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Irreversibility and Uncertainty in Multifunctional Forest Management Allocation

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1. Introduction

Forest multifunctionality refers to the valuation of both wood and non-wood forest services. Non-wood forest services are essentially environmental services such as bio-diversity, watershed protection, landscapes, carbon sequestration, or social services such as recreation. Strongly determined by natural forest attributes, forest multifunctionality is increasingly valued in consumers' preferences (Mill et al., 2007). However, most of the non-wood services are not valued in the market, although they could contribute to forest owners' benefits (Katila & Puustjarvi, 2004). Besides the private forest owner's capacity to respond to the increasing demand for non-wood services, the difficulty in quantifying the benefits coming from a multifunctional management puts in question the effective payments determining their participation (Engel et al., 2008).

In the literature, forest multifunctionality is generally modeled as a joint production process (Bowes & Krutilla, 1989; Gregory, 1955; OECD, 2001). Multifunctionality also raises the question of optimal timber rotation when considering non-wood services (Hartman, 1976). When adding a spatial dimension, forest multifunctionality may be analyzed at the larger scale of a forested landscape including more than one forest area. The question of spatial allocation of multifunctionality is crucial in the literature and at a political level (Andersson et al., 2005; Boscolo & Vincent, 2003). For instance, in a *New forestry* approach, Franklin (1989) suggests implementing multifunctionality in each forest area, as it is already experimented in tropical forest management. This conclusion turned out to be the core issue in the debate between *Old Forestry* and *New Forestry* in the United States, inducing theoretical developments on land use through multifunctionality in every forest area *versus* specialization (Helfand & Whitney, 1994; Vincent & Binkley, 1993; 1994). Empirical analyses of forest management have confirmed that there are situations where specialization may be the optimal management regime (Andersson et al., 2005; Boscolo & Vincent, 2003). Swallow et al. (1997) shows that accounting for spatial interaction due to ecological interactions also may prescribe a management which recommends specialization over space.

Added to spatial considerations, time also has an impact on forestry decisions. In particular, the irreversibility of forest management schemes condition the available strategies and future benefits. Natural resources management in a dynamic context can be analyzed by the quasi-option value approach (Arrow & Fischer, 1974; Henry, 1974). This approach takes into account the characteristics of irreversibility and uncertainty of the sequential decision

process. Quasi-option value is the value of information conditional on remaining flexible enough to use this information. Indeed, it represents the difference between the value of an option when considering that information is forthcoming (*closed-loop* rationality) and the value of this option without considering that information is forthcoming (*open-loop* rationality). Quasi-option value has been used in a forestry context to choose between strategies of preservation and development (Albers et al., 1996 a; Albers, 1996 b; Bosetti et al., 2004), to derive optimal harvest strategies (Jacobsen & Thorsen, 2003; Malchow-Møller et al., 2004) and forest stand regeneration policies (Jacobsen, 2007). Albers (1996 b) considers a multi-plot setting, focusing on the spatial interdependence and adjacency among forest plots. Our model relates to this literature in the measure that our framework uses irreversibility, uncertainty, and closed-loop rationality in a dynamic decision process. We also consider multiple forest areas setting, but these areas can be non-adjacent, which allows us to assume they can be subject to different environmental policies. Furthermore, our approach is characterized by the choice between two alternatives which represent two exclusive real options (Abildtrup & Strange, 1999; Geltner et al., 1996; Malchow-Møller & Thorsen, 2003). That is, both alternatives are associated with uncertain future pay-offs and the possibility to adapt future management according to forthcoming information. However, we are not estimating the optimal stopping rule, as in the above mentioned studies, but define the optimal strategy at a given decision point accounting for future information and the possibility to adapt management according to this information. The aim of our paper is to shed light on the reflections about the arbitrage between different strategies in the multifunctional forest management of multiple forest areas. By multifunctional, we mean a management ensuring both economic function (timber commercialization) and ecological function (biodiversity, water quality or other amenities) of the forest. Basically, we consider the two strategies, also analyzed by Vincent & Binkley (1994) : 1) multifunctionality in every forest area and 2) specialization of forest areas such that the forest area as a whole is multifunctional. However, we focus on identifying the optimal management strategy in a dynamic setting with uncertainty about future demand for forest services and where the different management strategies may have different degrees of irreversibility. We formulate a simple model which is used to derive general decision rules which can be applied in a given situation defined by the production function and uncertainty about future changes in policy. Such changes could be explained by new biological information or changes in the climate or in the preferences for different uses of the forest.

