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Investment in Land Use for Pollution Abatement Under Uncertainty

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Abstract

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 the decision is not irreversible. The establishment of a public policy to encourage wetland construction should take these aspects into consideration. The subsidy should 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 that contributes 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 Parks (1995) shows, sometimes these incentives do not achieve expected results because farmers seem to require higher payments in

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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).

order to take the investment decision to change land uses. According to Byström (2000), in the Swedish case 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 been changed recently and farmers have shown interest in restoring wetlands, at least in the Stockholm area[2]. Byström (2000) shows that the restoration of wetlands is worthwhile and the Swedish Government has explicit policies to further increase the area of restored wetlands.

But uncertainty is a pervasive phenomenon that can affect both the farmer's decision-making in relation to constructing wetlands and the establishment of an incentive policy to restore previously drained wetlands.

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

Considering the interest in an increase in wetland areas, what would be the necessary subsidy to give incentives for a farmer to convert productive land into wetlands in an uncertain world? What is the role of risk and risk aversion on the part of the agent and how does it affect the decision to invest in wetlands? How does the farmer decision vary under different information structures?

This 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 in order to reduce uncertainty. In a more dynamic framework, the *potential* irreversibility of the decision, the possibility of receiving new information, and uncertainty about prices play a role in delaying the *socially desirable* land use change and in making it *more expensive* from the point of view of the social planner. Even when the decision to change land use is not irreversible, as long as the reversibility involves some cost, the farmer will refrain from converting agricultural land into wetland. Thus the design of a subsidy would have to consider this result.

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[2] Personal communication with Henrik Scharin, from The Beijer Institute.

The paper is organized as follows. The first section has an introductory character and discusses both the importance of wetlands as ecosystems and the Swedish policies related to wetland construction and restoration. The second part introduces the issue of uncertainty and its importance when discussing land conversion decision-making. A simple static model introduces first the agents 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, the expected pay-offs change and a decision that would be rational in one case may be completely wrong in another. The third part is the core of the paper. It presents a proposition about the impact of different information availability on the farmer's decision to convert agricultural land into wetland. The concluding section discusses implications for policy making.

I. 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 of the Swedish policies designed to protect and increase wetlands.

I.1. Wetland ecosystems[3]

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

[3] Most of this section is based on Mitsch and Gosselink (1993). Thanks to Åsa Jansson and Lisa Deutsch for helpful comments.

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.[4]

The importance of wetland ecosystems relate 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 what makes them so interesting for our research work. Since they work as filters between the land and the sea, wetlands have been identified as a cost effective way to abate pollution from agricultural and other human activities[5].

In fact, according to Mitsch and Gosselink, mineral cycles can have wide variations from wetland to wetland, 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 flooded daily, about 80 percent of the nitrogen used by vegetation during a year is recycled from mineralized organic material"[6].

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

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

[6] Mitsch and Gosselink (1993), p. 205, citing Delaune and Patrick, 1979.

In this section of the paper we attempt to present some basic notions of ecology of wetlands and to discuss their benefits and costs and their role as 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 include also 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, like 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".[7] A wetland can be tidal or non-tidal, and be flooded permanently 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 that occurs in wetlands, the excess of nitrogen in the water inflow can be transformed again into atmospheric nitrogen and that is an important contribution from wetlands to the nitrogen cycle. Nitrogen is also retained

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[7] Mitsch and Gosselink (1993), p. 72.

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".[8]

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.[9] In fact, a wetland can be a source, a sink, or a transformer of chemicals, depending not only on its type and hydrologic conditions, but also on the length of time and the amount of chemical loadings the system has been subjected to. Permanent heavy loads of chemicals can be unsustainable, since a wetland can become saturated. This is more likely to happen in the case of phosphorus then in the case of nitrogen. As pointed out previously, under certain conditions, nitrogen can be transformed into atmospheric N_2 through denitrification. But in what concerns the phosphorus, either it is accumulated in a wetland and retained by the sediment and the soil or there may be leakages in case of heavy chronic loads.[10]

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. The plant diversity is also important, with many wetlands providing timber and other vegetation harvest.

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[8] Mitsch and Gosselink (1993), p. 140.

[9] See for example Arheimer and Wittgren (2002).

[10] Leonardson (1994).

One of the problems related to wetlands is mosquitoes. Because of the hydrological conditions, wetlands are potential mosquito breeding sites (particularly in the summer season, since during the cool season mosquito production diminishes). 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. Also 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[11].

According to Mitsch and Gosselink, the creation and restoration of wetlands have 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 as compensation for their destruction elsewhere, fail because it is relatively easy to restore or construct wetlands of low functional quality. The location factor is an important one because a wetland restored in an area may not provide the same services of another wetland in another area[12].

I.2. Wetlands in environmental policy making in Sweden

As Roseveare expresses, "the Swedish approach to policy-making in general could be characterized as a process of study, consultation and collective decision-making,

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

[12] Bockstael and Irwin (2000).

followed by decentralized implementation".[13] 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 one responsible for establishing the environmental goals for the Swedish society. Currently, 15 environmental quality objectives guide the governmental action[14], two of which, named "Zero Eutrophication" and "Thriving Wetlands", are of our direct concern in this paper.

