Cleaning of Eutrophic Inland Waters for Fishery and Amenities: On the Treatment of Dynamic Aspects in Political Economy Modeling of Statutory Regulations in Polluting Communities

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Abstract. Due to the immanent common property problem of water, non-point-pollution is the common feature of many inland waters and the eutrophic levels are alarmingly high. By high eutrophic levels fishery, drinking water and other services are negatively effected. Concerning causes of pollution, agriculture, subject to overuse of fertilizer and pesticides, is regarded as the main polluter. Environmental regulations on farm practices, such as animal waste and fertilizer application seek to minimize shocks imposed by eutrophying substance. Since many waters already show high concentrations of theses substance, even cleaning is needed.

In the dynamic context of eutrophication, that results from multiple polluters and is accumulated over time, damage on water quality depends on stocks and flows of pollutants. The paper presents a model that counts for limitation of inflows and attributed levels of farm activity to pollution. The paper applies a combination of dynamic control and political economy model, optimized by a manager of a common property, a clean lake, a river or more general an interconnected watershed. It seeks to achieve an agreed level of cleanness or eutrophic levels of water on behalf of a community. A political economy model depicts the bargaining process for the establishment of an objective function of the community. The manager is a partial manager, not a benevolent dictator, but has statutory power to regulate fertilizer application on lake shores and alleviate eutrophication with nutrients. Benefits are purified waters that benefit all members including fishermen. As institutions, the approach investigates the tragedy of the commons and statutory regulations. Financial innovations for compensation are also possible.

Keywords: cleaning of eutrophic lakes, common property management, political bargaining model and partial manager

1 Introduction

The eutrophication of lakes, fjords, slow moving rivers and also the consecutive eutrophication of down-stream estuarine and marine ecosystems is a serious and complex problem in environmental economics and policy (Barbier, et. al. 1994). In particular farmers are criticized for polluting local waters and consecutively criticized for contributing to ecological problems of larger aquatic ecosystems. The injection of fertilizer surplus, locally leached into smaller rivers and transported in larger interconnected watersheds, is a serious problem for the preservation of water quality of extended fresh water reservoirs. For instance, farmers are even blamed for ecological disasters in lakes; in particular, disasters which occur when a lake is loosing its natural habit due to eutrophication beyond a certain threshold. Many archetypal aquatic ecosystems, such as clear water lakes, fjords etc., but also adjacent wetlands, are nowadays characterized by high nutrient loads and become increasingly negatively effected and endangered in their natural status. Many lakes are exposed to a still ongoing inflow of nutrients and, generally, characterized by polluted water that harm other human activities. In worst cases inflows of nutrients can end up in what is called an ecological collapse or radical change of the environment; for instance, converting a lake into a swamp or marsh. Enrichment of nutrients and consecutively building up of organic matter can make lakes disappear, in particular, those with shallow water.

As a prime source of nutrient inflow agriculture could be forced to zero infiltration. In general, polluted water drains from farm land into ditches, then, into creeks and downstream into lakes etc. Since surplus nutrients from cultivated fields go comparatively easy in liquid phase, depend on local conditions and are invisibly solved in water, unidentifiable flows into creeks, rivers and streams are normal consequences of intensive farming. Unfortunately, supervision of particular nutrient inflows themselves are almost impossible or extreme costly. The observation remains, that lakes that show highest levels of eutrophication, are normally close to intensively used agricultural areas. So, why not restricting intensity in general? The answer is, farm profits are highest with highest intensity. A conflict: Ecologist foresee pertinent disasters in lakes and public awareness is increasing. Farmers are reluctant to change practice and insist on property rights to farm because of high profits. In essence: Eutropication looks for its reversal, cleaning, but, farmers object and want high intensity, i.e. profits, and no general restrictions.

However, eutrophication is a non-point pollution problem of communities that share a common property, which is: "Clear waters", in other words functioning aquatic ecosystems. Hence a common property management problem exists. Cleaning is not only a technical problem. It can be regarded as a common property management problem. The task is to limit inflows such a way that cleaning occurs, costs of cleaning are minimized, i.e. foregone profits, and benefits are recognized, i.e. welfare from public goods. The management of cleaning a lake, as understood in this paper, is a co-management problem of benefits from reduced nutrient inflow from farming, adjacent to lakes, and costs from restrictions on land use. The question is how to achieve cleaning, if the political will exists, but free-riding is the pertinent strategy. Further questions are: What are the ecological prerequisites, the economic incentives and the necessary institutions?

On the ecological side, we first presume that a lake, given reduced nutrient inflows, has the potential to clear himself. Second, on the economic side, we presume that farmers, that live close to the lake, have an interest in better water quality. Third, we presume that an institutional setting may exist that will overcome the problem of non-point pollution. In principle, we will hand over the task to clean the lake to a manager of the common property, water quality. But, we will not naively presume that the manager is maximizing social welfare. Unfortunately, common property management maybe exposed to political economy influence; or as a role the interest and the political power of interest groups will determine the outcome of negotiated and environmentally motivated measure. Though, this situation most likely is still welfare improving, since as a reference situation, in reality, we have an open access or tragedy of the common situation, it is not a Pareto-optimal situation of a benevolent manager.