The starting point is the following : we consider a forest owner/manager of two forest areas. We suppose that this manager is constrained by society to implement a multifunctional management of their total forest area. An immediate problem arises about the best option for the manager in order to maintain multifunctionality for their total forest area. Indeed, a first option consists of specializing one forest area through a *Clear-cutting* management while the other forest area is specialized for full *Preservation* of the ecological function, without any timber harvesting. The other option is to implement a mix of the previous strategies in each forest areas (*Mixed regime* in all the forest areas) where timber is harvested but part of the ecological value is preserved. This two forest areas framework is the simplest one to embed the problem of the arbitrage between the two alternatives for multifucntional forest management (mixed or specialized). For the general and more realistic multiple forest areas case, one can think of our two alternatives as : 1) all forest areas managed under mixed regime *versus* 2) a proportion close to 50% of clear-cut areas while the rest is preserved (for the specialization option).

The choice between a mixed regime and specialization is a fundamental decision problem for many forest managers. For example, in France the government encourages forest owners to increase their harvest of timber because it is considered that forests are exploited less than socially optimal[1]. This concerns, among others, forests in mountain regions. If timber should be harvested in hitherto unexploited mountain forests the manager will have to choose an exploitation strategy subject to the imperative protection functions of mountain forests. The relevant alternatives may include : 1) selective harvesting in all forests (mixed regime in all forests) and 2) clear cutting of some forests and letting other forest areas under protection (specialization). However, the forest manager will also have to account for future changes in the demand for the different uses of the forests. The demand may change due to changes in preferences of the population or climate change may imply that the relative value of different functions changes, and these changes in demand may be site specific. Our model considers how uncertainty and irreversibility influence this decision problem.

A first key issue that conditions the choice of forest management in each forest area is the relationships of irreversibility among management regimes. *Clear-cutting* a forest area is more irreversible than implementing *Mixed regime*, which is more irreversible than full *Preservation*. A second key issue is the uncertainty about the future environmental policy, coming from society and defined for each forest area, when the initial forest management decisions for each forest area take place.

In order to examine the implications of irreversibility and uncertainty in managing multifunctionality, we propose a simple framework where there are only two forest areas in a two-period decision process with two initial choices for multifunctionality (specialization and mixed regime in both forest areas). In the first period the manager makes management choices for each forest area, taking into account the economic and ecological values of the management regimes, the irreversibility relationships among regimes and the priors on the information to come from society about the environmental policies affecting each forest area. In the second period, the information is revealed and the manager chooses again a management regime for each forest area, being constrained by the choices made in the first period. The time elapse between the two periods is supposed to be long enough to have an uncertainty about the forthcoming environmental policy but short enough for the irreversibility relationships to be relevant (no regeneration of the forest).

Our objective is to compare these two management options and determine the conditions for choosing one or the other. Due to the difficulty of applying a standardized valuation method for multifunctional management, our method consists of building a model around assumptions describing the "worst" (reasonable) case for the option of mixed regime in all forest areas. In this way we obtain a benchmark scenario where this option is favored as little as possible, in order to determine the conditions for choosing it, within the corresponding set of restrictive assumptions. The idea is that if the mixed regime option is optimal within conditions in the worst case scenario, then, in reality, this option must be even more suitable. In order to do so, we intentionally make the following assumptions :

(i) Although society is supposed to target multifunctionality, we assume that once the information on the environmental policy is revealed, it can only be a *Preservation* or a *Clear-cutting* policy. In this case, multifunctionality is achieved by society thanks to a mix of specialization incentives.

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[1] See the Grenelle Environment Round Table, www.legrenelle-environnement.fr

(ii) The mixed regime is modeled as an intermediate management regime, whose value is always inferior to the management that perfectly matches the environmental policy. More precisely, from an economic point of view, the mixed regime is supposed to have less value than the clear-cutting regime but more value than the preservation regime. In a similar way, from an ecological point of view, the mixed regime is supposed to have more value than the clear-cutting regime and less value than the preservation regime.

