Agriculture and resource exploitation: a dynamic bioeconomic model of agricultural effort and land use determination.

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Abstract

This paper presents a dynamic analysis of land uses and agricultural effort in a heterogeneous environment, by a risk neutral agent endowed with a biotic renewable resource on his land. This resource is adversely affected by the agricultural effort exerted by the agent and by its habitat induced by the allocation of land. The farmer's production depends upon land, agricultural effort and upon the biotic resource. Facing long term preferences protected by a property regime, the risk neutral farmer maximizes his discounted expected agricultural profit with respect to his agricultural effort and to the land uses under the constraint of evolution of the renewable resource.

I identify the optimality conditions that determine the effort and land use choices and show how farmer's anticipations on the evolution of the resource and farming orientation are involved in the exploitation and the management of the renewable resource. Finally, I study the effect of diverse agrienvironmental policies on the farmer's choices. The covered policies are the establishment of well defined and secure property rights, the land set aside policy, the taxation of conventional crop production and the implementation of payments for environmental services.

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1 Introduction

”*The most insignificant insects and reptiles are of much more consequence, and have much more influence in the Economy nature, than the incurious are aware of; and are mighty in their effect, from their minuteness, which renders them less an object of attention; and from their numbers and fecundity. Earth-worms, though in appearance a small and despicable link in the chain of nature, yet, if lost, would make a lamentable chasm. For, to say nothing of half the birds, and some quadrupeds, which are almost entirely supported by them, worms seem to be the great promoters of vegetation, which would proceed but lamely without them, by boring, perforating, and loosening the soil, and rendering it pervious to rains and the fibres of plants, by drawing straws and stalks of leaves and twigs into it; and, most of all, by throwing up such infinite numbers of lumps of earth called worm-casts, which, being their excrement, is a fine manure for grain and grass.*”[1]
To be less restrictive, the set of species living in a given space, the set of interaction among species and between species and their physical environment, the set of flow of matter and energy that glances trough the species and the environment constitute an ecosystem and biodiversity is commonly perceived as a generator of the ecosystem. These ecosystems and more specially agroecosystems- ecosystems that have been deliberately simplified by people for purpose of the production of specific goods of value to humans- are suffering of the excesses of the agriculture. The current main reasons of the degradation (Tilman et al.) are the massive diffusion and the excessive use of chemical fertilizers and xenobiotic compounds (intensive characteristic of agriculture) but also the simplification of habitat (conversion of natural habitat into crop land, crop land expansion).

The loss and the fragmentation of habitat and agricultural intensification are then the most detrimental forces that yield the decline of natural resources (in number) and then the loss of biodiversity. From the biological point of view, the degradation of habitat yields a reduction of biodiversity, firstly in number of individuals (by population), then in number of populations and then of species (Teyssèdre 2005). A first reaction in the end of the XX^{th} century, to prevent this loss of biodiversity was the creation of protected areas. But, in 2001, M. Rosenzweig demonstrates that a given fraction of protected areas surrounded with inhospitable human habitats, can not carry on the long run, more than the same fraction of species living with this area. In other words, preserving only the tenth of world territories (the decision of the World Conservation Union(IUCN),in Caracas in 1993) can only conserve the same tenth of current known species. But it amounts to the sacrifice of the remaining 90 percent of world wild biodiversity. For this reason, caring for the natural resources in anthropogenic areas is a crucial and recent issue in biodiversity conservation. Rosenzweig claims then for the ”reconciliation” of economy and biology. (Teyssèdre et al., Rosenzweig) In the natural resource economic sphere it is known as the sustainable exploitation of resources. This ”reconciliation” consists in the association of biodiversity with the economic development. Recognizing a value for biodiversity in the

[1]Gilbert White in ”The Natural History of Selborne”, (1789), quoted in ”Nature’s Economy” by Donald Worster (1985).

economy will then help to preserve this resource at the basis of the economic development thanks to the services it generates.

At the agroecosystem scale, the preservation of soil fertility and soil functions glance trough the preservation of soil biota. The soil biota regroups the productive biota (crop, livestock), the resource biota (decomposer) and the destructive biota (pests). The short term farmer's preferences consist in maximizing the productive biota at the expense of the two others. Nevertheless, the functions and services of the resource biota in the agroecosystem are recognized and documented, although rarely quantified (Swift, Beare, Daily). Daily references these services among which, the mitigation of droughts and floods, the dispersal of seeds, the cycling and the movement of nutrients, the generation and the preservation of soils and the renewal of their fertility, the pollination of crops and natural vegetation, the control of the vast majority of potential agricultural pests and the maintenance of biodiversity. The relationship between the agriculture and the environment then looks like a mutualism association[2].
I then propose to study the decision making of an agent exploiting indirectly a resource with long term perspectives, so that he is able to integrate and thus to manage the function and the evolution of the resource biota. The mutualism relationship is integrated via the specification of the low evolution of the resource biota and via the production function. Indeed, the renewal of the resource is negatively affected by the xenobiotic compounds and adversely affected by the land uses. And the resource is an input of the production function, as well as the chemical fertilizers. Finally, destructive biota (pests) are also considered via the introduction of a natural nuisance cost in the objective function.
The objective of this paper is twofold. I firstly identify the determinant of land uses and of the agricultural effort for a risk neutral agent endowed with a renewable resource biota in his land. Then I propose to study the effects of some agrienvironmental policies onto the decision making of the farmer. The selected instruments are the establishment of secure property rights and land set aside for the command and control instruments, and the tax on production and the implementation of resource conditional payments or payment for environmental services for the market based instruments.
The paper is then organized as followed. In section 2, I review the literature of renewable resource exploitation and presents the settings of the model. Section 3 solves the optimal control problem and presents an interpretation of the optimality conditions in terms of property rights effects. Section 4 analyzes the farmer's responses to the policy instruments and section 5 gives some conclusions and remarks.

[2]Tree categories of species associations are referenced by biologists. Parasitism describes cases where one lives in the detriment of the other, commensalism for cases where the benefits are unilateral but not detrimental for the other and mutualism for cases where the benefits are mutual.

2 Review of the literature and singularity of the model

There are two groups of natural resource conservation models: those focusing on the intensive aspect of human activities: pollution emissions, production technics adoption and those focusing on the extensive side: habitat protection, reserve creation. So that, the literature frequently presents a dichotomic vision of the agriculture and the environment. Most of the models consider that the agriculture produces a damage on the environment, damage not internalized by the agent but included in the social benefit function, so that the farmer exerts more effort than the socially optimal level. But in that kind of model that I call "dichotomic" models , the environment or the natural resource is not integrated per se in the model, thus the farmer does not control the resource by changing his decision variables. These models do not consider the semi-public property of natural resources, meaning that some of the services generated by the environment benefit to the farmer. The approach developed here consists in integrating the environment-the natural resource- and the agriculture-the agricultural effort- in a bioeconomic model.

Resource extinction problems often consider free access resource exploitation (Clark, Swanson, Skonhoft) which is not the matter of this paper and often consider equilibrium model whereas I derive optimal trajectories. This will then allow to deal with the sustainability of economic activities. The object of the paper is thus to investigate resource conservation issues on private lands. But to do so, I derive the model from open access resource exploitation models.

One of the first models dealing with resource extinction is the Clark model (1973). He shows that three causes may lead to extinction by profit maximization: free access, a low cost-price ratio of harvesting and a low intrinsic growth rate of the resource. Swanson (1994) proposes a "revisited and revised" version of the model: extinction results of a low investment in the resource which depends upon its productivity with respect to other assets, a low investment in the habitat that supports the resource. He also suggests to revise the approach in the modeling by considering that available habitat must be taken into account in the resource growth function[3]. Finally, the last cause he identifies and which constitutes a criticism of Clark's model is the low investment in the institutions for resource management. Free access regime would not be the direct cause of extinction but the reason for insufficient investment in management resource services. If the problem I focus on deals with the conservation of a resource on private land, it could be extended to the free access case if there exist institutions able to invest in the resource.

About bioeconomic modeling, this paper builds on Wilen and Sanchirico model of renewable resource management in a heterogeneous environment formed with patches. They show that fishery management can be performed by appropriate marine protected areas. Under conditions of selection of the reserve, double dividends are extractable: benefits for fishermen and benefits for environmentalists. This principle of considering an heterogeneous environment can be adapted to terrestrial resource management. It has already

[3]The carrying capacity in the logistic growth function must be a function of the habitat available for the resource.

been designed for large mammals and arboreal species, but it has not been modeled for agriculture and less valued species like insects or invertebrates that generate an environmental services to agricultural activities. The main difference with terrestrial ecosystem is the existence of alternative uses of the space and of the resource since a large number of activities is in competition with the habitat of terrestrial species. There exists an opportunity cost of land use that is not found in marine resource.
I thus retain their definition of a patch as a "location in space that contains or as the potential to contain an aggregation of biomass". Then, the environment subject to human activities is a heterogeneous environment not so because of its typographical properties but because of its biomass richness. If Wilen and Sanchirico identify the best zone to generate double dividends under different types of migration of the resource from one patch to the other, this article doesn't consider such a distinction.

According to the exploitation of terrestrial species, Skonhoft (1999) analyzes the effects of changes of the structural parameters on the stock and available habitat of the resource. By introducing the notion of nuisance cost of wildlife on the economic activity, he extends the usual model of resource exploitation. This cost variable allows him to distinguish two cases that condition the conclusion on resource extinction: the "normal" case and the "nuisance" case. He shows that under the "normal" case, where the marginal nuisance cost is relatively low with respect to the marginal benefit generated by the resource, an increase in the opportunity cost of habitat[4] reduces the stock and the available habitat for wildlife. The same result on the stock and the natural habitat depletion occurs when the rate of discount increases and when the nuisance cost increases. He also analyzes the impact of a shift in the price of the harvested resource on habitat and on the stock. This effect is not so clear since an increase in the willingness to pay for harvesting is a motive of stock disinvestment but makes habitat investment more attractive.
The hypothesis of a resource growth as a function of the available habitat will be retained in the model, (Swanson 1994). The nuisance cost existence will also be selected to complete the realism of the model even if Skonhoft considers that this cost is representative of large mammals which frequently destroy agricultural production but not of less valued species (e.g. insects, invertebrates). I do not consider this restriction since a great number of "Lilliputian" species can produce damages to crop lands. Although biological resources can generate a nuisance cost to farming activities, they also provide a great number of environmental services. Institutions of biological conservation have designed payments for environmental services (PES) in order to make conservation a profitable land use. Several authors have studied the efficiency of direct conservation payments versus indirect ones, in a dynamic setting (Ferraro and Conrad) or in a static one (Ferraro and Simpson). They show that direct payments, payments to the landowner for the resource conservation he performs, are always more efficient than indirect ones- payment to "a non-habitat input that contributes to an eco-friendly activity", and that under some conditions, the donor

[4] The opportunity cost of habitat increases when human activities is more profitable.

and the recipient can both prefer direct payments for conservation. In section 4.2.2, I discuss the effect of PES on the farmer decision making in a dynamic setting. The derivation of the optimality condition on land will show that the adoption conservation type land-uses can be chosen even without PES.
Nevertheless, I do not restrict the alternatives offered to the agent allowing for land use rotation, while models a la Ferraro are resource conservation model in which rotation is not desired from natural to agricultural land. I set aside irreversibility considerations which can be excessive in the case of forests but not so in the case of grasslands. Finally, since the timing needed to recover a semi natural state of the land will be as long as the ecosystem is damaged, it is important to consider the "history" of the land, a land use rotation setting fulfills this issue by considering the past states of land-uses.