In the paper we will follow the line of thoughts of political economy modeling of environmental policy that have been developed in political bargaining models (Harsanyi, 1963). On the basis of a design of statutory regulations in communities of common property users (Rausser and Zusman, 1996) we will derive rules on land use in farming areas surrounding lakes. In particular instrument variables are distance from waters that become under strict rules of restrained agricultural practice. The waiver on certain farm practices in specified as distances to lakes translates into the dynamics of fertilizing a lake. The fertilization of the lake impacts on the growth of bacteria and algae that reduce visibility in the lake. These aspects are treated dynamically and a dynamic optimization model is presented. However, the dynamic optimization is understood as the optimization of a manager that is subject to political pressure of interest groups.

The paper is organized in four chapters. First, we will look at the dynamics of water quality and nutrients in lakes applying two differential equations. Second, we will state farmers objective functions with regard to waivers on land use. Third, we will show exactly how the tragedy of the common situation can be modeled and limited cleaning prevails. Fourth, a political economy model will show how a particular cleaning can occur under given interest and power structure in a community to be managed by a partial manager. Finally, suggestions for application will give hints for empirical research.

2 Dynamics of water quality and nutrients in lakes

The water quality of a lake or fjord can be described by a Secchi-disk that measures visibility. As discussed elsewhere (Sandström, 1996), water quality is associated with visibility and has several implications for the provision of public goods. Services of lakes such as fishery, amenities, natural habitats etc are . As a measurable variable of eutrophication (indicator), visibility is, in principle, accepted as a major quantitative classification of water quality. Visibility can change and is subject to growth of algae, bacteria etc. The growth of these organisms is stimulated by fertilization and nutrient content of lakes. Beside natural fertilization, artificial, unintended fertilization is nowadays mostly imposed by farmers or households living on shores or close to the lake, a non-point-pollution phenomena. Apparently, there might have been other source of eutrophication, historically, and lakes clean themselves in the long run, since they have natural inflows and outflows of nutrients. Nevertheless, whose eutrophic lakes that are currently of interest for public policy, since they show over-eutrophication, feature the situation of been heavily fertilized by human externalities.

To present the dynamics of visibility of lakes in conjunction with nutrient enrichment, we use a differential equation for the movement of water quality such as:

$$\dot{V}(t) = -\varphi V(t) + \kappa [N^0 - N(t)] \qquad (1)$$

where: V(t) : visibility at time t
N(t) : nutrient content

The first part of the equation describes a natural cleaning system. It models the change in visibility at given nutrient availability. Presuming that visibility is associated with increasing or declining prevalence of fast growing organisms in the lake, a first order differential equation with a coefficient of "φ" below 1 implies that the lake is still capable to clean himself over time. However, the size of "φ" determines the time period need; values close to 1 mean very long periods of low water quality while values close to zero mean strong cleaning. Moreover, nutrient available plays a major role. For instance, presuming a constant level of nutrient availability or fertilization from outside measured by "N^0", the system would move to a steady state of visibility; from a modeling point of view the steady state visibility conditions are given as $\kappa N^0/\varphi$. Hence, N^0 can be used for calibration of the upper end of visibility. Different levels in availability of nutrients gradually change the steady states and cleaning capacity. Special cases can be distinguished. In case of N equals

N^0, evidently, the model would move to lowest visibility. On the other extreme visibility can reach the maximum at N^0. Cases one can imply a collapse of the lake while tow is "ideal" without human influence.

Because human inflows of nutrients changes water quality, we have to model nutrient flows. While a certain fixed inflow of nutrients N reduces visibility towards a steady state of V, we want to analyze the dynamic effects from reduced fertilization of lakes with nutrients; N(t) can not be perceived as constant. The change of nutrients is primarily a dynamic process which can be described as:

$$\dot{N}(t) = -\beta N(t) + \sum n_j(t)] \qquad (2)$$

where: $N(t)$: nutrient content at time t
$n_j(t)$: individual contributions of small-holders

In equation (2) the change (decline or enrichment) of nutrient content "$\dot{N}(t)$" dependents on the level of nutrient concentration N(t) ($\beta<1$ reflects natural outflow) and on annual intake from various farmers $n_j(t)$ (diffuse source). The total of individual contributions (sum of farmers' provision) is collectively determined. Though, every farmer may decide individually by his farm practice (nitrogen, phosphor etc. application) on the nutrient status of the lake, collective action is relevant. If the community will decide on less fertilization, lake fertility can be reduced.

The question remains, how can one model the contribution of diffuse inflows and what could be a measure to decrease the inflows? In this paper we follow a pragmatic view or approach to regulations. We state that bans on fertilizer use in distance "d_j" to ditch, creek, river etc. shores maybe an appropriate tool. In fact, some local regulations in some countries work already with this measures. In general, given a certain latitude of a plot of a farmers a_j, and a factor that translates the size of a plot into fertilizer surplus γ, the individual inflow can be given by the maximum distance minus regulated reduction $\gamma \cdot a_j \cdot [d^0_j - d_j(t)]$. The constant provides an upper distance d^0_j from where no more inflow can be expected. Condition (2') models a dependency of nutrient statuses of lakes as subject to individual and collective farm behavior (sum):

$$\dot{N}(t) = -\beta N(t) + \gamma[\sum a_j[d^0{}_j - d_j(t)]] \qquad (2')$$

Concerning regulations, the natural wash out effect of nutrients in lakes can become under-compensated by intakes from agricultural land. Cleaning of lakes, however, can be obtained only if intakes from farm land are minimized such a way that subsequent deliveries from the farm sector are lower than natural wash outs. The environmental economic problem is to regulate the behavior of farmers.