(iii) Finally, we work in a risk neutral environment. In this case, there is no difference in terms of expected value between betting on a perfect match with the environmental policy through specialization (thus taking the risk of mismatch), and ensuring an intermediate benefit in any case *via* a mixed regime in all forest areas.

Relaxing any of the restrictive assumptions above would favor the initial choice of mixed regime in all forest areas since the corresponding conditions for choosing this initial option would be less restrictive. Indeed, if we relax assumptions we see that :

(i') Considering that society could call for a mixed regime in a particular area would be anticipated by the manager and favor the initial choice of mixed regime in all forest areas. There are cases where society may call for a mixed regime (van Rensburg et al., 2002).

(ii') Considering that the mixed regime has a greater value than the specialization regimes would trivially make the choice of mixed regime optimal in every management period. In real life, in some particular cases, the mixed regime may have a greater economic or ecological value than the extreme management regimes. Biodiversity can be greater when encouraged by an appropriated mixed management than in total preservation. For instance, some bird species such as the red-cockaded woodpecker requires low density older trees that are maintained today with active forest management. In a region where such bird species would be in danger of extinction, this would add ecological value to the mixed regime compared to a full preservation. Another example is that recreation might have more value in a forest that is managed in a sustainable way than in a preserved one that could be more difficult to visit.

(iii') The interest of choosing mixed regime in all forest areas would be greater in a risk aversion framework, since this option ensures the best adaptability to the forthcoming environmental policy. Let us consider, as it can be the case in reality, that the forest owner is risk averse. We have modeled the mixed regime so that it has the same expected value than betting on one the two extreme values of preservation and clear-cutting (see *(ii)*), but mixed regime still represents a less risky initial choice. For instance if a specialization choice in period 1 for the two forest areas happened to be opposite to what society calls for at period 2 (complete mismatch of initial choice and society's preferences), then the forest owner would get the worst possible payoff. This worst payoff would never be obtained when choosing a mixed regime in period 1 (although the best possible payoff would not be reachable either, since the only way to obtain it is to bet on a specialization strategy in period 1 that result in a perfect match in period 2 with society's preferences). A risk averse forest owner would take this into account and choose the less risky initial option of mixed strategy, sacrificing the perfect match payoff, but avoiding the mismatch payoff.

In the benchmark scenario resulting from *(i)*, *(ii)* and *(iii)*, we thus eliminate from the mixed regime all the advantages that are not directly related to the irreversibility among regimes and the adaptability to the second period information about the adopted environmental policy.

2. The model

We consider two forest areas (area 1 and area 2) that are identical *ex-ante*. As we will see they may differ *ex-post* in terms of environmental policies. For each forest area, there exist three management regimes P, M and C. Regime P (*Preservation*) is assumed to guarantee a greater ecological value of the forest (greater biodiversity, for instance). To simplify, we assume that in this regime the forest remains un-cut. Regime C (*Clear-cutting*) leads to greater monetary incomes through intensive timber commercialization. We assume clear-cutting management. We choose extreme scenarios for the management regimes P and C as this is sufficient to generate the stylized facts we wish to bring to the fore. Between these two extreme regimes, M corresponds to an intermediate management regime to which we will refer to as *Mixed regime*. Regime M ensures both ecological and economic functions of the forest. It is assumed to be ecologically less good than P and economically less good than C, but it is ecologically better than C and economically better than P, since only part of the timber is harvested.

Irreversibility. Because trees have a long production period, there exists a natural relationship of irreversibility among the management regimes. This irreversibility is described in Assumption A1: $P \rightarrow M \rightarrow C$, which means that P can lead to any of the three regimes and M can only lead to M or C, while C is a dead-end.

In other words, clear-cutting is the completely irreversible option, while preservation is the more flexible one. M is modeled as an intermediate regime that has an intermediate flexibility. These irreversibility relationships are linked to an underlying assumption about the considered time frame. For given forest manager's time horizon and forest regeneration cycle there exists always a time frame in which these relationships apply. We restrict our analysis to this time frame because our model focuses on irreversibility issues. It is evident that over this time frame our irreversibility relationships may no longer be valid since, for instance, a clear-cut forest area can grow and even become a preserved forest area. In short, the time frame between periods 1 and 2 is long enough for the information revealed at period 2 to be uncertain at period 1, but too short for the forest to have time to regenerate (irreversibility among regimes play a role).

