Investment in Wetlands for Pollution Abatement Under Uncertainty

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Abstract
Wetlands have been identified as a cost effective way of abating pollution from agricultural and other human activities. The establishment and restoration of wetlands is one of the policy measures implemented by the Swedish government to reduce excessive nutrient input from non-point sources of pollution that contribute to the eutrophication of the Baltic Sea. This paper discusses the issue of how uncertainty affects the decision of a landowner to convert agriculturally productive land into wetlands. Three issues are dealt with. First, how does uncertainty affect the risk averse farmer's decision about constructing wetlands. Second, what is the effect of different information structures on the level of land conversion carried out. And finally, what is the role played by irreversibility in the decision-making process. Land conversion might result from a risk averse farmer trying to diversify her investment options. The possibility of receiving more information in the future leads to either a delay in the farmer's decision to restore wetlands or to the requirement of a higher subsidy for the decision to be made, even when it is not irreversible. The establishment of a public policy to encourage wetland construction should take these aspects into consideration. The subsidy could be designed as an insurance mechanism and the policy maker should consider the effect of the information availability on the agent's behavior.

Introduction

One of the measures implemented by the Swedish Government to reduce the excessive nutrient input from non-point sources of pollution that contribute to the eutrophication of the Baltic Sea is the establishment and restoration of wetlands[1]. As in other countries, the Swedish Government has established subsidies to encourage farmers to convert agricultural productive land into wetlands. As shown by Parks (1995), these incentives do sometimes not achieve the expected results because farmers seem to require higher payments to take the investment decision to change land uses. According to Byström (2000), in the Swedish case, the interest in changing land use varies across regions. Thus, a subsidy established for wetland construction does not have the same effect in southern Sweden as in other regions of the country. The Swedish incentive mechanism has recently been

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[1] Among other environmental services, wetland areas have proved to contribute to the removal of nutrients and pollutants from the water both through chemical processes in the sediments and plant growth. According to the Swedish Environmental Protection Agency, "at least 12,000 hectares of wetlands and ponds will be established or restored on agricultural land by 2010" (Environmental Quality Objective: Thriving Wetlands).

changed and farmers have shown an interest in restoring wetlands, at least in the Stockholm area[2]. Byström (2000) shows that the restoration of wetlands is worthwhile from a social point of view and the Swedish Government has explicit policies to further increase the area of restored wetlands.

But uncertainty, either about crop prices or about wetland subsidies, is a pervasive phenomenon that can affect the farmer's decision-making in relation to constructing wetlands and the results of an incentive policy to restore previously drained wetlands. Byström et al. (2000) address the uncertainty of wetlands' abatement capacity and show that under certain conditions, wetlands can be a rational instrument to use when both emissions (agricultural run-off, in that case) and nitrogen abatement capacity are stochastic.

This paper discusses how uncertainty influences a farmer's decision-making process and how different information structures might affect the private decision to change land uses from agricultural or other uses into wetlands.

The analysis of the behavior of farmers under uncertainty is of importance since the Swedish government has shown an interest in promoting a further increase in wetland areas and uncertainty affects the private decision-making process, thus also the outcome of the public policy. What does economic theory say about the behavior of a farmer who receives a subsidy to convert productive land into wetlands in an uncertain world? What is the role of risk and risk aversion for the agent and how does it affect the decision to invest in wetlands? How does the farmer's decision vary under different information structures?

Most of the recent literature on farmer's investment under irreversibility and uncertainty employs option value theory (for example, Chavas, 1994, Purvis et. Al., 1995, Pietola and Myers, 2000, and Carey and Zilberman, 2002). As described by Fisher and Hanemann (1990), there is a variety of option value concepts. But "whenever a decision has the characteristics that one of the possible outcomes is irreversible, and there is some prospect of gaining better information about the future benefits and costs of these outcomes, a kind of extra benefit attaches to the reversible outcome. This extra benefit is known as option value, and it can, and properly should, affect a choice among the outcomes"[3]. This paper follows this literature on uncertainty, learning and irreversibility in the line of Arrow and Fisher (1973) and Epstein (1980), and its contribution is the application of this literature to the specific case of investment in wetlands.

The paper shows that, in a static world, the decision to invest in wetlands can be the result of the risk averse farmer trying to diversify her investments to reduce uncertainty. In a more dynamic framework, the *potential* irreversibility of the decision, the possibility of receiving new information and uncertainty play a role in delaying the *socially desirable* land use change and making it *more costly* from

[2] Personal communication with Henrik Scharin, formerly at The Beijer Institute, currently at the Swedish Environmental Protection Agency.

[3] Fisher and Hanemann (1990), p. 167.

the point of view of the social planner. Moreover, even when the decision to change land use is not irreversible, the farmer will refrain from converting agricultural land into wetland as long as the reversibility involves some cost. Thus, the design of a subsidy would have to consider this result.

The paper is organized as follows. The first section introduces the issue of uncertainty and its importance when discussing land conversion decision-making. A simple static model introduces the agent's risk aversion and a simple two-time-period tree model presents the issue of how information availability affects the decision-making when the decision is irreversible. When no new information is forthcoming, it is shown that the farmer makes decisions on the basis of expected pay-offs. But when irreversibility and the possibility of getting new information are considered, there is a change in the expected pay-offs and a decision that would be rational in one case may be completely wrong in another. The second section is the core of the paper. It presents a proposition about the impact of different information availability and learning on the farmer's decision to convert agricultural land into wetland. The concluding section discusses implications for policy making. Appendix A discusses both the importance of wetlands as ecosystems and the Swedish policies related to wetland construction and restoration. Appendix B revisits a known result about risk aversion and risk premium and the third appendix presents the proof of the proposition that is the main aspect of the paper.

I. Uncertainty, risk aversion and information

As previously mentioned, this paper discusses two important aspects of the uncertainty problem in decision-making. The first is risk aversion and the second is information availability for the decision. To simplify the discussion of these aspects, we use two different models. Section I.2 presents a discussion of the risk aversion aspect only. Section I.3 presents a discussion of the information problem when the decision is irreversible; and section II further discusses the information availability aspect when the decision to be taken is not irreversible, but when its reversibility imposes a cost.

I.1. Uncertainty[4]

In the context of the farmer's decision about converting agricultural land into wetlands, different aspects of the uncertainty problem can be discussed. Both input prices and agricultural prices represent a source of uncertainty affecting the farmer's decision. The same is valid for the subsidies and how the incentive policy will evolve over time. Even when the subsidy is certain, future inflation can affect its value if it is not fixed in real terms, also affecting the pay-offs of different strategies upon which the farmer must decide. Another possible source of

[4] It is quite common to make a distinction between risk – when a probability based on past experience can be attached to an event – and uncertainty – where the probability of a certain event is unknown. This distinction is not made here and both terms are used.

uncertainty is the cost of constructing and reconverting wetlands into agricultural land.

The ecological functioning of ecosystems presents another possible source of uncertainty. The issue of how wetlands work as pollution sinks or how much of this service they can provide is crucial for policy design. Analytically, this type of uncertainty works in the same way as the first one mentioned above. The difference is that, in this case, as long as the farmer does not take the ecosystem services from a wetland into consideration in her decision, they are an externality. The uncertainty, in this case, would mostly affect the central planner decision-making about policies to try to “internalize” these positive externalities.

The issue of how information is acquired and disseminated is crucial in economics. Uncertainty may arise in the interaction of agents possessing different levels of information, i.e., in the presence of asymmetric information. In her paper, Crépin (2002) explores the issue of asymmetric information in wetland creation.
Another aspect of the uncertainty issue is related to lack of knowledge or lack of information about the decision to be made. The risk related to a certain decision may change over time because agents may get new information and learn from that. The importance of learning and different information availability for the decision maker is the central issue in section I.3. of this paper.

The agent’s behavior towards uncertainty is another aspect deserving attention. Risk aversion can be defined as the fact that when facing choices with comparable returns, an agent would tend to choose the alternative presenting less risk. Another way of defining risk aversion is by saying that a risk averse agent would reject any investment portfolio that is a fair game, i.e. that offers a zero risk *premium*. As discussed in the next section, in this case uncertainty is of importance because any risk averse farmer would require a *premium* when taking the decision to invest in wetland construction.

I.2. Risk aversion

We start with a very simple model, where the farmer has access to a total land area of $\bar{A}$ that she can either use in agriculture A^A or convert into wetlands A^W.
The choice between A^A and A^W depends on the marginal net benefits from the use of the land in one activity or the other[5]. Thus, the benefits from conventional agricultural production (using A^A) versus non-conventional agricultural products (such as pollutant sinks, from converting A^A into A^W) must be examined.
Conventional agricultural production is a function of the land used in agriculture A^A and some other factor of production that could be labor, L^A:

$$Q^A = f(L^A, A^A)$$

[5] This is the case if we assume convexity. If not, we know that the comparison must be made using total benefits.

$$f' > 0, f'' < 0 \,.$$

From conventional agricultural production, the farmer earns profits equal to

$$\pi^A = pQ^A - C^A(Q^A),$$

where p stands for the price of agricultural production and $C^A(Q^A)$ is some cost function defined by the production function, given factor prices.

