ”n” different firms. This information requirement may be unrealistic or costly to obtain. If we include information costs into the design of incentive schemes for NPS pollution abatement, it is doubtful whether optimal contracts based on individual contracts would be the least-cost way of abating NPS pollution. The complexity of the design may destroy the efficiency gains induced by optimal contracting.

An assumption in these studies is that the agents are risk neutral, implying that agents have identical risk preferences[1]. If contracts are individual, non-homogenous risk preferences does not pose any problems since each contract can be designed to reflect individual risk-preferences; an optimal allocation of abatement is reached. Xepapadeas (1992) suggests uniform contracts for all the polluters. In this case a cost-effective solution may not be achieved if farmers are not homogeneously risk-averse. Xepapadeas does not allow for any side-payments and thus closes the possibility for polluters to improve their utility by trading pollution with others.

Suggested incentive scheme

In this section we suggest an alternative design of incentive schemes for NPS pollution. As pointed out earlier in this paper, the costs of information are significant for the government. Due to asymmetric information between farmers and government, farmers have an informational advantage. The information possessed by farmers can not be used by the government unless an incentive scheme is designed in such a way that farmers can use their private information to improve overall welfare. We suggest an incentive scheme that: i) reduces information requirement on the government; and ii) forces farmers to reveal their factor use.

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[1] This assumption is implicit in Xepapadeas and Segerson

We propose an incentive scheme that is not based on individual contracts. The suggested system rests on collective payments and an ambient standard for a watershed. A similar system was proposed in Holmström (1982) and in Meran&Schwalbe (1987), the difference here is that we propose non-individual contracts with the polluters. We also allow the farmers to negotiate and trade water quality improvements amongst themselves. Using contracts that are not individual allows us to reduce the information requirements for the government. Allowing for negotiations among farmers ensures that a cost-effective solution can be reached even under non-homogenous risk aversion and different preferences. In this sense, the suggested incentive scheme is a ”virtual” tradable permit system.

Assume that emissions from a particular farm can not be observed. The government can, however, observe ambient water quality along a river or stream. Based on observed ambient water quality, the government then formulates an incentive scheme according to the following criteria:

Let $T(e)$ be a payment scheme that is identical for all farms, let e^* be the minimum required ambient water quality, and the observed ambient water quality, $e(\mathbf{a}, \delta)$, where $\mathbf{a} = (a^1,...,a^n)$. $T(e)$ will be zero if ambient water quality is higher than the required e^*, and strictly positive if the observed water quality is below e^*. We can thus write $T(e)$ as:

$$T(e) = \begin{Bmatrix} 0 & if & e \geq e^* \\ \beta & if & e < e^* \end{Bmatrix}$$

where $\beta > 0$. It was noted earlier that the observed quality is stochastic, $e=e(\boldsymbol{a},\delta)$. This means that even though all firms comply with the standard, there is a risk that water quality will be less than that required by the ambient standard. The probability for paying the penalty is therefore never zero, but varies with the input use of farmers, and with the ambient standard, e^*, set by the government. We can write the probability of paying the penalty as $\int_0^{e^*} f(e;\boldsymbol{a})de$, that is, the probability that observed water quality will be less than the required e*, given farmer's expenditure on water quality. The probability of paying the penalty decreases with expenditures in water quality since increased expenditure gives increased water quality. This means that $\int_0^{e^*} f_{a^i}(e;\boldsymbol{a})de < 0$, where subscripts denotes the derivative with respect to farm i's expenditures.

We will also allow a payment among farmers where they can buy or sell water quality improvements. Instead of increasing the efforts at their own farms, farmers may choose to bribe other farmers and thereby affect the probability of paying the penalty. The payment that a bribing farmer will make to the others will then be a function of other farmers' costs, risk aversion, and current allocation of factors. Let us write farmer *i's* bribing cost function as $B^{-i}(\boldsymbol{a})$.