Options for multifunctionality. We assume that the manager targets a multifunctional management of the forest as a whole (area 1 plus area 2) and that the questions of the forest owner's incentives to participate in a multifunctional management are solved. Such multifunctionality can only be implemented in two ways. First, the manager can adopt a specialization strategy in which one area is preserved and the other is clear-cut. Without loss of generality, we can assume in this case that area 1 is preserved, so that this option is denoted PC. Second, the manager can choose a mixed regime in both forest areas (denoted MM). In short, only options PC and MM are considered. Both regimes are multifunctional as they maintain both ecological and economic characteristics of the forest as a whole. Our goal is to compare these two management options and to determine the conditions for choosing one or the other. To solve this arbitrage, it is necessary to observe the consequence of the irreversibility relationships (Assumption A1) on the 2 forest areas. More precisely, option PC at $t = 0$ can lead to 3 regimes at $t = 1 : PC, MC, CC$. Option MM can lead to 4 regimes at $t = 1 : MM, MC, CM, CC$.

Information about environmental policy. We consider a two-period management framework. As mentioned before, at $t = 0$ the manager chooses a strategy in $\{PC, MM\}$. We assume that at $t = 0$ there is no information on whether it is beneficial to preserve the forest areas or if they have no great ecological value and it is better to clear-cut. We assume that at $t = 1$

society reveals information $I \in \{P,C\} \times \{P,C\}$ concerning the environmental policy (P or C) that is suitable for each forest area. More precisely, the information that is revealed at $t = 1$ can be written $I = (i_1, i_2)$ with i_1 and i_2 in $\{P,C\}$. At society's level, we assume that a multifunctional management of the forest is targeted. Indeed, nowadays most forest countries have taken consciousness that it is not suitable to only consider forests as a source of timber, nor to renounce on timber commercialization by integrally preserving the whole forest area. Because there are many forest areas, multifunctionality can be achieved at a country level with some forest areas being preserved for their ecological value and others being used for timber harvesting, depending on the knowledge about the presence or absence of ecological interest of each particular forest region. We suppose that when having enough information on the ecological value of a particular forest region, society gives a signal to the corresponding private forest managers by revealing which management is suitable in this region. This results in a combination of environmental policies (information $I = P$ or $I = C$). If, for instance, preservation is targeted, society may set taxes for the clear-cut forests areas and subsidies for the protected forests areas inside the region. This environmental policy would change the economic values of the management options in managers' eyes. Forest managers have to choose their individual strategies in the forest areas they manage, depending on their priors about these environmental policies (forthcoming information).

The assumption according to which information I belongs to $\{P,C\} \times \{P,C\}$ means that we assume that society, even though targeting multifunctionality at an aggregated level, never calls for M as a suitable management in a given forest area. As a result, M is modeled as an intermediate regime between P and C, and not as an optimal regime (see Assumption A2). Allowing the environmental policy to be M would favor the initial choice MM. Given the information at $t = 1$, the manager chooses a new management strategy under constraints of irreversibility. Interestingly, the two-areas framework embeds two different kinds of flexibility. One is linked to the irreversibility relationships among regimes : C is more irreversible than M which is more irreversible than P. The other corresponds to an adaptability to the environmental policies revealed at $t = 1$. This adaptability comes from the fact that when starting from option MM the manager can choose the more profitable regime between MC or CM, given the revealed information. There is no such adaptability if PC is chosen at $t = 0$, because the clear-cutting implemented in area 2 is irreversible. The interest of considering a two-areas framework resides in the arbitrage between these two kinds of flexibility.

Manager's priors. We assume that the manager is risk neutral. Let $v_t(X)$ be the payment corresponding to regime $X \in \{P,M,C\} \times \{P,M,C\}$ at time $t \in \{0,1\}$. At time $t = 0$, $v_0(X)$ is deterministic and known by the manager whereas $v_1(X)$ is a random variable, which distribution is assumed to be known and corresponding to the manager's priors on the forthcoming information on the environmental policy. The priors at $t = 0$ on this information $I \in \{P,C\} \times \{P,C\}$ are described by the probabilities μ_I, verifying $\mu_{PP} + \mu_{PC} + \mu_{CP} + \mu_{CC} = 1$. At time $t = 1$, the value $v_1(X)$ is revealed to the manager since the environmental policy is then known for each forest area. To put aside the impact of the payments of the first period, we assume $v_0(PC) = v_0(MM)$. Therefore we can normalize these initial values to zero and simplify the notation at $t = 1$, $v_1(X) = v(X)$. This assumption is consistent with the fact that the manager wonders about the best alternative between PC and MM, because giving them different initial values would favor one or the other of these alternatives. In this way we only focus on the flexibility of the options and the value of the information revealed at $t = 1$.