3 The model of resource exploitation

3.1 The model

In a mutualism vision, the agent exploits the resource but the counterpart is that he cares for the resource replenishment. Thus, it departs from the dichotomic vision of agriculture and conservation and integrates the biological resource in the economic activity.

The agricultural exploitation represents a heterogeneous environment formed of patches α_{ikt} representing a fraction of the exploitation[5]. Thus, index i defines the land-use type on patch i. Conventional crops are indexed by $i = 1, ..., C_1$ and conserved areas like grasslands or fallows by $i = C_1 + 1, ..., C_2$.
Two indexes are needed to define a patch and his state in a rotation model. Thus, index i defines the state of the patch at date t and index k for the period $t-1$. Land-uses are then defined as follows:

- Crop lands are a land cultivated with conventional crops at date t whatever its state at date $t-1$.
- Conserved lands are land protected at date t whatever its state at date $t-1$.

The renewable resource represents the fauna[6] of the soil. This quasi invisible fauna, often neglected is useful and numerous. For example, in grasslands of Normandie, Ricou has observed some picks of 350 kg/ha for the aerial fauna and the annual mean is about 100 kg/ha. The grassland's pedofauna (endogaion) is dominated by worms whose biomass can

[5] $\sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ikt} = 1$

[6] This fauna is divided into an aerial fauna (hypergaion), a fauna of detritivors eating mould (epigaion) and an underground fauna composed of detritivor earthworm (endogaion).

achieve or exceed the cattle's biomass: it has been found up to 4 millions worms per hectare on grasslands, weighting 2 tons per hectare. The fertility of soil is improved by organic matter transformation, and the assimilation of the organic matter by plants is improved by such a transformation (case of the Modlybdene, a trace element that participates in the nitrogen fixation by plants). Earthworms produce a matter that is, in comparison with the corresponding soil, 5 times richer in nitrogen (N), 2 times richer in calcium (Ca), 2.5 times richer in magnesium (Mg), 7 times richer in phosphorus (P) and 11 times richer in potassium (K). The weight of this earthworm's production in permanent grasslands is about 50 tons per hectare per year; in mean, 1 million of earthworms of 600 mg, that is 0.6 tons per ha, produce yearly 52 tons of vegetable mould per hectare, to which it must be added the 13 tons per ha of enchytraeides production produced by 100 million of individuals. More specifically, the role of earthworms is studied by Fragoso et al. (1997). It is demonstrated that they "usually affect crop growth in a positive manner." Gilot (1994) observed a maximum increase of 18% and 12% in maize grain and stalk production respectively.

Nevertheless, this fauna is not uniformly distributed on the different ecosystems[7].

Table 1: Mean abundance of the fauna of the soil

Biotope	Insects and larvas	Earthworms		Enchytraeide		Collemboles	Acarinas
	Nb/m^2	Nb/m^2	kg/ha	Nb/m^2	kg/ha	Nb/m^2	Nb/m^2
Forêts	3.10^3	78	400	$3,5.10^3$	100	4.10^4	8.10^4
Prairies	$4,5.10^3$	97	500	$10,5.10^3$	300	2.10^4	4.10^4
Cultures	1.10^3	41	200	2.10^3	60	1.10^4	1.10^4

An agricultural exploitation is a heterogeneous environment. Thus, the renewable resource (B_{it}) obeys to a different growth function depending on the habitat it is located. The overall biomass of the ecosystem is then simply the sum of the biomass of the patches. But the resource obeys to a migration dispersal. Wilen and Sanchirico (1998) have specified different types of inter-patches migration but I will just consider that the migration is such that the observed biomass of a patch is a fraction γ_{it} of the total biomass (B_t), fraction specific to the patch i and time t.
Thus,

$$B_{it} = \gamma_{it} B_t$$

Terrestrial ecosystems are polluted by the agricultural effort in the sense that agriculture disturbs natural soils cycles. Technics devoted to reduce production barriers, such as the regrouping of land (land clearing, hedges pulling up) and the use of biocides. The impacts of these practices are diverse. Fertilizers deplete the organic matter of the soil, speed up the disappearing of humus by mineralization. The excessive use of nitrogen favors the proliferation of pests; the excess of nitrogen in plants brings on an upset of

[7]"La synthèse écologique" of P. Duvigneau, 1974, page 125.

protein's metabolism in favor of glucides and makes the plant more "tempting" for devastators[8]. The deep plowing of the soil changes the equilibrium of microbial colonies by plowing under those that need oxygen and live in the superficial layers. The introduction of pesticides in the trophic chain after their absorption by plants and by accumulation in the organs may be heavily detrimental. For instance, the substances that destroy parasitic fungus are elaborated with toxic heavy metals that are accumulating in the soil and in the plants. The effects of these chemical products used to struggle the first organism of the trophic chain propagate up to the top of the chain.
The materialisation of the negative impact of the agricultural effort E_{it} on the resource B_{it} occurs through the harvest function $H(E_{it}, B_{it})$, note that this harvest has no market value (it's a mortality function). Thus, the effect of the agricultural effort is to reduce the stock of the resource for the next period: the effort then produces a damage on the growth function of the biomass.

The low of motion of the resource is as follows:

$$B_{t+1} = \sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ki,t+1}[G_i(B_{it}) - H_i(E_{it}, B_{it})]$$

The intrinsic growth function is a logistic function such that:

$$G_i(B_{it}) = B_{it}\left[1 + r_i\left(1 - \frac{B_{it}}{\kappa_i}\right)\right]$$

where

r_i is the intrinsic growth rate of the patch.

κ_i is the carrying capacity of the patch.

The harvest function takes the form of the shaefer production function:

$$H_i(E_{it}, B_{it}) = B_{it}\varphi_i E_{it}$$

where φ_i is a mortality coefficient due to effort.

The farmer gets two inputs for the production. The renewable resource, noted B that regroups the fauna of the soil at the origin of soil fertilization and production and the agricultural effort, noted E. The yields depend upon the agricultural effort in two opposed

[8]P. Desbrosses in "L'impasse alimentaire",2004

manners. The direct effect is the provision of chemical fertilizers "useful" to the plant and the other effect is the negative externality it produces on the resource through the harvest function.
The agricultural yields are supposed to be concave and given by the following function:

$$Q_{it} = Q_{it}(B_{it}, E_{it})$$

The farmer manages his ecosystem deciding the allocation of land-use on his farm and the level of effort. He decides the land uses at the end of the harvest, so that all patches are either under a conventional cropping state or a conservation state. This supposes that there is no intermediate time between both states of the land.

Concerning the costs of production. The agent bears the cost of the agricultural effort, $C_i(E_{it})$ but also a cost induced by the conservation, $C_i(B_{it})$ the nuisance cost due to the existence of wildlife in the exploitation and damages it can cause. These costs are increasing in their argument. Nevertheless, the specificity of the nuisance cost can be used to introduce an aversion for an excess of resource. Indeed, as developed by Heal and Small (HB 2002) the dependence of anthropogenic activities to ecosystem make the activity risky. In that case, the excess of biotic resource can attract pests or predators that could also damage crop lands. Then, a convex nuisance cost function may reveal this kind of aversion for the resource.

The profits are decomposed in four types: the sells and subsidies from "crop-crop" land and from "grassland-crop" lands (i.e.,patches that were under land use "grassland" at time $t-1$ and under "crop" land use at time t.). Then, the subsidies for retired land from cultivation and for already conserved lands.

The profits are then as follows:

$$\begin{aligned}
\Pi_t &= \sum_{k=1}^{C_1}\sum_{i=1}^{C_1}[P_{it}Q_{it}(B_{it}, E_{it}) + S_{it} - C_i(E_{it}) - C_i(B_{it})]\alpha_{ikt} \\
&+ \sum_{k=C_1+1}^{C_2}\sum_{i=1}^{C_1}[P_{it}Q_{it}(B_{it}, E_{it}) + S_{it} - C_i(E_{it}) - C_i(B_{it})]\alpha_{ikt} \\
&+ \sum_{k=1}^{C_1}\sum_{i=C_1+1}^{C_2}[S_{it} - C_i(E_{it}) - C_i(B_{it})]\alpha_{ikt} + \sum_{k=C_1+1}^{C_2}\sum_{i=C_1+1}^{C_2}[S_{it} - C_i(E_{it}) - C_i(B_{it})]\alpha_{ikt} \\
\Pi_t &= \sum_{k=1}^{C_2}\sum_{i=1}^{C_1}[P_{it}Q_{it}(B_{it}, E_{it}) + S_{it} - C_i(E_{it}) - C_i(B_{it})]\alpha_{ikt} + \sum_{k=1}^{C_2}\sum_{i=C_1+1}^{C_2}[S_{it} - C_i(E_{it}) - C_i(B_{it})]\alpha_{ikt}
\end{aligned}$$

3.2 The resolution

The problem of the farmer is to find the optimal land uses allocation and the optimal level of agricultural effort, knowing that the effort input produces a negative effect on the renewable resource input.
It is supposed that the farmer is a risk neutral agent, so that he maximizes the discounted profit expectation, under the law of motion of the resource.

$$\max_{\alpha,E} E_t \left[\sum_{s=t}^{T} \frac{\Pi_s(B,E,\alpha)}{(1+\tau_s)^{s-t}} \right]$$

where

$$\Pi_t = \sum_{k=1}^{C_2}\sum_{i=1}^{C_1}[P_{it}Q_{it}(B_{it},E_{it}) + S_{it} - C_i(E_{it}) - C_i(B_{it})]\alpha_{ikt} + \sum_{k=1}^{C_2}\sum_{i=C_1+1}^{C_2}[S_{it} - C_i(B_{it})]\alpha_{ikt} \quad (1)$$

and τ_s is the interest rate of the period $s = t, t+1, ..., T$.