3 Objective functions

3.1 Farmers' objective function

Allocation of land with different fertilizer application rates can be seen in conjunction with the overall use of agricultural land and farmers' objective functions. The applied micro-theory (Varian, 1994), used in this paper, is similar to the one of Nuppenau and Slangen (1998). In the case of eutrophication of lakes we will distinguish between farming on remaining area and application of constrained farm practices on land adjacent to lakes. At the maximum given restrictions in farm practices are no artificial fertilizer and manure application (as special case; also, no farming may occur while special practices can be allowed dependent on biological prerequisites). Farmers loose profits as negative effects of regulating fertilization. Positive effects (higher visibility, for instance, due to higher water quality, more fish, wildlife etc.) are regarded as public goods "V". The adjusted total profit is recalculated using crop yields and gross margins on farms “j”. Profits are altered by land allocation between the rest of the farm and land adjacent to lakes. The policy variable is distance to the water "d_j". The objective function of a representative farmer in provision of land corresponds to a constrained profit optimization (Chambers, 1988). Recognizing water quality as a public good in a given utility function of profits "P" and visibility "V" we get for 0 to T:

$$U_{j,[0,T]} = \int_o^T e^{-\rho t}\{U(V(t), P_j(t)]\}\,dt \qquad (3)$$

where additionally : $U(t)$: utility at time t
$P_j(t)$: individual profits
ρ : discount rate

This utility function needs an explicit specification in terms of land allocation, i.e. distance to water, and the recognition of utility in common property to be managed:

can ripe benefits from public good properties of water. Landowners many offer private waivers. Institutional changes on property rights and payments are possible.

$$U_{j,[0,T]} = \int_o^T e^{-\rho t}\{\alpha_0 V(t) + \alpha_1 V^2(t) + \alpha_2[1 + \frac{\alpha_3}{\alpha_2} V(t)][pa^*_j(1-d_j(t)) - C(a_j(1-d_j(t)), d_j, r_j) + P^e_j]\}\,dt \qquad (4)$$

where: increase: “⇑” and decrease “⇓” :
p = gross margins per ton of yield, (profit⇑)
a_j = yields per hectare including size (profit⇑)
d_j = distance to water of area cropped, (profit⇓);
C(.) = cost function on quantity of q_j yield $a = q_{ij}/l_{ij}$, (cost⇑=>profit⇓)
$(1-d_j)$ = production effect on unit costs (ambiguous)
d_j = distance, cost reducing by biological activity (cost⇓)
r_j = input costs, farm specific (cost⇑=>profit⇓)
V = Visibility of the lake based common property (utility⇑)
P^e = external profit not from farming (utility⇑)

Assuming homogeneity in land with respect to the cost function, equal time horizons for all farmers, and interaction with utility derived from visibility of lakes (2) the relationship (6) could be used for social optimization in the traditional sense. Notice, we have to elaborate on the distinction between the sector approach and sum of farms. So far only individual farmers are recognized. Even more pronounced and from an institutional point of view, the specified objective function could be straight forward applied, only if one big land lord would be the owner of all agricultural land and the lake (the sum Σd_j becomes n·d). Moreover, the recognition of utility derived from water quality needs further explanation. First, the above specified temporal utility function can be generally applied to all citizens linked to a lake. But, Equation (4) primarily models farmers who will contribute to cleaning by following regulations on pollution control. Citizens that have no land are still part of the exercise, since they will merely have interest in the provision of public good: water quality. In its initial version the model will focus on statutory regulations on inflows caused by farmers. Communities that are engaged in common property management, are homogeneous insofar as landowners are the prime users of the lake. This can be justified since owners

Services to outsiders in conjunction with land use are most noticeable, if tourism is directly involved and tourists pay farmers. But, landowners living as residents on lake shores are very often also interested in fishing and hunting etc. themselves. Hence utility derived from the water quality is normally not only direct utility but mostly a mix of direct utility, commercial interests and extra profits derived from the water quality.

3.2 Social welfare function and optimization

In the case of a benevolent manager, that maximizes social welfare, social welfare is the sum of individual welfare. A benevolent manager should look for long run profitability (sustainability), i.e. optimize utility of all clients, that depend on water quality. He should seek, to maximize benefits of his clients, regardless of distribution consequences; not only maximize short run benefits but balance them with long run impacts from sustaining water quality (apparently, a norm which has to be justified). From the perspective of the management of water quality, it is his task to create a temporal welfare function including all members of the community. Given a number of farmers, we can formally represent the problem as:

$$W_{[0,T]} = \sum_j U_{j,[0,T]} \tag{4}$$

We can further establish the problem as an temporal optimization problem. Most easily, we start with identical farmers. Presuming "n" farmers and optimizing over a time horizon from 0 to T, we get the objective function (5).