By only considering the available options at $t = 1$ (given the irreversibility relationships), we can denote by $v^I(X)$ the benefit from implementing a management $X \in \{PC, MM, MC, CM, CC\}$ on the forest areas under information $I \in \{P, C\} \times \{P, C\}$. This 2-areas benefit is simply defined as the sum of the benefits of the two forest areas. More precisely, for forest area k (with $k \in \{1, 2\}$) we denote by $v^{i_k}(x_k)$ the value associated with implementing a management $x_k \in \{P, M, C\}$ under information $i_k \in \{P, C\}$, then for $X = (x_1, x_2)$ and $I = (i_1, i_2)$, we have $v^I(X) = v^{i_1}(x_1) + v^{i_2}(x_2)$.

Hierarchy among regimes. The values of the 2-areas management regimes in each information configuration are assumed to be known, and all the uncertainty is concentrated on the fact that the manager does not know at $t = 0$ the information configuration at $t = 1$. We assume there is a hierarchy among the management regimes under the information i, in terms of value : Assumption A2 : If the manager is informed about a preservation environmental policy ($i = P$) for a particular forest area, then, whatever the management of the other area is, $v^P(P) > v^P(M) > v^P(C)$. On the contrary, if ($i = C$), then $v^C(C) > v^C(M) > v^C(P)$.

This very intuitive assumption just means that it is suitable to choose the management regime that matches the revealed information about the environmental policy. This hierarchy is justified economically by the fact that an *ex-post* perfect match to the environmental policy can lead to subsidies and a mismatch to environmental taxes. Of course, the irreversibility constraints might not always allow a perfect adaptation of the regime to the policy. Also note that mixed regime M never gives the best value, whatever the information is.

Assumption A2 has an immediate consequence on the 2-areas regime valuation given information $I \in \{P, C\} \times \{P, C\}$. Given the first period decisions (PC or MM) and the irreversibility relationships determining the available regimes at $t = 1$, the optimal 2-areas regime choices are obtained thanks to :

$$\max_X [v^I(X)] = \max_{x_1} [v^{i_1}(x_1)] + \max_{x_2} [v^{i_2}(x_2)]$$

As a result, if regime PC is chosen at $t = 0$, the optimal regime at $t = 1$ depending on the revealed information I is :

$$PC \text{ if } I = PP$$
$$PC \text{ if } I = PC$$
$$CC \text{ if } I = CP$$
$$CC \text{ if } I = CC$$

If regime MM is chosen at $t = 0$, the optimal regime at $t = 1$ is :

$$MM \text{ if } I = PP$$
$$MC \text{ if } I = PC$$
$$CM \text{ if } I = CP$$
$$CC \text{ if } I = CC$$