Let $V(B_t)$ be the maximum value function. According to Bellman dynamic programming, this value satisfies the Bellman's equation:

$$V_t(B_t) = \max E_t[\Pi_t + \frac{1}{1+r_t}V_{t+1}(B_{t+1})]$$

The low of motion of the state variable is:

$$B_{t+1} = \sum_{k=1}^{C_2}\sum_{i=1}^{C_2} \alpha_{ki,t+1}\left[G_i(B_{it}) - H_i(E_{it}, B_{it})\right] \quad (2)$$

where

$$B_{it} = \gamma_{it}B_t \quad (3)$$

$G(B_{it}) = B_{it}\left[1 + r_i\left(1 - \frac{B_{it}}{\kappa_i}\right)\right]$ and $H_i(E_{it}, B_{it}) = \gamma_{it}\varphi_i E_{it}B_t$

- **Derivative with respect to the state variable B_t**

$$\frac{\partial V_t(B_t)}{\partial B_t} = \sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ikt}[P_{it}\frac{\partial Q_{it}}{\partial B_{it}}\frac{\partial B_{it}}{\partial B_t} - \frac{\partial C_i}{\partial B_{it}}\frac{\partial B_{it}}{\partial B_t}] + \beta_t E_t\left\{\frac{dV_{t+1}}{dB_{t+1}}\frac{dB_{t+1}}{dB_t}\right\}$$

with $\beta_t = \frac{1}{1+r_t}$.

Intermediate calculus and notations:

- $\frac{dB_{t+1}}{dB_t} = \sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ki,t+1} \left[G_i^B - H_i^B \right]$

- $G_i^B \equiv \frac{\partial G_i(B_{it})}{\partial B_t}$, $\frac{\partial B_{it}}{\partial B_t} = \gamma_{it}$, $\frac{\partial C_i}{\partial B_t} \equiv C_i^B$ and $\frac{\partial Q_{it}}{\partial B_t} \equiv Q_i^B$

Hence,

$$\frac{\partial V_t(B_t)}{\partial B_t} = \sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ikt} \left[P_{it}\gamma_{it}Q_{it}^B - \gamma_{it}C_i^B \right] + \beta_t E_t \left\{ \frac{dV_{t+1}}{dB_{t+1}} \sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ki,t+1}(G_i^B - H_i^B) \right\} \tag{4}$$

- **First order condition with respect to the agricultural effort E_{it}**

$$\frac{\partial V_t(B_t)}{\partial E_{it}} = 0 \Leftrightarrow \sum_{k=1}^{C_2} \alpha_{ikt} \left\{ P_{it}\frac{\partial Q_{it}}{\partial E_{it}} - \frac{\partial C_i}{\partial E_{it}} \right\} + \beta_t E_t [\frac{dV_{t+1}}{dB_{t+1}} \frac{\partial B_{t+1}}{\partial E_{it}}] = 0$$

if $E_{it} > 0$

Intermediate calculus and notations:

- $\frac{\partial B_{t+1}}{\partial E_{it}} = -\sum_{k=1}^{C_2} \alpha_{ki,t+1} \frac{\partial H_i}{\partial E_{it}} = -\sum_{k=1}^{C_2} \alpha_{ki,t+1} H_i^E$

- $\frac{\partial C_i}{\partial E_{it}} \equiv C_i^E$ and $\frac{\partial Q_{it}}{\partial E_{it}} \equiv Q_{it}^E$

$$\frac{\partial V_t(B_t)}{\partial E_{it}} = 0 \Leftrightarrow \sum_{k=1}^{C_2} \alpha_{ikt} \left\{ P_{it}Q_{it}^E - C_i^E \right\} - \beta_t E_t \left\{ \frac{dV_{t+1}}{dB_{t+1}} \sum_{k=1}^{C_2} \alpha_{ki,t+1} H_i^E \right\} = 0$$

if $E_{it} > 0$

Multiplying this equation by: $\frac{G_i^B - H_i^B}{H_i^E}$ and summing over $i = 1, ..., C_2$, we get:

$$\sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ikt}\frac{G_i^B - H_i^B}{H_i^E}\left[P_{it}Q_{it}^E - C_i^E\right] - \beta_t E_t\left\{\frac{dV_{t+1}}{dB_{t+1}}\sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ki,t+1}(G_i^B - H_i^B)\right\} = 0 \quad (5)$$

The right terms of equation (5) and equation (4) are the same so that, equation (4) becomes:

$$\begin{aligned}\frac{\partial V_t(B_t)}{\partial B_t} &= \sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ikt}\left[P_{it}\gamma_{it}Q_{it}^B - \gamma_{it}C_i^B\right] + \sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ikt}\frac{G_i^B - H_i^B}{H_i^E}(P_{it}Q_{it}^E - C_i^E) \quad (6)\\ &= \sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ikt}\left[P_{it}\left(\gamma_{it}Q_{it}^B + \frac{G_i^B - H_i^B}{H_i^E}Q_{it}^E\right) - \gamma_{it}C_i^B - \frac{G_i^B - H_i^B}{H_i^E}C_i^E\right] \quad (7)\end{aligned}$$

We deduce the expression of the marginal value of the resource for the date $t+1$ and then the optimal effort is given by:

$$\begin{aligned}\frac{\partial V_t(B_t)}{\partial E_{it}} &= \sum_{k=1}^{C_2}\alpha_{ikt}(P_{it}Q_{it}^E - C_i^E) - \beta_t \times\\ & E_t\left\{\sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ik,t+1}(P_{i,t+1}\left(\gamma_{i,t+1}Q_{i,t+1}^B + \Phi_{i,t+1}Q_{i,t+1}^E\right) - \gamma_{i,t+1}C_i^B - \Phi_{i,t+1}C_i^E)\sum_{k=1}^{C_2}\alpha_{ki,t+1}H_i^E\right\}\\ &= 0\end{aligned}$$

if $E_{it} > 0$, with $\Phi_{i,t+1} = \frac{G_i^B - H_i^B}{H_i^E}$
Otherwise, if $E_{it} = 0$, this expression is strictly negative.

Remark: $\sum_{k=1}^{C_2}\alpha_{ikt} = \sum_{k=1}^{C_2}\alpha_{ki,t+1}$. (Thomas 2003)

The areas i at date t with origin k are equals to the areas k coming from land use i at date $t-1$. For instance, $\sigma\%$ of areas under land use i at the period t with origin land use k (e.g., its previous state) can be transformed for the period $t+1$. Thus, in $t+1$, we have these $\sigma\%$ of soils under land use k. (This is due to the switch from one period to the other.

Finally, the optimal effort is given by:

$$P_{it}Q_{it}^{E}-C_{i}^{E}-\beta_{t}E_{t}\left\{H_{i}^{E}\sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ik,t+1}[P_{i,t+1}(\gamma_{i,t+1}Q_{i,t+1}^{B}+\Phi_{i,t+1}Q_{i,t+1}^{E})-\gamma_{i,t+1}C_{i,t+1}^{B}-\Phi_{i,t+1}C_{i,t+1}^{E}]\right\}=0 \quad (8)$$

if $E_{it}>0$, with $\Phi_{i,t+1}=\frac{G_i^B-H_i^B}{H_i^E}$
Otherwise, if $E_{it}=0$, this expression is strictly negative.

- **First order condition with respect to the land use α_{ikt}**

$$\frac{\partial V_t(B_t)}{\partial \alpha_{ikt}}=0 \Leftrightarrow P_{it}Q_{it}(B_{it},E_{it})+S_{it}-C_i(E_{it})-C_i(B_{it})+\beta_t E_t\left[\frac{dV_{t+1}}{dB_{t+1}}\frac{\partial B_{t+1}}{\partial B_t}\frac{\partial B_t}{\partial \alpha_{ikt}}\right]=0$$

if $\alpha_{ikt}>0$

With :

- $\frac{dB_{t+1}}{dB_t}=\sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ki,t+1}(G_i^B-H_i^B)$
- $\frac{dB_t}{d\alpha_{ikt}}=G_k(\gamma_k B_{t-1})-H_k(E_{k,t-1},B_{k,t-1})$

So,

$$P_{it}Q_{it}(.)+S_{it}-C_i(E_{it})-C_i(B_{it})=-\beta_t[G(B_{k,t-1})-H(E_{k,t-1},B_{k,t-1})]\times$$
$$E_t\left[\sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ik,t+1}[P_{i,t+1}(\gamma_i Q_{i,t+1}^{B}+\Phi_{i,t+1}Q_{i,t+1}^{E})-\gamma_i C_{i,t+1}^{B}-\Phi_{i,t+1}C_{i,t+1}^{E}]\sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ki,t+1}(G_i^B-H_i^B)\right]$$

