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Effects of Public Compensation for Disaster Damages on Private Insurance and Forest Management Decisions *

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Résumé

Cet article part de l'observation selon laquelle les pouvoirs publics ont tendance à compenser financièrement les victimes de catastrophes naturelles. Ainsi, l'objectif de ce papier est d'analyser l'impact de tels programmes publics sur les dépenses d'assurance et les activités de gestion forestière des propriétaires forestiers privés non-industriels. Les auteurs développent un modèle théorique de demande d'assurance et d'activités de gestion forestière dans un contexte risqué comprenant un nombre fini d'états de la nature et une perte proportionnelle à la valeur du peuplement forestier. Le modèle prévoit les dépenses privées optimales pour l'assurance et les pratiques de gestion forestière. Les effets de statique comparative des variations du prix de l'assurance, de l'attitude envers le risque, de la valeur du peuplement forestier ainsi que de l'ampleur et de la fréquence des compensations publiques sur les dépenses d'assurance et les activités de gestion forestière sont fournis. Leurs implications en termes de politiques publiques sont également examinées. Cette analyse montre que délivrer une aide financière publique après une catastrophe peut réduire les incitations des propriétaires forestiers privés non-industriels à investir dans l'assurance et dans les mesures de prévention avant une catastrophe.

Mots clés : gestion forestière, risque, assurance, compensation publique, statique comparative.

Abstract

Politicians have a tendency to compensate victims of natural disasters. This article explores the impact of such public relief programmes on a non-industrial private forest owner's insurance expenditures or on forest management activities. We develop a theoretical model of insurance demand or forest management activities in a risky context with a finite number of states of nature and a loss proportional to the forest value. The model predicts the optimal private expenditures of insurance and forest management activities. The comparative static effects of variations in the level of insurance price, attitudes toward risk, stand value, and the magnitude and frequency of the public compensation on insurance expenditures and on forest management activities are also characterised, and their implications for government policies are examined. Providing public financial assistance after a natural catastrophe may reduce the incentives of nonindustrial private forest owners to invest in insurance and protective measures prior to a disaster.

Key words : Forest management, risk, insurance, public compensation, comparative statics.
Classification JEL : D81, Q23, Q54, Q58

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1 Introduction

In Europe, several public programmes (Bianco, 1998; CEC, 2006; FAO 2007) encourage non-industrial private forest owners[1] to reduce the risk of property damage from natural disasters. These programmes recommend risk management activities that are likely to reduce the potential financial losses due to natural disasters. Principally, such activities are private insurance or stand management practices such as the installation of artificial firebreaks or other measures that facilitate access to the stand. However, it has been observed in Europe that insurance may be an unusual practice (for example, in Germany and in France, only 2% and 5% of the private forest owners, respectively, are insured against windstorms, whereas roughly 68% of non-industrial private forest owners in Denmark and more than 90% in Sweden are covered against these risks), and risk stand management activities are not generally used (Holecy and Hanewinkel, 2006). Moreover, over the last decades, in many European countries affected by severe storms, social and political considerations have forced public authorities to grant financial help to victims of windstorm disasters through compensation programmes, grants or low-interest loans, in spite of the existence of private insurance, principally in countries where few non-industrial private owners are insured. For example, after the natural catastrophes of 1999, the German government set up a programme of public financial assistance of 15.3 million euros. In France, the *'Plan Chablis'* was implemented after the storms, Lothar and Martin, in 1999, for a total of 91.5 million euros. More recently, after Hurricane Gudrun in 2005, the Danish government gave a public lump-sum grant to replant and clear the storm-felled forest areas for each forest owner with damaged forest, but only for owners who had purchased a basic forest insurance policy. After the same windstorm,

[1] Non-industrial private forest owners hold roughly 67% of forested areas in European countries.

we can observe that the Swedish government allocated 2 million euros, not to compensate the financial losses of private forest owners but only to facilitate the evaluation of damages and to inform owners. These common public practices are generally implemented regardless of the disincentives created for efficient expenditures on insurance and/or on forest management practices of non-industrial private forest owners.