The optimal decision exists and is unique for both alternatives PC or MM. Note that regime MC which is available starting from PC is never chosen at $t = 1$. The decision tree depicted in figure 1 takes into account the irreversibility relationships and summarizes the optimal regime choices depending on the information revealed.
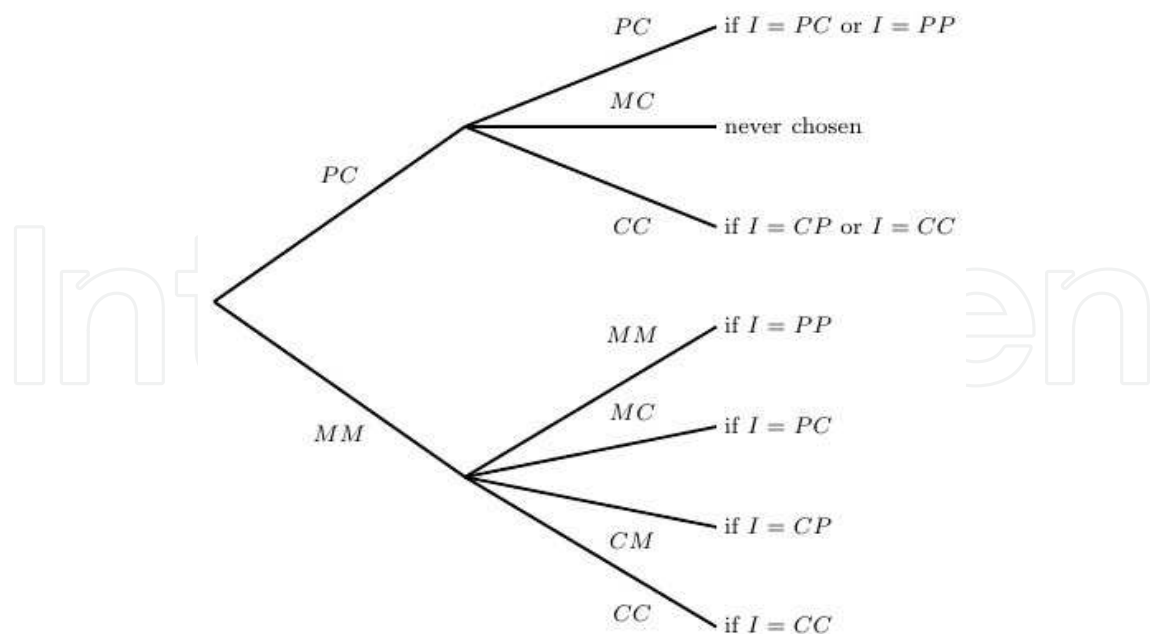
Fig. 1. Regime decisions depending on environmental policies

3. Result

We have seen that if the information is known, the manager can choose the best option at $t = 1$. However, when the initial decision takes place at $t = 0$, information I is not available. We must compare options PC and MM at $t = 0$ in terms of expected value. We assume that the manager uses the following rationality :

$$\hat{V}(PC) = E[\max\{v(PC), v(MC), v(CC)\}]$$

and

$$\hat{V}(MM) = E[\max\{v(MM), v(MC), v(CM), v(CC)\}]$$

where $\hat{V}$ gives the expected value at $t = 0$ of the initial decision in a *closed-loop* information structure[2], *i.e.* by taking into account that information is forthcoming at $t = 1$. Given the optimal strategies at $t = 1$ we can write the expressions of the expected values at $t = 0$ for each option :

$$\hat{V}(PC) = \mu_{PP} v^{PP}(PC) + \mu_{PC} v^{PC}(PC) + \mu_{CP} v^{CP}(CC) + \mu_{CC} v^{CC}(CC)$$

and

$$\hat{V}(MM) = \mu_{PP} v^{PP}(MM) + \mu_{PC} v^{PC}(MC) + \mu_{CP} v^{CP}(CM) + \mu_{CC} v^{CC}(CC)$$

By using $v^I(X) = v^{i_1}(x_1) + v^{i_2}(x_2)$, we finally obtain condition C :

$$\hat{V}(PC) \geqslant \hat{V}(MM)$$

$$\Leftrightarrow$$

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[2] The closed-loop information structure differs from the open-loop one, in which the agent does not consider that the information is forthcoming. In an open-loop information structure, we would have for the option PC that $V^*(PC) = \max\{E[v(PC)], E[v(MC)], E[v(CC)]\}$. The *quasi-option value* corresponds to the difference $\hat{V} - V^*$, see Arrow & Fischer (1974); Henry (1974).

$$(\mu_{PP} + \mu_{PC})[v^P(P) - v^P(M)] \geqslant (\mu_{PP} + \mu_{CP})[v^P(M) - v^P(C)]$$

3.1 Analysis of the results

Let us analyze the choice condition of the previous section. Condition C determining the initial choice of PC or MM depends on the relative value of regime M under $I = P$, and on the priors of the manager on the information to come.