If the farmer converts some of the agricultural land into wetlands, the revenues from this new land use would be equal to a payment she would get for setting aside land for environmental purposes[6]. This payment, Q^W, is a function of the area converted into wetland, $Q^W = g(A^W)$. The profit from the wetland recovery is this payment minus the costs of the investment, $C^W(A^W)$:

$$\pi^W = Q^W - C^W(A^W).$$

For simplification, the payment is here assumed to be a linear subsidy per unit of area restored into wetlands, so $Q^W = sA^W$. The total profits are then

$$\pi = \pi^A + \pi^W \text{, or}$$

$$\pi = \pi^A(p, A^A) + sA^W - C(A^W). \qquad (1)$$

We assume the profits to be uncertain, mainly because crop prices are uncertain. But the uncertainty could also come from the subsidy policy. [7]

The farmer maximizes expected utility by choosing how much land to convert into wetlands.

We assume utility to depend on total profits in the following way:

$$E[U(\pi)] = E[U(\pi^A + \pi^W)] = E[U(pQ^A - C^A(Q^A) + Q^W - C^W(A^W)].$$

The farmer's maximization problem is, then, for each time period:

$$\underset{A^A, A^W}{Max}\, E\{U[\pi^A(p, A^A) + sA^W - C(A^W)]\}.$$

[6] Here, we do not consider the possibility of farmers having "good will". Söderquist (2002) discusses this issue.

[7] Price uncertainty is here introduced as a proxy for other possible sources of uncertainty. For example, if a subsidy were to be established in relation to the amount of nutrient reduced by a wetland, the uncertainty in the functioning of the ecosystem and in the amount of nutrient reduced by a certain wetland area would have to be considered. The linear payment per hectare implicitly assumes that the amount of nutrients absorbed by a wetland is proportional to the area and this might not be correct.

A quadratic approximation around $\overline{\pi}$ (expected profits) is used to investigate the role of risk aversion. It is shown that:

$$E(U(\pi)) \cong U(\overline{\pi}) + \frac{1}{2}U''(\overline{\pi})Var(\pi) \cdot$$

The difference between $E(U(\pi))$ and $U(\overline{\pi})$ could be interpreted as an indicator of the agent's attitude towards risk[8]. Appendix B shows that the risk averse private agent would be willing to pay to avoid the uncertainty in profits. This risk *premium* would be equal to

$$r = -\frac{1}{2}.\frac{U''(\pi)}{U'(\pi)}.Var(\pi),$$

since the Arrow-Pratt absolute risk aversion coefficient is defined as

$$r_A = -\frac{U''(\pi)}{U'(\pi)}.$$

The risk *premium*, or the difference between the expected return and the certainty equivalent profit, is

$$r = \frac{1}{2}.r_A.Var(\pi).$$

Now, it is interesting for us to see what lies behind the variance in profits. Going back to our model, we said that profits are uncertain because prices and the subsidy are uncertain (p and s in equation (1)). How does this uncertainty affect profits? The variance in profits is equal to

$$Var(\pi) = \frac{\pi^A}{\pi}Var(\pi^A) + \frac{\pi^W}{\pi}Var(\pi^W) + 2.\frac{\pi^A}{\pi}.\frac{\pi^W}{\pi}Cov(\pi^A, \pi^W) \qquad (2)$$

and

$$Var(\pi^A) = (Q^A)^2 Var(p)$$

$$Var(\pi^W) = (A^W)^2 Var(s)$$

$$Cov(\pi^A, \pi^W) = Q^A Q^W Cov(p, s).$$

[8] If the utility function is assumed to be concave, it is a measure of the degree of risk aversion of the agent or the cost of risk bearing. If the utility function is convex, it is a measure of risk attraction and if there is no difference, we are in the presence of a linear utility function and risk neutral behavior.

Since the variances are positive, what is important here is to know how prices p and subsidy s relate to each other, thus affecting the variance in profits (2). If the covariance in (2) is negative, the diversification between agricultural land and wetlands can be attractive to the risk averse farmer, because it would reduce the variance in profits. In this framework, with uncertainty in prices and subsidy, the restoration of wetlands could be seen as a rational decision from a risk averse farmer.

Under which conditions would that covariance be negative? What would be expected is that agricultural prices and wetland subsidies are positively correlated. The government agency interested in more wetland restoration would increase the subsidy when agricultural prices are increasing, in order to keep the land use conversion attractive. But it might also be the case that the wetland incentive is designed in such a way as to provide "insurance" to the risk averse farmer.

For example, in Sweden, as in other countries, farmers have the right to receive some payment for covering crop losses in case of "natural disasters" or weather conditions that destroy their crops. Attaching the payment of the "crop insurance" to the size of the agricultural area that the farmer reserved for wetlands could be a policy representing, at the same time, income insurance for farmers and incentives for wetland restoration. In other words, the higher the ratio A^{W} / A, the higher would be the payment that a farmer could get for her crop losses.

If we drop the assumption of uncertain subsidies, the fact that the wetland subsidy policy directly provides some kind of profit "certainty" for some time period will make it attractive for the private agent to convert agricultural land into wetlands. The risk averse farmer's choice between an uncertain expected pay-off and a certain one, even if this last one is somewhat smaller, could then explain at least some wetland restoration.

I.3. Uncertainty, irreversibility and different information availability

In this section, the important features are the timing and availability of the information, together with the irreversibility of the decision. We assume risk neutrality, linearity in the benefit functions and only two possible strategies between which the farmer can choose. The model is adapted from Arrow and Fisher (1974) and Mäler (2002).

A rational farmer has an area A of land under agricultural exploitation. She is uncertain about the evolution of crop prices and she must decide whether to keep her land as agricultural land or convert it (or part of it) into wetlands. To give incentives to restore the wetland, the social planner has established a subsidy to cover part of the conversion costs and the maintenance cost for the wetland area throughout the years, as well as a payment to cover the forgone crop profits.

For simplicity, we assume that agricultural crop prices can take two values, a high (ph) and a low one (pl). The subsidy is known and the net benefits from the agricultural activity (B^A) are assumed to be higher (lower) than the net benefits from the wetland restoration (B^W) in case of high (low) agricultural prices:

$$B^A_{ph}(t) > B^W(t) > B^A_{pl}(t), \quad t = 1,2. \qquad (3)$$

The farmer does not know the crop prices with certainty, so the profit from agricultural production is uncertain. The subsidy has been established and is known, so the farmer must analyze and compare the expected profits from the agricultural activity and the future flow of subsidy payments and decide whether to convert land into wetlands. We assume B^W to be the same in both period t=1 and t=2.

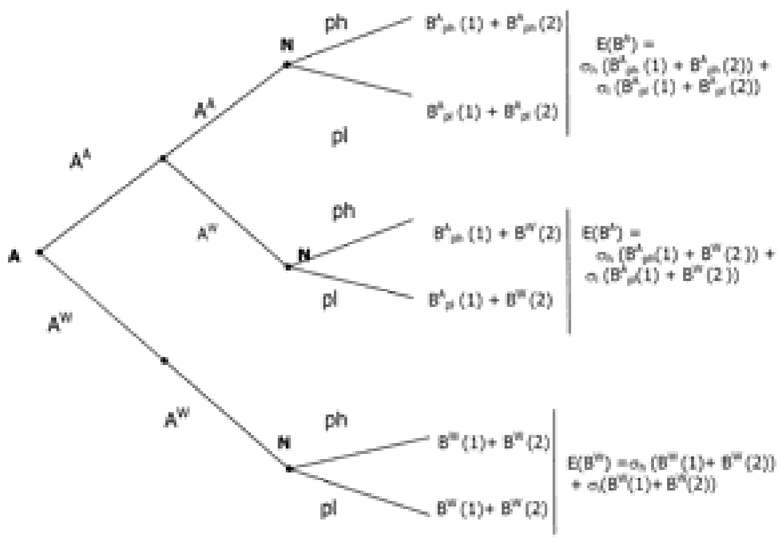
If the farmer does not convert her productive land into wetland, she can still take the decision next year, keeping the option of converting and the possibility of getting more (new) information before taking the decision. If the decision to convert is taken, there is an "institutional irreversibility" produced by the fact that, after signing the contract with the governmental institution responsible for the policy[9], the farmer cannot undo the wetland, at least for a certain number of years. Besides, we assume irreversibility related to the fact that there are sunk costs, i.e. expenditures that cannot be recovered.

We will first analyze the case (a) where there is no forthcoming information and later take the case (b) when new information is available by the end of the first period.

No forthcoming information

In Figure 1, the problem when there is no new information is presented. The decision maker must decide at the beginning of the first period, on basis of the expected pay-offs for both periods (expected benefits), and observe the results at the end of the second period. The results here are expressed in monetary values, not in utility terms. The σs are the priors or beliefs (probabilities) of the farmer in relation to prices, with σh representing the probability of high prices and σl representing the probability that agricultural prices will be low. Nature (N) determines if crop prices are high or low. The farmer has beliefs about it, but she will not know what the prices are until after her decision has been made.