These features raise several interesting issues: (i) What are the effects of public compensation for disaster damages on private insurance or forest management decisions? (ii) Are public relief programmes really a substitute for private coverage decisions? (iii) What are the differences of the effect of public post-disaster compensations contingent or not on coverage measures? The purpose of this paper is to analyse these unexplored issues. We have adopted a normative approach designed to provide a basic framework for studying these points. Before describing our model, we present a brief overview of the relevant existing literature, which provides additional motivation for our analysis.

Birot and Gollier (2001) were the first to indicate the implications of the expectation of public subsidies for insurance, but they do not explicitly formalise the interaction between insurance, forest management and public compensation programmes. More generally, some authors such as Kaplow (1991), Harrington (2000), Gollier (2001), Smetters (2005), Kunreuther and Pauly (2006) claim that the expectation of liberal disaster assistance following a catastrophic event can be a factor limiting homeowners to purchase insurance. Kim and Schlesinger (2005) have examined the impact of government assistance programmes on the demand for insurance in a simple two-state model of insurance demand with adverse selection. They found that government assistance alters agents' demand for insurance coverage. In the same way, Lewis and Nickerson (1989) analysed the effect of public disaster relief programmes on individual self-insurance expenditures in an expected-utility model under conditions of limited liability for financial loss and without market insurance. They compared the alternative levels of self-insurance activities that are optimal and that minimise the expected costs of public compensation. They found that an increase in the minimum property value guaranteed by public compensation has similar effects on both optimal levels of self-insurance expenditures at the qualitative level. These effects depend on the nature of the technology by which individuals protect their assets (risk-reducing or risky investments).

This paper explores various issues associated with insurance and risk stand management behaviour of non-industrial private forest owners when they face public compensation for disaster damages that guarantee some minimum wealth levels. We develop a theoretical model of insurance or forest management practices that emphasizes the interaction between market insurance or sylvicultural activities and public compensation programmes. We consider a risk-averse expected-utility-maximising forest owner exposed to a loss due to natural risk. This paper extends earlier analyses in several important respects. First, we generalise the traditional two-state model to a more representative framework with many states of nature and a loss depending on the forest value. In the literature, a two-state model is generally considered where an individual faces the risk of losing an exogenous financial amount L with probability p or not. Such a framework is not adapted to represent the risk in the forest sector because a natural disturbance occurs each time with a different intensity and the damages are never the same. In the same way, the loss in forest depends on the value of the forest. For this reason, we consider a loss depending on the value of the stand. Second, we develop the comparative statics of insurance and forest management by analysing the effects of insurance price, attitudes toward risk, stand value, and the magnitude and frequency of the public compensation on the optimal coverage decisions. Finally, we examine the effects of public financial assistance programmes on the forest owner's optimal coverage decisions. It is shown that for insurance as well as for forest management activities, public assistance programmes remove the private forest owner's incentives. However, we show that measures to adapt public financial assistance programmes to insurance coverage or to forest management activities makes these practices more attractive to the forest owners than when public assistance is not adapted to protection measures.

This paper is structured as follows. In Section 2, we present the model of insurance demand affected by the presence of government financial assistance programmes. We particularly focus on the analysis of comparative static results with respect to the price of insurance, the risk preferences of the forest owner, and the value of the forest. We then examine the effects of such a programme on the optimal coverage choices. In Section 3, we consider a model of forest management activities within the context of natural risk with many states of nature and a loss function of the value of the forest. After determining some results of comparative statics, we study the impact of government assistance programmes on optimal forest management decisions. In Section 4, we make some public policy recommendations that could be applied at the governmental level. Section 5 provides some concluding comments.

2 Optimal insurance activity in the context of a public programme

The analysis of insurance choices has received considerable attention in the literature. The standard theoretical framework used to study insurance demand (Mossin, 1968; Schlesinger, 2000) seems to be adapted to representing the problem of insurance in risky forest management. Only a few previous works in the area of experimental economics (Mc Clelland et al., 1993; Ganderton et al., 2000; Stenger, 2004; Kunreuther and Pauly, 2006) have analysed insurance demand within the context of natural risks. Stenger (2004) deals with non-industrial private forest owners' insurance activities toward natural risks. She shows that forest owners tend to buy insurance when windstorms are frequent. When the windstorms are frequent, the rejection of insurance is due more to potential loss than to the probability of occurrence. In this paper, we propose a theoretical model of forest insurance against natural risks. We first analyse the insurance decision of a non-industrial forest owner without public compensation. We then concentrate on the problem of insurance choices with public financial assistance. In both of these cases, we used the framework described below.