Incentives to wetland creation in Sweden

Since 1989, there has existed in Sweden some policy mechanism to give incentives to farmers to create wetlands[15]. From 1989 until 1992, the main policy instrument was the NYLA (nya inslag i landscapet, new features in the landscape), a voluntary mechanism giving a lump sum compensation for farmers who created an approved wetland. After that, the Omställning 90 (Conversion 90) was introduced, with a bigger budget, to give incentives to farmers to reduce their arable land area, either through wetlands creation or 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 (miljöstöd) consisted of a contract with 20 years of duration. During that period, the farmer who created a wetland was entitled to receive SEK 4,800 per hectare per year during the first 5

[13] Roseveare (2001), p. 5

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

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

years of the contract, and then SEK 2,500 for the rest of the 20year period. In addition to that amount, 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 is covered; there is a payment of SEK 800 per hectare for maintenance and management costs; and, the farmer receives a per hectare annual compensation for loss in production.[16]

But how does the subsidy affect the farmer's decision-making? The next section reviews a theoretical framework for the farmer's decision-making about converting agricultural land into wetland and discusses the role of uncertainty and risk aversion.

II. Uncertainty, risk aversion and information

As mentioned before, 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. For the discussion of these aspects we use two different models. Section II.2 presents a discussion of the risk aversion aspect. Section II.3 presents a discussion of the information problem when the decision is irreversible and section III discusses further the information availability aspect when the decision to be taken is not irreversible, but when its reversibility imposes a cost.

II.1. Uncertainty[17]

Even though an important part of economic theory has developed as if individuals made decisions in a world of certainty, in a variety of real-world situations

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

[17] 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 in unknown. This distinction is not made here and both terms are used.

uncertainty about the outcome of the decisions taken by economic agents is the only sure thing.

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 consist in a source of uncertainty affecting the farmer's decision. The same is valid for the subsidies and how the incentive policy will evolve in time. Even when the subsidy is certain, future inflation can affect its value if it is not fixed in real terms, affecting also the pay-offs of different strategies the farmer must decide upon. Another possible source of 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 into consideration the ecosystem services from a wetland 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. The importance of different information availability for the decision maker is the central issue in section III 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 it is discussed in the next section, in this case uncertainty matters because any risk averse farmer would require a *premium* when taking the decision to invest in wetland construction.

II.2. Risk aversion

We start with a very simple model, where the farmer has access to a total land area of $\overline{A}$ 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 in the other[18]. Thus, the benefits from conventional agricultural production (using A^A) versus non-conventional agricultural products (like pollutant sinks, from converting A^A into A^W) must be examined.

The 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:

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

$$f' > 0, f'' < 0$$

From the 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 the factor prices.

If the farmer converts some of the agricultural land into wetlands, the profits from this new land use would be equal to a payment she would get for setting aside land

[18] This is so if we assume convexity. If not, we know that the comparison has to be made using total benefits.

for environmental purposes[19]. 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, we assume here that the payment is a linear subsidy per unit of area restored into wetlands, so $Q^W = sA^W$. The total profits are, then: $\pi = \pi^A + \pi^W$. We assume that the profits are uncertain, mainly because crop prices are uncertain. But the uncertainty could also come from the subsidy policy. [20]

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

We assume that utility depends on total profits in the following way:

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

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

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

[19] Here we don't consider the possibility of farmers having "good will". Söderquist (2002) discusses this issue.

[20] The price uncertainty is introduced here as a proxy for other possible sources of uncertainty that we could explore later. For example, if a subsidy would be established in relation to the amount of nutrient reduced by a wetland, one would have to consider the uncertainty in the ecosystem functioning and in the amount of nutrient reduced by a certain wetland area. 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.

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

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

The difference between $E(U(\pi))$ and $U(\overline{\pi})$ could be interpreted as an indicator of the attitude of the agent towards risk[21]. The Appendix 1 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 is 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). How does this uncertainty affect profits? The variance in profits is equal to

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

[21] 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 presence of a linear utility function and a risk neutral behavior.

and

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

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

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

Since the variances are positive, what is important here is to know how prices p and subsidy s relate to each other, affecting the variance in profits. If the covariance is negative, the diversification between agricultural land and wetlands can be attractive to the risk averse farmer. 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 one would expect is that agricultural prices and wetland subsidies would be 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 could also be that the wetland incentive is designed in a way to provide "insurance" to the risk averse farmer.

For example, in Sweden, as in other countries, the farmers have the right to receive some payment for covering crop losses in case of "natural disasters" or weather conditions that destroy their crops. A policy that could represent, at the same time, income insurance for farmers and incentive to wetland restoration could be to attach the payment of the "crop insurance" to the size of the agricultural area that the farmer reserved for wetlands. In other words, the higher the ratio $A^W / \overline{A}$, 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 provides directly some kind of profit "certainty" for some time period would 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[22].