Fig. 1



In the case where the expected pay-off from the agricultural activity ($E(B^A)$) is higher than the pay-off from the wetland restoration ($E(B^W)$), the farmer would choose A^A, and get the pay-off

$$E(B^A) = \sigma_h(2.\ B^A{}_{ph}) + \sigma_l(2.B^A{}_{pl}). \qquad (4)$$

If $E(B^W) = B^W(1) + B^W(2) > E(B^A) = \sigma_h(2.\ B^A{}_{ph}) + \sigma_l(2.B^A{}_{pl})$, the farmer would be interested in converting at least some area from agricultural use into wetlands to get the pay-off

$$E(B^W) = B^W(1) + B^W(2). \qquad (5)$$

In both situations, and because of the assumptions we make about no new incoming information, the farmer would not choose A^A in the first period and change the choice to A^W in the second period, or vice-versa. On the one hand, we are assuming that the choice of A^W is irreversible. On the other, the farmer would never get the payoff of $B^A{}_{ph}(1) + B^W(2)$, since with the expectation of high agricultural prices (valid for both periods, since no new information would arrive), there would not be any conversion into wetlands in any of the periods.

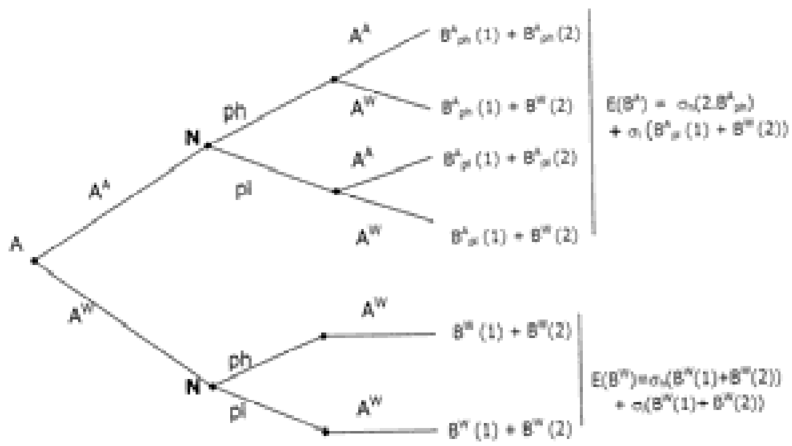
Where no new information is added, the farmer must compare, on basis of her beliefs or priors about crop prices, the expected benefits from the agricultural activity, $E(B^A)$, with the expected benefits from the wetland restoration, $E(B^W)$, to make a decision.

[9] In the Swedish case, the local government or “länsstyrelsen” (the county administration). Cf. Appendix 2 (section A1.2) for a description of how the Swedish policy works.

With new information

A more interesting case is that depicted in Figure 2. Here, at the end of the first period, our farmer gets to know if the prices will be high or low[10]. As in the previous case, the decision tree is depicted as if it were a "game" between the farmer and Nature (**N**), which determines if crop prices are high or low.

Fig. 2



In case of high agricultural prices, if the farmer has chosen A^A in the first period, she will continue with A^A, the agricultural activity, also for the second period, getting the pay-off of

$$B^A = B^A_{ph}(1) + B^A_{ph}(2). \qquad (6)$$

In case the farmer had chosen the agricultural activity in the first period, in face of low agricultural prices, she changes her mind at the end of the first period and decides to convert some land into wetlands, getting the pay-off of

$$B^{AW} = B^A_{pl}(1) + B^W(2). \qquad (7)$$

If the farmer has chosen to convert (some) land into wetlands before obtaining the information at the end of the first period, this decision cannot be changed for the second period. We assume the restoration of wetlands in an agricultural area to be irreversible, at least in the short run. This means that the farmer knows from the beginning that her pay-off in this case will be equal to

[10] Somehow the assumption here is that crop prices in the second time period are perfectly correlated with the observed crop prices in the previous period (or at least a good "signal"). Another way of thinking of this is that the farmer gets information by the end of the first period on how the prices will behave in the future.

$$E(B^W)= \sigma_h (B^W(1)+B^W(2)) + \sigma_l(B^W(1))+ B^W(2)) \; = B^W (1) + B^W (2). \quad (8)$$

The farmer will decide to restore wetlands in an agricultural area before getting information if she expects that the benefits from the change in land use will be higher than the benefits from the agricultural activity.

In this case, the farmer compares her expected benefits from the wetland restoration in (8)) with the expected benefits from taking the decision of keeping the area in agricultural production, i.e.,

$$E(B^A) = \sigma_h(2.B^A{}_{ph}) + \sigma_l (B^A{}_{pl} (1) + B^W (2)). \quad (9)$$

As in the case of there being no new information, if $E(B^W) > E(B^A)$, the first decision is in the direction of A^W, and if $E(B^W) < E(B^A)$, the first move is towards A^A.

The difference here is that the availability of new information changes the expected values, as can be observed in the following table summarizing the expected pay-offs in the different cases (superscripts a and b to make the difference between expected benefits of agriculture in both cases):

Cases		a) no new info	b) new info
Expected values	A^A as first move	$E^a(B^A) = \sigma_h (B^A{}_{ph} (1) + B^A{}_{ph} (2)) + \sigma_l (B^A{}_{pl} (1) + B^A{}_{pl} (2))$	$E^b(B^A) = \sigma_h(B^A{}_{ph} (1) + B^A{}_{ph} (2))+ \sigma_l (B^A{}_{pl} (1) +B^W (2))$
	A^W as first move	$E(B^W)=\sigma_h (B^W(1)+B^W(2)) + \sigma_l(B^W(1)+ B^W(2))$	$E(B^W)=\sigma_h (B^W(1)+B^W(2)) + \sigma_l(B^W(1)+ B^W(2))$

If the agricultural activity is the best choice after the new information arrives, it means that it would also have been the best choice before the new information was available. This is the case because, according to our original assumption in (3), $B^A{}_{ph}(t)> B^W(t)> B^A{}_{pl}(t)$, and:

$$E^a(B^A) = \sigma_h (B^A{}_{ph} (1) + B^A{}_{ph} (2)) + \sigma_l (B^A{}_{pl} (1) + B^A{}_{pl} (2)) \quad (4)$$
$$<$$
$$E^b(B^A) = \sigma_h(B^A{}_{ph} (1) + B^A{}_{ph} (2)) + \sigma_l (B^A{}_{pl} (1) +B^W (2)). \quad (9)$$

The same is not true in the case of the decision about restoring wetlands. The fact that the decision to restore wetlands involves some degree of irreversibility implies that, if the farmer has chosen A^W in the first period and, at the end of that period, she gets to know that the agricultural prices are high, she cannot go back on her decision to get the payoff of $B^W (1) + B^A{}_{ph} (2)$. In case of low agricultural prices,

with new information, A^W is chosen as a second move at the end of the first period, and the farmer gets the pay-off of $B^A_{pl}(1) + B^W(2)$.
If A^W were the best choice when no new information was forthcoming, it was because the benefit from the wetland restoration was expected to be greater than the expected benefit from the agricultural activity, i.e.,

$$E^a(B^A) = \sigma_h (B^A_{ph} (1) + B^A_{ph} (2)) + \sigma_l (B^A_{pl} (1) + B^A_{pl} \quad (2))$$
$$<$$
$$E(B^W) = B^W(1)+ B^W(2). \qquad (10)$$

But, taking the new information into account, the comparison the farmer must make in order to invest in wetland restoration is no longer between the benefits from wetlands and the original (uninformed) expected benefits from the agricultural activity, as in (10). The decision must be taken by comparing

$$E(B^W)=\sigma_h (B^W(1)+B^W(2)) + \sigma_l(B^W(1)+ B^W(2)) \quad (4)$$

with

$$E^b(B^A) = \sigma_h(B^A_{ph}(1) + B^A_{ph}(2))+ \sigma_l (B^A_{pl}(1) + B^W(2)), \qquad (9)$$

the latter being greater than the expected benefits from agriculture in the “no new information” case.

As we can see, the difference between (4) and (9) is equal to $\sigma_l (B^W - B^A_{pl})$. This could be seen as the value of the information received or, alternatively, the value of not having engaged in an irreversible activity when new information is forthcoming.