But, $\sum_{k=1}^{C_2}\alpha_{ikt}=\sum_{k=1}^{C_2}\alpha_{ki,t+1}$

The optimal land allocation is driven by :

$$P_{it}Q_{it}(.)+S_{it}-C_i(E_{it})-C_i(B_{it})+[G(B_{k,t-1})-H(E_{k,t-1},B_{k,t-1})]\left(\sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ikt}(G_i^B-H_i^B)\right)$$

$$\times\beta_t E_t\left[\sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ik,t+1}[P_{i,t+1}(\gamma_{i,t+1}Q^B_{i,t+1}+\Phi_{i,t+1}Q^E_{i,t+1})-\gamma_{i,t+1}C^B_{i,t+1}-\Phi_{i,t+1}C^E_{i,t+1}]\right]=0 \quad (9)$$

if $\alpha_{ikt} > 0$.
with $\Phi_{i,t+1} = \frac{G^B_{i,t+1}-H^B_i}{H^E_i}$

3.3 Interpretation of the first order conditions: an issue on property rights

In the literature on natural resource conservation, property rights through the establishment of institutions of wildlife control (Swanson 1994) play a major role in the sustainable use of these resources. This issue on linking conservation to property is among the oldest issues. Gray (1913) wondered if "...private property in natural objects [is] favorable or unfavorable to the realization of the ideals of the conservationist?" Property rights create the incentives to invest in services of management of natural resources and conserve the resources (Smith 1975). The common agreement behind this, is that institutions or local communities, holding secure rights on the resource will have a long term management of wildlife and will then be able to invest in natural resource conservation (Kiss 1990, Swanson and Barbier 1992). Nevertheless, the response of Gray (1913) to his issue on private property is clear: "This depends upon the extent to which the individual will find it profitable to employ methods of conservation in the utilization of the natural resources under his control." The interactions and the conflicts between wildlife and human activities determine the trade off between the resource use and the resource conservation and are then the principal determinant of the success of the establishment of property rights on nature conservation (Skonhoft and Solstad 1998, Skonhoft 1999, Johannesen and Skonhoft 2004). In a bioeconomic model of hunter-agrarian households with long term preferences, Johannesen and Skonhoft show that when wildlife is synonymous of nuisance to the household, the effort in hunting is larger compared to a myopic situation. In contrast, when the wildlife is not harmful, households invest more in wildlife when they face long term preferences and this results in more resource conservation at the equilibrium. This section illustrates how, when property regime are effective, farmer's anticipations on the evolution of the resource and farming technology orientations enter in the determination of the profitability in the "utilization of the natural resources under [farmer] control." To do so, I consider a benchmark: the de facto open access situation and compare the property right regime to this benchmark; this is equivalent to compare static and dynamic problems, short term and long term preferences of the agent. Long term preferences mean that the agent possesses full property rights, this agent is said to be the owner of the resource. The agent has access, can withdraw, manage, exclude others and alienate the resource, (Ostrom 2000). When the agent cannot monitor the use of the resource, that is when property rights are imperfectly protected then the agent has short term preferences (Skonhoft and Solstad 1998). This results in a de facto open access situation (Ostrom 2000). The optimality conditions (equations 8 and 9) consider an agent facing long term preferences, but the de facto open access situations results when the discounted expected terms of both expressions vanish.

The determination of optimal land uses and the determination of the optimal agricultural effort are both partly driven by the marginal value of the biological resource all over the patches, i.e. the sign of dV_{t+1}/dB_{t+1}. The sign of this value can change according to the bioeconomic state the farm is in.

The marginal value of the resource is given by :

$$\begin{aligned}\frac{dV_{t+1}}{dB_{t+1}} &= \sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ik,t+1}[P_{i,t+1}(\gamma_{i,t+1}Q^B_{i,t+1}+\Phi_{i,t+1}Q^E_{i,t+1})-\gamma_{i,t+1}C^B_{i,t+1}-\Phi_{i,t+1}C^E_{i,t+1}] \\ &= \sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ik,t+1}[(P_{i,t+1}\gamma_{i,t+1}Q^B_{i,t+1}-\gamma_{i,t+1}C^B_{i,t+1})+\Phi_{i,t+1}(P_{i,t+1}Q^E_{i,t+1}-C^E_{i,t+1})]\end{aligned}$$

Table 2: Sign of the marginal value of the resource

	Normal	**Nuisance**
Sustainable	$\frac{dV}{dB} > 0$	$\frac{dV}{dB} < 0$
Non-Sustainable and NRO	$\frac{dV}{dB} > 0$	$\frac{dV}{dB} < 0$
Non Sustainable and AEO	$\frac{dV}{dB} < 0$	$\frac{dV}{dB} > 0$

As proposed by Skonhoft (1999), this sign depends upon nuisance the resource can generate. Then, the "Normal" situation describes a case where the marginal cost of nuisance of the resource does not exceed the marginal benefit and the "Nuisance" situation describes a situation where the presence of the resource is marginally more costly than beneficial. Here, I generalize the notion of nuisance to the situations where the input use generates marginally more costs than benefits, the nuisance is then charging both inputs: the effort and the wildlife.

Nevertheless, farmer's preferences do not reduce to this single arbitrage of nuisance but also involve farmer's anticipations on the exploited stock of natural resources and farming orientations.

Farmer's anticipations on the stock of exploited natural resources defines the state of future fluctuations of the stock according to the level of agricultural effort. If the agricultural effort exceeds a threshold then the stock of the natural resource will decline otherwise it will increase. The former case defines an anticipation that results in a "Non-Sustainable" utilization of the resource and the latter anticipation results in a "Sustainable" use of the resource. This distinction is driven by the sign of $\phi_{i,t+1}$ in the marginal value equation, $\frac{dV_{t+1}}{dB_{t+1}}$. A positive $\phi_{i,t+1}$ corresponds to the sustainable use of the resource[9], the agricultural effort is below the critical threshold. A negative $\Phi_{i,t+1}$ describes the "Non-Sustainable" exploitation of the resource.

Farming orientations informs on the technology and are of two kinds: natural resource orientation (NRO) or agricultural effort orientation (AEO). If the technology of the farm is such that natural resource are more productive at the margin than is the agricultural effort then the farm is said to be Natural Resource Oriented[10], otherwise it is Agricultural Effort Oriented[11]. The NRO means that the marginal value of the resource is mainly derived from its marginal productivity, while AEO means that the valuation is derived from the conservation value of the resource, i.e. the incremental value due to a change in the level of agricultural effort. Farming orientations describes then the determinants of the valuation of the resource.
But such distinction is only relevant in the case of Non-Sustainable use of the resource, i.e. when the stock of the resource is declining because this decline could be compensated by conservation measures adopted by the farmer (a radical change in the level of agricultural effort that could make the resource marginally positively valued). In the opposite sustainable case, such compensation measures are useless because the stock is increasing and thus the sign of the marginal value of the resource depends purely on nuisance consideration. It then appears as described in table2 that a farmer will not always positively value the resource when it is not synonymous of nuisance and negatively valued it when the resource is perceived as a pest.

3.3.1 The optimal level of agricultural effort

It is given by:

$$P_{it}Q_{it}^E - C_i^E - \beta_t E_t \left\{ H_i^E \sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ik,t+1} [(P_{i,t+1}\gamma_{i,t+1}Q_{i,t+1}^B - \gamma_{i,t+1}C_{i,t+1}^B) + \Phi_{i,t+1}(P_{i,t+1}Q_{i,t+1}^E - C_{i,t+1}^E)] \right\} = 0$$

if $E_{it} > 0$

[9] $\Phi_{i,t+1} \geq 0 \Leftrightarrow G_{i,t+1}^B \geq H_{i,t+1}^B \Leftrightarrow \varphi_i E_{i,t+1} \leq 1 + r_i - \frac{2r_i B_{t+1}}{\kappa_i}$

[10] (NRO):$| \sum_{i=1}^{C_2} \Phi_{i,t+1}(P_{i,t+1}Q_{i,t+1}^E - C_{i,t+1}^E) | < | \sum_{i=1}^{C_2} P_{i,t+1}\gamma_{i,t+1}Q_{i,t+1}^B - \gamma_{i,t+1}C_{i,t+1}^B |$

[11] (AEO):$| \sum_{i=1}^{C_2} \Phi_{i,t+1}(P_{i,t+1}Q_{i,t+1}^E - C_{i,t+1}^E) | > | \sum_{i=1}^{C_2} P_{i,t+1}\gamma_{i,t+1}Q_{i,t+1}^B - \gamma_{i,t+1}C_{i,t+1}^B |$

with $\Phi_{i,t+1} = \frac{G_i^B - H_i^B}{H_i^E}$, with $H_{it}^E \geq 0$.

The farmer with long term preferences, getting property rights on the land and on the resource on his land chooses its optimal level of effort such that he equates the instantaneous marginal benefit generated by the effort to the discounted future value of the effort.

The following table summarizes the fluctuations[12] of the effort according to the state of the system, compared to a static decision making.

Table 3: The variations of the agricultural effort

	Normal	**Nuisance**
Sustainable	-	+
Non Sustainable and NRO	-	+
Non Sustainable and AEO	+	-

In a dynamic setting, the intensification of the agricultural effort is driven by the anticipation of the farmer on the future value of the effort he will exert. If the farmer anticipates that this value is positive he will then chose a higher level of effort than he would have chosen in a myopic maximization. Otherwise, if this value is negative he prefers to reduce the effort and then to invest in the biological resource.[13].

Three reasons justify the investment in the biological asset through a reduction of the effort (" $-$ " in Table3):

- The resource does not generate too strong nuisance to the activity and can sustain the agricultural effort since the stock is increasing (Normal-Sustainable case). In that case, the farmer anticipates that the stock is increasing and not harmful relatively to the benefits it generates so that the resource is an input-asset to invest in.
- The resource is not harmful relatively to the benefits it generates but although the stock is declining, the technology is natural resource oriented so that the resource is positively valued and it justifies to invest in it and reduce the level of the agricultural effort (Normal-Non Sustainable and NRO).
- Both inputs are relatively costly and since the technology of the farm is agricultural effort oriented it justifies the disinvestment in the effort and the investment in the

[12] "$-$" means that the effort is lower than in a myopic case and "+" it is higher than in a myopic case.
[13] The fluctuation of the value of the effort is negatively related to the fluctuation of the value of the resource, since the effort affects negatively the resource.

natural resource because the nuisance is compensated by the decline of the stock (Nuisance-Non Sustainable and AEO).