II.3. Uncertainty, irreversibility and different information structures

This section sketches a simple model to understand the role of uncertainty in the decision to convert agricultural land into wetlands. Now the important features are the timing and availability of the information, together with the irreversibility of the decision, and not the agent's risk aversion. The model is adapted from Arrow and Fisher (1974) and Mäler (2002). We assume risk neutrality, linearity in the benefit functions and only two possible strategies for the farmer to choose between.

A farmer has an area A of land under agricultural exploitation. She is uncertain about the evolution of crop prices and she has to decide whether to keep her land as agricultural land or to 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 revenues.

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 of the agricultural activity (B^A) are assumed to be higher (lower) than the benefits from the wetland restoration (B^W) in case of high (low) agricultural prices:

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

The farmer does not know crop prices with certainty, so the profit from the 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 or not. We assume that B^W is the same in both period (1) and (2).

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[22] See Appendix 1.

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 social planner[23], you 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.

a) No forthcoming information

In Fig. 1 the problem when there is no new information is presented. The decision maker must decide in the beginning of the first period, on the basis of the expected pay-offs for both periods (expected benefits), and observe the results in 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 σ_h representing the probability of high prices and σ_l 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 is made.

In the case where the expected pay-off from the agricultural activity ($E(B^A)$) is higher than the pay-off for the wetland restoration ($E(B^W)$), the farmer would choose A^A, and get the pay-off $E(B^A) = \sigma_h(2.\ B^A_{ph}) + \sigma_l(2.B^A_{pl})$.

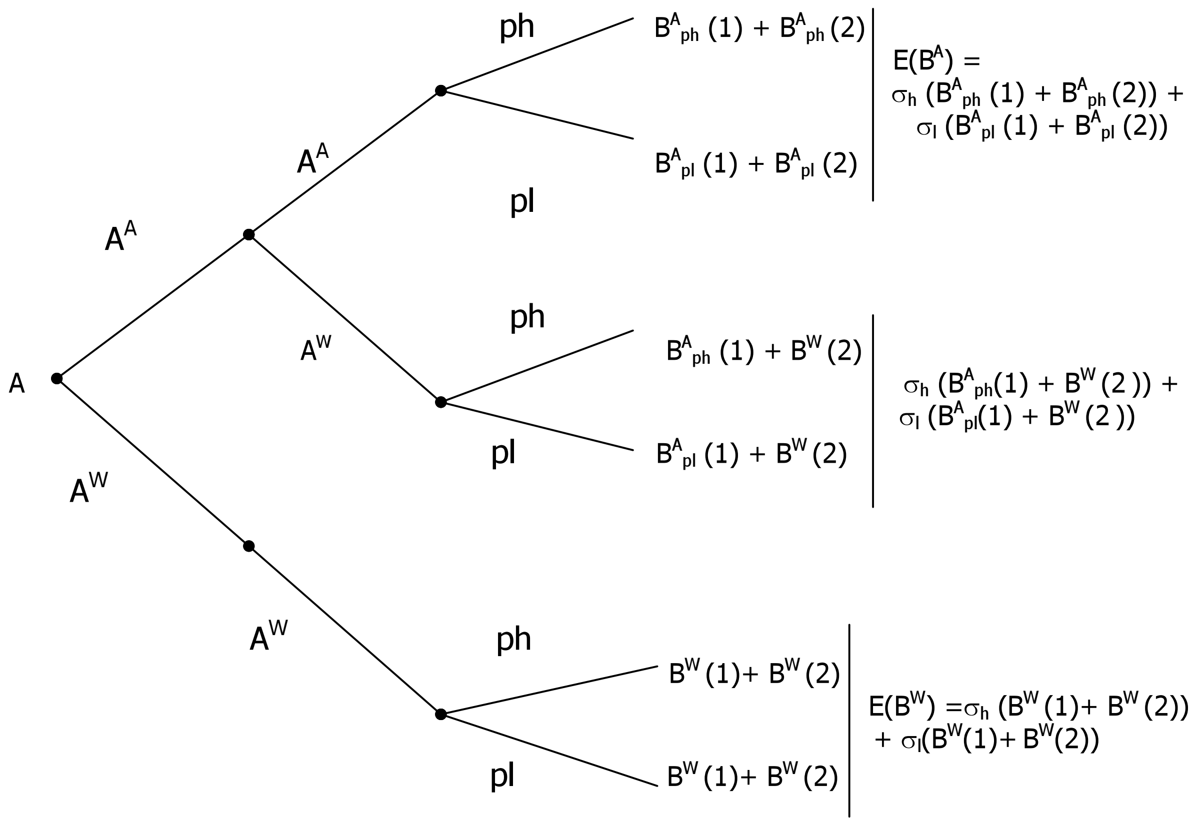
If $E(B^W) = B^W(1) + B^W(2) > E(B^A) = \sigma_h(2.\ B^A_{ph}) + \sigma_l(2.B^A_{pl})$, then the farmer would be interested in converting at least some area from agricultural use into wetlands to get the pay-off $E(B^W) = B^W(1) + B^W(2)$.