We will assume that farmers are risk averse and put some value to a certain income. Let *V(...)* denote the utility of income. Farmers will maximize utility with respect to both their own efforts and with respect to the efforts of other farmers. There is an interdependence between farmers in that the probability of paying the penalty is determined through the efforts of all farmers. The side-payments, B^{-i}, increases farmers' possibilities to affect the expected penalty, and also ensures that water quality is produced in a cost-effective way since farmers can trade water quality improvements.

To simplify notation, we can write farmers' objective function as a function only of water quality production. The maximization problem for farmer *i* is then:

$$\underset{a^i, a^j}{Max} \quad V\left[py(c^i - a^i) - \int_0^{e*} f(e;\mathbf{a})de\beta \right] - c^i - B^{-i}$$

Farmers maximize their profits and take the levels of penalty and ambient standard as given. Note that the probability of paying the penalty is affected by the level of the ambient standard. We can write the first-order conditions for the maximization problem as[2]:

$$V'[\cdot]\left[py_{a^i} - \int_0^{e*} f_{a^i}(e;\mathbf{a})de\beta \right] - 1 - B^{-i}_{a^i} = 0$$

$$-V'[\cdot]\int_0^{e*} f_{a^j}(e;\mathbf{a})de\beta - B^{-i}_{a^j} = 0$$

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[2] $B^{-i}_{a^i} = V_j'[\cdot]\int_0^{e*} f_{a^i}(e;\mathbf{a})de\beta$ and $B^{-i}_{a^j} = -V_j'[\cdot]\left[py_{a^j} - \int_0^{e*} f_{a^j}(e;\mathbf{a})de\beta \right] + 1$

From the first-order conditions we can derive optimal allocations between crop production and water quality. If we denote farmer i's optimal allocation by a^i*, the profit is now given by:

$$\pi^i(a*;e) = V\left[py(c^i - a^i*) - \int_0^{e*} f(e;\mathbf{a*})de\beta*\right] - c^i - B^{-i}*$$

where $B^{-i}* = B^{-i}(\mathbf{a*})$. There is a possibility that farmers' profits will be negative in this case, depending on the probability of paying the penalty, and the shape of their utility function.

Now, how large is the payment B^{-i} , and why do we need this payment ? Let us begin with the latter question: Assume that farmers have different attitudes towards risk. A risk-averse farmer will then undertake more efforts to reduce the probability of paying the penalty than will a risk-neutral farmer. If farmers also have different endowments, their production possibilities, and thus costs, will vary. The difference in factor use among farmers opens the possibility of trade. By trading abatement efforts, cost-effective pollution abatement can be ensured since farmers will seek to equalize their marginal abatement costs.

Without side-payments, each farmer will equate the first of the first-order conditions. If farmers want to affect each others abatement, they must pay the difference between marginal income and marginal cost that appears in the other farmers' first-order conditions. This means that the payment is simply the first-order conditions of the other farmers. Thus, by the side-payment B^{-i} we convert the farmer's profit maximization problem into that of joint profit maximization for all farmers. The bribe is the key to why non-individual contracts can be used. If we denote the net marginal cost for increasing abatement effort by *v*, then the expected value of the penalty must be at least as large as the marginal costs in optimum, i.e $k>v>0$, where k is the expected value of the penalty. Now, if marginal costs are equalized among farmers, such that $v^1 = v^2 = \ldots = v^n$, then one standard contract with $k>v^i>0$ for all *i* is obviously sufficient to reach cost-effectiveness in the abatement process[3].

With this formulation of the problem we have reduced the information requirement on the government. We assume that farmers hold information, not only about their own profit function, but also about the behavior of other farmers. However, each farmer's own information does not have to be substantial. A farmer will offer to buy abatement efforts from other farmers as long as the expected profit for that service is greater than undertaking efforts at the own farm. Other farmers will accept this offer if it can increase their profits. Therefore, by using a uniform contract, and by allowing for side-payments, we can reduce the information requirement on the government and force farmers to reveal their abatement efforts.