When secure property rights on the resource are given to the farmer, while in Johannesen and Skonhoft the nuisance and the normal case always results respectively in lower and greater investment in the resource than in the myopic case, here, it is clear that farmers do not always play the same strategy inside each situation (normal and nuisance). Anticipations on the level of the resource by the farmer are then another determinant of his strategy. When these anticipations are such that the farmer believes that the stock will increase when he exerts an effort (sustainable case in the table) then Johannesen and Skonhoft conclusion are verified: the farmer with full property rights invests more in the wildlife in the normal case than if the rights are not secure, and in the nuisance case the farmer increases the pressure on wildlife. In contrast, when he anticipates that the resource stock is declining (non sustainable cases), the farmer can choose a different strategy because of farming orientations. Indeed, in the normal case, the farmer can chose to make more effort when he holds property rights on the resource, under the condition that the production technology is agricultural effort-oriented. Under this same condition on the technology (AEO), a farmer with long term preferences but facing nuisance, chooses to invest in the wildlife since the high cost of the agricultural effort justifies the disinvestment in the effort and the decline of the resource compensates its nuisance and justifies to invest in it.
Symmetrically, one can find three reasons to intensify the agricultural effort and to disinvest in the natural resource; (*i*) the farmer uses the negative effect of the effort on the resource to control a resource that is harmful, he anticipates that his profit will be more and more negatively affected by the pest-resource and prefers to reverse this tendency, (*ii*) the resource is harmful to the activity which is natural resource oriented so that the effort is used to control the nuisance and the decline of the stock makes the case for the disinvestment in the natural resource when the activity is natural resource oriented, (*iii*) the activity is agricultural effort oriented so that it justifies the investment in the effort and the decline of the stock of the resource which is not harmful makes the case for the disinvestment in the natural resource.

The establishment of property rights to private agents or local communities gives then singular results on the investment in wildlife conservation. Indeed, investment in renewable resources can then be realized even when the stock of the resources is declining and also even when this stock is harmful for the economic activity. Reasons of investment in wildlife are then driven by nuisance considerations but also farmers anticipations on the fluctuations of the exploited resource and on farming orientations.

3.3.2 The optimal land use allocation

$$P_{it}Q_{it}(.) + S_{it} - C_i(E_{it}) - C_i(B_{it}) + \beta_t \left[G(B_{k,t-1}) - H(E_{k,t-1}, B_{k,t-1})\right] \left(\sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ikt}(G_i^B - H_i^B) \right) \times$$

$$E_t \left[\sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ik,t+1}[(P_{i,t+1}\gamma_{i,t+1}Q^B_{i,t+1} - \gamma_{i,t+1}C^B_{i,t+1}) + \Phi_{i,t+1}(P_{i,t+1}Q^E_{i,t+1} - C^E_{i,t+1})] \right] = 0$$

if $\alpha_{ikt} > 0$. with $\Phi_{i,t+1} = \frac{G^B_{i,t+1} - H^B_{i,t+1}}{H^E_{i,t+1}}$, with $H^E_{i,t+1} \geq 0$.

The optimal choice, in a long term perspectives, is driven by the principle of equalizing the instantaneous benefit of a land-use with the expected discounted value of the land-use. The intuition driving investment in the land in a dynamic setting is that the farmer will invest more in a landuse if he expects that the value of this land in the future will be positive. Otherwise, if the landuse value will be negative, he anticipates this value and chooses to reduce this landuse, when he holds the property rights on land and hence on the wildlife of this land.

Nevertheless, the dynamic decision to invest in land is more complex and need to be detailed. Since the function G includes the stock plus its growth, then the term $[G(B_{k,t-1}) - H(E_{k,t-1}, B_{k,t-1})]$ can be null or strictly positive. Whether it is null or strictly positive is determined by the effect of landuse expansion on the population: if landuse expansion drives the stock to zero then this term is null otherwise it is strictly positive. To analyze the contribution of the dynamic, I will restrict to the strictly positive case: when the effect of landuse expansion does not drive the wildlife to zero.

The following table summarizes the cases where the farmer expands(+) or reduces (-) his land use when he holds property rights. The definitions of "Normal", "Nuisance", "Sustainable" and "Non sustainable" are the same as for the agricultural effort interpretation.

Table 4: The variations of landuses

	Normal	**Nuisance**
Sustainable	+	-
Non Sustainable and NRO	-	+
Non Sustainable and AEO	+	-

The settings of the model do not allow to find an arbitrage between investment in land-uses of the crop land type and investment in the reserve land's type. The following interpretation are valid for both types of land uses.

Table4 indicates that three reasons justify the expansion of a given land use when the farmer holds property rights, compared to a myopic maximizing farmer.

- When the resource living in that land is not harmful relatively to the benefits it generates and when the stock of the resource is increasing then it justifies to invest in that land to exploit and manage the resource of that land (Normal-Sustainable).
- When the resource is not harmful, although its stock is declining the farmer expands his land use because the technology is agricultural effort oriented so that it will be profitable to exert this effort on larger land and thus the natural resource is a minor input (Normal-Non Sustainable and AEO).
- Although the resource is harmful to the activity, this is compensated by its decline, but as the technology is natural resource oriented, expansion of the land is a tool to capture and exploit more resource (Nuisance-Non sustainable and NRO).

One can then remark that land expansion is either used to continue the exploitation of a profitable and growing resource or is a tool to capture more resource (let say by "assimilation") of an harmful but declining resource.
Symmetrically, one can find three reasons to justify a voluntary land use reduction because of property rights in induced long term preferences. (*i*) The farmer chooses to cultivate less land of a given crop because the resource is harmful and its stock is increasing so that the resource will be more and more harmful, thus the farmer prefers to reverse this tendency an reduce the land, (*ii*) the technology is natural resource oriented but the stock of the resource is declining so that he chooses not to expand because he anticipates that the benefits generated by the resource will be smaller and smaller, (*ii*) the farmer reduces his specific land use because on one side his production is agricultural effort oriented and the effort is costly and on the other side natural resource considerations are useless because the technology is AEO so that it does not matter that the nuisance is of the resource is compensated by the decline of its stock which could constitute an argument for land expansion.

Holding property rights on the land and thus on the wildlife of this land does not necessarily mean conservation of the resource. Indeed, a farmer endowed with a resource whose stock is declining can continue to expand his land and/or increase his agricultural effort. This choice of increasing the pressure on the natural resource is then driven by nuisance, anticipations and technological orientation considerations.

Finally, looking at the arbitrage between intensive or extensive farming when the agent holds property rights, (Table3 and Table4), it appears that the farmer substitutes the land to the effort only when the exploitation of the biological resource is sustainable: the choice between intensive and extensive farming is then not ambiguous and depends on the level of the nuisance. When the resource exploitation is sustainable and when it is not harmful the farmer chooses extensive farming because he reduces his optimal effort and expands his land. Otherwise when the resource is harmful, he prefers an intensive farming. In all other cases, the choice is undetermined since the effort and the land uses fluctuate in the same direction. Either the farmer chooses to make less effort when he exhibits long term preferences but also chooses less land for a given land use or he chooses to expand and exploit the resource but also chooses to make more effort.

The interpretation of the optimality conditions then clearly illustrates the importance of targeting environmental regulation policies because farmers are heterogeneous because their decision making is driven by the properties of their agroecosystem.

4 Farmer's responses to environmental regulation.

An environmental agency is interested in the regulation of the level of agricultural effort and the regulation of land uses. Typically, this agency will use instruments that will influence the decision making of the farmer to make them match the social preferences. But in the case of landscapes and more generally in the case of biodiversity, the modeling of social preferences is costly because of the diversity of these preferences. These preferences should take into account for example, the level of the natural resource, the size of the patches, the fragmentation of the habitat, the number of patches, the level of the agricultural production so that it is easy to understand that this modeling will be costly. I will then not make such an exercise and just study the response of the farmer to some policies referred as:

- the command and control policy: the creation of a protected area.
- the market based instrument policy: the tax of the production, the payment for environmental services.

4.1 The command and control instrument

Suppose that the regulatory agency imposes, without any compensations, the farmer to divert land from production so that these lands are protected under a status of fully protected areas (PA). I also assume that the nuisance costs also disappear of the profit expression: since there is no production and no compensation payments on these lands ($i = C_1 + 1, ..., C_2$) there is no more nuisance cost (the nuisance is measured as a loss of production).

This decision changes the marginal value of the resource. I call $(\frac{dV_{t+1}}{dB_{t+1}})^L$, the marginal value under a liberal policy (the no-conservation policy case) and $(\frac{dV_{t+1}}{dB_{t+1}})^{PA}$ the marginal value under the protected area policy.

Under a protected area policy, the marginal value of the overall resource is the following:

$$(\frac{dV_{t+1}}{dB_{t+1}})^{PA} = \sum_{k=1}^{C_2}\sum_{i=1}^{C_1} \alpha_{ik,t+1}[(P_{i,t+1}\gamma_{i,t+1}Q^B_{i,t+1}-\gamma_{i,t+1}C^B_{i,t+1})+\Phi_{i,t+1}(P_{i,t+1}Q^E_{i,t+1}-C^E_{i,t+1})] \quad (10)$$

$(\frac{dV_{t+1}}{dB_{t+1}})^L$ is the same expression but for $i = 1, ..., C_2$.

The issue is to identify the sign of the contribution of the biomass of protected areas in the marginal value of the overall biological resource.

So the absolute value of the difference of the two marginal value of the resource is:

$$|(\frac{dV_{t+1}}{dB_{t+1}})^L - (\frac{dV_{t+1}}{dB_{t+1}})^{PA}| = |\sum_{k=1}^{C_2}\sum_{i=C_1+1}^{C_2} \alpha_{ik,t+1}[(P_{i,t+1}\gamma_{i,t+1}Q^B_{i,t+1} - \gamma_{i,t+1}C^B_{i,t+1}) + \Phi_{i,t+1}(P_{i,t+1}Q^E_{i,t+1} - C^E_{i,t+1})]|$$

The sign of this difference is given in table2.
To compare the marginal value of the resource with and without the CAC policy, I assume that the distribution of the marginal value of the resource on each type of land is asymmetric: the marginal value on the reserve land type and on the cultivated land type that define the overall marginal value of the resource have the same sign, before and after the policy is implemented. More explicitly, this means that a farmer stays in his original state (normal, nuisance, sustainable...) after the policy is implemented. Otherwise, the implication of the environmental policy discussed here could not be analyzed.
Under this assumption, it can be deduced under which policy the marginal value of the resource is the greatest.

Table 5: Policies and the marginal value of the resource

	Normal	**Nuisance**
Sustainable	$0 < (\frac{dV}{dB})^{PA} < (\frac{dV}{dB})^L$	$0 > (\frac{dV}{dB})^{PA} > (\frac{dV}{dB})^L$
Non Sustainable and NRO	$0 < (\frac{dV}{dB})^{PA} < (\frac{dV}{dB})^L$	$0 > (\frac{dV}{dB})^{PA} > (\frac{dV}{dB})^L$
Non Sustainable and AEO	$0 > (\frac{dV}{dB})^{PA} > (\frac{dV}{dB})^L$	$0 < (\frac{dV}{dB})^{PA} < (\frac{dV}{dB})^L$

The resource can then be more valued under a liberal policy than under the policy of

protected area creation.
This table also illustrates why protected area policies are sometimes not well perceived by agents that value the resource through the productive benefits it generates. Indeed, because the agent can not value the resource coming from protected areas directly via the production or indirectly via non-consumptive revenues (ecotourism,...) then the protected areas policy lowers the marginal value of the resource for these agents. For this reason, this policy will not be popular without an appropriate compensation otherwise these agents may change their level of agricultural effort on the remaining lands.