In both situations, and because of the assumptions we make about no new information coming, 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 one hand, we are assuming

[23] In the Swedish case, the local government or "länsstyrelsen" (county administration).

that the choice or A^W is irreversible. On the other, the farmer would never get the payoff of $B^A_{ph}(1) + B^W(2)$, because 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.

Fig. 1



Where no new information is added, the farmer must compare, on the 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.

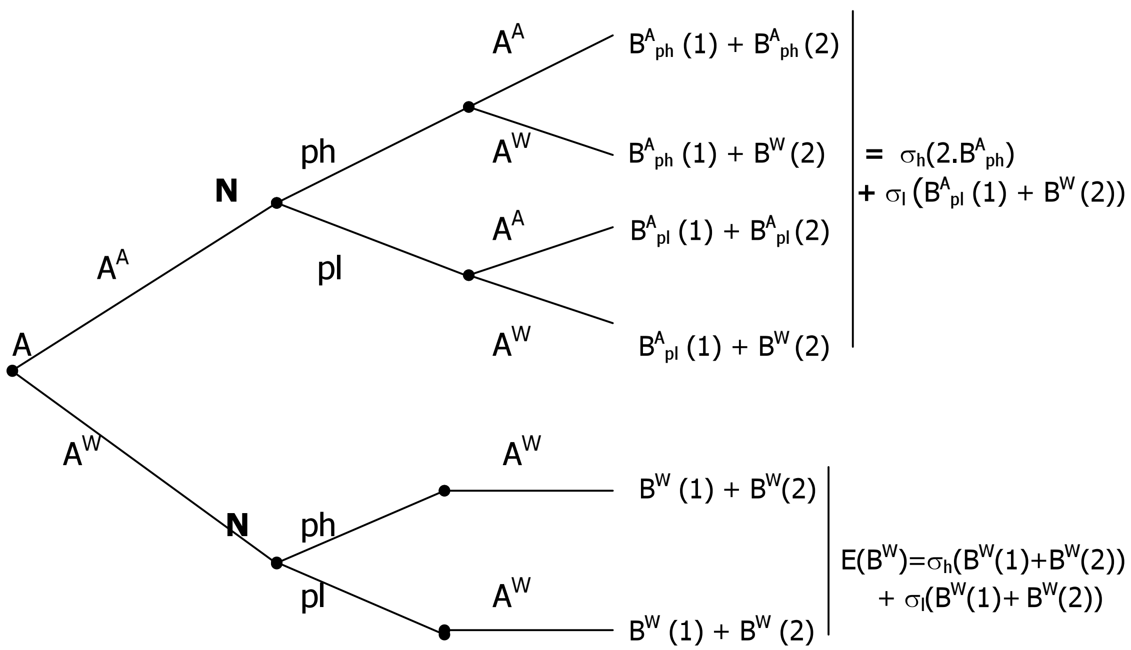
b) With new information

A more interesting case is the one depicted in Figure 2. Here, in the end of the first period, our farmer gets to know if the prices will be high or low[24]. As in the previous case, the decision tree is depicted as if it was a "game" between the farmer and Nature (**N**), who determines if crop prices are high or low.

In case of high agricultural prices, if the farmer had chosen A^A in the first period, she continues with A^A, the agricultural activity, for the second period also, getting the pay-off of $B^A_{ph}(1) + B^A_{ph}(2)$.

In the case the farmer had chosen the agricultural activity in the first period, in face of low agricultural prices, she changes her mind in the end of the first period and decides to convert some land into wetlands, getting the pay-off of $B^A_{pl}(1) + B^W(2)$.

Fig. 2



[24] Somehow the assumption here is that crop prices in the second time period are perfect correlated to crop prices in the previous period (or at least a good "signal"). Whether this is a reasonable assumption or not is probably an empirical issue.

If the farmer had chosen to convert (some) land into wetlands before the information arrived in the end of the first period, this decision cannot be changed for the second period. We assume that the restoration of wetlands in an agricultural area is 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

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

The farmer will decide to restore wetlands in an agricultural area before getting information if she expects that the benefits of 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 $(E(B^W)=\sigma_h (B^W(1)+B^W(2)) + \sigma_l(B^W(1)+ B^W(2)) = B^W(1)+ B^W(2))$ with the expected benefits from taking the decision of keeping the area in agricultural production, i.e.,

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

As in the case of no new information arriving, 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 we can observe in the following table summarizing the expected pay-offs in the different cases:

<table>
<tr><th colspan="2">Cases</th><th>a) no new info</th><th>b) new info</th></tr>
<tr><td rowspan="2">Expected values</td><td>A^A as first move</td><td>$E(B^A) = \sigma_h (B^A{}_{ph}(1) + B^A{}_{ph}(2)) + \sigma_l (B^A{}_{pl}(1) + B^A{}_{pl}(2))$</td><td>$E(B^A) = \sigma_h(B^A{}_{ph}(1) + B^A{}_{ph}(2)+ \sigma_l (B^A{}_{pl}(1) +B^W(2)$</td></tr>
<tr><td>A^W as first move</td><td>$E(B^W)=\sigma_h (B^W(1)+B^W(2)) + \sigma_l(B^W(1)+ B^W(2))$</td><td>$E(B^W)=\sigma_h (B^W(1)+B^W(2)) + \sigma_l(B^W(1)+ B^W(2))$</td></tr>
</table>