Let us take a step back and look what happens when the penalty scheme is introduced. Farmers will lose income equal to β, unless they adjust their behavior to the penalty system. The way that this is stated in the maximization problem indicates that once the penalty scheme is introduced, water quality can be treated as a normal good with a ”normal” price. Farmers can reduce their expected payment by shifting factors from crops to water quality, or from another perspective; profits increase as water quality increases. The ”income” that a farmer receives from

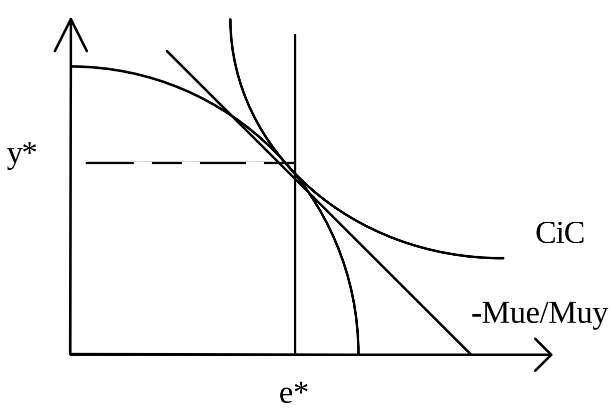
[3] For a more rigorous discussion of this problem, see Holmström (1982)

improving water quality is the reduced probability of paying the penalty. This means that we can set up the problem in a traditional way, where output prices will determine the allocation of factors between production of two goods.

The equilibrium levels of consumption and production, can be seen if we again examine the production possibility frontier and the preferences of society (CiC) . When farmers can buy and sell crops and water quality among each other, the production possibility frontier is given by their joint production possibilities, where at each point on the curve, production costs are minimized.

The price-line in figure 2 is given by consumers' marginal utility of crops and water quality. It is worth noting that the government has to set the ambient standard such that it gives a production of (e*,y*). It also has to set the penalty such that relative prices reflect marginal utilities for the goods. This delicate balance between setting the ambient standard and determining the level of the penalty illustrates the government's problem.

Figure 2. Welfare maximizing allocation of water quality and crops



Assume that the government maximizes welfare of the country, and that we have identical consumers, such that we can represent all consumers by one utility function, $U(y, e)$. We have assumed earlier that we can not observe farmers' choices of factor use. The government therefore makes decisions based on observed levels of water quality and output of crops. In reality there will be a time lag between farmers' choice of factor allocation and output observation. This time lag does not significantly change the solution, and we will therefore ignore it when solving the welfare maximization problem. We can now write the welfare maximization problem as:

$$\underset{e,y,\beta}{Max} \quad U(y,e) + \int_0^e f(e;\mathbf{a})de\beta$$

s.t

$$V'[\cdot]\left[py_{a^i} - \int_0^{e^*} f_{a^i}(e;\mathbf{a})de\beta\right] - 1 - B_{a^i}^{-i} = 0$$

$$-V'[\cdot]\int_0^{e^*} f_{a^j}(e;\mathbf{a})de\beta - B_{a^j}^{-i} = 0$$

In order to assure incentive compatibility, we require that farmers' profits are maximized under the incentive scheme and thus that farmers have no incentives to cheat on the contract. The optimal level of water quality is $e*$ according to earlier notation. The optimal standard and penalty are then $e*$, and $\beta*$, where farmers' actions are such that $\sum_i e_i(a*) \leq e*$

The level of the ambient standard is determined by the demand for water quality. The observed level of water quality is also affected by the stochastic variable δ. Uncertainty means that even though the suggested scheme of standards and penalties yields a water quality that*on average* corresponds to the desired water quality, it will not always be within the prescribed limits. The implication of this is that consumers' attitudes towards risk also play a role in determining the level of NPS pollution abatement. Including risk attitudes into policy formulation can have an important impact on social costs. For instance; McSweeny&Shortle (1990) show that abatement costs increase dramatically if we want to ascertain a specific water quality.