II. Forthcoming information, reversibility costs and land conversion

This section develops the initial model for the risk averse farmer decision to include two time periods. It shows that, even when there is no irreversibility, if reverting the decision to invest implies some cost, the farmer will refrain from taking the decision as a first step or will convert less wetland than he would in other circumstances. And this occurs even with the assumption of risk neutrality that we use here[11].
In our initial model, the farmer has access to a total land area of $\bar{A}$ that she can either use in agriculture A^A or convert into wetlands A^W. Assuming that utility depends on total profits in the following way

$$E[U(\pi)] = E[U(\pi^A + \pi^W)] = E[U(pQ^A - C^A(Q^A) + Q^W - C^W(A^W))], \quad (11)$$

the farmer’s maximization problem for each time period is

[11] The irreversibility assumption used in the previous section is also relaxed in this section.

$$\underset{A^A, A^W}{Max}\, E\{U[\pi^A(p, A^A) + sA^W - C(A^W)]\} \quad (12)$$

and the first-order condition (foc) for maximization is:

$$p.f_A - s + \frac{dC}{dA^W} = 0 \text{ or } -p.f_A + s - \frac{dC}{dA^W} = 0. \quad (13)$$

In the one period case, the farmer will produce at the level where the subsidy for wetland conversion covers the cost of wetland construction and the foregone production from the lost agricultural area.

The simple graphic model of the previous section (Figures 1 and 2) showed the difference in the farmer's decision-making when time is taken into consideration and the decision involves irreversibility.

In this section, once more considering two time periods, two cases are analyzed separately, depending on the amount of information to which the farmer has access and the timing of its availability. There is no irreversibility here. The assumption is that the decision about constructing a wetland is reversible, but it implies a cost. The model presented here is a two-period analysis of behavior under uncertainty, with two situations differing in the amount of information available for the decision maker. In his paper, Epstein (1980) shows that "the prospect of greater future information discourages the adoption of an irreversible decision"[12]. He also shows situations where less extreme irreversibility leads to different results according to the kind of models used for the analysis. Here, an alternative version to Epstein's framework is used to show that, in what concerns a farmer's decision to convert agricultural land into wetlands, there is no need for the decision to be irreversible to discourage the investment. This would suggest the need for greater incentives for the farmer to restore wetlands than what is the case when no new information is expected, even in the absence of irreversibility.

II.1. The case without new forthcoming information

In this case, the farmer decides at the beginning of the first period how much land she will convert into wetlands in both periods, i.e., she decides about A_1^W (total area converted into wetlands by the end of period 1) and A_2^W (total area converted into wetlands by the end of period 2)[13].

The farmer's maximization problem is:

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[12] See p. 270.

[13] See the notation. While A_1^W represents both the total area converted into wetlands in period 1 and the total area converted into wetlands by the end of period 1, A_2^W represents the total area converted into wetlands by the end of period 2, which means that (A_2^W - A_1^W) is the amount of land converted into wetlands in period 2.

$$\underset{A_1^W, A_2^{W1}}{Max}\ E(U(\pi)) = E\{\ \left[U(\pi_1^A(p_1, 1-A_1^W) + s_1 A_1^W - C_1^W(A_1^W)\right] + \qquad (14)$$
$$+\beta\left[U(\pi_2^A(p_2, 1-A_2^W) + s_2 A_2^W - C_2^W(A_1^W, A_2^W)\right]\ \},$$

where:

π refers to profits, the superscript denoting agriculture (A) or wetland (W) area, the subscript denoting the time period (1 or 2)

p and s are agricultural prices and subsidies, the subscript denoting the time period (1 or 2)

C is the cost function associated with the conversion of land into wetland, which depends on the amount of land converted, A, the superscript W denoting wetland area, the subscript denoting the time period (1 or 2)

β is the discount rate.

The discount factor β does not affect the main results of the model. Therefore, it can be removed or assumed to be equal to 1. The first-order conditions are, then:

$$E\left\{U'(\pi_1)\left[-p_1 f_A + s_1 - \frac{dC_1^W}{dA_1^W}\right] - \beta U'(\pi_2)\frac{\partial C_2^W}{\partial A_1^W}\ \right\} = 0 \qquad (15)$$

$$E\left\{U'(\pi_2)\left[-p_2 f_A + s_2 - \frac{\partial C_2^W}{\partial A_2^W}\right]\ \right\} = 0 \cdot \qquad (16)$$

Two different cost functions are used: one for the first period, only depending on the area the farmer decides to convert into wetlands in that period ($C_1^W(A_1^W)$); and another ($C_2^W(A_1^W, A_2^W)$) depending on both the area converted in the first period (A_1^W) and the total wetland area at the end of the second period (A_2^W).

As previously mentioned, in this formulation, the total area converted in the second period is equal to the difference A_2^W - $A_1^W = \Delta A^W$. We assume the cost function to be of the type $C_2^W = C_2^W(A_1^W, A_2^W) = \gamma(A_2^W - A_1^W)^2$. This means that the larger is the difference between the wetland areas in both periods, the greater is the cost the farmer will have to bear.

For such a cost function, the marginal costs would be equal to

$$\frac{\partial C_2^W}{\partial A_1^W} = -2\gamma(A_2^W - A_1^W) \text{ and } \frac{\partial C_2^W}{\partial A_2^W} = 2\gamma(A_2^W - A_1^W),$$

and their derivatives would be equal to

$$\frac{\partial^2 C_2^W}{\partial A_2^{W\,2}} = \frac{\partial^2 C_2^W}{\partial A_1^{W\,2}} = 2\gamma$$

$$\frac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W} = \frac{\partial^2 C_2^W}{\partial A_2^W \partial A_1^W} = -2\gamma \cdot$$

This means that, depending on the relative sizes of A_1^W and A_2^W, the marginal cost of increasing the wetland area in the first or the second period would have the following signs:

$$\text{If } A_2^W > A_1^W \Rightarrow \frac{\partial C_2^W}{\partial A_1^W} < 0 \text{ and } \frac{\partial C_2^W}{\partial A_2^W} > 0 \cdot$$

$$\text{if } A_2^W < A_1^W \Rightarrow \frac{\partial C_2^W}{\partial A_1^W} > 0 \text{ and } \frac{\partial C_2^W}{\partial A_2^W} < 0 \cdot$$

The shape of the cost function is extremely important in this model, because it contains the idea of both a cost of constructing wetlands and a cost of undoing previously constructed wetlands. It is this idea that will lead us to the main result of the model.

II.2. When new information is forthcoming

The problem becomes different when the farmer knows that new information will be available at the end of the first period. The farmer only chooses A_1^W at the beginning of the first period, leaving the decision about A_2^W to be taken on the basis of the new information (which could be about agricultural prices or any other new information relevant for the decision).
To solve the problem, the starting point is the farmer's decision about how much wetland to have in the second period (A_2^W), taking what was already converted in the first period (A_1^W) as given.

The farmer then solves the following maximization problem:

$$\underset{A_1^W}{Max}\left[U(\pi^A(p_1,1-A_1^W)+s_1A_1^W-C_1^W(A_1^W))\right]+E\,\underset{A_2^W}{Max}\left[U(\pi^A(p_2,1-A_2^W))+s_2A_2^W-C_2^W(A_1^W,A_2^W)\right]\cdot$$

(17)

The first-order condition for the second period is

$$U'(\pi_2)\left[-p_2f_A+s_2-\frac{\partial C_2^W}{\partial A_2^W}\right]=0\cdot \qquad (18)$$

Assuming that $U'(\pi_2)\neq 0$, then

$$-p_2f_A+s_2-\frac{\partial C_2^W}{\partial A_2^W}=0\Rightarrow +s_2=+p_2f_A+\frac{\partial C_2^W}{\partial A_2^W}\cdot$$

The subsidy must, thus, compensate for the loss in productivity due to the reduction in the agricultural area, plus the cost of increasing or restoring the wetland area.

From this condition, the expression for $\frac{\partial A_2^W}{\partial A_1^W}$ is calculated to see how the decision (already) made in the first period affects the amount of wetland constructed in the second period.

Taking the condition for solving the maximization problem in the second period and using the implicit function theorem, we have:

$$\left[-p_2 f_A + s_2 - \frac{\partial C_2^W}{\partial A_2^W} \right] = 0$$

$$\frac{\partial C_2^W}{\partial A_2^W} = \frac{\partial C_2^W (A_1^W, A_2^W (A_1^W))}{\partial A_2^W}$$

$$\left[-p_2 f_A (A_2^W (A_1^W)) + s_2 - \frac{\partial C_2^W (A_1^W, A_2^W (A_1^W))}{\partial A_2^W} \right] \equiv 0 \cdot$$

Deriving it with respect to A_1^W, we get:

$$\frac{d \frac{\partial C_2^W}{\partial A_2^W}}{dA_1^W} = \frac{\partial^2 C_2^W}{\partial A_2^W \partial A_1^W} + \frac{\partial^2 C_2^W}{\partial A_2^{W\,2}} . \frac{\partial A_2^W}{\partial A_1^W}$$

$$p_2 f_{AA} \frac{\partial A_2^W}{\partial A_1^W} - \frac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W} - \frac{\partial^2 C_2^W}{\partial A_2^{W\,2}} . \frac{\partial A_2}{\partial A_1} = 0 \cdot$$

We then obtain the following expression:

$$\frac{\partial A_2^W}{\partial A_1^W} = \frac{\frac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}}{p_2 . f_{AA} - \frac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}, \qquad (19)$$

where $\frac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W} < 0$, $\frac{\partial^2 C_2^W}{\partial A_2^{W\,2}} > 0$, and $f_{AA} < 0$.