If the agricultural activity is the best choice after the new information arrives, it means that it is also the best choice when there is no new information forthcoming. This is so because, according to our original assumption, $B^A_{ph}(t) > B^W(t) > B^A_{pl}(t)$, and:

$$\sigma_h \, (B^A_{ph}(1) + B^A_{ph}(2)) + \sigma_l \, (B^A_{pl}(1) + B^A_{pl}(2)) < \sigma_h(B^A_{ph}(1) + B^A_{ph}(2)) + \sigma_l \, (B^A_{pl}(1) + B^W(2)).$$

In the case of the decision about restoring wetlands, the same is not true. The fact that the decision to restore wetlands involves some degree of irreversibility implies that, if the farmer had 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 in 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 in the end of the first period, and the farmer gets the pay-off of $B^A_{pl}(1) + B^W(2)$.

If A^W was the best choice when no new information was forthcoming, it was because the benefit from the wetland restoration was expected to be greater that then the expected benefit from the agricultural activity, i.e.,

$$\sigma_h \, (B^A_{ph}(1) + B^A_{ph}(2)) + \sigma_l \, (B^A_{pl}(1) + B^A_{pl}(2)) < B^W(1) + B^W(2).$$

But, taking into account the new information, the comparison the farmer has to make in order to invest in wetland restoration is not anymore between $B^W(1) + B^W(2)$ and the original (uninformed) expected benefits from the agricultural activity, as in the previous paragraph. The decision has to be taken now by comparing

$$E(B^W) = B^W(1) + B^W(2)$$

with

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

the latter being greater than the expected benefits of agriculture in the "no new information" case.

As we can see, the difference is equal to σ_I (B^W - B^A_{pI}). 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. It could also be seen as the *premium* the farmer would require for taking the risk of the irreversible move in the first place.

III. 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 do in other circumstances. This happens even with the assumption of risk neutrality that we use here.

In our initial model the farmer has access to a total land area of $\overline{A}$ 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

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

the farmer's maximization problem for each time period is

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

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

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

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 agricultural area lost.

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

In this section, considering again two time periods, two cases are analyzed separately, depending on the amount of information the farmer has access to and on the timing of its availability. The model presented here is a two period analysis of behavior under uncertainty, with two situations that differ on 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"[25]. He also shows situations where less extreme irreversibility lead 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 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 more incentives for the farmer to restore wetlands.

III.1. The case without new forthcoming information

In this case, the farmer decides in the beginning of the first period about how much land she will convert into wetlands in both periods, i.e., she decides about A_1^W and A_2^W.

The farmer's maximization problem is:

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

[25] See p. 270.

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 to 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 results of the model. Therefore, it can be taken away or assumed to be equal to 1. The first order conditions are, then:

foc:

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

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

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

In this formulation, the total area converted in the second period is equal to the difference A_2^W - A_1^W = ΔA^W. We assume that the cost function is 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 bigger the difference between the wetland areas in both periods, the greater the cost the farmer would have to bear.

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

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

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

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

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 in the second period would have the following signs:

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

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

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 wetlands previously constructed. It is this idea that will lead us to the main result of the model.

III.2. When new information is forthcoming

When the farmer knows that new information will be available in the end of the first period, the problem becomes different. The farmer chooses only A_1^W in the beginning of the first period, leaving the decision about A_2^W to be taken on the basis of the new information (in this case, new information could be on agricultural prices or other new information relevant for the decision).

For solving the problem, the starting point is the farmer's decision making 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:

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

The following expression is the first order condition for the second period:

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

Assuming that $U'(\pi_2)\neq 0$, then $-p_2f_A+s_2-\frac{\partial C_2^W}{\partial A_2^W}=0\Rightarrow +s_2=+p_2f_A+\frac{\partial C_2^W}{\partial A_2^W}$. The subsidy, thus, has to 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 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

$$\left[-p_2f_A+s_2-\frac{\partial C_2^W}{\partial A_2^W}\right]=0$$

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

$$\left[-p_2f_A(A_2^W(A_1^W))+s_2-\frac{\partial C_2^W(A_1^W,A_2^W(A_1^W))}{\partial A_2^W}\right]\equiv 0$$

and deriving it with respect to A_1^W

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

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

it is possible to arrive to the following expression:

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

$\dfrac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W} < 0$, $\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}} > 0$, and $f_{AA} < 0$, so the expression $\dfrac{\partial A_2^W}{\partial A_1^W}$ is positive.

