Agriculture and habitat conservation: a dynamic bioeconomic model of agricultural effort and land use determination.

Sébastien Foudi*
Lerna, University of Toulouse

01 September 2005

Abstract

This paper presents a dynamic analysis of land uses and agriculture effort in a heterogeneous private environment, by a risk neutral agent endowed with a biotic resource on his land. The renewable resource represents the biotic biomass of the soil that participates in the formation of vegetable mould. Nevertheless, this resource is negatively affected by the agricultural effort exerted by the agent. The effort and biological variables are the two inputs of the production function but the effort generates a negative externality on the biological renewable resource.

The land is a heterogeneous environment formed of land plots. Land uses in each plot are different generating different levels of agricultural effort and of the renewable resources. The agent maximizes his discounted expected agricultural profit with respect to his agricultural effort and to the land allocated to production. However, the stock of the biotic resource which influences positively agricultural production is adversely affected, directly by the agricultural effort and indirectly by the reduction of habitat induced by allocation of land to agricultural production. Thus, the agent faces with a trade-off between intensive and extensive agriculture.

I identify optimality conditions that determine these choices and identify the paths to extinction or sustainable use of the resource. Tackling the problem of resource conservation from the dynamic decision making problems in discrete time instead of the equilibrium approach allows to extend the usual conclusions about resource extinction. Indeed, this leads to take into account the past state of the renewable resource in the habitat allocation decision.

Finally, it is shown that the success of natural habitat conservation policies depends on the bio-economic parameters of the targeted ecosystem when the agent manages his farm in a dynamic setting and some environmental regulations are developed.

JEL classification : Q12, Q15, Q20, Q24, Q57 .

Keywords: bioeconomic modeling, optimal exploitation, agricultural effort, land uses.

*I am grateful to my advisor Alban Thomas for helpful comments. Email: sebastienfoudi@yahoo.fr

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." [1]

Two centuries have been required for a communal sudden awareness and for the integration of nature services in economic policies. A great number of environmental reports (GEO3) observe that the soil quality is declining and the resources stock erosion is increasing at a critical rate; species are disappearing at a rate a hundred times higher than the natural rate, due to human activities. Since 1962, R.L. Carson pointed out the danger of an excessive use of insecticides or of "biocides" like she named them[2]. Indeed, these biocides used for agriculture like DDT brought on a great number of damages in the food chain. Another factor, after agricultural intensification and certainly the most important reason for the loss of wildlife is the loss of habitat. Deforestation is the most representative example and the scene is even darker when deforestation is followed by agriculture. During the nineties, almost seventy percent of deforested areas were changed to agricultural land, predominantly under permanent rather than shifting systems (GEO3). According to Tilman (2001) the excesses of agriculture generate a degradation and a considerable reduction of habitats. The current main reasons of this degradation are the massive diffusion and the excessive use of chemical fertilizers (nitrogen and phosphorus) and of pesticides on crop lands that drive soil and ground water and freshwater pollution but also that drive eutrophication of terrestrial, freshwater and near-shore marine ecosystems.

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 anthropic areas is a crucial and recent issue in biodiversity conservation. Rosenzweig claims then for the "reconciliation" of economy and biology. (Teyssèdre and 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 economy will then help to preserve this resource at the basis of the economic development thanks to the services it generates.

Ecosystems degradation would not be such a problem, if we abstract from ethical and moral considerations that are not the purpose of the discussion, if these ecosystems and their diversity had

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

[2] Silent Spring , chapter 2, page 8.

not any values and did not bring services to human activities. Daily (1997) references these services into fourteen categories, of which: the mitigation of droughts and floods, the dispersal of seeds, the cycling and the movement of nutrients, the generation and 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. Thus, the relationship between the agriculture and the environment cannot be described anymore as a "parasitism" association but as a "mutualism" association[3].

Despite the scientific recognition of this mutualism, agents have no incentives to preserve such a resource on the long run, without public intervention. Indeed, this resource is a semi public good facing the free rider problem (some benefits are excludable, local). Nobody is willing to pay for the conservation of this good whose benefits will also be captured by neighbors. The concerned institutions have responded in different ways, more or less direct (Kiss, Kiss and Ferraro). In the industrialized countries, the selected approach for conserving and preserving ecosystems is the conditional payment principle, that is founded in CAP reforms since 1992. This approach is identified by Kiss to be the more direct one: it regroups payments to withdraw cultivated areas from production, to conserve remarkable areas or to pay for performance in resource conservation.

Thereby, the model starts from the statement that the loss and the degradation of habitat are the two main factors driving down to extinction of the natural biotic resources. Thus, I focus on the determination of the optimal agricultural effort and optimal land uses on anthropized areas, representing the intensive and extensive aspects of agriculture. Because the final decision of conservation or exploitation belongs to the agent, I build a model of private farm management of space and resource and take into account the existence of market incentives to produce or conserve, such as agri-environmental payments designed by the CAP for the conservation part and agricultural subsidies, coupled to production.

For the biological aspect of the model, I focus on the management of a biotic renewable resource on a private exploitation. Property rights of the resource are supposed to be distributed over farmers. The biotic resource is a variable representing the fauna of the soil (lumbrics, insects,...) at the base of the bio-functioning of the soil and the creation of vegetable mould. This resource will be negatively affected by human activities like agricultural effort.

Finally, Heal and Small (HB 2002) describe ecosystems as "complex and unpredictable" introducing a form of risk in human activities if they are too much dependent on ecosystem services. This may partially explain the parasitism relationship one can find between human activities and nature. Without policy mechanisms, human activity extends at the expense of wildlife, the benefits are unilateral and detrimental for the dominated party. Nevertheless, in this paper, I consider the case of a risk neutral agent to have a simpler understanding of the implications of the integration of a natural resource in the management of farming activities, without special preferences toward risk.

In the next section , I will present the review of the literature on biodiversity and agriculture and states the singularity of the model. In section 3, I present and solve the model and propose an interpretation of the optimality conditions. Finally, Section 4 analyzes the farmer's response to different environmental regulations.

[3]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 papers 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[4]. 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 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 dif-

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

ferent types of migration of the resource from one patch to the other, this article doesn't consider such a distinction.

According to terrestrial species exploitation, 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[5] 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.