Consider a private forest owner who possesses an even-aged forest that procures an optimal revenue R that corresponds to the commercial value of a stand of trees at the optimal cut period. This revenue is subject to a possible risk of windstorm or fire and then to a possible loss. Let $\varepsilon \in [0, \overline{\varepsilon}]$ denote a random variable representing a state of nature, and let $L(R, \varepsilon)$ denote the size of loss when ε occurs that is a function of the revenue from the stand. Without loss of generality, we assume that a larger ε represents a worse state so that

$L_\varepsilon(R,\varepsilon) = \frac{\partial L(R,\varepsilon)}{\partial \varepsilon} > 0$ (henceforth, subscripts denote partial derivatives). To include the possibility of no loss, we have $L(R,0) = 0$. Let $f(\varepsilon)$ and $F(\varepsilon)$ denote the density and distribution functions for ε, respectively. We also assume that $0 \leq L(R,\varepsilon) \leq R$ and $L_R(R,\varepsilon) > 0$. The loss is always lower than the value of timber production. When the revenue from wood increases, financial loss rises as well.

2.1 Optimal insurance decision without a public programme

The private forest owner can purchase a co-insurance policy. This insurance contract consists of an indemnity function where the private forest owner receives payment $\alpha L(R,\varepsilon)$ in the event of a loss $L(R,\varepsilon)$, as well as a premium P, which must be paid no matter what. The forest owner chooses α between 0 and 1. The premium for the given indemnity function takes the form $P(R) = (1+\lambda)\alpha\mu(R)$ with $\mu(R) = E[L(R,\varepsilon)]$ where $\lambda \geq 0$ is the loading factor. We assume that there are no moral hazard problems and that the forest owner will not be more careless in forest management as a result of purchasing insurance. Furthermore, we assume that the insurer has the same information about risk as the forest owner, so that there will be no adverse selection problems.

Concerning the insurance market, the problem of the private forest owner is to choose α to maximise his/her expected utility:

$$Max_{\{\alpha\}} \int_0^{\overline{\varepsilon}} U\left[R - (1-\alpha)L(R,\varepsilon) - (1+\lambda)\alpha\mu(R)\right] f(\varepsilon)\, d\varepsilon \qquad (1)$$

where $U[.]$ is a strictly increasing and concave von Neumann-Morgenstern utility function.

The optimal insurance demand α^* is defined by the following condition:

$$\int_0^{\bar{\varepsilon}} \Big[U'[W(\alpha^*)](L(R,\varepsilon) - (1+\lambda)\,\mu(R))\Big] f(\varepsilon)\,d\varepsilon = 0 \tag{2}$$

where $W(\alpha^*) = R - (1-\alpha^*)\,L(R,\varepsilon) - (1+\lambda)\,\alpha^*\mu(R)$.

The problem of insurance here is quasi identical to the one analysed by Eeckhoudt and Gollier (1992) or by Schlesinger (2000)[2], except that the loss here is a function of the initial wealth. This difference does not change the result, referred to as Mossin's Theorem[3] (Mossin, 1968): if proportional insurance is available at a fair price ($\lambda = 0$), then full coverage is optimal ($\alpha^* = 1$); if the price of insurance includes a positive premium loading factor ($\lambda > 0$), then the partial insurance is optimal ($\alpha^* < 1$). There is a critical value of the loading factor for which the forest owner switches to zero coverage. Schlesinger (2000) examines the results of comparative statics with respect to changes in price. The author concludes that with a positive insurance loading factor, insurance cannot be a Giffen good if preferences exhibit constant absolute risk aversion (CARA) or increasing absolute risk aversion (IARA), but may be a Giffen good if preferences exhibit decreasing absolute risk aversion (DARA). Schlesinger (2000) also studies the impact of change in risk aversion on the optimal insurance decision. He concludes that an increase in the individual's degree of risk aversion at all levels of wealth will lead to an increase in the optimal level of coverage. It is easy to show that these two conclusions are also verified in our insurance model. Schlesinger (2000) shows that for an increase in the initial wealth, the optimal insurance level will decrease, be invariant or

[2] We do not develop the total analysis of this optimal insurance decision here. The interested reader can refer to this paper in order to have more precisions about the basic theoretical model of proportional co-insurance and the results of comparative statics.