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:

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

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

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

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

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

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

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

As it 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 the 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 the 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 information forthcoming ($\underline{A_1^W}$)? 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, when the wetland area by the end of the second period is bigger than what was converted in the first period. In this case, $A_2^W > A_1^W \Rightarrow \frac{\partial C_2^W}{\partial A_2^W} > 0$; $\frac{\partial C_2^W}{\partial A_1^W} < 0$; $\frac{\partial^2 C_2^W}{\partial A_2^{W\,2}} > 0$; $\frac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W} < 0$. 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 about her previous decision and decides now to "undo" part of the wetlands constructed. In this case, $A_2^W < A_1^W \Rightarrow \frac{\partial C_2^W}{\partial A_2^W} < 0$ 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 more informative than the other, the function φ is concave in A_1^W and the marginal cost function $\frac{\partial C_2^W(A_1, A_2(A_1, p_j)}{\partial A_1}$ is concave with respect to p, the area of agricultural land converted into wetland will be greater in the case of less information than in the case where there is forthcoming information[26].

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

More information forthcoming leads to less development in the first period, even in the case when there is no irreversibility. If there is a cost in reversing the previous investment made, 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 to consider this aspect, even when the land conversion decision does not involve irreversibility.

IV. Exploring possible policy implications

In the static approach discussed first, the conversion from a productive agricultural area into a restored wetland area could be the result of the behavior of a risk averse

[26] We assume that more information is always better in the case of one decision maker. This could be different in the case of a non-cooperative game or in the case of strategic interactions.

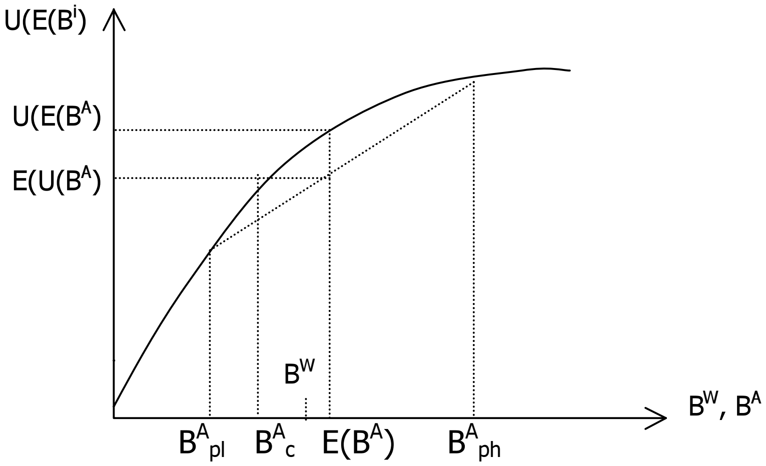
agent trying to diversify her investments in order to reduce uncertainty. We discussed two possibilities.

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

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 the covariance between them would have to be negative in order 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", through the governmental policy, the negative covariance.

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

If agricultural subsidies contribute to decrease uncertainty in crop prices, at the same time they 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 expensive to get more areas in wetlands and simultaneously give farmers the required income security.



In the framework of the model in section II.3, instead, and assuming risk neutrality, the agent now would 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 implies now that the farmer requires an extra *premium* payment in order to decide for the 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. This value is equal to $\sigma_l (B^W - B^A_{pl})$.

In section III, the approach attempts to integrate the ideas presented in section II 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 that involve a cost for reversing the decision. It is shown that the farmer would postpone the decision to convert agricultural land into wetlands, as long as there is the perspective of receiving more information in the future. And this is so even if the decision to restore wetlands is not an irreversible one. As long as the reversibility of the decision involves some cost, this will represent a disincentive to the wetland creation.

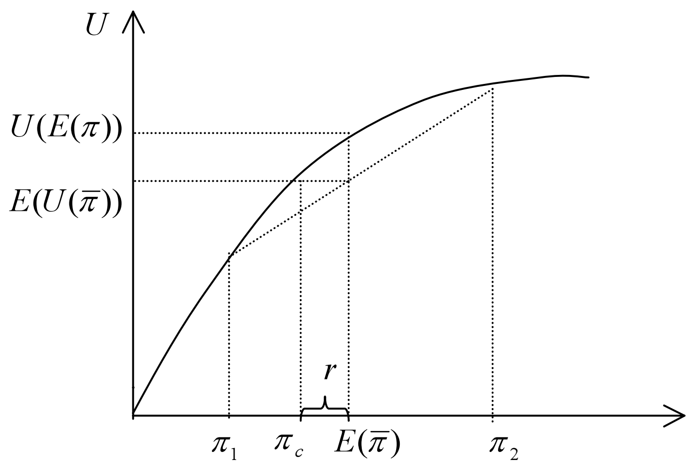
This paper is the result of a first exploration on the issue of uncertainty and how it affects both the farmer's behavior and the policy making related to pollution abatement to reduce eutrophication in the Baltic Sea.

A static approach to the role of risk aversion in the decision to convert land uses is presented and it is suggested that either the profit certainty from the wetland restoration or a negative correlation between crop prices and wetland subsidy could explain a farmer's decision to restore wetlands.