Finally, the notion of nuisance cost could be extended to the notion of risk or of preferences for the resource to join the Heal and Small's (2002) description of an ecosystem. In fact, this cost can be observed or not, quantified or not. It can represent a loss of production when it is visible but if it's not, it could translate the preferences of the agent for the presence of the resource in his vicinity.

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. Ferraro and Conrad study the efficiency of direct conservation payments versus indirect ones in a dynamic model, contrary to Ferraro and Simpson's static framework. 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 and the recipient can both prefer direct payments for conservation. The derivation of the optimality condition on land will show that for land-uses of biological interests, land-uses whose biological properties match with the habitat of the biotic resource, such as grassland for example, without direct payments such land-uses can not be adopted by the agent.

Nevertheless, they offer agents only two alternatives: either deforestation or protection. They start from the case of a zone subjected to deforestation for agriculture to design compensation payment offers. This limited case is representative of developing countries or countries endowed with large natural areas potentially exploited but is too restrictive for most European countries because the CAP policies offer a bunch of compensation payments that incite to restore lands and ecosystems. Thus, I would not restrict the alternatives offered to the agent to develop a land uses rotation model. This model is then not only specific to countries models having a strong political

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

institutions able to design compensation payments but also to countries benefiting of conservation programs designed by international institutions or NGOs.

Conditional payments and payments to withdraw land of production are the selected mechanism by the European Union to conserver ecosystem services. CAP offers a bunch of fourteen agri-environmental measures and sustainable contracts, like "PHAE"[6]. The agent receives payments from the EU for the state of his land: either his land is under a specified contract or agri-environmental measures, or any other non-contracted state. Thus, at date t, two land uses are observed: conservation land uses and production land uses. Let suppose there is no intermediate state of transition from one state to the other. But considering semi-natural space as a competitive alternative means that it is a managed areas in itself and thus makes fully part of land uses. So, land use is defined as the repartition of all managed areas, whether it is cultivated areas, semi-natural areas like grassland or agriforests, or natural areas like wetlands or forests. One of the characteristics of economic and administrative institutions is the existence of a bunch of incentives, sometimes in contradiction with environmental goals. The European Union for example offers subsidies encouraging production instead of conservation[7]. Focusing on conservation resource policies, some authors have studied the efficiency of "two-sided" subsidies. Plantinga (1999) analyzes the effect on the environment of a decrease of agricultural subsidies for conventional crops. Indeed, a lack of coordination between environmental and agricultural policies would reduce the efficiency of conservation (Kling and Weinberg). Thus, it is of interest to known if reducing or canceling economic distortions of subsidies would improve the production and the quality of the environment rather than increasing subsidies for conservation (Pagiola 1996).

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 fulfills this issue by considering the past states of land-uses.

To sum up, I will use the concept of resource management in a heterogeneous environment adapting it to terrestrial resources in order to design a dynamic land use model. I present this resource management model in a dynamic framework to take into account the willingness of the agent to postpone his choices and in a finite horizon case.

3 The model of resource exploitation

3.1 A general framework

This part is a general view of resource exploitation by an agent, owner of the resource. 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 opposition of agricultural and conservation and integrates the biological resource in the economic activity.

The environment is divided in several patches, α_{ikt} where the index i informs on the land-uses of date t while index k informs on the land-uses at the date $t-1$. Indexes $i, k = 1, ..., C_1$ correspond

[6] "Prime Herbagre agrienvironmentale" for agri-environmental payment for pasture

[7] Until the application of the uncoupling principle from 1^st January 2005.

to the areas submitted to human activities and $i, k = C_1 + 1, ..., C_2$ correspond to natural reserves. $\alpha_i kt$ measure the fraction of land under land-use i at date t while under land-use k at date $t-1$, the sum of patches is normalized to one.

The biological resource representing wildlife at time t is noted B_t. This stock exists in a given quantity on land i, a known proportion γ_i of the total stock[8].

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

According to where the resource is located, it is differently affected by human activities. It is then subjected to a harvesting function or mortality function, H which depends on the harvesting effort and on the resource. The resource is also affected by the "history" of the patch. The index k then represents the land use of the patch α at date $t-1$. The stock of the biological resource evolves as follows

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

where α is the habitat proportion and G the natural growth function of the resource.

The agent gets a benefit Π_t:

$$\Pi_t = \Pi_t[pQ(B,E), R(B), S, C(E,B)]$$

where Q is the production depending upon the resource B and the effort of production E sold at the price p, R is the revenue derived from protection, S are subsidies and payments for environmental services, $C(E)C(B)$ are the costs induced by the economic activity and the nuisance cost of wildlife. One can decompose these revenues in two: those obtain from patches already exploited, and those from patches newly exploited. If we think in the case of agricultural extension at the expanse of the forest as in Conrad and Ferraro, then the first revenues of the below equation are agricultural revenue, the second are deforestation revenues. Revenues from protection come from ecotourism and compensation payments from resource management institutions.

The benefits rewrites as:

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

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

[8]I do not consider a stochastic distribution of the resource as it can be done in fishery models.

In a dynamic land-use decision, the risk neutral agent maximizes his discounted expected benefits over a finite time horizon:

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

where τ_s is the interest rate at time $s = t, t+1, ..., T$.

This modeling can be adapted to several human activities when the relationship between the agent and the resource is a mutual one. It allows not to restrict the opportunities given to the agent: the possibility of a return to a natural state of the land is offered to the agent. In that sense, this is a land-use rotation model.

Examples of this relationship are numerous, mostly in agricultural fields. Wildlife services can be of an economic or cultural nature. For instance, the association of the pigeon and the crop fertilization. In French countries, farmers built dovecotes to harvest the guano, used as fertilizer. In another case, the cranes migrating from the north of Europe to the south stop in France on the way. Their "feeding" create conflict with farmers since the cranes eat the seeds and generate a strong nuisance cost for the farmer. Thus, a French NGO (the Ligue Protectrice des oiseaux) is working with these farmers to conserve some lands out of production where the cranes could feed by eating seeds. In that precise case, an external intervention is required to conserve the resource, the next section will identify all possible cases in which an intervention is or not useful.