The important question now, is to know how the farmer will respond to this regulation. A command and control policy defines the status of the land and then also the land uses allocation: the proportion of protected areas in the farm is thus chosen by the environmental agency. So, the question is how the farmer will adapt his effort to this policy?

Proposition 1: *A risk neutral agent oriented in a dynamic management of his resources, will not always increase his level of marginal agricultural effort when a regulatory agency imposes him to establish a protected area on his private exploitation.*

The optimal level of effort under the PA policy is given by:

$$P_{it}Q_{it}^{E} - C_{i}^{E} - \beta_t E_t \left\{ H_i^E \sum_{k=1}^{C_2} \sum_{i=1}^{C_1} \alpha_{ik,t+1} [(P_{i,t+1}\gamma_{i,t+1}Q_{i,t+1}^{B} - \gamma_{i,t+1}C_{i,t+1}^{B}) + \Phi_{i,t+1}(P_{i,t+1}Q_{i,t+1}^{E} - C_{i,t+1}^{E})] \right\} = 0$$

if $E_{it} > 0$
with $\Phi_{i,t+1} = \frac{G_i^B - H_i^B}{H_i^E}$, with $H_i^E \geq 0$.

Table 6: Environmental policies and the agricultural effort

	Normal	**Nuisance**
Sustainable	$E^{PA} > E^{L}$	$E^{PA} < E^{L}$
Non Sustainable and NRO	$E^{PA} > E^{L}$	$E^{PA} < E^{L}$
Non Sustainable and AEO	$E^{PA} < E^{L}$	$E^{PA} > E^{L}$

The agent will then make more agricultural effort on the crop land when the environmental regulatory agency imposes him the establishment of protected areas, if this spatial constraint on land reduces his valuation of the biological resource. Table5 indicates when the policy lowers the value of the resource and Table6 translates the effect of the PA policy in terms of changes in agricultural effort, when the farmer holds property rights on the remaining land and resource.

One can then wonder if this policy is efficient or not, efficient in sense that it yields a lower level of agricultural effort than the laisser-faire, the liberal case. Once again, it depends of the state of the agroecosystem and on farmer anticipations. We know from Table3 when the farmer chooses to invest in the resource through a reduction of the effort (Normal-Sustainable, Normal-Non sustainable and NRO, Nuisance-Non sustainable and AEO). It is precisely in these same cases that the farmer will invest less in the resource and exert more effort on the land because of the PA policy implementation. So, under the PA policy, the agent can invest less in the resource of the buffer zone than he would have done without intervention.

Thus, altering the property rights of the agent via the establishment of protected areas on a part of his land, results in an increase of the agricultural effort outside the reserve if and only if the reserve creation is costly for the agent (ie, when the creation of PA lowers his valuation of wildlife).

So, an agency can reduce the effort intensity on the land and then improve the stock of natural resources when his command and control policy allows to increase the marginal value of the resource. Hence, the choice of the plots under the PA status will then be the issue in the success of the PA policy, the agency should then target the plots where the value of the resource for the farmer is negative (Cf. table2) since in these cases the farmer intensifies his effort on the land and then increases the pressure on the stock of natural resources. The most valuable land are then not necessarily the lands to target if the institution of regulation wants to perform an integrated[14] management of the wildlife. This results joins the results of Sanchirico and Wilen (2001), that the areas with the greater biomass are not necessarily the patches to protect but rather those whose closure can generate the greater benefits, here, those whose closure makes the farmer positively value the wildlife of his land.

4.2 The market based instrument

4.2.1 Taxing the agricultural production

The price of the production is an instrument for agricultural and environmental policies: supported prices (with a negative tax) encourage the production while a positive tax of the product lower the profitability of the land-use. These is the two usual results of the static settings. But in dynamic models the effect of price policies on the control variable is not as clear because dynamic includes the willingness of the farmer to postpone his choices and create incentives to invest in conservation to increase future revenues. Moreover, the integration of a biological renewable resource makes the economic profitability biologi-

[14] both inside and outside the reserve

cally dependent (a bioeconomic model). A crucial assumption to conduct the analysis is that farmers do not anticipate the price change and consider that the price is permanent[15](Barrett 1991). In the literature on the effect of structural adjustment program on soil conservation, it is established that the agricultural products prices reform have a modest and ambiguous effect on conservation (Barrett 1991, Skonhoft 1999, Bulte and van Soest 1999). The ambiguity results in the long term management perspective of the resource: high prices encourage resource extraction but also creates incentives to invest in resource conservation to increase future revenues. Nevertheless, the ambiguity can be dissipated according to the sign of the future revenues (Skonhoft 1999). In this section, I discuss the effect of prices reform on the farmer's choices, when the farmer holds property rights on the land and consequently on the wildlife of his land.

Proposition 2: *When the marginal value of the resource is positive then, the effect on the level of agricultural effort of a variation of the production price is ambiguous. Whereas the effect is unambiguous when the marginal value of the resource is negative.*

Proof:
When the marginal value of the resource is positive, an increase (decrease) in the price of the production will increase (decrease) the marginal value of the resource which lowers (raises) the marginal value of the agricultural effort so that it raises (lowers) the farmer's willingness to forgo his agricultural effort. The farmer anticipates the damage of the agricultural effort on a resource positively valued so that he reduces (increases) his effort "as soon as" possible. So, the higher (lower) value of the resource is a motive of investment (disinvestment) in the stock by effort reduction (intensification). But on the other hand, a higher (lower) price of the production increases (reduces) the instantaneous profitability of the effort and then is a motive of disinvestment (investment) in the stock by agricultural effort intensification (reduction). The predominant effect is then ambiguous.

When the marginal value of the resource is negative, a negative (positive) tax on the output price will lower (raise) the marginal value the resource and then it increases (reduces) the expected discounted marginal value of the agricultural effort. Then the farmer anticipates this higher (lower) value of the effort and increases (reduces) it. So, a negative (positive) tax on the production price is a motive of disinvestment (investment) in the resource. Moreover, this higher (lower) production price raises (reduces) the profitability of the agricultural effort so that it is a motive of disinvestment (investment) in the stock by the intensification (reduction) of the agricultural effort. The effect is then not ambiguous. [•]

From table2 the situations favorable to a decline of the stock by the agricultural effort intensification can be extrapolated: each time the value of the resource is negative then

[15]Suppose that the price is constant in the time: $p_{it} = p_{i,t+1} = p_i$

the effect of a negative (positive) tax of the agricultural production is unambiguous and positive (negative) on the agricultural effort and thus negative (positive) on the stock of the resource. Each time this value is positive then the effect is ambiguous.

While Skonhoft (1999) finds that the effect of a higher price on the resource was ambiguous in the normal case, I find that this effect is clearly positive on the effort and negative on the resource in the normal case when the effort is not sustainable and when the production technology is not resource dependent (AEO). The other results are in line with Skonhoft conclusions on the ambiguous effect of supported prices: in the normal case, the effect of the price on the stock of the resource is ambiguous when the resource can sustain the level of effort and when the technology is resource dependent (NRO). So, when the resource has a positive marginal value then the effect is ambiguous in the normal situation.
In the nuisance case, it is also not as evident as in Skonhoft (1999) that the effect of the price on the stock of the resource is always positive. I find that this effect is ambiguous because the resource can be positively valued even if it is harmful.

To discuss the effect of the price on the land uses, I assume that the stock of the resource is not null.

Proposition 3: *When the marginal value of the resource is positive then, the effect on the land uses of a variation of the production price is unambiguous. Whereas the effect is ambiguous when the marginal value of the resource is negative.*

Proof:
When the marginal value of the resource is positive then the effect of a support (tax) on the price of the production increases (decreases) this value and increases (decreases) the instantaneous benefit of the land so that it is a double motive of land use expansion (reduction).
When the marginal value of the resource is negative then the effect of a support (tax) on the price of the output reduces (increases) the future value of the resource and is a motive of land use reduction (expansion) by anticipation. Nevertheless, the effect on the instantaneous benefits of land is positive (negative) and is a motive of investment (disinvestment) in the land. Hence, the global effect is ambiguous.[•]

The success of conservation policies through the tax of the production price policies are then highly dependent on the state of the agro-ecosystems the farmer is in and implicitly on the anticipation of the farmer on the price of the products. Here, I have assumed that the output price was constant over time but in reality agricultural prices are fluctuating. Considering a non constant price will then change the farmer willingness to postpone his choice depending not only on the state of the agro-ecosystem - nuisance, anticipations and technological orientation considerations but also on his anticipation on prices.

4.2.2 Payments for Environmental Services (PES)

The most direct instruments to biodiversity conservation is the "direct payment for the services of maintaining natural habitat and/or conserving biodiversity" (Kiss). In that case, the environmental agency is willing to pay for the rotation of cultivated land into conservation land. This case differs from the command and control instrument studied previously since there is no enforcement: the agency offers payments based on voluntary agreements. In that contract, the agent receives a payment for a land diverted from production, so that he cannot use this land for production. The agency is thus interested in purchasing the impure public good to a private owner. She then has to fully compensate the farmer for the induced losses, she must pay for the private total value of the purchased good. But allocating land to a specific and irremovable land use modify the marginal value of the resource since it reduces the production possibilities for the farmer. So, the total value of the natural resource is derived from the direct value of crop land uses ($i = 1, ...C_1$). As it has been shown previously, the sign of the value of the resource is determined by the ecological-economic characteristics of the farm, so that the situation may be improved or worsened with the PES.

Another implication of this instrument is the conditioning of the payment on the level of the natural resource. The eco-conditionality of environmental payments materializes by a payment $S_i(B)$ instead of S_i. It can be shown that the eco-conditionality will always increase the marginal value of the resource, whatever its sign. Eco-conditioning the payments for environmental services introduces one more variable in the dynamic decision making.