Note that in solving the pollution problem, we are not dependent on farmers' participation in the program. It is farmers' actions in the first place that cause the deterioration of water quality. That implies that if some of them go out of business it is only a way to increase water quality. If the threat of a penalty creates negative profits for some farmers, they may find ways (new technologies) to make profits non-negative, they may go out of business, or they may sell their farm to a more efficient farmer who can make the farm profitable even under the new circumstances. Either way, the threat of a penalty increases efficiency in farming, unless of course farmers are already efficient in their production[4] [5].

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[4] The way in which the problem is currently set up, there exist possibilities for financially stronger agents to ”play the game” and pay the penalty. Financially weak farmers then face the risk of losses, and may have to sell their farm. While this may not be a desirable result, it does not affect the effectiveness of the suggested incentive scheme in this paper. If an additional restriction requiring that all farmers should stay in business, i.e a participation

The international problem

In maximizing welfare the government must comply with international agreements, and thus pay attention to the water quality impact of pollution in other countries. Agricultural pollution from other countries affects domestic water quality. However, not all of the emissions in other countries are transferred to domestic waters. Denitrification and biological activity reduce the eutrophication impact of emissions in other countries (Fleischer et al 1989).

When pollution sources are international, the government would prefer to have some control over pollution in other countries. It is however not likely that the government of one country can dictate or enforce laws in other countries. If we follow the assumptions made earlier, the government can only measure ambient water quality. This means that even if a government could enforce laws in other countries, it would be difficult to identify in which country the laws should be enforced. Therefore, the government can not apply the same incentive scheme to farmers in other countries as was suggested in previous sections of this paper.

The problem of international pollution appears similar to the domestic farmer problem, only this time we have to deal with countries and not individual farmers: We can not measure the

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constraint, the cost of achieving the abatement is likely to increase. It is also questionable whether the idea of non-individual contracts holds under these circumstances.

[5] Meran&Schwalbe (1987) have an interesting note on the possibilities for legal enforcement of their suggested collective penalty system. "...our term 'collective penalty' may be somewhat misleading. To our knowledge there exists no criminal law, which allows punishment without evidence of guilt. But precisely this proof of guilt is ruled out in our model by the assumed informational structure". This problem is equally valid in this paper, but can be solved if one for instance convert the penalty system to a system of conditional subsidies.

contributions to water quality from each country. We will now make the following assumptions about countries affected by the water quality of the common water resource.

1. The government of each country strives to maximize welfare.
2. Each country will be better off under a joint welfare maximization among the countries involved, compared to a non-cooperative situation.
3. In the absence of financial penalties, each country will benefit by deviating from a cooperative solution.
4. Each government knows 1-3.

These assumptions mean that no government will waste resources on an international agreement unless it is associated with financial incentives to maintain a cooperative solution. On the other hand, assumption two implies that governments also have an incentive to search for a stable cooperative solution. A welfare maximizing government will participate in international cooperation if the costs for participating do not exceed the welfare gains that can be made.

In the domestic problem the solution was a principal (the government) with the authority and ability to create financial incentives by taxes/penalties on the farmers. In this case there exists no principal with authority to create legislation for all the countries. However governments would be willing to set up a ”super-state” authority (SSA), provided that i) the authority can ensure that a cooperative solution is stable, and that ii) costs for setting up the authority is less than the obtainable benefits from it.

We will examine two cases; first, when pollution levels from individual countries are observable; and second, when pollution is not observable and countries decide to set up an SSA.

In the first case water quality is observable for each country, by each country. If water quality is observable, a country can pay a subsidy to other countries to make them increase their water quality above their domestically preferred level of water quality. When water quality is observable for each country, the subsidy can be made contingent on observed water quality. Each country can then offer to pay for abatement in other countries as long as cleaning in other countries is less expensive than cleaning at domestic pollution sources.