The livestock and crop association is also a historical one. It presents a multiple interest since cattle is a source of income, provide fertilizer, but cultural aspects are also of importance. Indeed, farmers of the Andean Altiplano use the llama for fertilization, induced revenues from weaving and textile but also for religious rituals. Finally, another association, less valued, less visible is the one involving the living organisms of the soil that participate in the regeneration and the fertilization of the soil. I will focus on this particular case in the following section.

3.2 The agricultural version

3.2.1 The model

The agricultural exploitation represents a heterogeneous environment formed of patches α_{ikt} representing a fraction of the exploitation[9]. 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 $t-1$.

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

- Conserved lands are land protected at date t whatever its state at date $t-1$.

For biotic species, the soils are a habitat favorable to their proliferation. A data to take into account and underlying to the heterogeneous environment is that the resource migrates from one patch to the other and thus is not present in the same quantity inside patches. Cultivated patches would be certainly poorer in terms of resource stock and diversity than conserved patches that acts as a reserve of biomass. Moreover, due this low biological diversity, crop land pests are in a habitat propitious to their proliferation and their growth is as greater as their predators have been removed from this land due to the agricultural effort.

The renewable resource represents the fauna[10] 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 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 Modlybdne, 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. These figures translate the gigantic work done by these "lilliputian workers".

Nevertheless, this fauna is not uniformly distributed on the different ecosystems[11].

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 inter-patches migration but I will just consider that the migration is such that the observed biomass of a patch is always the same fraction γ_i of the total biomass (B_t), fraction specific to the patch i and time invariant.

[10] 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).

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

Thus,

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

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 protein's metabolism in favor of glucides and makes the plant more "tempting" for devastators[12]. 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 most affected carnivores are the birds of prey, fishes but also the waders.
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[13].

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 one of fishery models:

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

where φ_i is a mortality coefficient due to effort.

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

[13] Another way to introduce the effort would be to consider that it reduces the resource instantaneously but for ease of results interpretation the solution selected is better.

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 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 agricultural effort and the conservation per se induce some costs $C_i(E_{it}), C_i(B_{it})$. It corresponds to a management cost of the resource: a financial cost of the effort and nuisance cost due to the existence of wildlife in the exploitation and damages it can cause. The costs are increasing in its argument. Nevertheless, the specificity of the nuisance cost can be used to introduce a kind of risk aversion in the model or aversion for an excess of resource. Indeed, as developed by Heal and Small (HB 2002) the dependence of anthropic 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. Hence, 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:

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

Remark:

$$\sum_{k=1}^{C_1}\sum_{i=1}^{C_1}\alpha_{ikt}+\sum_{k=C_1+1}^{C_2}\sum_{i=C_1+1}^{C_2}\alpha_{ikt}+\sum_{k=1}^{C_1}\sum_{i=C_1+1}^{C_2}\alpha_{ikt}+\sum_{k=C_1+1}^{C_2}\sum_{i=C_1+1}^{C_2}\alpha_{ikt}=\sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ikt}=1$$

3.2.2 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

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

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

and

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

- **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:

- $\frac{dB_{t+1}}{dB_t} = \sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ki,t+1}\left[G_i^B - H_i^B\right]$
- $G_i^B = \frac{\partial G_i(B_{it})}{\partial B_t}$
- $\frac{\partial B_{it}}{\partial B_t} = \gamma_i$
- $\frac{\partial C_i}{\partial B_t} \equiv C_i^B$
- $\frac{\partial Q_{it}}{\partial B_t} \equiv Q_i^B$

Hence,

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

- **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:

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

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

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

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:

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

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

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

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

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

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

The areas i at date t with origin k are equals to the areas k coming from land use i at date $t-1$. Fro 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:

$$P_{it}Q_{it}^E - C_i^E - \beta_t E_t \left\{ H_i^E \sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ik,t+1} [P_{i,t+1}(\gamma_i Q_{i,t+1}^B + \Phi_{i,t+1} Q_{i,t+1}^E) - \gamma_i C_{i,t+1}^B - \Phi_{i,t+1} C_{i,t+1}^E] \right\} = 0 \tag{8}$$

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,

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

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

The optimal land allocation is driven by :

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

$$\times \beta_t E_t \left[\sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ik,t+1}[P_{i,t+1}(\gamma_i Q_{i,t+1}^B + \Phi_{i,t+1} Q_{i,t+1}^E) - \gamma_i C_{i,t+1}^B - \Phi_{i,t+1} C_{i,t+1}^E] \right] = 0 \quad (9)$$

if $\alpha_{ikt} > 0$.
with $\Phi_{i,t+1} = \frac{G_{i,t+1}^B - H_i^B}{H_i^E}$

3.2.3 Interpretation of the first order conditions

The determination of optimal land uses and the determination of the optimal agricultural effort are both driven by the marginal value of the resource all over the patches, i.e. the global marginal value of the biological asset, dV_{t+1}/dB_{t+1} . The sign of this value can change according to the bioeconomic state the farm is in. Two different situations appear: to use the words of Skonhoft (1996), the "Normal case" when the cost of nuisance do not exceed the marginal benefits or when the cost-price ratio is low, and the "Nuisance case" otherwise.
The singularity of this model makes that two other situations exist: the "Sustainable case" when Φ_{it} is positive[14]and the "Non sustainable case" otherwise. This case is defined as sustainable since the level of effort is such that it does not reduce the level of the stock of the resource. If on the contrary, the level of the optimal effort is such that it decreases the stock of the resource, it is considered as "Non sustainable".

The marginal value of the resource is given by :

$$\begin{aligned} \frac{dV_{t+1}}{dB_{t+1}} &= \sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ik,t+1}[P_{i,t+1}(\gamma_i Q_{i,t+1}^B + \Phi_{i,t+1} Q_{i,t+1}^E) - \gamma_i C_{i,t+1}^B - \Phi_{i,t+1} C_{i,t+1}^E] \\ &= \sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ik,t+1}[(P_{i,t+1}\gamma_i Q_{i,t+1}^B - \gamma_i C_{i,t+1}^B) + \Phi_{i,t+1}(P_{i,t+1} Q_{i,t+1}^E - C_{i,t+1}^E)] \end{aligned}$$

The following table illustrates the sign of this value.