$$W = \int_o^T e^{-\rho t}\{\sum_j [\alpha_0 V(t) + \alpha_1 V^2(t) + \alpha_2[pa_j^*(1-d_j) - C(a_j(1-d_j), d_j, r_j) + P_j^e]]\}\, dt \tag{5}$$
$$s.t \quad \dot{N}(t) - \beta N(t) + \gamma[\sum a_j[d^0{}_j - d_j(t)]] \quad and \quad \dot{V}(t) = -\varphi V(t) + \kappa[N^0 - N(t)]$$

Using similar arguments as above on gross margins and cost functions, given a time horizon T in terms of integrating long run welfare arguments, and now recognizing the temporal development of fertility from equation (1), we receive the optimization problem in equation (6):

In the beginning, only for simplification, we take a sector approach with n-equal farmers, It implies that the sums of farms (5) is substituted by a counting of "n" equal farms. In equation (6) the Hamilton function is specified as such.

$$H(N,V,d,t) = e^{-\rho t}\sum_j [\alpha_0 V(t) + \alpha_1 V^2(t) + \alpha_2[1 + \frac{\alpha_3}{\alpha_2}V(t)][pa_j^*(1-d_j(t)) - C(a_j(1-d_j(t)), d_j(t), r_j)] + P_j^e]$$
$$+ l_1(t)[\beta N(t) + \gamma[\sum a_j[d^0{}_j - d_j(t)]] - l_2(t)[-\varphi V(t) - \kappa[N^0 - N(t)]] \tag{6}$$

To the stated Hamilton function in equation (6) we are resuming a quadratic cost function. (Note, a quadratic function provides linear derivatives, see Nuppenau and Slangen, 1998, and the function of (7) rechecks cross effects).

$$C(a_j(1-d_j), d_j, r) = \gamma_{0j} d_j + 0.5\gamma_{1j} d_j^2 + \gamma_{2j} d_j r_j \tag{7}$$

The problem can be solved by control theory which requires a formulation of a "Hamilton" function (Tu, 1991). Standard mathematical approaches to solve dynamic optimization problems (Tu, 1992) has to fulfil 3 conditions for a maximum, equations (8):

$$H(t)_{N(t)} = -\dot{l}_1(t) \qquad H(t)_{V(t)} = -\dot{l}_2(t) \qquad H(t)_{d(t)} = 0$$
$$H(t)_{l_1(t)} = -\dot{N}(t) \qquad H(t)_{l_2(t)} = -\dot{V}(t) \tag{8}$$

The final specification of the problem (9) includes nutrient content "N" and visibility "V" as state variable and distance to the lake "d" as control variable; i.e. the size of land mastered under controlled agricultural practice is crucial for the nutrient content of the lake. Applying the optimality criteria (8) to the specified Hamilton function (9), 3 equations comprising 2 differential equations appear in the system of (10a to 10e), where N(t), V(t), $l_1(t)$, $l_1(t)$ and d(t) are the endogenous variables.

$$H(N,V,d,t) = e^{-\rho t} n[\alpha_0 V(t) + \alpha_1 V^2(t) + \alpha_2 [1 + \frac{\alpha_3}{\alpha_2} V(t)][pa^*(1-d(t)) - \gamma_0 d(t) - 0.5\gamma_1 d^2(t) - \gamma_2 d(t) r]]$$
$$+ l_1(t)[\beta N(t) + \gamma[n[d^0 - d(t)]] - l_2(t)[\varphi V(t) - \kappa[N^0 - N(t)]] \qquad (9)$$

those solution to optimization according to criteria (8) is:

$$[\beta - \rho] \cdot l_1(t) = -\dot{l}_1(t) \qquad (10a)$$
$$n\alpha_0 + n\alpha_1 V(t) + \alpha_3 [pa^*(1 - d(t)) - [\gamma_0 - \gamma_1] d(t) - \gamma_2 rd(t)] + [\varphi - \rho] l_2(t) = -\dot{l}_2(t) \qquad (10b)$$
$$\alpha_3 [\gamma_0 - \gamma_1] V(t) + n[pa - \gamma_0 + \gamma_2 r + \gamma_1 d(t)] - n\gamma a \cdot l_1(t) = 0 \qquad (10c)$$
$$\beta N(t) + \gamma[n[d^0 - d(t)] = -\dot{N}(t) \qquad (10d)$$
$$\varphi V(t) - \kappa[N^0 - N(t)] = -\dot{V}(t) \qquad (10e)$$

The system (10) can be solved for time dependent paths on the stage variable "visibility: V(t)", "nutrient content: N(t)" and on the control variable "distance to lakes: d(t)" (Tu, 1991). It provides the necessary distance of set aside land at shores by a representative farm, in order to change the water quality. However, the results are still independent from the composition of the farm sector; i.e. the system (10a to e) could be also applied to one large farm, a single owner of the lake and the adjacent land or an anonymous society. So to say, the aspect of many farms being involved in a common property management of communities has not been really tackled, so far. The solution in equations (10) serves as a reference in modeling.