[3] The proof of Mossin's Theorem within this framework is available from the authors upon request.

increase under DARA, CARA or IARA, respectively. Within our framework, this result is not totally proven because the impact of an increase in the stand value on the optimal level of insurance coverage consists of three effects. The first effect involves the substitution effect of an increase in the stand value. This effect is positive due to the higher stand value. The second effect involves an income effect, since a higher stand value would raise overall wealth. CARA preferences eliminate any income effect. Under DARA and IARA, this income effect is positive and negative, respectively. The third effect involves a loss effect of an increase in the stand value. This higher level of loss implies that the forest owner will purchase more insurance. Finally, under CARA or IARA, all these effects are not contradictory, making the forest owner's insurance demand higher when the stand value increases. Under DARA, the aggregate effect of an increase in the stand value is ambiguous[4].

We can observe that under the DARA assumption, which is generally admitted, forest owners may increase their insurance demand when the insurance price rises or when their risk aversion increases. On the contrary, forest owners may reduce or increase their insurance expenditures when their initial wealth increases. We can also observe that the decision of private forest owners to insure against natural risks is strongly linked to the price of insurance, the level of the stand value and their risk preferences. These factors can explain the diversity of observed insurance behaviours.

2.2 Optimal insurance decision with a public programme

We now focus on the impact of public compensation programmes on optimal insurance decisions. Private financial loss due to a natural disaster is limited by compensation from the

[4] A complete set of comparative statics is available from the authors upon request.

public disaster relief programme. Insurance decisions are made based on the knowledge of this programme and prior to an observation of the severity of an impending disaster. Public financial help can take two forms. In the first type of programme, the government financially compensates forest owners who are victims of natural disasters without any coverage condition (France). In the second one, the payment of the public financial post-disaster compensation is contingent on coverage decisions (Denmark). Consequently, we analyse these two situations.

We assume that the value of the private forest owner's revenue ensured by the programme after the occurrence of a disaster does not fall below some minimal value R_m, independent of insurance coverage. The level of this value is determined by social and political considerations and is public knowledge. This implies that the choice of R_m does not depend on the optimal insurance activity.

The private forest owner chooses the level of insurance to maximise her/his expected utility, taking the existence of the public compensation programme into account:

$$Max_{\{\alpha\}} \ \ EU(\alpha) = \int_0^{\widehat{\varepsilon}} U\left[R - (1-\alpha)\,L\,(R,\varepsilon) - (1+\lambda)\,\alpha\mu(R)\right] f\,(\varepsilon)\,d\varepsilon + \tag{3}$$

$$\int_{\widehat{\varepsilon}}^{\overline{\varepsilon}} U\left[R_m + R - (1-\alpha)\,L\,(R,\varepsilon) - (1+\lambda)\,\alpha\mu(R)\right] f\,(\varepsilon)\,d\varepsilon$$

The variable $\widehat{\varepsilon}$ is defined by the public relief programme and it is the threshold state of nature that defines the public assistance limit for financial loss.

The optimal level of insurance, $\widehat{\alpha}$, is defined by the following first-order condition:

$$\int_0^{\widehat{\varepsilon}} U' \left[\widehat{W}\right] (L(R,\varepsilon) - (1+\lambda)\mu(R)) f(\varepsilon)\, d\varepsilon + \int_{\widehat{\varepsilon}}^{\overline{\varepsilon}} U' \left[\widehat{W_m}\right] (L(R,\varepsilon) - (1+\lambda)\mu(R)) f(\varepsilon)\, d\varepsilon = 0 \tag{4}$$