These two conditions (* and **) are the asset portfolio arbitrage conditions: the marginal benefit of each asset (agricultural effort and biological resources) will determine the investment in this biological asset. They determine the origins of the marginal value of the natural resource: this value originates from direct use-value of the resource (the terms with B as top-index) and from an indirect value derived from resource conservation (the terms with E as sub-index). The dominating

[14] $\Phi_{it} \geq 0 \Leftrightarrow G_{it}^B \geq H_{it}^B \Leftrightarrow \varphi_i E_{it} \leq 1 + r_i - \frac{2 r_i B_t}{\kappa_i}$

Table 2: Sign of the marginal value of the resource

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

(*):$\mid \sum_{i=1}^{C_2} \Phi_{i,t+1}(P_{i,t+1}Q^E_{i,t+1} - C^E_{i,t+1}) \mid < \mid \sum_{i=1}^{C_2} P_{i,t+1}\gamma_i Q^B_{i,t+1} - \gamma_i C^B_{i,t+1} \mid$
(**):$\mid \sum_{i=1}^{C_2} \Phi_{i,t+1}(P_{i,t+1}Q^E_{i,t+1} - C^E_{i,t+1}) \mid > \mid \sum_{i=1}^{C_2} P_{i,t+1}\gamma_i Q^B_{i,t+1} - \gamma_i C^B_{i,t+1} \mid$

origin will then set the sign of the value of the resource.

The optimal level of effort
It is given by:

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

if $E_{it} > 0$
with $\Phi_{i,t+1} = \frac{G^B_i - H^B_i}{H^E_i}$, with $H^E_{it} \geq 0$.

The farmer chooses its optimal level of effort such that he equates the marginal benefit generated by the effort to the discounted future value of the effort.

The following table summarizes the fluctuations[15] 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 *	-	+
Non Sustainable and **	+	-

(*):$\mid \sum_{i=1}^{C_2} \Phi_{i,t+1}(P_{i,t+1}Q^E_{i,t+1} - C^E_{i,t+1}) \mid < \mid \sum_{i=1}^{C_2} P_{i,t+1}\gamma_i Q^B_{i,t+1} - \gamma_i C^B_{i,t+1} \mid$
(**):$\mid \sum_{i=1}^{C_2} \Phi_{i,t+1}(P_{i,t+1}Q^E_{i,t+1} - C^E_{i,t+1}) \mid > \mid \sum_{i=1}^{C_2} P_{i,t+1}\gamma_i Q^B_{i,t+1} - \gamma_i C^B_{i,t+1} \mid$

As long as the marginal value of the biological resource is positive, the farmer will invest in this asset and choose to make less agricultural effort than he would have exerted without considering

[15]"−" means that the effort decreases and "+" it increases.

the existence of nature's services (i.e, in static decision making).
Three reasons justify the investment in the biological asset:

- The resource does not generate too strong nuisance to the activity and can sustain the agricultural effort since the stock is growing . (Normal-Sustainable case)

- The resource does not generate too strong nuisance to the activity, its stock is declining but the asset portfolio condition makes it preferable to the agricultural effort asset because of the conditions on the origins of the value of the natural resource. (Normal-Non Sustainable and *)

- The stock is declining so that it cannot sustain the level of agricultural effort, the biological asset is synonymous of nuisance to the farmer but the marginal value of the natural resource is positive since its indirect value is positive and dominates the direct value which is negative.(Nuisance-Non Sustainable and **)

A farmer in the case "Normal-Sustainable", the case where the costs are not too high and where the resource is growing will then invest in the resource by limiting his agricultural effort while a farmer in the "Nuisance-Sustainable" case, with the same technology, will make more agricultural effort. The partial extinction, locally (on a given patch) is conceivable in the case where the marginal costs exceed the marginal benefits even if the resource is growing. One could find contradictory the fact that a farmer facing a low cost-price ratio and exploiting the resource in a sustainable manner ("Normal-Sustainable") will invest in the resource by limiting his agricultural effort, it could have increased his emissions since it is sustained by the biological resource. Nevertheless, he invests in nature's services since one less unit of effort will generate more benefit through the induced increase in the stock of the resource, than one more unit of agricultural effort.

Moreover, a resource whose stock is going down ($G_i^B < H_i^B$), can generate an investment in the "Normal" case as long as, the net marginal benefit generated by the resource is larger than the net marginal benefit of the effort (condition *). On the other hand, under this same portfolio condition, the farmer will not invest in the resource in the "Nuisance" case.

Similarly, local extinction of the resource, on a specific patch of the environment, may arise because of the intensification of the agricultural effort on this path for three reasons:

- The natural productivity is growing and the resource generates to much nuisance to the farmer. (Nuisance-Sustainable)

- The global value of the resource is negative since the direct value is negative and dominates the indirect value which is positive but as the resource is synonymous of nuisance the farmer prefers not to invest in it and to increase his marginal effort. (Nuisance-Non Sustainable and *)

- The resource does not create nuisance to the activity, its natural productivity is declining since the effort is not sustainable and the value of the resource is dominated by its indirect value which is negative because its natural productivity is declining (Φ_{it} negative) so that the agent does not invest in the resource. (Normal-NonSustainable and **)

The optimal land use allocation

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

if $\alpha_{ikt} > 0$. with $\Phi_{i,t+1} = \frac{G_{i,t+1}^B - H_{i,t+1}^B}{H_{i,t+1}^E}$, with $H_{i,t+1}^E \geq 0$.

The farmer choice is driven by the principle of equalizing the instantaneous benefit of a land-use with the expected discounted value of the land-use. Nevertheless, the dynamic choice to invest in the habitat of the resource is more complex. A farmer will invest in patch i, according to the marginal discounted value of the resource, according to the dynamic of the stock, $\left(\sum_{k=1}^{C_2}\alpha_{ikt}\sum_{i=1}^{C_2}G_i^B - H_i^B\right)$ and according to the preceding state of the resource, e.g, the term $G(B_{k,t-1}) - H(E_{k,t-1}, B_{k,t-1})$ in the equation: these three parameters are the determinant of the land-use value.