The optimality condition for the conservation land family is then:

$$S_{it}(B_{it}) - C_i(B_{it}) + \beta_t \left[G(B_{k,t-1}) - H(E_{k,t-1}, B_{k,t-1})\right] \left(\sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ikt}(G_i^B - H_i^B) \right) \times$$
$$E_t \left\{ \left[\frac{dV_{t+1}}{dB_{t+1}} \right]^{PA} + \sum_{k=1}^{C_2} \sum_{i=C_1+1}^{C_2} \alpha_{ik,t+1}\gamma_{i,t+1}(S_{i,t+1}^B - C_{i,t+1}^B) \right\} = 0$$

if $\alpha_{ikt} > 0$.
Where $\Phi_{i,t+1} = \frac{G_{i,t+1}^B - H_{i,t+1}^B}{H_{i,t+1}^E}$, with $H_{i,t+1}^E \geq 0$, $S_i^B \equiv \frac{\partial S_i(B_t)}{\partial B_t}$ and $\left[\frac{dV_{t+1}}{dB_{t+1}}\right]^{PA}$ is given by equation10.

This condition states that the level of the PES must equal the expected discounted marginal value of the conservation land and compensate the nuisance cost induced by the resource.

Proposition 4: *Payments for Environmental Services conditioned on the level of the natural resource are a source of perverse incentives in a dynamic decision making.*

Proof:
Let's consider the optimality condition on conservation types land-uses.
The optimality condition when the payment is not conditioned (NC) and the possibilities of rotation are restricted to non conservation lands (see equation (10) for the marginal value of the resource) rewrites as:

$$S_{it} - C_i(B_{it}) + \beta_t \left[G(B_{k,t-1}) - H(E_{k,t-1}, B_{k,t-1})\right] \left(\sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ikt}(G_i^B - H_i^B) \right) E_t \left\{ \left[\frac{dV_{t+1}(B)}{dB_{t+1}} \right]^{NC} \right\} = 0$$

With a PES, conditioned on the level of the resource, the decision rule writes as:

$$S_{it}(B_{it}) - C_i(B_{it}) + \beta_t \left[G(B_{k,t-1}) - H(E_{k,t-1}, B_{k,t-1})\right] \left(\sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ikt}(G_i^B - H_i^B) \right)$$
$$E_t \left\{ \left[\frac{dV_{t+1}(B)}{dB_{t+1}} \right]^{NC} + \sum_{k=1}^{C_2} \sum_{i=C_1+1}^{C_2} \alpha_{ik,t+1} \gamma_{i,t+1} (S_{i,t+1}^B - C_{i,t+1}^B) \right\} = 0$$

Thus, for unchanged properties of the bioeconomic system, the expected marginal value of the land use is larger with the PES than without conditioning the payment.
A conservation program targets damaged land and proposes farmers to recover a conservation land use. Thus, such program is designed for farmers that negatively value the conservation land uses in the future. PES are then implemented to give incentives to farmers that have a negative expected marginal value of land to adopt conservation land uses by subsidizing them "sufficiently"[16], to reverse their future expectations. Thus, if the subsidy is sufficient it gives the incentive to adopt conservation land uses and enter in a conservation program. Otherwise, if the subsidy is not sufficient, conservation land uses will not be adopted on damaged land, negatively valued for conservation.

Nevertheless, these conservation programs may generate perverse incentives to destroy the resources. Since conservation programs target damaged lands and farmers that negatively value these lands for conservation, farmers with positive expectations on the

[16]when $E_t \left\{ \sum_{k=1}^{C_2} \sum_{i=C_1+1}^{C_2} \alpha_{ik,t+1} (\gamma_{i,t+1} (S_{i,t+1}^B - C_{i,t+1}^B) \right\} > |E_t \left\{ \left[\frac{dV_{t+1}}{dB_{t+1}} \right]^{NC} \right\} |$

conservation land uses, do not match the program's inclusions characteristics and will not be rewarded for adopting these land uses because their expectations are per se a motive of investment in that lands. Thus, those farmers can be tempted to destroy their resources on conservation lands so that the value of land will be negative after the destruction and they can enter in the conservation program and get the reward.[•]

To avoid the perverse effect of the PES, conservation programs should then propose payments for the improvement of environmental services (PIES). In that case, when the payments is sufficiently large, the program will reverse the value of conservation land uses for the targeted farmers (those who had a negative expected marginal value of the conservation land before the program is implemented) and integrate farmers who already positively value conservation land uses giving them the incentives to conserve more instead of destroying to restore afterwards. But PIES supposes that it is possible for the environmental agency that implements the conservation program to ex ante observe the bioeconomic state of the farm. Moreover, one more issue remains for the agency : it is the one of signals given by conservation programs. In the first stage of the program the agency will observe the state of the nature to identify candidates to the programs but this gives a signal to agents.

Proposition 5: *The signal of designing an eco-conditional conservation program (PIES) may be enough to make farmers adopt or improve conservation practices, whatever the ex ante marginal expectations on conservation land uses.*

Proof:
The optimality condition without any conservation program writes as:

$$-C_i(B_{it})+\beta_t\left[G(B_{k,t-1})-H(E_{k,t-1},B_{k,t-1})\right]\left(\sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ikt}(G_i^B-H_i^B)\right)E_t\left\{\frac{dV_{t+1}(B)}{dB_{t+1}}\right\}=0$$

Then, farmers who have a negative marginal value of the conservation land use will not adopt it.

With the signal of a conservation program, conditioned on the level of the resource, the decision rule writes as:

$$-C_i(B_{it})+\beta_t\left[G(B_{k,t-1})-H(E_{k,t-1},B_{k,t-1})\right]\left(\sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ikt}(G_i^B-H_i^B)\right)\times$$
$$E_t\left\{\frac{dV_{t+1}(B)}{dB_{t+1}}+\sum_{k=1}^{C_2}\sum_{i=C_1+1}^{C_2}\alpha_{ik,t+1}\gamma_i(S_{i,t+1}^B-C_{i,t+1}^B)\right\}=0$$

Even without instantaneous payments, farmers with negative expectations can adopt conservation land uses if the payment is sufficient[17] because the signal increases the value of the farmer's expectations and the instantaneous nuisance cost may be compensated by the expectations of the farmer on conservation land uses.
Moreover, farmers with positive expectations will also be tempted to start improving the environmental services on these lands because the subsidy is a payment for improvements of the environmental services (the larger is the service B, the larger the payment received when the program will be effective).[•]

Then although one could thought that the signal of the implementation of a future conservation program makes agents passive and wait the program to adopt conservation land uses, this proposition states the contrary. Nevertheless, such intuitive result is not robust to the revision of farmer's expectations on the future value of the conservation land, if the program is not effective.

Finally, conservation policies using PIES instruments should also be associated to environmental regulation of the intensive aspect of farming (the regulation of agricultural effort on crop land) to perform an integrated management of biodiversity on private lands. The PIES may also have some spillover effects out of the conservation lands.

Proposition 6: *Conditional payments for environmental services give farmers the incentives to reduce their level of agricultural effort outside the conservation lands.*

Proof:
The optimality condition with respect to the agricultural effort writes as :

$$P_{it}Q_{it}^{E} - C_{i}^{E} =$$
$$\beta_t E_t \left\{ H_i^E \left[\frac{dV_{t+1}(B)}{dB_{t+1}} \right]^{NC} + H_i^E \left[\sum_{k=1}^{C_2} \sum_{i=C_1+1}^{C_2} \alpha_{ik,t+1}\gamma_{i,t+1}(S_{i,t+1}^B - C_{i,t+1}^B) \right] \right\}$$

if $E_{it} > 0$ and with $S_i^B \equiv \frac{\partial S_i(B_t)}{\partial B_t}$

Then, the marginal value of the resource is larger with the PES so that it is a motive of investment in it and a motive of reduction of the effort in the crop lands.(•)

If I extend the model to a larger scale, at the national instead of the farm level then this conclusion encourages the creation of a larger number of conservation reserves (what-

[17]when $E_t \left\{ \sum_{k=1}^{C_2} \sum_{i=C_1+1}^{C_2} \alpha_{ik,t+1}(\gamma_{i,t+1}(S_{i,t+1}^B - C_{i,t+1}^B) \right\} > |E_t \left\{ \frac{dV_{t+1}}{dB_{t+1}} \right\}|$

ever size issues) associated with the regulation of the agricultural effort in the vicinity of these reserves (in the so called buffer zones): thus, the greater the number of reserves the greater the integrated conservation of biodiversity.

5 Discussion and conclusion

This paper has presented a model of renewable resource exploitation by a risk neutral agent, owner of the resource. The exploited resource represents, in the special case of agriculture, the resource biota of the soil that participate in the fertility of the soil. The resource is evolving in a heterogeneous environment formed of different plots determined by the land uses choices of the farmer and in which the farmer exerts an agricultural effort, defined as the use of xenobiotic compounds such a mineral nitrogen and pesticides. The renewing of the resource considers in addition to the biological parameters two anthropogenic variables. Indeed, the stock of the resource is directly negatively affected by the agricultural effort via a harvest function a la Schaefer and adversely effected by the allocation of land. This two variables - agricultural effort and land use - allows then to introduce in the evolution of the resource the intensive and extensive effects of agriculture on the natural resource. To be more complete in defining the relationship of the agent with the resource as a mutualism relationship, nuisance considerations (pests biota) are also introduced and appear as a cost to the agent and the agent benefits of the resource biota in his production. The resource biota and the agricultural effort are then two inputs of the production.

The optimal determination of the agricultural effort and of the land use has highlighted the effects of the establishment of property rights on the management of the resource and describes the determinants of the management of a renewable resource by an agent exhibiting long term preferences compared to a myopic agent. It then appears that in combination with the nuisance considerations described by Skonhoft, two others determinants of profitability have to be considered: the anticipations of the farmer on the evolution of the resource and its farming orientations. The anticipations on the stock are either sustainable or non sustainable, meaning in the first case that the level of agricultural effort is low enough to maintain a growing resource and the farming orientations describes the technology. This technology can be natural resource oriented or agricultural effort oriented. This means that in the latter case the productivity is dominated by the productivity of the agricultural effort while in the former case it is dominated by the productivity of the resource biota. The combination of these three elements: nuisance-anticipations-orientations, defines then the cases favorable to the conservation of the resource via a reduction of the agricultural effort and/or via a reduction of a specific land use.
The study of the effects of some agrienvironmental policies on the decisions of the farmer

has covered two command and control instruments (property rights and protected areas) and two marked based instruments (conditional payments and a tax on the production). An overall conclusion on the policy effects will reinforce the role of nuisance, anticipations and orientations onto the conservation of the resource.