The aspect of multiple agents is most evident, when the actual objective of cleaning in communities becomes reconsidered. In the given framework, "clean" should be stated as a final situation of maximal visibility. Maximal visibility or hundred percent clean fixes V(T) at V(T)=κ N^0/φ and N(T)=0, i.e. at predetermined values, whereas changes become zero and shadow prices $l_1(T)$ and $l_1(T)$ and distance d(T) are endogenously given; a simple transversality conditions, more complex end values maybe discussible. Correspondingly, the system tells the planner which measures have to be taken recursively to reach that state after the time frame "T" has been exogenously given. Perhaps, these results are very wishful from a society point of view, but, unrealistic to conduct. The question is how can a benevolent planner be established or what would happen, if nor planner is equipped with coercion to enforce mandatory regulations. What happens, if not enforcement exist, is the currently predominant situation with open access to pollution and an institutional deficit has created the situation.

4 Tragedy of the common

The question remains: Will individual optimization in farm behavior go for recognizing the positive effects of water quality, i.e. visibility. In principle, farmers are not pure profit optimizers, rather the specification of the objective function includes explicitly the recognition of water quality. Cleaning would imply consequently an increase in welfare, but, what are individual costs, benefits, and incentives? Nothing has been said on voluntary provision of cleaning services or waivers of fertilizer use close to waters. As a public good water quality "V(t)" at any stage in t has a history of contributions from initial periods to t, i.e. the empirically measurable equivalent of quality in a *community* is subject to choices *of farmers* in the past. Cleaning is of potential interest, but may not appear due to common property problems. To sketch the arguments, we look at the optimization of individual utility U_j at given V in equation (11):

$$U_j(t) = \alpha_0 V(t) + \alpha_1 V^2(t) + [1 + \frac{\alpha_3}{\alpha_2} V(t)]\alpha_2 [pa_j^*(1-d_j) - C(a_j(1-d_j), d_j, r_j)] + P_j^e$$

Calculating first derivatives (for simplicity we acknowledge only quadratic terms as above) in equation (12):

$$-[pa_j^* + \gamma_0 + \gamma_1 \gamma_2 r]\alpha_3 V(t) + \alpha_2 pa_j^* + \gamma_0 + \gamma_1 d_j(t) + \gamma_2 r = 0$$

a functional relationship between V(t) and $d_j(t)$ appears. As verbal argument: We can see a link between individual optimization $d_j(t)$ and V(t) derived from the marginal utility function. In comparison to the benevolent planer situation only the individual behavior "d_j" -no longer the collective decision V(t)- is optimized. We have to see V(t) as a unspecified activity and the case of the tragedy of the common appears since V(t) is exogenous to the farm decision making. An institutional deficit prevails! How can we model the determination of V(t)? For instance, looking at "n" "equal" farmers with equal factor endowments "a" and cost functions we can sum up, having "V" unspecified but equal for all farmers:

$$\frac{na\gamma}{\gamma_1}[\alpha_2 pa_j^* + \gamma_0 + \gamma_2 r] + \frac{na\gamma}{\gamma_1}[pa_j^* + \gamma_0 + \gamma_1 \gamma_2 r]\alpha_3 V(t) - na\gamma d(t) = 0 \qquad (13)$$

Technically this allows us to express farm behavior and lake dynamics using the dynamics of nutrients first

$$\dot{N}(t) = -\beta N(t) + \gamma nad^{0} - \gamma nad(t) \quad (14)$$

Expressed in one equation after subtracting (13) and (14), we receive a dynamic differential equation:

$$\dot{N}(t) = -\beta N(t) - \frac{na\gamma}{\gamma_1}[pa_j^* + \gamma_0 + \gamma_1\gamma_2 r]\alpha_3 V(t)$$

$$+ \gamma nad^0 + \frac{na\gamma}{\gamma_1}[\alpha_2 pa_j^* + \gamma_0 + \gamma_2 r] \quad (15)$$

Moreover, the notation in (15) can be modified to a new

$$\dot{N}(t) = \beta_0 - \beta_1 N(t) + \beta_2 V(t) \quad (15')$$

equation (15') if coefficients are recalculated. Combined with the dynamics of visibility in the initial visibility: $\dot{V}(t) = -\varphi V(t) + \kappa[N^0 - N(t)]$, a new steady state "$t\rightarrow\infty$" can be determined:

$$\begin{bmatrix} V^*(t) \\ N^*(t) \end{bmatrix} = \begin{bmatrix} -\varphi & \kappa \\ -\beta_1 & \beta_2 \end{bmatrix}^{-1} \begin{bmatrix} \kappa N^0 \\ \beta_0 \end{bmatrix} \quad (16)$$

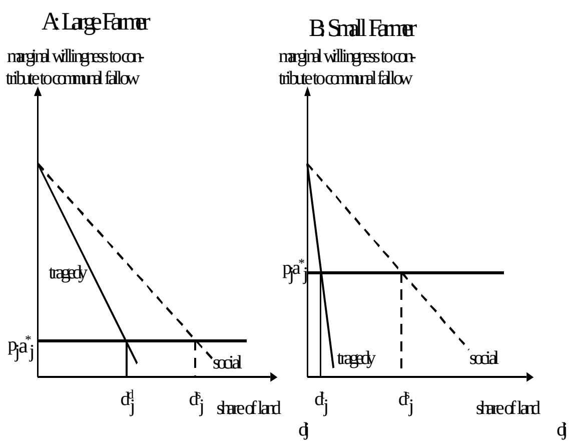


Figure 1: Farmers' individual willingness to contribute

In principle, this steady state of the tragedy of the common "$V(\infty)$" is expressed as ratio between a nominator and a denominator, that represents the overall situation of the lake. The denominator increases with n. The nominator is constituted by the size of N^0, partly by d^0.