Consequently, the case "Normal" still states a case in which the cost-price ratio is low and the case "Nuisance" in which the cost-price ratio is high.
The case of "Overexploitation" in the previous period states that $\frac{dB_t}{d\alpha_{ikt}} < 0 \Leftrightarrow G(B_{k,t-1}) - H(E_{k,t-1}, B_{k,t-1}) < 0$ and "Exploitation" means $\frac{dB_t}{d\alpha_{ikt}} > 0$. This deals with the spatial exploitation of the biological resource. Finally, the case "Sustainable" means $\frac{dB_{t+1}}{dB_t} = \sum_{k=1}^{C_2}\sum_{i=1}^{C_2}\alpha_{ikt}(G_i^B - H_i^B) > 0$ and "Non Sustainable" $\frac{dB_{t+1}}{dB_t} < 0$. This is then the same as considering that $\Phi_{it} = \frac{G_i^B - H_i^B}{H_i^E}$ is respectively positive and negative. Hence, these two cases correspond also to the effort optimality condition, so if Φ_{it} is positive then so is $\frac{dB_{t+1}}{dB_t}$.

Table 4: Sign of the marginal value of land-uses

	Normal		**Nuisance**	
	Overexploitation	**Exploitation**	**Overexploitation**	**Exploitation**
Sustainable	-	+	+	-
Non Sustainable and $*$	+	-	-	+
Non Sustainable and $**$	-	+	+	-

$*$: $\mid \sum_{i=1}^{C_2}\Phi_{i,t+1}(P_{i,t+1}Q_{it}^E - C_{i,t+1}^E) \mid < \mid \sum_{i=1}^{C_2}P_{i,t+1}\gamma_i Q_{i,t+1}^B - \gamma_i C_{i,t+1}^B \mid$
$**$: $\mid \sum_{i=1}^{C_2}\Phi_{i,t+1}(P_{i,t+1}Q_{it}^E - C_{i,t+1}^E) \mid > \mid \sum_{i=1}^{C_2}P_{i,t+1}\gamma_i Q_{i,t+1}^B - \gamma_i C_{i,t+1}^B \mid$

Then, the combination of these three cases will determine the sign of the marginal value of a land-use. Thus, whether the marginal value of the land use is positive, whether the farmer will expand this particular land-use. The following table illustrates the sign of the marginal value of land and so, the cases more (+) or less (−) favorable to land use extension, compared to a static decision making.

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. Nevertheless, extrapolation can be done.

Six different states of the bio-economic system explain the reasons why a farmer invests in land-use i, when he cares for his resources (in dynamic management).

- The stock of the natural resource is growing, the resource does not generate a too strong nuisance to the activity and the resource was not spatially over-exploited at the previous period. (Normal-Sustainable-Exploitation).
  This case could illustrate the sustainable development case, when the activity expands but not at the expense of nature. A example of that kind is the nomad activity in Mongolia: these nomads get permits for the grazing of their yaks, they stay on patch as long as the pressure of the animals is sustainable for the biological resource (here, the grass) and they move to a land that was not previously over-exploited.

- The resource is declining, it was previously spatially over-exploited but the portfolio arbitrage condition favors the biological resource asset. The farmer invests in this land because the biological resource contained on it is more profitable than is the agricultural effort: it is more profitable to expand rather than to intensify the activity by increasing the effort without expanding. (Normal-Overexploitation-Non Sustainable and *)

- The cost-price ratio is low and the resource asset is less profitable than the agricultural effort asset and the marginal value of the resource is negative because of the non sustainability of the conservation benefits (ϕ_{it} negative). The resource was not spatially over-exploited so that the benefits from expansion are greater than those of intensification of the effort without expanding. (Normal-Exploitation-Non Sustainable and**).

- The resource can sustain the level of effort, it is synonymous of nuisance to the farmer and its marginal value is negative and it was over-exploited. The farmer invests in this land because it was over-exploited so that it compensates the nuisance suffered and the growth of the resource. (Nuisance-Over Exploitation-Sustainable)

- The marginal value of the resource is negative since both the indirect value and the direct value are negative (i.e., the indirect negative value means that conservation is non sustainable and the negative direct value comes from the high nuisance). As the level of agricultural effort is not sustainable, expansion towards non over-exploited land is the way to increase the profitability of the activity rather than intensifying the effort. (Nuisance-Exploitation-Non Sustainable and *)

- The cost-price ratio is high, the marginal value of the resource is positive because the indirect value is positive and dominates the negative direct value of the resource. The resource was spatially over-exploited and the effort is not sustainable (natural growth rate of the resource is negative) so that it compensates its nuisance and is a motive of investment in that land (Nuisance-Overexploitation-Non sustainable and **).

All these six justifications of land-use expansion are not all good for the resource but explain why some land still be overexploited while other still be preserved although exploited. Indeed, as it has been quoted, only one among these six reasons illustrates a sustainable development of the economic activity.

It thus also allows to understand the reason of the status-quo in land uses: why overexploited ecosystems still be overexploited and why preserved ecosystems remain preserved?
The first status-quo (overexploitation) is explained by three reasons. The first is that the cost-price ratio is low (normal case), the dynamic of the resource is negative (Non sustainable) and the input resource is more productive than the input effort ($*$ condition). The second reason is that the cost-price ratio is high (nuisance case), the dynamic of the stock is positive (Sustainable) or if it is negative then the input resource is less productive than the effort input ($**$ condition).

The principle of land use rotation is that the land use of a patch is different from one period to the other. So, if we suppose that the "Overexploitation case" is more representative of conventional crops surfaces since it corresponds to overexploitation of the resource at time $t-1$ and that the case "Exploitation" is more representative of conserved areas like grasslands then this model illustrates the interest of land use rotation.
Indeed, the farmer will choose to implant a crop i on a land that was not previously overexploitated (fallows, grasslands), on which the applied effort could maintain the resource in a positive dynamic and on which the resource will not have too much perverse effects on the activity due to the nuisance cost, the case "Normal-Exploitation-sustainable".
On the other side of the rotation, the farmer could be tempted to convert conventional crops into conserved lands since these protected lands are more subject to be in a state previously overexploitated and where the applied effort will not change instantaneously the dynamic of the resource, the case Normal-Overexploitation-Non Sustainable and ($*$).

If we look at the arbitrage between extensive and intensive agriculture: the simultaneous determination of the effort and land uses, an agent in a Normal-Sustainable situation, where the costs are moderated and the effort is sustainable, will be able to invest in the resource by limiting his effort and this same agent will invest in the resource by increasing the share of the protected lands only if the resource was not previously overexploited.