By using Arrow and Fisher's framework, it is shown that the *potential* irreversibility of the wetland restoration, together with the possibility of getting more information in the future, would either delay the farmer's decision into converting land uses or make it *more expensive* from the social planner point of view, since the farmer would require a *premium* to engage in the irreversible activity, therefore a higher wetland restoration subsidy.

Besides, 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. The conclusion is that to obtain more wetland restoration the policy maker should consider these results and design an incentive mechanism that takes uncertainty and information for the decision into consideration.

Appendix 1 - Risk *Premium* and Risk Aversion



π_c is the certainty equivalent of the profits and it gives, as shown in the figure, the same utility as the expected utility of profits. The question here is to find out what is r, the risk *premium* that 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

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

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

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

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

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

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

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 2 – Proving the Proposition

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

From the farmer's maximization problem,

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

From the first order condition,

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

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

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

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

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

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

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

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

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

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

For this expression to be negative, which is the condition for the function φ to be concave in A_1^W, the expression $\left(\dfrac{\dfrac{\partial^2 C_2^W}{\partial A_1^{W\,2}}\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}{\left(\dfrac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}\right)^2} + \dfrac{\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}{p_2 . f_{AA} - \dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}\right)$ should be greater than zero. If $p_2 . f_{AA}$ was equal to zero, the expression $\dfrac{\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}{p_2 . f_{AA} - \dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}$ would be equal to –1. For any other value of $p_2 . f_{AA}$, $-1 < \dfrac{\dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}{p_2 . f_{AA} - \dfrac{\partial^2 C_2^W}{\partial A_2^{W\,2}}} < 0$

In other words, if $\frac{\frac{\partial^2 C_2^W}{\partial A_1^{W\,2}} \frac{\partial^2 C_2^W}{\partial A_2^{W\,2}}}{\left(\frac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W}\right)^2} > 1$, the function φ is concave in A_1^W.

This condition is fulfilled if $\begin{vmatrix} \frac{\partial^2 C_2^W}{\partial A_1^{W\,2}} & \frac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W} \\ \frac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W} & \frac{\partial^2 C_2^W}{\partial A_2^{W\,2}} \end{vmatrix} > 0$, 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 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 taken only on the basis of expected values of the relevant variables. In the second case, there is information available for the decision in the second period.

The same function φ of before becomes here ψ for the probability vector of states of the uncertain variable p to be included in the analysis.

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

Perfect information is defined here as a situation where a given signal y brings information on the behavior of the random variable p:

$P(p = p_i | y = y_j) = 1$ if i=j

$P(p = p_i | y = y_j) = 0$ if i≠j

With perfect information, instead of taking the decision on the basis of the prior beliefs about how the variable will behave (expected values), the farmer takes an informed decision in the second period.

It is assumed that the farmer would be in a better situation with information rather than without, i.e., $\psi(A_1^W,\omega) > \psi(A_1^W,\omega')$, if ω is more informative than ω'.

i) In the no information case

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

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

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

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

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

ii) with forthcoming information (perfect information case)

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

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

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

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

Since $\frac{\partial U(A_1^W, A_2^W, p_j)}{\partial A_2^W} = 0$ is a first order condition for the utility maximization in the second period, then:

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

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

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

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

The difference between the two first order conditions is:

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

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

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

To establish the inequality (between $\Sigma r_j\frac{\partial C_2^W(A_1^W,A_2^W(A_1^W,p_j))}{\partial A_1^W}$ 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 is 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 $\frac{\partial^2 C_2^W}{\partial A_1^W \partial A_2^W} < 0$ 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:

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

Deriving the previous expression with respect to p gives:

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

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

Deriving again with respect to p gives:

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

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

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

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

References

Ahreimer, Berit, and Hans B. Wittgren (2002), "Modelling nitrogen removal in potential wetlands at the catchment scale", *Ecological Engineering* 19:63-80.

Arrow, Kenneth J. and Anthony C. Fisher (1974), "Environmental Preservation, Uncertainty, and Irreversibility", *The Quarterly Journal of Economics* 88(2): 312-319.

Bockstael, Nancy E. and Elena G. Irwin (2000),"Economics and the land use-environment link", *The International Yearbook of Environmental and Resource Economics 2000/2001: A Survey of Current Issues*, edited by Tom Tietenberg and Henk Folmer, Edward Elgar, 1-54.

Byström, Olof (2000), "The Replacement Value of Wetlands in Sweden", *Environmental and Resource Economics* 16(4):347-362.

Crépin, Anne-Sophie (2002), "Incentives for wetland creation", *Tackling the economics of ecosystems*, Dissertations in Economics 2002:6, Department of Economics, Stockholm University, pp. 117-142.

Epstein, Larry G. (1980), "Decision Making and the Temporal Resolution of Uncertainty", *International Economic Review*, Volume 21, Issue 2 (Jun.), 269-283.

Fernandez, Linda (1999), "An analysis of economic incentives in wetlands policies addressing biodiversity", *The Science of the Total Environment* 240:107-122.