where $\widehat{W} = R - (1-\widehat{\alpha})L(R,\varepsilon) - (1+\lambda)\widehat{\alpha}\mu(R)$ is the forest owner's final wealth without public financial assistance, and $\widehat{W_m} = R_m + R - (1-\widehat{\alpha})L(R,\varepsilon) - (1+\lambda)\,\widehat{\alpha}\mu(R)$ is the final wealth with the public compensation programme. It is interesting to compare the optimal level of insurance obtained with public programme $\widehat{\alpha}$ to the optimal level of insurance obtained without public programme α^*. We evaluate the first-order condition (4) defining $\widehat{\alpha}$ at α^*. We note that $EU(\alpha)$ is concave in α. It is easy to show that $\frac{dEU(\alpha)}{\alpha}|_{\alpha^*} < 0$ where the inequality follows from the concavity of U. This last expression equals zero by the first order condition for $\widehat{\alpha}$. Since $EU(\alpha)$ is concave in α, the inequality implies that $\alpha^* > \widehat{\alpha}$. The existence of a public compensation programme has the effect of lowering the optimal level of insurance coverage.

The public post-disaster programme affects the optimal insurance decision of the forest owner by the threshold of compensation $\widehat{\varepsilon}$ and the minimal value R_m. Therefore, we can analyse the effect of change in public compensation programmes through $\widehat{\varepsilon}$ or R_m on optimal insurance, $\widehat{\alpha}$, by defining the signs of $\left(\frac{d\widehat{\alpha}}{d\widehat{\varepsilon}}\right)$ and $\left(\frac{d\widehat{\alpha}}{dR_m}\right)$.

The sign of $\left(\frac{d\widehat{\alpha}}{d\widehat{\varepsilon}}\right)$ is the same as the sign of the expression

$$\left(U' \left[\widehat{W}|_{\widehat{\varepsilon}}\right] - U' \left[\widehat{W_m}|_{\widehat{\varepsilon}}\right]\right) \left(L\left(R,\widehat{\varepsilon}\right) - (1+\lambda)\,\mu(R)\right)$$

where $\widehat{W}|_{\widehat{\varepsilon}} = R - (1-\widehat{\alpha})L(R,\widehat{\varepsilon}) - (1+\lambda)\widehat{\alpha}\mu(R)$ and $\widehat{W_m}|_{\widehat{\varepsilon}} = R_m + R - (1-\widehat{\alpha})L(R,\widehat{\varepsilon}) - (1+\lambda)\,\widehat{\alpha}\mu(R)$. Because U is increasing and concave, $\left(U'\left[\widehat{W}|_{\widehat{\varepsilon}}\right] - U'\left[\widehat{W_m}|_{\widehat{\varepsilon}}\right]\right) > 0$. The term $\left(L\left(R,\widehat{\varepsilon}\right) - (1+\lambda)\,\mu(R)\right)$ can be positive or negative. For a given R, in the case of exceptional disasters where $\widehat{\varepsilon}$ is high, $L\left(R,\widehat{\varepsilon}\right)$ is greater than $(1+\lambda)\,\mu(R)$ and, $\left(\frac{d\widehat{\alpha}}{d\widehat{\varepsilon}}\right) > 0$; otherwise, in the case of small disasters ($\widehat{\varepsilon}$ low), $\left(\frac{d\widehat{\alpha}}{d\widehat{\varepsilon}}\right) < 0$. A threshold state of nature $\widehat{\varepsilon^*}$ exists, defined by $L\left(R,\widehat{\varepsilon^*}\right) = (1+\lambda)\,\mu(R)$.

Proposition 1 *: If the public assistance programme only occurs for exceptional disasters, then forest owners respond to greater uncertainty about the size of loss by increasing their optimal insurance demand. The existence of public compensation for natural disasters with state greater than* $\widehat{\varepsilon}$ *has the effect of improving the distribution of states of nature over which forest owners bear full financial loss. It may be immediately deduced from this that the optimal level of insurance coverage will increase. If the public compensation programme exists for small disasters, then forest owners decrease their optimal level of insurance when the government raises the compensation threshold to the level of the state of nature threshold,* $\widehat{\varepsilon^*}$*. The increase of the distribution of states of nature over which forest owners bear full financial loss makes the optimal level of insurance coverage lower.*