The interpretation of the optimality conditions then clearly illustrates the importance of targeting environmental regulation policies because the decision making of the farmer is driven by the properties of his agroecosystem. Some policies may be inefficient if not well targeted: for example, Table**??** clearly shows that a farmer facing a low cost-price ratio and a positive dynamic of the resource will get more incentives to protect the resource than a farmer with a high cost price ratio with the same dynamic of the resource so that these two farmers will not respond to environmental policies in the same way.

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 areas.

- 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).

Remark: I rule out the moral hazard problem of observing the effort and distinguishing the origins of the productions. I suppose that there is no illegal harvest, sold on a parallel market.

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:

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

Recall that $(\frac{dV_{t+1}}{dB_{t+1}})^L$ is the same expression but for $i = 1, ..., C_2$.
Note that the resource is valued only through the production so that there is no compensation revenues able to influence the marginal value of the resource. Subsidies for environmental services should then be added in the model instead of subsidies coupled to production. (see comments on section 5).

The problem 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:

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

Table 5: Sign of the marginal value of the resource under Pa policy

	Normal	**Nuisance**
Sustainable	>0	<0
Non Sustainable and *	>0	<0
Non Sustainable and **	<0	>0

*: $|\sum_{i=1}^{C_1}\Phi_{i,t+1}(P_{i,t+1}Q^E_{it} - C^E_{i,t+1})| < |\sum_{i=1}^{C_1}P_{i,t+1}\gamma_i Q^B_{i,t+1} - \gamma_i C^B_{i,t+1}|$
**: $|\sum_{i=1}^{C_1}\Phi_{i,t+1}(P_{i,t+1}Q^E_{it} - C^E_{i,t+1})| > |\sum_{i=1}^{C_1}P_{i,t+1}\gamma_i Q^B_{i,t+1} - \gamma_i C^B_{i,t+1}|$

At that point, I need to assume that the contribution of one kind of plot to the marginal value of the resource is "marginal" to the overall ecosystem state, not able to reverse the marginal value of the resource. This means that I suppose that the distribution of the marginal value of the resource is asymmetric; both contribution (from protected areas or from crop lands) are positive or negative. This hypothesis minimizes the role of each land use in the overall state of the ecosystem, not allowing it to reverse the marginal value of the resource. Under this hypothesis, protected areas and crop lands will not be able to reverse the value of the exploitation but only to improve it or to reduce it. 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, I can deduce under which policy the marginal value of the resource is the greatest.

Table 6: 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 *	$0 < (\frac{dV}{dB})^{PA} < (\frac{dV}{dB})^L$	$0 > (\frac{dV}{dB})^{PA} > (\frac{dV}{dB})^L$
Non Sustainable and **	$0 > (\frac{dV}{dB})^{PA} > (\frac{dV}{dB})^L$	$0 < (\frac{dV}{dB})^{PA} < (\frac{dV}{dB})^L$

*: $|\sum_{i=1}^{C_1}\Phi_{i,t+1}(P_{i,t+1}Q^E_{it} - C^E_{i,t+1})| < |\sum_{i=1}^{C_1}P_{i,t+1}\gamma_i Q^B_{i,t+1} - \gamma_i C^B_{i,t+1}|$
**: $|\sum_{i=1}^{C_1}\Phi_{i,t+1}(P_{i,t+1}Q^E_{it} - C^E_{i,t+1})| > |\sum_{i=1}^{C_1}P_{i,t+1}\gamma_i Q^B_{i,t+1} - \gamma_i C^B_{i,t+1}|$

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 benefit 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. The two control variables are the agricultural effort and the land use allocation.
Let's suppose that the command and control policy, defines the status of the land but also the land uses allocation: the proportion of protected areas in the farm is 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:

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

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 7: Environmental policies and the agricultural effort

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

$*$: $\mid \sum_{i=1}^{C_1} \Phi_{it}(P_{i,t+1}Q_{it}^E - C_{i,t+1}^E) \mid < \mid \sum_{i=1}^{C_1} P_{i,t+1}\gamma_i Q_{i,t+1}^B - \gamma_i C_{i,t+1}^B \mid$
$**$: $\mid \sum_{i=1}^{C_1} \Phi_{it}(P_{i,t+1}Q_{it}^E - C_{i,t+1}^E) \mid > \mid \sum_{i=1}^{C_1} P_{i,t+1}\gamma_i Q_{i,t+1}^B - \gamma_i C_{i,t+1}^B \mid$

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 constraint on land is "costly" for his activity: that is, when the cost-price ratio is low and the effort is not detrimental for the growth of the resource (case Normal-Sustainable) or when it is detrimental, when the marginal benefit of the resource is larger than the marginal benefit of the effort (case Non sustainable and *) or when the cost-price ratio is high and the effort is non sustainable but marginally profitable (case Nuisance, non sustainable and **).
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. We know from Table**??** that in the three preceding quoted cases (Normal-Sustainable, Normal-Non sustainable and *, Nuisance-Non sustainable and **), the farmer would have invested in the resource by reducing its level of effort on land i. But under the PA policy, the agent will invest less in the resource than he would have done without intervention. (Table**??**). Nevertheless, the PA policy makes better than the agent would have done, in term of conservation by a reduction of the intensity of the agricultural effort in the remaining cases: the normal-non sustainable and **, nuisance-sustainable and nuisance-non sustainable and *.

So, the agency makes better than the agent in conservation perspectives when she allows to increase the marginal value of the resource. The agency makes better in the sense that she allows to decrease the marginal level of effort on the exploitation.

4.2 The market based instrument

4.2.1 Taxing the agricultural production

The price[16] of the production is an instrument of 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 were the two usual results of the static framework literature. But in this dynamic model the effect of these two policies on the control variable is not as radical because dynamic models include the willingness of the farmer to postpone his choices and the integration of a biological dynamic resource makes the economic profitability biologically dependent (a bioeconomic model).

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 discounted expected marginal value of the agricultural effort since it is a source of damage to the biological resource 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). Finally, the predominant effect is ambiguous.