Concerning the relative value of M, we know (Assumption A2) that under information $I = P$, $v^P(P) > v^P(M) > v^P(C)$. Condition C shows that a value of M close to the value of C (respectively P) weights in favor of choosing PC (respectively MM) at $t = 0$, but that this is not sufficient to determine this choice because of the impact of the probabilities of occurrence of the environmental policies. The impact of the relative value of M is only avoided for $v^P(M) = (v^P(P) + v^P(C))/2 = \tilde{v}_M$. In this case, $[v^P(P) - v^P(M)] = [v^P(M) - v^P(C)]$ and condition C becomes :

$$\hat{V}(PC) \geqslant \hat{V}(MM) \Leftrightarrow \mu_{PC} \geqslant \mu_{CP}$$

Concerning the impact of the priors, let us first deal with some extreme cases. If $\mu_{CC} = 1$, then $\mu_{PP} = \mu_{PC} = \mu_{CP} = 0$, and condition C shows that the manager is indifferent between MM and PC. Indeed, if information CC is certain, management CC is always possible at $t = 1$, no matter what the initial choice is. Interesting cases are those for which $\mu_{CC} < 1$.

If we now consider that the manager has no idea of the forest area that is more likely to be subject to one or the other environmental policy at $t = 1$, that is to say if $\mu_{PC} = \mu_{CP}$, we then remark that the probabilities do not play anymore in the arbitrage, but only the relative value of M does, since condition C becomes :

$$\hat{V}(PC) \geqslant \hat{V}(MM) \Leftrightarrow v^P(M) \leqslant \tilde{v}_M$$

This is in particular the case when the forest areas are adjacent in terms of location. It is rational to think that such forest areas will be subject to the same environmental policy, so that $\mu_{PC} = \mu_{CP} = 0$.

In the light of these extreme cases, we can rewrite condition C by introducing the center of the interval of possible values of $v^P(M)$:

$$\tilde{v}_M = \frac{v^P(P) + v^P(C)}{2}$$

and the ratio γ of probabilities characterizing the asymmetry between priors :

$$\gamma = \frac{\mu_{PP} + \mu_{PC}}{\mu_{PP} + \mu_{CP}}$$

We have that :

$$\hat{V}(PC) \geqslant \hat{V}(MM)$$
$$\Leftrightarrow$$
$$\gamma[v^P(P) - v^P(M)] \geqslant [v^P(M) - v^P(C)]$$
$$\Leftrightarrow$$
$$(\gamma + 1)v^P(M) \leqslant \gamma v^P(P) + v^P(C)$$
$$\Leftrightarrow$$

$$v^P(M) \leqslant \tilde{v}_M - \frac{v^P(P) + v^P(C)}{2} + \frac{\gamma v^P(P) + v^P(C)}{\gamma + 1}$$

And we finally obtain a new expression for condition C :

$$\hat{V}(PC) \geqslant \hat{V}(MM)$$

$$\Leftrightarrow$$

$$v^P(M) \leqslant v_M^* = \tilde{v}_M + \frac{\gamma - 1}{2(\gamma + 1)} [v^P(P) - v^P(C)]$$

If $\mu_{PC} = \mu_{CP}$, then $\gamma = 1$ and the threshold over which mixed regime in both forest areas is preferred over specialization is $\tilde{v}_M$. This means that half of the range of values (from the lowest $v^P(C)$ to the highest $v^P(P)$) leads to the choice of the mixed regime in both forest areas. Over the threshold the expected value of regime M (coming from timber harvesting and the subvention rewarding the environmental quality of this regime) is big enough to make it attractive to choose this regime for both forest areas at $t = 0$. Under the threshold, it is specialization the is optimal at $t = 0$.

However if the priors are not symmetric anymore, say if $\mu_{PC} > \mu_{CP}$, then $\gamma > 1$ and the threshold v_M^* is greater than $\tilde{v}_M$. The interval of values of M that is favorable to specialization is increased in a proportion $(\gamma - 1)/2(\gamma + 1)$ of the length of the interval of the possible values of M under information P, i.e. $[v^P(P) - v^P(C)]$. This can be interpreted as the added value of the information about which area is more likely to be subject to one or the other environmental policy. For example for a system of priors such that $\mu_{PP} = \mu_{CC} = 0$ and $\mu_{PC} = 2\mu_{CP} = 2/3$, then $\gamma = 2$ and $(\gamma - 1)/2(\gamma + 1) = 1/6$. In this case $1/2 + 1/6 = 2/3$ of the interval of possible values of M lead to choosing specialization at $t = 0$.