The compensation that a country demands for increasing its water quality is the net marginal cost of increased water quality, that is, the difference between local marginal utility and marginal cost. The solution to this problem implies that abatement of pollution will be cost-effective. Each country has access to the least costly technologies for abatement, merely through the payment of a lump-sum subsidy to other countries. There is no need for an SSA if pollution is nationally observable; each country can make their subsidies contingent on observed water quality in other countries. Thereby the necessary financial incentives are created.

When a country's water quality impact is not known, a payment system can not be based on each country's contributions to water quality. In the second case, only ambient water quality is assumed observable. It is not possible to determine each country's contribution to water quality. Therefore it is also not possible to design any incentive schemes based on each country's pollution.

We propose an SSA to act as a principal. Assume that the SSA has the authority to formulate and enforce laws in any member country. We also assume that the objective of the SSA is to maximize overall welfare in the area. Countries will be members of the SSA if the costs[6] of membership are less than the expected welfare gains. Assume that the SSA knows the utility (or welfare) function of each country. Based on information about ambient water quality and utility functions, the SSA seeks to define an optimal contract.

Unlike the situation with farmers, it is essential that countries are members of the SSA and that they "stay in business". When countries' individual emissions are not observable for the SSA, nor for the countries themselves, there can be no side-payments among countries. Therefore contracts have to be individually designed for each country. This means that we can not use the same incentive system as was proposed for the domestic water quality problem. The scheme proposed here is however not so different from the previous. A collective penalty is introduced. If the ambient water quality standard, e^{**}, is violated, every country has to pay a penalty, whether or not they try to increase water quality. Water quality is only observable at the ambient level, and therefore, liability can only be determined on an aggregate level. In this situation, each country will not pay the same amount of penalty. The incentive scheme that is proposed here follow Meran&Schwalbe (1987). We can write the penalty for each country k as follows:

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[6] Note that costs can be interpreted in a wide sense here. For instance costs of lost autonomy can prevent a country from joining the SSA

$$P_k = \begin{cases} 0 & if \quad e \geq e^{**} \\ b_k & if \quad e < e^{**} \end{cases}$$

The level of the penalty is individually determined, for each country, to offset cheating but encourage membership in the SSA. Note that if the payment scheme would not allow individual contracts, the solution make possible that some countries face negative welfare. That of course would not be encouraging for participation in a joint program for improved welfare and water quality.

In the domestic case it did not matter whether farmers participated in the program. The international case is different in that we now have nations instead of farmers. We can not let nations ”go out of business”. It is not plausible that countries would be members of a SSA if it threatened to drive the country out of business. Therefore maximization of overall welfare is subject to the constraint that each country’s welfare under the new incentive scheme must be greater than, or equal to, the attainable welfare from not participating. We also introduce a membership fee that each country has to pay. The fee has to be such that total costs for the SSA are covered. We denote this fee by F_k. Total costs for the SSA reflects its costs for administration and more importantly; its costs for obtaining information. F_k will be an important determinant to whether a country should join the SSA. If costs of information are too high, countries will be better off when maximizing welfare without the aid of an SSA. There is also a possibility that this membership fee could be negative: If a country would lose welfare from joining the program, a negative membership fee could be paid as subsidy. The requirement is of course that overall welfare can be increased by having this country join the SSA.

The problem for the SSA is to maximize the sum of welfares in the member-countries. A water quality standard is set the same for all countries. For each country, the SSA determines membership fee and the size of the penalty. This means that we assume that the SSA possesses all information that is held by governments. For the sake of simplicity, we assume that crop production is constant. We can then write the maximization problem of the SSA as:

$$\underset{e,y^k,\beta^k}{Max} \quad \sum_k U(y,e) + \int_0^e f(e;\boldsymbol{a})de\beta$$

s.t

$$V'[\cdot]\left[py_{a^i} - \int_0^{e*} f_{a^i}(e;\boldsymbol{a})de\beta \right] - 1 - B_{a^i}^{-i} = 0$$