Beyond illustrating the farmer decision making on land uses and effort determination, the model can be linked to the CAP reform of June 2003 aiming at instituting the decoupling principle. Improving the relative profitability of conventional production through direct subsidies linked to the production creates a distortion in the choice in land use allocation in favor of cultivated areas. This appears in the optimality condition on land uses. But, increasing cultivated lands ($\alpha_{c.t} = \sum_{k=1}^{C_2} \alpha_{ckt}$) penalizes the total level of biological resources in the exploitation since the bioeconomic characteristics of cultivated areas make it less favorable to the resource than the protected areas because of the agricultural effort considerations. The repartition principle of the resource makes that there is less resource (compared to the no-distortion case) on each patch. Ceteris paribus, the net yields at date t are negatively affected. But knowing that the cultivated lands at date t can be switched in date $t+1$, the resource for the date $t+1$ will be lower than under the non distorted case. The net yields for next period will then be lower. Consequently, for unchanged levels of effort and subsidies, the farmer responds by increasing the proportion of cultivated lands, unique way to increase his yield since the effect of this decision will be to increase the resource biota on these lands and thus to increase the yields. In the next period, the farmer will get more cultivated lands but then less resource biota and so on and so forth. One solution for the social planner could be to increase the subsidies to prevent the farmer from increasing the share of conventional crop land but this makes in the same time this land use more attractive and reinforces the distortion. In the end, the situation is the following in the EU[18]: about 400 euros per hectare are given for corn, one of the most polluting crops, and about 50 euros per hectare are offered for fodder crops.

References

Beare M.H., Vikram Reddy M., Tian G., Srivastava S.C., (1997), "Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of decomposer biota",Applied Soil Ecology Vol.6: 87-108.

"Biodiversité et changements globaux. Enjeux de société et défis pour la recherche" 2005, directed by Barbault R. and Chavassus-au-Louis B. Ed. Adpf.

Bockstael N. E, (1996), " Modeling economics and ecology: the importance of spatial perspective", American Journal of Agricultural Economics Vol. 78.

[18]This coupling principle will be abolished, partially the 1^st of January 2006 in France

Bulte E.H., Horan R.D., (2003), "Habitat conservation, wildlfe and agricultural expansion", Journal of Environmental Economics and Management 45 : 109-127.

Bulte E., Bouman A.M., Plant R., Nieuwenhuyse A. and Jansen Hans G.P., (2000), "The economics of soil nutrient stocks and cattle ranching in the tropics: optimal pasture degradation in humid Costa Rica", European Review of Agricultural Economics, Vol.27(2): 207-226.

Bulte E. and van Soest D., (1999), "A note on soil depth, failing markets and agricultural pricing", Journal of Development Economics (58): 245-254.

Carson R., (1962), "Silent Spring", Edition Mariner Books,(2002).

Chomitz K.M. and Thomas T.S., (2003), "Determinants of Land Use in Amazonia: A fine-Scale Spatial Analysis", American Journal of Agricultural Economic, Vol. 85(4): 1016-1208.

Clark Colin W., (1973), "Profit maximization and the extinction of animal species", Journal of Political Economy, Vol.81: 950-961.

Conrad John M. and Paul J. Ferraro, (2000), "Habitat Conservation: the dynamics of direct and indirect payments".

Ferraro, P.J. and R.D. Simpson, (2002). The Cost-effectiveness of Conservation Performance Payments. Land Economics 78(3): 339-353.

Fragoso C., Brown G.G., Patron J.C., Blanchart E., Lavelle P., Pashanasi B., Senapati B., Kumar T. (1997), "Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of earthworms", Applied Soil Ecology, Vol. 6:17-35.

Gilot C., (1994), "Effets de l'introduction du ver gophage tropical Millisonia anomala omodeo en suystèmes cultivés sur les caractéristiques des sols et la production végétales en moyenne Côte d'Ivoire. PhD Thesis. INRA Paris-Grignon.

Gray L.C., (1913), "The economic possibilities of conservation", The Quaterly journal of economics, Vol 27(3): 497-519.

Greiner R., Herr A. and Stoeckl N., (2003), "Policies aims at overcoming impediments to the implementation of on-farm conservation activities", Bioecon workshop.

Groeneveld R., (2003), Optimizing spatial nature conservation in agricultural landscapes: an ecological-economic modeling synthesis", Bioecon workshop.

Heal G.M. and Small A.A., (2002) "Agriculture and ecosystems services", Handbook of Agricultural Economics, Vol.2, Chap.25.

Johannesen A.B. and Skonhoft A., (2004), "Property rights and natural resource utilization. A bioeconomic model with numerical illustrations from the Serengeti-Mara ecosystem, Environmental and Resource Economics, 28: 469-488.

Kinyua P.I.D., van Kooten G.C. and Bulte E.H., (2000), "African Wildlife Policy: Protecting wildlife herbivores on private game ranches", European Review of Agricultural Economics, Vol.27(2): 227-244.

Kiss A., (2002), "Making biodiversity conservation a land use priority", available on: http://epp.gsu.edu/pferraro/special/AgiBookChapter2002.pdf

Kling Catherine L., Marca Weinberg (1996), "Uncoordinated agricultural and environmental policy making : an application to irrigated agriculture in the west", American Journal of Agricultural Economics Vol. 78.

Kling Catherine L., Kurkalova L. and Zhao J. (2003), "Green subsidies in agriculture: estimating the adoption costs of conservation tillage from observed behavior".

Laxminaryan R. and Simpson R.D. (2002), "Refuge Strategies for Managing Pest resistance in Transgenic Agriculture", Environmental and Resources Economics, Vol. 22, 521-536.

Lichtenberg E., (2002), "Agriculture and the environment", Handbook of Agricultural Economics, Vol.2, Chap.23.

Ministère de l'écologie et du développement durable (2004),"Stratégie nationale pour la biodiversité".

Ostrom E. (2000), Private and common private property, Encyclopedia of law and economics Volume II. Civil Law and Economics , Cheltenham, Edward Elgar.

Pagiola S. and Kellenberg J. (1997), Mainstreaming Biodiversity in Agricultural Development: Toward Good Practice, World Bank environment Paper Number 15.

Pagiola S., (1996), "Price Policy and Returns to Soil Conservation in Semi-Arid Kenya", Environmental and Resource Economics, Vol.8: 255-271.

Pagiola S., (1998), "Economic analysis of incentives for soil conservation", World Bank.

Plantinga A.J, (1996), "The effect of agricultural policies on land use and environmental quality" American Journal of Agricultural Economics, Vol. 78-1.

Plantinga A.J., Miller D J (1999), "Modeling land use decision with aggregate data", American Journal of Agricultural Economic, Vol.81-1.

PNUE, (2002), GEO-3, L'avenir de l'environnement modial 3, Programme de Nations Unies pour l'Environnement, Editions De Boeck.

Rosenzweig M.L., (2001), "Loss of speciation rate impoverish future diversity", Proceedings of National Academy of Sciences of the USA, N98, p.5404-5410.

Sanchirico J.N. and J.E. Wilen, (2001),A Bioeconomic Model of Marine Reserve Creation (with James Sanchirico). Journal of Environmental Economics and Management 42(3).

Sanchirico J.N. and J.E. Wilen, (1998), "Bioeconomics of Spatial Exploitation in a Patchy Environment", Journal of Environmental Economics and Management 37: pp 129-151.

Sanchirico J.N. and J.E. Wilen, (2000), "Dynamics of Spatial Exploitation: A Metapopulation Approach", Resources for the Future, Discussion paper 00-25.

Simpson D. (2002),"What is biodiversity worth? And to whom?",Resources For the Future.

Simpson D. and Sedjo R. (1996), Paying for the conservation of endangered ecosystems: a comparison of direct and indirect approaches", Environment and development economics (1).

Skonhoft A. (1999), "On the Optimal Exploitation of Terrestrial Animal Species", Environmental and Resource Economics, vol.13: 45-57.

Skonhoft A. and Solstad J.T., (1998), "The political economy of wildlife exploitation", Land Economics, Vol.74(1):16-31.

Smith V.L., (1975), "The primitive hunter culture, pleistocene extinction, and the rise of agriculture", The Journal of Political Economy, Vol.83(4): 727-756.

Swanson T. (1994), "The economics of extinction revisited and revised: a generalized framework for the analysis of the problems of endangered species and biodiversity losses", Oxford Economic Papers ,vol.46: 800-821.

Swanson, T and Barbier, E (1992) Economics for the Wilds Earthscan: London.

Swift M.J., Izac A-M.N., van Noordwijk M., (2004), "Biodiversity and ecosystem services in agricultural landscapes- are we asking the right questions?", Agriculture, ecosystems and Environment Vol.104: 113-134.

Teyssèdre A., Couvet D. and Weber J., (2005), "Le pari de la réconciliation", Chap.VII, p180-187, in "Biodiversité et changements globaux. Enjeux de société et défis pour la recherche" directed by Barbault R. and Chavassus-au-Louis B. Ed. Adpf.

Teyssèdre A. (2005), "Les quatre grandes menaces sur la biodiversité", Chap.II, p37-40, in "Biodiversité et changements globaux. Enjeux de société et défis pour la recherche" directed by Barbault R. and Chavassus-au-Louis B. Ed. Adpf.

Tilman D., Fargione J., Wolff B., D'Antonio C. and al., (2001), "Forecasting agriculturally driven global environmental change", Science 292, p.281 − 284.

Thomas A., (2003), "A dynamic model of on-farm integrated nitrogen management", European Review of Agricultural Economics 30: 439-460.

Watzold F. and Drechsler M. (2003), "Spatial Differentiation of Compensation Payments for Biodiversity-Enhancing Land Use Measures", Bioecon workshop.

Wier , Hasler B. Andersen J.M. and Jensen J.D., (2001), "Environmental and economic effects of a fall in cereals prices in the EU internal market: the case of Danmark", Environmental and Resource Economics Vol.20.

Wilen J.E. 1985, "Bioeconomics of Renewable Resource Use", Handbook of natural resource and energy economics, Vol. 1: 61-123.