Therefore, the expression in (19) is positive.

The intuition behind this is that, as long as the cost increases when there is an increase in the difference between the areas, when the farmer converts one additional unit of area in the period 1, she will also be interested in increasing the total area converted in period 2 by the same amount, in order to avoid an increase in costs.

The difference between the two problems is that, without new information, the farmer solves the following maximization problem by observing the two first-order conditions:

$$\underset{A_1^W, A_2^W}{Max}\, E\left\{U\left[\pi^A(p_1, A_1^A) + s_1 A_1^W - C_1^W(A_1^W)\right] + \left[U(\pi^A(p_2, A_2^A) + s_2 A_2^W - C_2^W(A_1^W, A_2^W))\right]\right\} \quad (20)$$

$$E\left\{U'(\pi_1)\left[-p_1 f_A + s_1 - \frac{dC_1^W}{dA^W}\right] - U'(\pi_2)\frac{\partial C_2^W}{\partial A_1^W}\right\} = 0 \quad (21)$$

$$E\left\{U'(\pi_2)\left[-p_2 f_A + s_2 - \frac{\partial C_2^W}{\partial A_2}\right]\right\} = 0, \quad (22)$$

while, with new forthcoming information, the new problem and the first-order conditions are:

$$\underset{A_1^{W1}}{Max}\left\{\left[U(\pi^A(p_1, 1 - A_1^W) + s_1 A_1^W - C_1^W(A_1^W))\right] + E\,\underset{A_2^{W1}}{Max}\left[U(\pi^A(p_2, 1 - A_2^W) + s_2 A_2^W - C_2^W(A_1^W, A_2^W))\right]\right\}$$

(23)

$$U'(\pi_1)\left[-p_1 f_A + s_1 - \frac{dC_1^W}{dA_1^W}\right] + E\left\{U'(\pi_2)\left[\left(-p_2 f_A + s_2 - \frac{\partial C_2^W}{\partial A_2^W}\right)\frac{\partial A_2^W}{\partial A_1^W} - \frac{\partial C_2^W}{\partial A_1^W}\right]\right\} = 0$$

(24)

$$U'(\pi_2)\left[-p_2 f_A + s_2 - \frac{\partial C_2^W}{\partial A_2^W}\right] = 0. \quad (25)$$

As can be observed, in the first case the agent maximizes over two periods without receiving any new information, which means that $\overline{A}_1^W$ is chosen on basis of the expected values of $U(\pi)$ for both periods.

In the case with new information, the maximizer $\underline{A_1^W}$ is chosen on basis of the expected value of $U(\pi)$ for the first period, plus the expected value of the function φ, defined as

$$\varphi = \underset{A_2^{W1}}{Max}\left[U(\pi^A(p_2, 1 - A_2^W) + s_2 A_2^W - C_2^W(A_1^W, A_2^W)\right].$$

The question that remains to be answered is about the size of A_1^W in both cases. Is A_1^W larger when there is no forthcoming information ($\overline{A}_1^W$) or when there is forthcoming information ($\underline{A_1^W}$)? In which of the cases would the farmer convert more land into wetland in the first period?

The answer to this question depends on the cost curve $C_2^W = C_2^W(A_1^W, A_2^W)$. Here, as before, there are two different cases to analyze.

The first case is when the wetland area by the end of the second period is larger than that which was converted in the first period.

In this case, $A_2^W > A_1^W \Rightarrow \dfrac{\partial C_2^W}{\partial A_2^W} > 0$; $\dfrac{\partial C_2^W}{\partial A_1^W} < 0$; $\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}} > 0$; $\dfrac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W} < 0$.

In the second case, the total area converted into wetland by the end of the second period is smaller than the area converted in the first period. This means that the farmer regretted her previous decision and now decides to "undo" part of the constructed wetlands. In this case,

$$A_2^W < A_1^W \Rightarrow \frac{\partial C_2^W}{\partial A_2^W} < 0 \text{ and } \frac{\partial C_2^W}{\partial A_1^W} > 0; \frac{\partial^2 C_2^W}{\partial A_2^{W\,2}} > 0; \frac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W} < 0.$$

The importance of this difference relates to the fact that, with the possibility of the farmer receiving new information later in time, the uncertainty about how much land to convert into wetland combined with the cost of deconstructing the wetlands already restored may lead the farmer to postpone her decision until more information is available.

Proposition If there are two possible situations, one that is more informative than the other, if the function φ is concave in A_1^W and if the marginal cost function $\dfrac{\partial C_2^W(A_1, A_2(A_1, p_j)}{\partial A_1}$ is concave with respect to p, the area of agricultural land converted into wetland will be greater in the case of no information than in the case of forthcoming information[14].

Proof: see Appendix C

The farmer would convert more land into wetlands in case of no information than in the case when new information arrives. This is the case because the information we are referring to concerns market prices for agricultural output. Because of the concavity of the cost function with respect to prices, the expected cost of land conversion will always be smaller than the real cost. No information would then lead to greater conversion.

More forthcoming information leads to less development in the first period, even in this case where there is no irreversibility. If there is a cost for reversing the previous investment, then it will always be better for the farmer to postpone the investment decision. From a normative point of view, the subsidy for wetland creation should be higher (other things equal) in order to consider this aspect, even when the land conversion decision does not involve irreversibility.

III. Exploring possible policy implications

In the static approach first discussed, the conversion from a productive agricultural area into a restored wetland area might be the result of the behavior of a risk averse agent trying to diversify her investments to reduce uncertainty. We discussed two possibilities.

The first possibility is that of a certain subsidy. In this case, it is rational for the risk averse agent to take B^W, instead of facing the uncertainty of $E(B^A)$, even if the benefits from wetland restoration (B^W) are not greater than the expected benefits from the agricultural activity ($E(B^A)$), as long as B^W is greater than the certainty equivalent benefit from agriculture ($B^A{}_c$).

Another possibility is that of uncertainty in both crop prices (p) and subsidy (s). In this case, both p and s are random variables and their covariance would have to be negative for the wetland restoration to reduce the farmer's profit variability. If that is the case (negative covariance), conversion could be a rational choice by the risk averse farmer willing to reduce the uncertainty (variance) in profits. In this case, instead of the design of a direct subsidy as an incentive to restore wetlands, it could be more interesting to have an indirect incentive linking income stabilization and wetland restoration to "create" the negative covariance through the governmental policy.

[14] We assume more information to always be better in the case of one decision maker. This might be different in the case of a non-cooperative game or in the case of strategic interactions.

In this context, the uncertainty in crop prices "helps" the decision to restore wetlands, even when no risk aversion is considered. If this is the case, and if there is an objective of increasing the area dedicated to wetlands at the least cost, it might be interesting to further explore the connection between agricultural prices and subsidies and incentives to wetland restoration. By providing agricultural subsidies to guarantee a minimum income for farmers, public policy could be creating a false price certainty that might prevent farmers from converting agricultural land into other more "environmentally friendly" uses.[15]

If agricultural subsidies contribute to decrease uncertainty in crop prices, they also make it necessary for the government to give higher subsidies to wetland restoration. If this were the case, a better coordination of both policies would make it less costly to get more areas in wetlands and simultaneously give farmers the required income security.

In the framework of the model in section I.3, and assuming risk neutrality, the agent would now instead avoid taking the decision to convert agricultural land into wetlands, because of the assumptions of irreversibility in the investment in wetlands and the possibility of receiving new information to feed the decision-making process. The irreversibility now implies that the farmer requires an extra *premium* payment to decide on conversion as a first move. This "premium" corresponds to the value of the information, i.e., the difference between the expected value of the benefits from the agricultural activity without information and those benefits when information is forthcoming.

In section II, the approach attempts to integrate the ideas presented in section I in a simple model of behavior under uncertainty with different information availability for the decision. It illustrates the potential connections between uncertainty in crop prices and decisions involving a cost for reversing the decision. It is shown that even when the decision to restore wetlands is not irreversible, the rational farmer will invest less in land conversion as a first step when there is uncertainty and with the possibility of receiving more information in the future. As long as the reversibility of the decision involves some cost, the farmer will avoid creating wetlands. The conclusion is that to obtain more wetland restoration, the policy maker should consider these results and design an incentive mechanism taking uncertainty and information for the decision into consideration.

[15] The European Common Agricultural Policy (CAP) has changed, in some senses, from being an incentive for production into representing a fixed income per cultivated area. To which point this policy counteracts other environmental friendly incentives might be the objective of a more empirical paper to test the hypothesis.

Appendix A - Why wetlands?

Wetlands are important as nutrient sinks and also because of other ecosystem services they provide. This is a motivation for public policies encouraging wetland construction and restoration. This section presents a brief description of wetlands as ecosystems and the Swedish policies designed to protect and increase wetlands.