$$-V'[\cdot]\int_0^{e*} f_{a^j}(e;\boldsymbol{a})de\beta - B_{a^j}^{-i} = 0$$

$$U_k(y,e) - F_k \geq U_k(y,e**)$$

$$U_k'(y,e) = 0$$

$$\sum_k F_k \geq TC$$

From the first two of the constraints we have the familiar constraint that farmers' profits under the scheme must be greater than the attainable profits of any other allocation. The third constraint says that each country's welfare from participating in the abatement program must be greater than the welfare that can be obtained by staying outside. The fourth constraint says that a country's welfare from participating and complying with the standard must be greater than the welfare gained from participating in the program and deviating from the postulated behavior. Lastly, the fifth constraint tells us that the membership fees must be at least as great as the total costs for running the SSA.

An optimal contract has to be designed for each country. The contract has to be such that it yields enough welfare to encourage membership in the SSA, but offsets free-riding on other countries. Let this contract be characterized by $(e^{**}, \beta_k^{**}, F_k^{**})$, such that the expression above is maximized[7].

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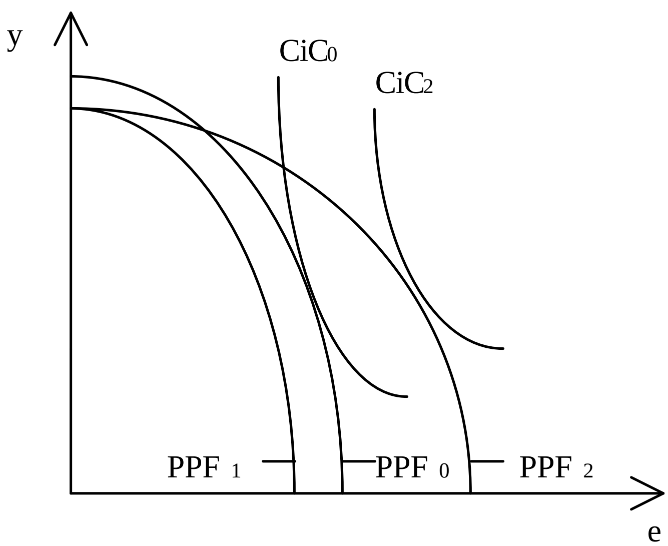
[7] The presented incentive scheme of virtual permits is static. The underlying problem of farmers is dynamic. One question that is not clear from above is when the penalty should be paid. Farmers and countries can make an advance payment which will be refunded if water quality is acceptable. The other alternative is that they pay ex-post when the state of the world is known. If farms and countries make an advance payment of the penalty, they will use factors to get their deposited penalty back. Under this type of payment they are working towards a positive payback of their investments in water quality. When the penalty is paid ex-post farmers and countries instead strive to avoid the penalty payment. If farmers would make an ex-ante payment of the penalty, their maximization problem becomes

$$\pi(a,e) = \underset{a^i, a^j}{Max} \quad V\left[py(a^i) + \left(1 - \int_0^{e^*} f(e;\mathbf{a}) de \beta \right)\right] - c^i - B^{-i} - \beta$$

If we take the first order conditions for this expression we see that they are identical to the ones stated earlier in the paper. As was shown before, farmers' first-order conditions will enter as the incentive compatibility constraint, when welfare is to be maximized. When first-order conditions are identical, the constraint will be identical and thus farmers' contracts are not affected by the timing of the payment. When the SSA maximizes overall welfare it also has to ensure the participation of the member countries. The participation constraint that was stated in the maximization problem does not change by an advance payment instead of an ex-post; each country must make the advance payment of the penalty, if water quality is too poor the government will get refund from the farmers since they then have to make the payment. If water quality is acceptable, the government will get its money back from the SSA. Therefore advance or ex-post payment does not matter, the welfare of one country is not affected. This conclusion is contingent on the implicit assumption of perfect capital markets.