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

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 table**??** 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 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 rhythm of effort is non sustainable and when the marginal unit of effort is more profitable than one more unit of resource. This could illustrate the case of a "hyper" effort-intensive farmer: even if his level of effort is not sustainable for the resource, his production technology is such that one more unit of effort is preferred to one more unit of resource (condition **) so a higher price reinforces the hyper effort-intensity of this farm and the decline of the resource. The other results are in line with Skonhoft conclusions: in the normal case, the effect of the price on the stock of the resource is ambiguous when the resource growth can sustain the level of effort or otherwise when the marginal benefit of the natural resource is larger than the marginal benefit of the effort. 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 it is only the case of the "hyper" effort-intensive farmer. The higher price for this farmer acts as a boost or as a "justification" to make make more effort and reduce the stock of natural resources. And the effect is ambiguous in the other nuisance cases.
To mitigate the differences with Skonhoft results, remember that Skonhoft (1999) model is an equilibrium model. So, he analyzes changes in the economic parameters at the steady state and then avoid sustainability considerations in his model.

The effect of the production price on land uses is once again more complex. It depends not only on the sign of the marginal value of the resource and the sustainability of the agricultural effort but also on the state of the ecosystem: exploited or overexploited. The combination of these situations will then state the sign of the discounted marginal value of the land. Table**??** illustrates the sign of this value in the different states of the agro-ecosystem.

So, two scenarios appear: either the expected discounted value of the land is positive or it is negative. When it is positive then the effect of taxing the output is unambiguous. The increase in the price of the production of land i may increase the share of land-use i because it increases the instantaneous profitability of this land-use and the farmer anticipates that the value of the land will be higher which is also a motive of land-uses expansion. Similarly, a decrease in the price may

reduce the profitability of the land-use i and then reduce the share of land-use i. This output tax also reduces the discounted marginal value of the land-use i so that the farmer anticipates this and reduces the proportion of this land-use.
But the effect of a change in the production price is ambiguous when the discounted term of the optimality condition is negative. In that case, a change in the price will affect the willingness of the farmer to postpone his land-use allocation decision: the farmer anticipates the constant change of the price.
In the case of an increase in the price when the discounted value of the land is negative, the farmer will forgo his land use i at date t because he anticipates that this increase of the price will lower the value of his land so this negative tax is a motive of disinvestment in the considered land-use. Nevertheless, this negative tax of the output raises the instantaneous profitability of this land use and thus is a motive of investment in this land-use. The effect is then ambiguous. In the case of a decrease in the price of the production, the same ambiguous effect still exists: on the one hand, it lowers the instantaneous profitability of the land but it increases the willingness not to forgo the land because a lower price of the production corresponds to a higher value of the land.

Table 8: Sign of the marginal value of the land

	Normal		**Nuisance**	
	Overexploitation	**Exploitation**	**Overexploitation**	**Exploitation**
Sustainable	-	+	+	-
Non Sustainable and $*$	+	-	-	+
Non Sustainable and $**$	-	+	+	-

$*$: $\mid \sum_{i=1}^{C_2} \Phi_{i,t+1}(P_{i,t+1}Q_{it}^E - C_{i,t+1}^E) \mid < \mid \sum_{i=1}^{C_2} P_{i,t+1}\gamma_i Q_{i,t+1}^B - \gamma_i C_{i,t+1}^B \mid$
$**$: $\mid \sum_{i=1}^{C_2} \Phi_{i,t+1}(P_{i,t+1}Q_{it}^E - C_{i,t+1}^E) \mid > \mid \sum_{i=1}^{C_2} P_{i,t+1}\gamma_i Q_{i,t+1}^B - \gamma_i C_{i,t+1}^B \mid$

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 forgo depending not only on the state of the agro-ecosystem but also on his anticipation.

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 retried from production, so that he cannot use this land neither for production. In the model, this means focusing on the optimality condition of land use determination. 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 loss, 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 rotation possibilities for the farmer. So, the total value of the natural resource is derived from the direct value of cropland 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, in the ability of the farmer to forgo his decisions but the counterpart is that it increases the level of the payments proposed to farmers to withdraw land from production.

The optimality condition for the conservation land family is then:

$$S_{it}(B_{it}) - C_i(B_{it}) = -\beta_t \left[G(B_{k,t-1}) - H(E_{k,t-1}, B_{k,t-1})\right] \left(\sum_{k=1}^{C_2} \sum_{i=1}^{C_2} \alpha_{ikt}(G_i^B - H_i^B) \right) \times$$
$$E_t \left\{ \sum_{i=1}^{\mathbf{C_1}} \alpha_{i\cdot,t+1} \left[P_{i,t+1}(\gamma_i Q_{i,t+1}^B + \Phi_{i,t+1} Q_{i,t+1}^E) - \gamma_i C_{i,t+1}^B - \Phi_{i,t+1} C_{i,t+1}^E + \sum_{i=C_1+1}^{C_2} \gamma_i (S_{i,t+1}^B - C_{i,t+1}^B) \right] \right\}$$

if $\alpha_{ikt} > 0$.
Where $\Phi_{i,t+1} = \frac{G^B_{i,t+1} - H^B_{i,t+1}}{H^E_{i,t+1}}$, with $H^E_{i,t+1} \geq 0$ and where $\alpha_{i\cdot,t+1} = \sum_{k=1}^{C_2} \alpha_{ik,t+1}$ and $S_i^B \equiv \frac{\partial S_i(B_t)}{\partial B_t}$.

This condition states that the level of the PES must equals the expected discounted marginal value of the conservation land and compensate the nuisance cost induced by the resource. But, since this marginal value of land can be negative according to the bio-economic properties of the land of the agent[17], PES hide the perverse effect of making non (positively) valued land valuable land, even if it is for conservation goals. Indeed, the PES can create perverse incentives to the farmer to damage the lands that were positively valued before the PES is contracted to become a eco-friendly farmer and receive the payments. A way to avoid such perverse contracts is to pay for the improvement of the resource and not for the resource per se: the agency could then propose payments for the improvement of environmental services (PIES) but this regards the definition of the environmental contracts.

[17]Table4 illustrates the sign of the marginal value of land uses.