$$V(\infty) = \frac{N^0[...] + nad^0[...]}{n[...]} \quad (17)$$

Equation (17) shows the relationship between the number of farmers and the visibility in the long run. Inserting this equation (17) in the initial farm profit optimization of a "normal" farm (12), we receive a steady state condition that expresses individual behavior as related to the behavior of fellows in the community, i.e. $V(\infty)$ has been internalized. In essence, visibility can be substituted by an individual profit fraction in total land use to be managed in a common property scheme.

$$-[pa_j^* + \gamma_0 + \gamma_1\gamma_2 r]\alpha_3 \frac{P_j(...)}{nad^0[...]} V(t) +$$

$$\alpha_2 pa_j^* + \gamma_0 + \gamma_1 d(t) + \gamma_2 r = 0 \quad (19)$$

For interpretation: From the point of view of an individual citizen farmer, it makes no sense to care about visibility, if the number of co-fellows in his community is large; there is an institution deficit with small-holders. Equation (19) consists of two parts: The first part shows that the determination of land set aside at waters is dependent on *normal private* marginal costs. The second part is read as the share of farm j's profit in the provision of the *public good.*

We assume, that this share is small for large numbers of farms. If individual shares can be neglected, selfish and narrowly rational farmers will not provide the envisaged main structure. Instead, they will focus on the first part. If no political pressure exists that "provides" guarantees and optimizes collectively "property" in terms of visibility $V(\infty)$, land for cleaning will not be provided or at low levels. Since the impact of individual land to the provision of the public good can be neglected, i.e. a limited share in V ($\lim V \rightarrow 0$), a dominant strategy is no co-operation; the tragedy of the commons argument applies (the argument follows Rausser and Zusman, 1992). However, the size, distribution and intensity of farming normally matters (recognized in a varying a^*_j). The situation is verified in Figure 1. Farmers in small groups would differently contribute, but, at very low levels to communally set aside land for lake cleaning. The willingness to contribute, in the case of the tragedy of the common (equation 12), becomes dependent of the potential level of "cleanness: V" and a divergence between social and private (tragedy) willingness to contribute occurs, if "n" increases. The divergence between individually and collectively motivated willingness to contribute disappears, if farms become sufficiently large. For instance, a landlord owning a whole lake and adjacent land will have sufficient interest to clean. However, small-scale farmer will avoid to contribute land (tragedy of the common). Institutions on land ownership or common property management matter! There is scope for institutional design to get land.

In Figure 1, a shift due to increased (V) in the marginal willingness to contribute from an individual point of view is welfare improving and occurs if farmers are sure, that others contribute. The question is: How can we achieve this shift and can we establish a social welfare function? The answer is yes and no; and depends on policy.

5 Political economy bargaining model and game solution

In the initial chapter we have presumed a benevolent or impartial manager who inter-temporally optimizes the set aside regime. In the following chapters, we have modeled the tragedy of the common looking at long run impacts of water quality. In reality the community has not only the choice between the tragedy of the common or a manager that is impartial, but, can equip a manager with political power for statutory regulations; a benevolent manager is a fiction and a partial manager is subject to political influence. A situation with a partial manager coincides with a political bargaining game. Our model of bargaining centers around Harsanyi's (1963) multiple agent model.

$$L = [\prod_j (I_j - I_j^0)](I_m - I_m^0) \qquad (20)$$

The mathematical presentation of a bargaining solution (20) refers to a situation with lobbying and interest functions. Technically, it maximizes the product of differences between the cooperative value of each participant in the game and its possible disagreement value (Rausser and Zusman (1992). The manager "m" is subject to a lobbying "s" that increase his welfare, whilst individuals use resource to lobby "c"; in traditional societies one would speak of gifts. The manager becomes a quasi landlord.

Taking the logarithm of the above specification and recognizing the sum of lobbying activities $s_j=s(c_j,\alpha_j)$ as a function, the bargaining can be more explicitly expressed as a joint function:

$$\ln W = \ln[W_m + \sum_j s_j(c_j, \alpha) - I_m] + \sum_j \ln[W_j - c_j - I_j] \qquad (21)$$

where: W_m : is the welfare of the community
W_j : are individual welfare of farmers.
s_j : "political gifts" by j to the manager
c_j : "costs of lobby" of j

Moreover, an interior solution can be derived that is similar to the one prescribed by Rausser and Zusman (1992), resulting in a weighted objective function. In that function, individual weights correspond to the power of the pressure group and reflect the bargaining function s(...). Moreover, it has to be noticed, that the bargaining solution differs from a policy preference function approach. Instead, as the authors show, weights reflect the analytic properties of both aspects, the "production function" aspect and the "resources devotion" aspect in bargaining. However, integrating over time gives equation (22).