After the ambient standard, e^{**}, is set, β has to be determined for each country such that expected marginal benefits of environmental quality are equalized among countries. If marginal benefits are equalized, then cost-effectiveness is ensured. A membership fee has also to be determined for each country. The fee, F_k , could be distributed among countries in various combinations. This in turn opens the field for negotiations; every country wants to minimize its payment for the benefits obtained.

The choice of a country is illustrated in figure three. Before joining the SSA, production is taking place where the PPF-curve (PPF_0) is tangent to the community indifference curve (CiC_0). When the country joins the SSA, it has to pay a membership fee corresponding to F_k. This reduces production possibilities to PPF_1. At the same time the country gets access to the abatement technologies of other countries. Therefore its possibilities to produce water quality increases, and we get the new production possibilities in PPF_2. If tangency between PPF_2 and an indifference curve enables a higher welfare, then the country will join the SSA.



The motivation for having a ”super-state” is not that we have asymmetric information among countries, but that we have no information. Water quality is assumed to be not observable or not available on a national level for all countries. This means that even if one country knows its own emissions, there is no way for another country to access this information, unless it is given freely.

While it can be argued that the existence of a ”super-state” authority is an unreasonable assumption, the suggested incentive scheme above shows how the problem of non-observability of pollution among countries can be solved. The ”super-state” requires that member countries give up some of their autonomy in exchange for increased welfare. This assumption is not entirely unrealistic. We can easily find parallels with the European Union, which is built on the same principles. Countries join the union in order to get access to the free inner market.

Summary and Conclusions

In this paper we suggested the use of non-individual contracts to control agricultural NPS-pollution. We show that for a domestic pollution problem, abatement efficiency can be obtained even though contracts, between farmers and an environmental agency, are not individual. The reason that this type of contract works, is that we allow farmers to trade pollution among each other. This requires that farmers know the abatement costs and the risk aversion of at least a few other farmers. While it can be argued that this type of contracting require farmers to hold extensive information, we think it is more plausible that farmers hold some information about each other than to assume that the regulating authority has sufficient information to formulate individual contracts with farmers.

The suggested incentive scheme rests on collective penalties for farmers. All farmers have to pay the penalty if water quality is less than dictated by an ambient environmental standard. As has been pointed out in Meran&Schwalbe (1987), a system of collective penalties has weak legal support, since criminal law generally requires that liability is established on an individual level. The incentive system also does not require that farmers ”stay in business”. If implementation of the incentive scheme means that some farmers go out of business, this does not affect the mechanism of the suggested system. Farmers may go out of business for various reasons. Some may be ”too” risk-averse relative to the other farmers, such that they undertake a large share of the abatement. Other reasons may be that some farmers are relatively less efficient in their production, or perhaps financially weaker, than other farmers in the region. Traditional agricultural policy tends to protect farmers from going out of business. If this is an issue, the suggested incentive scheme can easily be converted to a system of conditional subsidies, yielding the same financial incentives to farmers.

To solve the international problem of agricultural pollution to a common water resource, we suggest the use of an international authority (SSA) to act as a principal for the countries. The international authority is a member organization consisting of the countries affected by the water quality of the common water resource. A country will join the organization if membership increases the country’s welfare. To join, each country has to submit its environmental policy for the water resource to the SSA. The SSA then signs individual contracts with each country. The incentive scheme is also here based on collective penalties. Each country pays a penalty if the water quality standard is not met. These country-specific penalties are set such that the expected cost of deviation from the incentive scheme, is higher than the expected benefits. For the international problem, our notion of an international agency for pollution control, is what enables the type of contracting suggested in the paper.

It can be argued that our suggestion of an SSA to which countries submit their environmental policy is not realistic. However, this type of arrangement can be compared to organizations such as the EU, or with free-trade agreements among countries; it increases welfare and promotes efficiency in member countries.

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