A1.1 Wetland ecosystems[16]

Wetlands are important ecosystems corresponding to 6% of the land surface on Earth. They can be found in all continents except Antarctica and, even though they can be as diverse as the tundra in cool regions and the mangrove forests in tropical areas, they consist of three basic features: a) the presence of shallow water or saturated soil; b) unique soil conditions not found elsewhere; c) the presence of vegetation adapted to wet conditions and the absence of flooding-intolerant vegetation.

In Sweden, they consist of 20% of the country's total land area, totalizing some 93 thousand square kilometers. Even though this is a significant area corresponding to three times the area of a country like Belgium, Swedish wetlands have been destroyed by different human activities throughout the last few decades. According to the Swedish Environmental Protection Agency, over 15,000 km^2 of wetlands have been drained through forestry.[17]

The importance of wetland ecosystems relates to the goods and services they provide. A large number of animals, birds, fish, and shellfish depend on wetlands during the whole or part of their life cycle. Some wetlands also provide timber and fibers. In terms of ecosystem services, wetlands provide water storage and filtration, improving water quality and mitigating the effects of floods.

The fact that wetlands are often transition zones between uplands and deepwater aquatic systems makes them function as organic exporters or inorganic nutrient sinks. Wetlands have important roles to play in the global cycles of nitrogen, sulfur, methane, and carbon dioxide. It is exactly this last feature that makes them so interesting for our research. Since they work as filters between the land and the sea, wetlands have been identified as a cost effective way of abating pollution from agricultural and other human activities[18].

In fact, according to Mitsch and Gosselink, mineral cycles can have wide variations between wetlands, depending on how open the system is or how fast the surface water is replaced. But "even in a system as open as a salt marsh that is

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[16] Most of this section is based on Mitsch and Gosselink (1993).

[17] www.internat.environ.se/documents/nature/nacatego/wetlands/wetlands.htm (Swedish EPA homepage).

[18] See, for example, Gren (1995) and Gren, Turner and Wulff (2000), and Ribaudo et al. (2001).

flooded daily, about 80 percent of the nitrogen used by vegetation during a year is recycled from mineralized organic material" [19].

In this section of the paper, we attempt to present some basic notions of ecology of wetlands and discuss their benefits and costs and their role as a final nutrient disposal technology.

Hydrology of wetlands

One of the most important factors characterizing a wetland is the water inflow and outflow, the so-called water budget. Inflows include precipitation, flooding rivers, groundwater, surface flows and tides (in case of coastal wetlands). Hydrologic conditions in a wetland also include the surface contours of the landscape and the geological conditions, and they affect the nutrient availability, the species composition, the abundance of biota, in other words, the whole structure and functioning of the system. Biotic factors, in turn, such as vegetation or animals, can also affect the hydrology of a wetland.

Every wetland is characterized by a hydroperiod, a "seasonal pattern of the water level, like a hydrologic signature of each wetland type".[20] A wetland can be tidal or non-tidal, and be permanently flooded or not, throughout the hours of the day (tides) or the months and years. This variable amount of water in a wetland depends on the precipitation, the surface and groundwater inflows and outflows, the evapotranspiration, and the tides.

Biogeochemical cycles

Through water inflows and atmospheric depositions, wetlands receive nutrients, whose transformation and availability to the vegetation are also affected by the hydroperiod of the wetland. Transformations of nitrogen, phosphorus, sulfur, and other minerals take place in wetland ecosystems. Nitrogen from the atmosphere can be fixed by some plants and microorganisms and converted into organic form. Through denitrification, a process occurring in wetlands, the excess of nitrogen in the water inflow can once more be transformed into atmospheric nitrogen which is an important contribution from wetlands to the nitrogen cycle. Nitrogen is also retained in wetlands by sedimentation and through its absorption by the vegetation. In the case of phosphorus, its retention in litter and peat or in the sediments "is considered one of the most important attributes of natural and constructed wetlands".[21]

Even though wetlands have been identified as nitrogen and phosphorus sinks, not all wetlands are nutrient sinks and the patterns of capture, storage, and release of nutrients vary across wetlands, seasons, and years. Some uncertainty remains about the actual amount of nutrients that a wetland is able to retain.[22] In fact, a wetland can be a source, a sink, or a transformer of chemicals, not only depending on its type and hydrologic conditions, but also on the length of time and the

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[19] Mitsch and Gosselink (1993), p. 205, citing Delaune and Patrick, 1979.
[20] Mitsch and Gosselink (1993), p. 72.
[21] Mitsch and Gosselink (1993), p. 140.
[22] See, for example, Arheimer and Wittgren (2002).

amount of chemical loadings to which the system has been subjected. Permanent heavy loads of chemicals can be unsustainable, since a wetland can become saturated. This is more likely to occur in the case of phosphorus than in the case of nitrogen. As previously pointed out, under certain conditions, nitrogen can be transformed into atmospheric N_2 through denitrification. But in what concerns the phosphorus, it is either accumulated in a wetland and retained by the sediment and the soil or there may be leakages in case of heavy chronic loads.[23]

Biodiversity

As Mitsch and Gosselink (1993) and Folke and Jansson (2000) remind us, wetlands are multifunctional in the sense that they provide several environmental goods and services at the same time.

Besides the already mentioned nutrient abatement function and the buffering of water, wetlands support biological diversity. At the same time, the different plants and animal groups found in a wetland ecosystem shape the functions and structure of the system. From mammals to reptiles, different kinds of birds, fish and shellfish, a wide range of animals depend on wetland ecosystems. Plant diversity is also important, with many wetlands providing timber and other vegetation harvest.

One of the problems related to wetlands is mosquitoes. Due to the hydrological conditions, wetlands are potential mosquito breeding sites (particularly in the summer season, since mosquito production diminishes during the cool season). Even though they are also part of the food chain and important for the biodiversity preservation, in tropical areas mosquitoes are associated with disease transmission to humans and other nuisances.

Restored or Created Wetlands

There are different reasons for the restoration or creation of wetlands, from the enhancement of wildlife to water treatment or flood control. Moreover, the destruction of wetlands throughout the years has stimulated the establishment of public policies to mitigate the loss of these ecosystems through the restoration of previously destroyed wetlands or simply the creation of new ones[24].

According to Mitsch and Gosselink, the creation and restoration of wetlands has been successful in many cases, but there are also examples of failure, mainly because of hydrologic factors. The uncertainty related to the functioning of a wetland seems to increase in the case of created ones. Construction and maintenance costs depend on each case and are also difficult to determine.

In some cases, "wetlands mitigation policies", i.e., policies to foster the creation of wetlands in compensation for their destruction elsewhere, fail because it is relatively easy to restore or construct wetlands of low functional quality. The location factor is important because a wetland restored in an area may not provide the same services as another wetland in another area[25].

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[23] Leonardson (1994).

[24] See, for example, the "no net loss" policy in the US (Heimlich (1994)).

[25] Bockstael and Irwin (2000).

A1.2. Wetlands in environmental policy making in Sweden

As expressed by Roseveare, "the Swedish approach to policy-making in general could be characterized as a process of study, consultation and collective decision-making, followed by decentralized implementation".[26] In what concerns environmental policy making, the main governmental agencies and institutions involved are the following: the Parliament, the Ministry of the Environment (coordination responsibility, 13 agencies for the implementation of policies, including the Environmental Protection Agency), the Ministry of Finance, the Ministry of Agriculture, the Ministry of Industry, Employment and Communications, the Swedish Environmental Advisory Council, and Local Authorities (Local Investment Programmes).

The Parliament is the government agency responsible for establishing the environmental goals for Swedish society. Currently, 16 environmental quality objectives guide the governmental action[27], two of which, named "Zero Eutrophication" and "Thriving Wetlands", are of direct concern in this paper.

Incentives to wetland creation in Sweden

Since 1989, there has existed some policy mechanism in Sweden to give incentives to farmers to create wetlands[28]. From 1989 until 1992, the main policy instrument was the NYLA[29], a voluntary mechanism giving a lump-sum compensation for farmers who created an approved wetland. Since then, "Omställning 90" (the Conversion 90) has been introduced, with a larger budget, to give incentives to farmers to reduce their arable land area, either through wetlands creation or the conversion of agricultural land into forestry or energy crops areas.

Since 1995, when Sweden joined the European Union (EU) and adopted the Common Agricultural Policy (CAP), a new policy has been implemented, in accordance with EU principles. The new environmental subsidy then created (so-called "miljöstöd") consisted of a contract with a twenty-year duration. During that period, the farmer who created a wetland was entitled to receive SEK 4,800 per hectare per year during the first five years of the contract, and then SEK 2,500 for the rest of the twenty-year period. In addition, the farmer could apply for another SEK 1,000 for maintenance.