Conversely, if $\mu_{PC} < \mu_{CP}$ then $\gamma < 1$ and $(\gamma - 1)/2(\gamma + 1) < 0$. This time the range of values of M that is favorable to specialization decreases $(v_M^* < \tilde{v}_M)$. However, this situation can only occur in a situation in which the manager has asymmetric priors but cannot adapt, because of technical constraints, the first period specialization strategy in order to match these priors. In this case, although information $I = CP$ is more probable than $I = PC$, the available strategies at $t = 0$ are only PC and MM. This of course favors option MM since choosing PC could lead to a mismatch with the environmental policies at $t = 1$. If there is no such technical constraints, having priors such that $\mu_{PC} < \mu_{CP}$ should rather lead to compare CP and MM at $t = 0$. The arbitrage is then solved like in the case where PC and MM are compared by renaming forest area 1 into forest area 2 and *vice versa*, and we find again that $v_M^* > \tilde{v}_M$, that is to say a situation that is more favorable to specialization than the symmetric case $\mu_{PC} = \mu_{CP}$.

4. Concluding remarks

We have considered that when a manager of two forest areas targets a multifunctional use of the forest in the context of irreversibility among regimes and uncertainty about the forthcoming information on environmental policy affecting the forest areas, two alternatives must be compared : *Specialization* of the areas and implementation of *Mixed regime* in both forest areas. Added to the flexibility of management regimes, considering 2 areas gives rise to another kind of flexibility : the better adaptability to forthcoming information.

Our model shows that the choice of mixed regime in both forest areas depends upon the relative expected value of a forest area in a mixed regime compared to a preserved one : mixed regime should not adversely affect the ecological value of the forest too much. More precisely,

the value of a mixed regime should be at least greater than the average value of preservation and clear-cutting regimes for a forest area that is subject to a preservation environmental policy. In the case where the manager has priors on which forest area is more likely to be subject to one or the other environmental policy, this favors the choice of specialization if we consider that the manager can choose the management matching these priors. The interval of expected values of the mixed regime that ensures the choice of mixed regime in both forest areas in the first period is therefore reduced. We give an expression of the resulting variation of the threshold in function of the priors of the manager. This variation can be interpreted as the added value of the information about the asymmetry in the probabilities of occurrence of the environmental policies for each forest area.

Let us underline that the range of expected values of the mixed regime that is favorable to implementing mixed regime in all forest areas has been obtained within a framework designed in order to not favor the mixed regime (worst case framework). This was aimed at finding the minimal conditions of emergence of such forest management (see assumptions i, ii, and iii in the introduction). Relaxing any of these assumptions in our framework would favor the choice of mixed regime in both forest areas over specialization. Our model, thus, provides minimal requirements for the mixed regime to be an attractive solution for owners/managers, which could be helpful to have in mind when setting minimal subventions levels.

Even though the model is theoretical it provides relatively simple decision rules which applies to a range of empirical problems. The choice between clear cutting and selective harvest strategies in hitherto un-managed forest areas is one example of a decision where the presented framework applies. However, it applies more generally to choice situations where increased intensity of land use may have an irreversible impact on the supply of ecological services and where there is uncertainty about the future location-specific demand for these services. Determining whether *Specialization* or *Mixed regime* will be the optimal strategy will, of course, depend on an assessment of the joint production function of the different ecosystem services, i.e. assessing to which degree there are synergies or conflicts in joint production of the considered services or goods.

In the present paper we considered the choice of a private forest owner facing uncertainty about future forest policy (e.g. payments for ecological services). The model applies also to situations with state forests where the forest managers are constrained by the population's current demand for ecosystem services but also consider the uncertainty about the future demand for ecosystem services.

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Global Perspectives on Sustainable Forest Management
Edited by Dr. Dr. Clement A. Okia

This book is dedicated to global perspectives on sustainable forest management. It focuses on a need to move away from purely protective management of forests to innovative approaches for multiple use and management of forest resources. The book is divided into two sections; the first section, with thirteen chapters deals with the forest management aspects while the second section, with five chapters is dedicated to forest utilization. This book will fill the existing gaps in the knowledge about emerging perspectives on sustainable forest management. It will be an interesting and helpful resource to managers, specialists and students in the field of forestry and natural resources management.

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