Where the $[1+w_j]$'s reflect the recognition of the objective function of a partial manager (i.e. his weight is 1, the reference numeraire). "Plus"-weights ($w_1,...,w_m$) give the corresponding achievements of farmers in bargaining (optimal interest function in bargaining).

$$W = \int_0^T e^{-\rho t}\{\sum_j [1+w_j][\alpha_{0j}V(t) + \alpha_{1j}V^2(t) + [1+\frac{\alpha_{3j}}{\alpha_{2j}}V(t)]\alpha_{2j}[pa_j^*(1-d_j) - \gamma_{0j}d(t) - 0.5\gamma_{1j}d^2(t) - \gamma_{2j}d(t)r]]$$
$$- \upsilon_0 \sum_j a_j d_j(t) + \upsilon_1 \sum_j [d_j(t) - \bar{d}(t)]^2\}\, dt \qquad (22)$$

The two final parts in equation (22) reflect transaction costs associated with regulatory variety (Transaction costs increase with the size and the deviation of individual regulations departing from average). I.e., if the size of set aside at shores of waters, to be controlled, increases control costs increase and complexity of regulation matters.

Weights can also be calculated as the first derivative of the strength, acquired from the threat strategy not to cooperate) minus the reference interest. We get this by:

$$w_1 ...;\ w_j = \frac{(I_C^{opt.} - I_C^0)]}{(I_j^{opt.} - I_j^0)]} = \frac{\partial s(c_j, \delta_j)}{\partial c_j};...;\ w_n \qquad (23)$$

Weights from equation (23) are to be interpreted as calculation of political power, reflecting a particular situation of outcome in the regulatory capacity of the manager, and they can be inferred. Vice versa given weights and coefficients in the underlying profits functions, the manager can control the provision of land set aside. Now, we respecify the dynamic Hamilton problem of equation (6) making use of multiple control variables $d_j(t)$. Formally this means, calculating derivatives '$d_j(t)$', 'l(t)s', F(t) and 'V(t)' of the extended public welfare function "W". Finally setting them zero, provides the bargaining solution. Mathematically, because linear supply and factor demand functions correspond to quadratic functions, i.e. adopting a similar cost function as above (7), we receive a treatable expression of the bargaining solution solvable for d_j's (d^b_j's) that are embedded in the dynamics of nutrient content F(t) and visibility V(t). The system of (25) is an extension of equations (10a to 10e). It recognizes the individual contributions instead of one normalized provision.

The system of equation (25) is still dynamic and mathematically it can be solved by first eliminating all instrument variables d^b_j. For further notice: To calculate a solution like (25) means, to derive a system of individual contributions $d_j(t)$. Contributions are the results of negotiations between a manager and land landowners. In the bargaining landowners partly suspend their claim on property rights on land in exchange for having clearer water, and the system simultaneously includes the manager's decision on V(t) and F(t), to guarantee cleaning.

$$\mathrm{H}(\mathrm{V},\ \mathrm{N},\ \mathrm{d},\ \mathrm{t}) = e^{-\rho t}\{\sum_j [1+w_j][\alpha_{0j}V(t)+\alpha_{1j}V^2(t)+[1+\frac{\alpha_{3j}}{\alpha_{2j}}V(t)]\alpha_{2j}[pa_j^*(1-d_j)-\gamma_{0j}d(t)-0.5\gamma_{1j}d^2(t)-\gamma_{2j}d(t)r]$$

$$-\upsilon_0\sum_j a_j d_j(t)+\upsilon_1\sum_j [d_j(t)-\bar{d}(t)]^2\}+l_1(t)[\beta N(t)+\gamma[d^0-\sum a_j d_j(t)]]-l_2(t)[\varphi V(t)-\kappa[N^0-N(t)]] \quad (24)$$

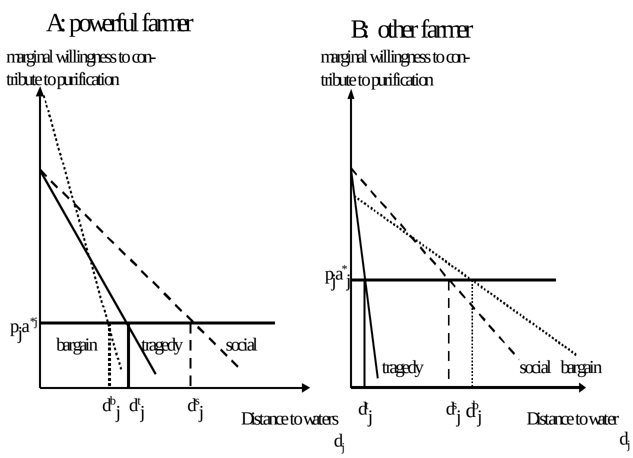
those solution using criteria (8) from control theory is:

$$\begin{bmatrix} -(1+w_1)\alpha_{21}\gamma_{11} & \dots & [1+w_n][\varphi-w_n a_n] & \gamma\alpha_1 & 0 & 0 & (1+w_1)\alpha_{31}p_1 a_1 \\ 0 & \dots & \dots & \dots & \dots & \dots & \dots \\ [1+w_1][\varphi-w_1 a_1] & \dots & -(1+w_n)\alpha_{2n}\gamma_{1n} & \gamma\alpha_n & 0 & 0 & (1+w_n)\alpha_{3n}p_n a_n \\ 0 & \dots & 0 & \beta+\rho & 0 & 0 & 0 \\ (1+w_1)\alpha_{31}p_1 a_{11} & \dots & (1+w_n)\alpha_{3n}p_n a_n & 0 & \varphi+\rho & 0 & \sum w_j a_{1j} \\ \gamma a_1 & \dots & \gamma a_n & 0 & 0 & \beta & 0 \\ 0 & \dots & 0 & 0 & 0 & 0 & \kappa \end{bmatrix} \begin{bmatrix} d^b{}_1(t) \\ .. \\ d^b{}_n(t) \\ l_1(t) \\ l_2(t) \\ N(t) \\ V(t) \end{bmatrix} = \begin{bmatrix} (1+w_1)[p_1 a_1-\gamma_{01}-\gamma_{21}r_1]-\upsilon_0 a_1 \\ .. \\ (1+w_n)[p_n a_n-\gamma_{0n}-\gamma_{21}r_{1n}]-\upsilon_0 a_n \\ -\dot{l}_1(t) \\ -\dot{l}_2(t) \\ \dot{F}(t)+\gamma d^0 \\ \dot{V}(t)-\kappa N^0 \end{bmatrix} \quad (25)$$

In the solution (25), we explicitly model the economic and political component of bargaining on cleaning assuming certain properties on cost functions and political support functions. The solution sketches an economically, ecologically and politically feasible equilibrium. The solution is a mixture of a lake and a common property management.

For its numerical treatment, the system needs transitory conditions. In the case of an agreement on well specified visibility at a given final time of "planning" $V(T)= V^{fix}$, we can derive the constants of integration in the four differential equations (Tu, 1992). As a stead state on nutrient level $N(T)= N^{fix}$. The dynamics of conditions on nutrients in the lake are no longer natural science oriented rather the economic conditions and political will and power of interest groups explicitly impacts on water quality. In numerical simulations it can be shown how certain parameters, for instance, whose that reflect the political power of vested interest modifies the water quality. Also, graphically, solutions can be provided that contrast opposing ordinary farmers and powerful farmers. Figure 2 can be either used to demonstrate short, medium or long term commitments to cleaning by different interest groups. Finally, we can calculate the total contribution of farmers and forego profits in exchange for purer water.

Figure 2: Bargaining solution and contribution



Note, the institutional framework now given by a manager of the common property, who uses mandatory regulations for water quality, cleaning or de-nitrification. The vector $d^{b\prime}=[d^{b}_{1},...,d^{b}_{n}]$ is the instrument that is negotiated and conducted in the community.

6 Application, empirical background and outlook

The analysis, presented so far, puts its major emphasis on a theoretical model that describes a political economy model for a common property management. The ecological context of water quality, nutrient prevalence in lakes and farmers' waiver on fertilization of land strips at lake shore as well as shores of contributing waters is depicted by a two stage model of visibility and nutrient dynamics in lakes. The corresponding parameters of the model can be gained from ordinary flow analysis and detection of water quality in lakes. Quantified examples of ecosystem behavior of lakes will provide the numerical support basis for empirical analysis. For instance, as has been mentioned in the introduction, visibility or eutrophication in lakes can stretch from clear water, over limited visibility, till nil visibility. Nutrient contents are traceable from muddy shores, which is a situation of a dying lake, to low freights which is a clear water lake. However, as put forward, it is this reversibility that is the major goal in the given model and empirical experiments are necessary.

Natural science investigations will quantify self cleaning based on reduced nutrient inflow. This analysis on dynamics in lakes has to be supplemented with the corresponding inflow model from shores. It can be expected that the inflow of nutrients is already considerably reduced, if distances of 100 to 200 m become applicable. Reduced fertilization of farm land, apparently, depends on soil quality etc. In small-holder communities, depending on the intensity of farming, however a distance of 200 m multiplied by 200 m of lake shore means already 4 hectares and 4 hectares can be, for instance, in vegetable or fruit production an income loss of 4000 US$ or more if the gross margin per hectare is 1000 US$ and even higher.

The last aspect will be reflected in the economic modeling of interest functions. Surveys of particular "homogenous" interest groups can be the basis for the estimation of loss functions due to land and practice restrictions. Much attention has to be devoted to clarify the interest in land use and fertilization of land close to lakes under local conditions of intensity in farming. It can be assumed that large land holdings imply low losses while intensive farming of small-scale farms is the major problem. However, vice versa, the problem of strong non-point pollution of lakes will be most prominent in intensively farmed area. Therefore, the specification of loss functions is the most crucial aspect, since farmers are strongly objecting, if their income per hectare is considerable reduced and no alternatives on land markets exist. However, cases on diversified interest can be comparatively easy been dealt with given the above theory.

It will be more complicated to detect preferences between income and water quality. There is a tendency of farmers that see the danger to be restricted in farm practice to focus on income losses and to appreciate potential gains from better environment rather moderately. Apparently, contingent valuation is the most common tool. But, in the case of the suggested lake cleaning, evaluation of benefits shall be based on political economy modeling and contingent valuation is only a supplementing tool. However, it maybe even more appropriate to use the more elaborated technique of choice experiments and make the whole exercise a participatory approach. That raises the question of involvement of stake-holders. The model can easily be extended in order to include fishermen and recreation enterprises. Apparently, then, a re-specification of interest functions is needed and a clarification of property rights and payments for compensation should complement the analysis. Theoretically, the current model is capable to recognize financial transfers and allows to investigate institutional innovations.

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