More recently (2000), some new changes have been made to the subsidy policy. The new subsidy varies according to the region where the wetland is to be constructed. From 50 to 90% of the construction cost are covered; there is a

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[26] Roseveare (2001), p. 5

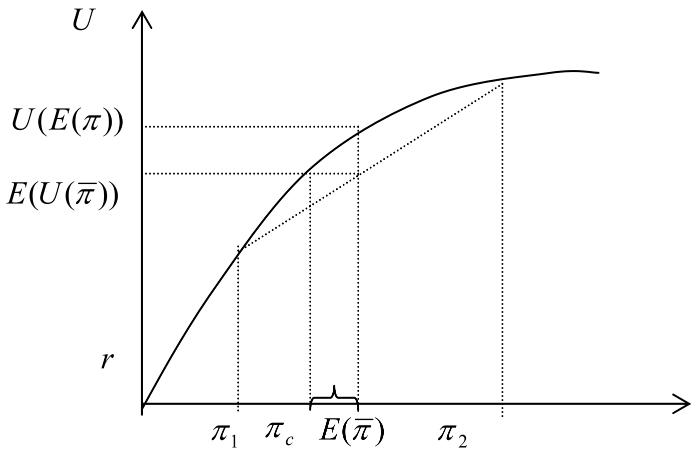
[27] Swedish Environmental Protection Agency, http://www.naturvardsverket.se/

[28] For an overview of Swedish policies for wetland creation, see Lindahl (1998a) and (1998b), whose articles constitute sources for this section.

[29] From the Swedish "nya inslag i landscapet", i.e. new features in the landscape.

payment of SEK 800 per hectare for maintenance and management costs; and, the farmer receives a per hectare annual compensation for production loss.[30]

Appendix B - Risk *Premium* and Risk Aversion



π_c is the certainty equivalent of the profits and, as shown in the figure, it gives the same utility as the expected utility of profits. The question here is to find out what is r, the risk *premium* the farmer is willing to pay for avoiding the uncertainty in profits, and how it relates to the degree of risk aversion of the agent.

Through a first-order approximation for the utility of the certainty equivalent profits

$$U(\pi_c) = E(U(\overline{\pi}))$$

$$\begin{aligned}
U(\pi_c) &= U(E(\pi) - r) = E(U(\overline{\pi})) \\
U(\pi_c) &\cong U(E(\pi)) + U'(E(\pi)).(\pi_c - E(\pi)) \\
U(\pi_c) &\cong U(E(\pi)) + U'(E(\pi)).-r \\
U(\pi_c) &\cong U(E(\pi)) - U'(E(\pi)).r
\end{aligned}$$

and a second-order approximation of the expected utility around the mean $\overline{\pi}$

[30] According to Henrik Scharin (personal communication), the compensation amounts to SEK 3,000 in the Mälar region.

$$E(U(\pi)) \cong U(\overline{\pi}) + p_1 U'(\overline{\pi}).(\pi_1 - \overline{\pi}) + (1-p_1)U'(\overline{\pi}).(\pi_2 - \overline{\pi}) +$$
$$\frac{1}{2}\left[p_1 U''(\overline{\pi}).(\pi_1 - \overline{\pi})^2 + (1-p_1)U''(\overline{\pi}).(\pi_2 - \overline{\pi})^2\right] =$$

$$\cong U(\overline{\pi}) + U'(\overline{\pi})\left[p_1(\pi_1 - \overline{\pi}) + (1-p_1)(\pi_2 - \overline{\pi}\right] + \frac{1}{2}U''(\overline{\pi})E(\overline{\pi} - \pi_i)^2$$

$$E(U(\pi)) \cong U(\overline{\pi}) + \frac{1}{2}U''(\overline{\pi})Var(\pi),$$

and taking into consideration the equality between $U(\pi_c) = E(U(\overline{\pi}))$, it is shown that

$$U(E(\pi)) - U'(E(\pi)).r = U(\overline{\pi}) + \frac{1}{2}U''(\overline{\pi})Var(\pi)$$

$$-U'(E(\pi)).r = \frac{1}{2}U''(\overline{\pi})Var(\pi)$$

$$r = -\frac{1}{2}.\frac{U''(\pi)}{U'(\pi)}.Var(\pi).$$

Since the Arrow-Pratt absolute risk aversion coefficient is defined as

$$r_A = -\frac{U''(\pi)}{U'(\pi)},$$

the risk *premium*, or the difference between the expected return and the certainty equivalent profit is

$$r = \frac{1}{2}.r_A.Var(\pi)$$

Appendix C – Proving the Proposition

Step 1 – Showing under which conditions the function φ is concave in A_1^W

From the farmer's maximization problem in (23), let us use φ, the value function the farmer must maximize in the second period:

$$\varphi(A_1^W) = \underset{A_2^W}{Max}(p_2 f(A_2^W) + s_2 A_2^W - C_2^W(A_1^W, A_2^W)). \quad (26)$$

From the first-order condition in (25), we know that

$$-p_2 f_A + s_2 - \frac{\partial C_2^W}{\partial A_2^W} = 0.$$

If the area converted into wetland by the end of the second period is a function of the area converted in the first period, then $A_2^W = A_2^W(A_1^W)$ and at the optimum

$$-p_2 f_A\left(A_2^W(A_1^W)\right) + s_2 - \frac{\partial C_2^W\left(A_1^W, A_2^W(A_1^W)\right)}{\partial A_2^W} \equiv 0.$$

Our function φ then becomes:

$$\varphi(A_1^W) \equiv p_2 f\left(A_2^W(A_1^W)\right) + s_2\left(A_2^W(A_1^W)\right) - C_2^W\left(A_1^W, A_2^W(A_1^W)\right).$$

By the envelope theorem, the first derivative is equal to:

$$\varphi' = \frac{\partial \varphi}{\partial A_1^W} = -p_2 f_A \frac{\partial A_2^W}{\partial A_1^W} + s_2 \frac{\partial A_2^W}{\partial A_1^W} - \frac{\partial C_2^W}{\partial A_1^W} - \frac{\partial C_2^W}{\partial A_2^W}\frac{\partial A_2^W}{\partial A_1^W} = -\frac{\partial C_2^W}{\partial A_1^W}.$$

The second derivative is

$$\varphi'' = -\frac{\partial^2 C_2^W}{\partial A_1^{W\,2}} - \frac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}\frac{\partial A_2^W}{\partial A_1^W}$$

$$\varphi'' = -\frac{\partial^2 C_2^W}{\partial A_1^{W\,2}} - \frac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}\frac{\dfrac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}}{p_2 . f_{AA} - \dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}$$

$$\varphi''=\frac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}\left(\frac{-\dfrac{\partial^2 C_2^W}{\partial A_1^{W\,2}}}{\dfrac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}}-\frac{\dfrac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}}{p_2.f_{AA}-\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}\right)$$

$$=\frac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}\left(\frac{-\dfrac{\partial^2 C_2^W}{\partial A_1^{W\,2}}}{\dfrac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}}-\frac{\dfrac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}}{\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}\frac{\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}{p_2.f_{AA}-\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}\right)$$

$$=-\frac{\left(\dfrac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}\right)^2}{\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}\left(\frac{\dfrac{\partial^2 C_2^W}{\partial A_1^{W\,2}}\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}{\left(\dfrac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}\right)^2}+\frac{\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}{p_2.f_{AA}-\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}\right). \quad (27)$$

For function φ to be concave in A_1^W, the whole expression in (27) must be negative, which means that the expression

$$\left(\frac{\dfrac{\partial^2 C_2^W}{\partial A_1^{W\,2}}\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}{\left(\dfrac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}\right)^2}+\frac{\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}{p_2.f_{AA}-\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}\right)$$

should be greater than zero. If $p_2.f_{AA}$ were equal to zero, the expression

$$\frac{\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}{p_2.f_{AA}-\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}$$

would be equal to –1. For any other value of $p_2.f_{AA}$,

$$-1 < \frac{\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}{p_2.f_{AA} - \dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}} < 0 \, .$$

In other words, if

$$\frac{\dfrac{\partial^2 C_2^W}{\partial A_1^{W\,2}} \dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}{\left(\dfrac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}\right)^2} > 1 \, ,$$

the function φ is concave in A_1^W. This condition is fulfilled if

$$\begin{vmatrix} \dfrac{\partial^2 C_2^W}{\partial A_1^{W\,2}} & \dfrac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W} \\ \dfrac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W} & \dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}} \end{vmatrix} > 0 \, ,$$

i.e., if the determinant of the Hessian matrix of the cost function is positive.

Step 2 – Analyzing the relationship between the two maximization problems and comparing A_1 in both cases

The main difference between the two maximization problems in (20) and (23) lies in the information aspect. In the first case, it is assumed that the farmer has no information whatsoever to feed the decision-making, i.e., the decision about converting agricultural productive land into wetlands is only taken on basis of expected values of the relevant variables. In the second case, information is available for the decision in the second period.