Folke, Carl, and Åsa Jansson (2000), "Wetlands as Nutrient Sinks", in Gren, Ing-Marie, Kerry Turner and Fredrik Wulff (ed.), *Managing a Sea: The Ecological Economics of the Baltic*, Earthscan, 28-39.

Freixas, Xavier, and Jean-Jacques Laffont (1984), "On the irreversibility effect", Chapter 7, *Bayesian Models in Economic Theory*, edited by M. Boyer and R.E. Kihlstrom, Elsevier, 105-114.

Gren, Ing-Marie (1995), "The Value of Investing in Wetlands for Nitrogen Abatement", Beijer Reprint Series No. 47, reprinted from *European Review of Agricultural Economics* 22:157-172.

Gren, Ing-Marie, Kerry Turner and Fredrik Wulff (ed.) (2000), *Managing a Sea: The Ecological Economics of the Baltic*, Earthscan.

Hamilton Army Airfield Wetland Restoration Feasibility Study (1998), Final EIR/EIS, Chapter 7, Public Health, December. Available at: http://www.spn.usace.army.mil/hamilton/

Heimlich, Ralph E., "Costs of an Agricultural Wetland Reserve", *Land Economics*, 70(2):234-46.

Henry, Claude (1974), "Investment Decisions Under Uncertainty: The 'Irreversibility Effect'", *The American Economic Review*, 64(6):1006-1012.

Leonardson, Lars (1994), "Wetlands as nitrogen sinks: Swedish and international experience, Summary and conclusions", *Våtmarker som kvävefällor: Svenska och internationella erfarenheter*, Rapport 4176, Naturvårdsverket, 31-51.

Leonardson, Lars (1994), "Wetlands as nitrogen sinks: Swedish and international experience, Summary and conclusions", *Våtmarker som kvävefällor: Svenska och internationella erfarenheter*, Rapport 4176, Naturvårdsverket, 31-51.

Lindahl, Therese (1998a), "Wetland Creation in Sweden in an Agricultural Policy Context", Beijer Discussion Paper Series No. 113, Mars.

Lindahl, Therese (1998b), Monitoring Subsidised Wetland Creation in Sweden: A game theoretic approach", Beijer Discussion Paper Series No. 120, December.

Marschak, Jacob, and Koichi Miyasawa (1968), "Economic Comparability of Information Systems", *International Economic Review*, Volume 9, Issue 2, (Jun.), 137-174.

Mäler, Karl-Göran (2002), "Environment, Uncertainty, and Option Values", *Beijer Discussion Paper Series* No. 153, Beijer Institute.

Mitsch, William J. and James G. Gosselink (1993), *Wetlands*, Second Edition, Van Nostrand Reinhold, New York.

Mitsch, William J. and James G. Gosselink (2000), "The value of wetlands: importance of scale and landscape setting", *Ecological Economics* 35:25-33.

Narain, Urvashi, Michael Hanemann, and Anthony Fisher (2002), "Uncertainty, Learning, and the Irreversibility Effect", Working Paper No. 935, Department of Agricultural and Resource Economics and Policy, University of California at Berkeley, September.

Nicholson, Walter (1995), "Choice in uncertain situations: Expected Utility and Risk Aversion", Chapter 9 in *Microeconomic Theory: Basic Principles and Extensions*, The Dryden Press, 6th edition.

Parks, Peter J. (1995), "Explaining 'Irrational' Land Use: Risk Aversion and Marginal Agricultural Land", *Journal of Environmental Economics and Management* 28:34-47.

Parks, Peter J. and Randall A. Kramer (1995), "A Policy Simulation on the Wetlands Reserve Program", *Journal of Environmental Economics and Management* 28:223-240.

Pindick, Robert S. (2000), "Irreversibilities and the timing of environmental policy", *Resource and Energy Economics* 22:233-259.

Ribaudo, Marc O., Ralph Heimlich, Roger Claassen and Mark Peters (2001), "Least-cost management of nonpoint source pollution: source reduction versus interception strategies for controlling nitrogen loss in the Mississippi Basin", *Ecological Economics* 37:183-197.

Roseveare, Deborah (2001), "Encouraging Environmentally Sustainable Growth in Sweden", Economics Department Working Papers No. 289, ECO/WKP(2001)15, OECD.

Swedish Ministry of Agriculture, "Sweden: Incentives for Environmental Management of Farmland with High Biological Values", in: Helsinki Seminar on Environmental Benefits from Agriculture, Country Case Studies, OCDE/GD(97)110, OECD, 1997, 129-132.

Söderqvist, Tore, "Are farmers prosocial? Determinants of the willingness to participate in a Swedish catchment-based wetland creation programme", *Ecological Economics* ?:?-?.

Turner, R. Kerry et al. (2000), "Ecological-economic analysis of wetlands: scientific integration for management and policy", *Ecological Economics* 35:7-23.

Weisbrod, Burton A. (1964), "Collective-Consumption Services of Individual-Consumption Goods", *The Quarterly Journal of Economics* 78(3): 471-477.