Proposition 3: *Payments for Environmental Services conditioned on the level of the resource are a source of perverse incentives because of the 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 (**??**) 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:

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

Thus, for unchanged properties of the bioeconomic system, the expected discounted marginal value of the land use is larger with the PES than without conditioning the payment. Nevertheless, conditioning the payment on B may reverse the sign of the marginal value of the biological resource (i.e., the expected term in the equation): conditioning may make negatively valued land uses positively valued.[18]

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"[19], to reverse their future expectations. Thus, if the subsidy is sufficient it gives farmers the right incentive to adopt durably 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 (with positive expected marginal value of the conservation land uses), do not match the program's inclusions characteristics and will not be rewarded for adopting these conservation 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

[18] A PES cannot make positively valued land negatively valued.

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

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 4: *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 expected discounted 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[20] 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).

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

Then while 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. (see references on this result). Nevertheless, such 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, at once on conservation lands and on close crop lands. The PIES may also have some spillover effects out of the conservation lands.

Proposition 5: *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 :

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

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 (whatever 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

Beyond illustrating the farmer making decision on land uses and effort determinations, the model can be linked to the CAP reform of June 2003 aiming at instituting the uncoupling principle. To illustrate this, let's consider a static version of the model where the effort is constant and exogeneous.
The optimality condition on land is then: $P_{it}Q_{it}(B_{it}, E_{it}) + S_{it} - C_i(E_{it}) - C_i(B_{it}) = 0$.

This simple condition allows to understand the effect of subsidies coupled to production in the agricultural system.
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. 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 biological characteristics of cultivated areas make it less favorable to the resource than the protected areas. 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 biomass on these lands, by transfer from plots, and thus to increase the yields. In the next period, the farmer will get more cultivated lands but then less natural resources and so on and so forth.
One solution for the social planner is 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[21]: 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.
But, in a dynamic vision of the land-use these payments are not the only determinant in the management of the exploitation since the agent considers the bio-economic parameters of the ecosystem such as the state of the resource, the dynamic of the resource and the value of such a resource. Thus, the efficiency of conservation payments can be reduced or boosted by the property of the ecosystem. One could then imagine the establishment of a zero subsidy policy when agents manage their farm with a dynamic perspective. The integration of the value of the resource could replace institutional payments costly for the social planner: the intertemporal valuation of the resource in the farming activities in the bioeconomic model makes the farming decision making in line with the state of the farm's environment whereas subsidies move these decisions away of the ecosystem characteristics: subsidies maintain artificially the agricultural effort of agents that value positively the resource whereas the optimality conditions state for a lower agricultural effort of these agents. Nevertheless looking at the optimality condition of land-uses, when the focus is on the protected areas policies that forbid agricultural productions, the compensation payments (as agri-environmental measures) are necessary to make these land-uses profitable. Moreover, it has been shown that the protected areas approach could reduce the marginal valuation of the resource in some specific bioeconomic cases so that the farmer will make more effort out of the reserve. In these cases where the marginal value of the resource is smaller under the protected area project than under the liberal project, biologically conditional payments will allow to increase the value of the resource since the farmer receives a payment dependent on the biological resource. Explicitly, instead of having simply a payment S_i in the profit function, the farmer will receive a payment $S_i(B)$, conditional to the resource, so that the compensation payment enters in the marginal value of the resource and can compensate or exceed the loss of valuation under the protected area project. Finally, the farmer will always make less effort out of the reserve when the conservation project is adopted because the conditional payments always increases the marginal value of the natural

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

resource.

So, a first point is that when agents integrate the intertemporal valuation of the resource in their decision making, a zero subsidy policy will not maintain artificially the agricultural effort. Coupled subsidies are then not environmentally friendly and thus the CAP 2003 reform acts in the sense of zero coupled subsidies but a right to payment is offered to farmers on the basis of the land-use history of his exploitation ("the individual historical reference"), a non-resource conditional payment. A possible criticism of the developed model is the dynamic oriented management of the farm. Some can doubt that farmers "care" for their biological resource. Then, conditioning the "right to payment" to the environmental taking into account in the management will certainly be a better allocation of these financial resources than the non conditional right to payment. The counterpart of the right to payment could be for example the education of the farmer to such a management. A second point is that payments for environmental services or compensation payments should be conditional to the resource to improve the value of the resource and thus improve the quality of the environment.

If Swanson has identified three driving forces of biodiversity losses: a low investment in the resource, a low investment in the habitat feeding the resource, a low investment in resource managements institutions, Skonhoft enlarges the analysis by adding a nuisance cost of the resource and shows that resource extinction depends upon the value of this cost. Reusing the existence of this cost for a non market valued resource, I've applied it to the private resource and effort management decision making. The decline of the resource may result from intensive or extensive agriculture, the two decision variable of the model. The singularity of this dynamic decision model allows to enlarge the study of resource decline on private lands. The "ecological" state of the resource is a reason that participates in the resource extinction. Indeed, two states of the ecosystem have been stated: the "Sustainable" state and the "Non sustainable" state, which combined with Skonhoft cases make appear more or less favorable conditions for the conservation of the resource.
About investment in the habitat of the resource, the combination of situations described above remains and a third case appears: the state of the resource per se, overexploited or exploited in the space. For a private agent, overexploitation can justify the expansion of his crop land: overexploitation of the resource then becomes a motive of more overexploitation of the environment. Considering a dynamic vision allows to have more information on resource-investment decisions, through the quality of the ecosystem via the intensity of the agricultural effort and/or the space allocated to the resource preservation.

Integrating a renewable biological resource in the agent decision making problem of allocating optimally land-uses and the agricultural effort then mitigates the usual results of conservation policies of the "dichotomic" models of agriculture and the environment. It is then no more always true that the agent's response to a positive production tax is the reduction of his effort or the reduction of the land allocation of this taxed crop. The farmer's response depends on the bioeconomic state of his ecosystem. Moreover, it is no more always true that the farmer's response to protected areas policies is to intensify his agricultural effort on the remaining crop lands. Once again, this will depend on the bioeconomic state of his ecosystem. The success of environmental policies is then strongly conditional to the characteristics of the ecosystem.

The dynamic decision making allows considering more information on the land uses and agricultural effort decisions, more precisely it takes into account the capacity of the farmer to forgo his decisions which leads to consider the issues of sustainable development of human activities.

References

"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.

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

Bulte E.H., 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.

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.

Greiner R., Herr A. and Stoeckl N., (2003), "Policies aimes 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.

Kinyua P.I.D., van Kooten G.C. and Bulte E.H., (2000), "African Wildlife Policy: Protceting 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".

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, (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.

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.

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.