The maximization problem now becomes ψ and the probability vector ω of states of the uncertain variable p is included in the analysis.

$$\psi(A_1^W, \omega) = \underset{A_1^W}{Max} \sum \omega_j U(A_1^W, A_2^W, p_j), \omega_i \geq 0, \sum_i \omega_i = 1 \, .$$

Information is here understood as a situation where a given signal y brings information on the behavior of the random variable, p. With perfect information, the farmer knows for sure, with probability P=1, what value the random variable will assume, i.e.,

$$P(p = p_i | y = y_j) = 1 \quad \text{if } i=j$$

$$P(p = p_i | y = y_j) = 0 \quad \text{if } i \neq j.$$

For our purposes, ω is more informative than ω' if it gives perfect information in the second period, while ω' does not give this information.[31]

The farmer is in a better situation with rather than without information, i.e., $\psi(A_1^W, \omega) > \psi(A_1^W, \omega')$, if ω is more informative than ω'. The intuition is that without information, the farmer takes the decision by optimizing the expected value of the value function

$$\psi'(A_1^W, \omega') = \underset{A_2}{Max} \sum \omega_j U(A_1^W, A_2^W, p_j),$$

while with information, the decision is taken through an average over possible optimal values

$$\psi(A_1^W, \omega) = \sum \omega_j \underset{A_2}{Max} U(A_1^W, A_2^W, p_j),$$

with ω_j representing the specific probabilities attached to different prices p_j. It is then clear that $\psi(A_1^W, \omega) > \psi'(A_1^W, \omega')$.

i) In the no information case

$$\psi'(A_1^W, \omega') = \underset{A_2}{Max} \sum q_j U(A_1^W, A_2^W, p_j)$$

$$U = p.f(A_1^W) + sA_1^W - C_1^W(A_1^W) + \underset{A_2}{Max} \sum r_j (p_j f(A_2^W) + sA_2 - C_2^W(A_1^W, A_2^W))$$

$$= p.f(A_1^W) + sA_1^W - C_1^W(A_1^W) + \sum r_j (p_j f(A_2^W(A_1^W)) + sA_2^W(A_1^W) - C_2^W(A_1^W, A_2^W(A_1^W)))$$

$$\frac{\partial \psi'}{\partial A_1^W} = p\ f_A + s - \frac{dC_1^W}{dA_1^W} + \sum r_j \left[\left(p_j f_A + s_2 - \frac{\partial C_2^W}{\partial A_2^W} \right) \frac{\partial A_2^W}{\partial A_1^W} - \frac{\partial C_2^W}{\partial A_1^W} \right] =$$

$$= p\ f_A + s - \frac{dC_1^W}{dA_1^W} - \sum r_j \frac{\partial C_2^W(A_1^W, A_2^W)}{\partial A_1^W}.$$

ii) with forthcoming information (perfect information case)

$$\psi(A_1^W,\omega)=\sum q_j \underset{A_2}{Max}\, U(A_1^W, A_2^W, p_j)$$

$$\psi(\omega)=\underset{A_1}{Max}\sum r_j \underset{A_2}{Max}\, U(A_1^W, A_2^W, p_j)$$

$$\frac{\partial\psi(A_1^W,\omega)}{\partial A_1^W}=\frac{\partial U(A_1^W, A_2^W(A_1^W,p_j),p_j)}{\partial A_1^W}$$

$$\frac{d\psi(A_1^W,\omega)}{dA_1^W}=\left[\frac{\partial U(A_1^W,A_2^W,p_j)}{\partial A_1^W}+\frac{\partial U(A_1^W,A_2^W,p_j)}{\partial A_2^W}\frac{\partial A_2^W}{\partial A_1^W}\right]$$

Since $\dfrac{\partial U(A_1^W,A_2^W,p_j)}{\partial A_2^W}=0$

is a first-order condition for the utility maximization in the second period:

$$\frac{\partial\psi(A_1^W,\omega)}{\partial A_1^W}=\left[\frac{\partial U(A_1^W,A_2^W,p_j)}{\partial A_1^W}\right]$$

$$U=p.f(A_1^W)+sA_1^W-C_1^W(A_1^W)+\sum r_j \underset{A_2}{Max}(p_j f(A_2^W)+sA_2^W-C_2^W(A_1^W,A_2^W))$$

$$\frac{\partial\psi}{\partial A_1^W}=p\ f_A+s-\frac{dC_1^W}{dA_1^W}+\sum r_j\left[\left(p\ f_A+s_2-\frac{\partial C_2^W}{\partial A_2^W}\right)\frac{\partial A_2(A_1^W,p_j)}{\partial A_1^W}-\frac{\partial C_2^W}{\partial A_1^W}\right]=$$

$$=pf_A+s-\frac{dC_1^W}{dA_1^W}-\sum r_j\frac{\partial C_2^W(A_1^W,A_2^W(A_1^W,p_j))}{\partial A_1^W}.$$

The difference between the two first-order conditions is:

$$\frac{\partial\psi}{\partial A_1^W}-\frac{\partial\psi'}{\partial A_1^W}=-\sum r_j\,\frac{\partial C_2^W(A_1^W,A_2^W(A_1^W,p_j))}{\partial A_1^W}+\sum r_j\,\frac{\partial C_2^W(A_1^W,A_2^W)}{\partial A_1^W}=$$

$$=-\sum r_j\,\frac{\partial C_2^W(A_1^W,A_2^W(A_1^W,p_j))}{\partial A_1^W}+\frac{\partial C_2^W(A_1^W,A_2^W(A_1^W,\overline{p})}{\partial A_1^W}.$$

What is needed now is to know which one is greater.

To establish the inequality (between

$$\sum r_j\,\frac{\partial C_2^W(A_1^W,A_2^W(A_1^W,p_j))}{\partial A_1^W}\ \text{ and }\ \frac{\partial C_2^W(A_1^W,A_2^W(A_1^W,\overline{p})}{\partial A_1^W}),$$

the marginal cost function and its behavior in relation to the price variable are analyzed in what follows:

$$\frac{\partial}{\partial p_j}\frac{\partial C_2^W(A_1^W,A_2^W(A_1^W,p_j))}{\partial A_1^W}=\frac{\partial^2 C_2^W}{\partial A_1^W\partial A_2^W}\frac{\partial A_2^W}{\partial p_j}$$

$$\frac{\partial^2}{\partial p_j^2}\frac{\partial C_2^W(A_1^W,A_2^W(A_1^W,p_j)}{\partial A_1^W}=\frac{\partial^2 C_2^W}{\partial A_1^W\partial A_2^W}\frac{\partial^2 A_2^W}{\partial p_j^2}+\frac{\partial^3 C_2^W}{\partial A_1^W\partial A_2^{W\,2}}\left(\frac{\partial A_2^W}{\partial p_j}\right)^2.$$

Since $\frac{\partial^2 C_2^W}{\partial A_1^W\partial A_2^W}<0$, $\frac{\partial^3 C_2^W}{\partial A_1^W\partial A_2^{W\,2}}<0$, and $\left(\frac{\partial A_2^W}{\partial p_j}\right)^2>0$, it is now necessary to check the sign of the expression $\frac{\partial^2 A_2^W}{\partial p^2}$.

From the condition for optimization in the second period, $p_j f(A_2^W(A_1^W))+sA_2^W(A_1^W)-C_2^W(A_1^W,A_2^W(A_1^W)=0$, we can get the relationship between A_2^W and prices p_j so that :

$$p_j f_A+s-\frac{\partial C_2^W}{\partial A_2^W}=0\Rightarrow A_2^W=A_2^W(A_1^W,p_j).$$

Deriving the previous expression with respect to p gives:

$$f_A + pf_{AA}\frac{\partial A_2^W}{\partial p} - \frac{\partial^2 C_2^W}{\partial A_2^{W\,2}}\frac{\partial A_2^W}{\partial p} = f_A + \left(pf_{AA} - \frac{\partial^2 C_2^W}{\partial A_2^{W\,2}} \right)\frac{\partial A_2^W}{\partial p} = 0 \cdot$$

Since f_A, pf_{AA} and $-\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}$ are negative, $\dfrac{\partial A_2^W}{\partial p}$ must be smaller than zero for the previous equation to hold.

The second derivative with respect to p gives:

$$f_{AA}\frac{\partial A_2^W}{\partial p} + f_{AA}\frac{\partial A_2^W}{\partial p} + pf_{AAA}\frac{\partial A_2^W}{\partial p} + pf_{AA}\frac{\partial^2 A_2^W}{\partial p^2} - \frac{\partial^2 C_2^W}{\partial A_2^{W\,2}}\frac{\partial^2 A_2^W}{\partial p^2} = 0 \cdot$$

Since the first three terms of the previous expression are positive, $\dfrac{\partial^2 A_2^W}{\partial p^2}$ should be positive for the expression to hold.

These lead to the conclusion that $\dfrac{\partial^2}{\partial p_j^2}\dfrac{\partial C_2^W(A_1^W, A_2^W(A_1^W, p_j)}{\partial A_1^W} < 0$, which means that the marginal cost function $\dfrac{\partial C_2^W(A_1^W, A_2^W(A_1^W, p_j)}{\partial A_1^W}$ is concave with respect to p. If this is the case, then going back to the difference between $\dfrac{\partial \psi}{\partial A_1^W}$ and $\dfrac{\partial \psi'}{\partial A_1^W}$, it is concluded that it is negative, which means that in the case of perfect information, A_1^W is smaller than $A_1^{W}{}'$.

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