When the threshold of compensation is higher, the government intervenes more rarely; forest owners then react by increasing their insurance demand. This result is consistent with Birot and Gollier's conclusion. Therefore, when public financial assistance is scarce, forest owners prefer to protect themselves by taking out insurance contracts. The incentive to insure is thus decreased due to the existence of a public financial assistance programme. Anticipating the existence of such a programme, forest owners do not take efficient measures to insure against natural disasters because they are partially insured against financial loss by a public relief programme. Browne and Hoyt (2000) define this behaviour as "charity hazard". Forest owners' failure to purchase insurance is a consequence of the compensation provided by government disaster relief programmes.

The sign of $\left(\frac{d\widehat{\alpha}}{dR_m}\right)$ is the same as the sign of the expression

$$\int_{\widehat{\varepsilon}}^{\overline{\varepsilon}} U'' \left[\widehat{W_m}\right] (L(R,\varepsilon) - (1+\lambda)\mu(R)) f(\varepsilon)\, d\varepsilon$$

that is positive or negative. For a given R, in the case of exceptional disasters ($\widehat{\varepsilon}$ high), we have $\left(\frac{d\widehat{\alpha}}{dR_m}\right) < 0$; otherwise, in the case of small disasters ($\widehat{\varepsilon}$ low), we have $\left(\frac{d\widehat{\alpha}}{dR_m}\right) > 0$.

Proposition 2 *: If the public programme is established for exceptional windstorms, then an increase in the minimum value of revenue guaranteed by public compensation reduces the forest owners' loss of damage, leading to greater inefficiency in private insurance coverage. If the public programme is set up for small disasters, a higher guaranteed revenue increases the optimal level of insurance coverage.*

Generally, the public relief programme is implemented for exceptional disasters. In this case, increased public disaster relief payments are associated with reduced insurance purchases. This conclusion can explain why so few private forest owners are insured against natural disasters.

We now consider that the public assistance level depends on the forest owner's insurance decision. Within this context, the forest owner decides to insure if her/his expected utility with the insurance and public programme is greater than her/his expected utility without insurance: $\alpha > 0$ if:

$$\int_0^{\widehat{\varepsilon}} U\left[R - (1-\alpha) L(R,\varepsilon) - (1+\lambda)\alpha\mu(R)\right] f(\varepsilon)\, d\varepsilon + \tag{5}$$

$$\int_{\widehat{\varepsilon}}^{\overline{\varepsilon}} U\left[R_m + R - (1-\alpha) L(R,\varepsilon) - (1+\lambda)\alpha\mu(R)\right] f(\varepsilon)\, d\varepsilon > \int_0^{\overline{\varepsilon}} U\left[R - L(R,\varepsilon)\right] f(\varepsilon)\, d\varepsilon$$

Since it is very difficult to directly verify if this inequality (5) is satisfied without function specification, we assume that the assistance level is proportional to the insurance choice: αR_m. Moreover, we consider that when α increases, public assistance also increases. This type of programme considers that insurance coverage is easily observable by the governmnent.

The private forest owner chooses the level of insurance to maximise her/his expected utility:

$$Max_{\{\alpha\}} \int_0^{\widehat{\epsilon}} U[R - (1-\alpha)L(R,\epsilon) - (1+\lambda)\alpha\mu(R)]f(\epsilon)d\epsilon + \tag{6}$$

$$\int_{\widehat{\epsilon}}^{\overline{\epsilon}} U[\alpha R_m + R - (1-\alpha)L(R,\epsilon) - (1+\lambda)\alpha\mu(R)]f(\epsilon)d\epsilon$$

The optimal level of insurance when the public programme is adapted to insurance conditions, $\widehat{\alpha}_c$, is defined by the following first-order condition:

$$\int_0^{\widehat{\epsilon}} U'(\widehat{W_c})[L(R,\epsilon) - (1+\lambda)\mu(R)]f(\epsilon)d\epsilon + \int_{\widehat{\epsilon}}^{\overline{\epsilon}} U'(\widehat{W_{mc}})[R_m + L(R,\epsilon) - (1+\lambda)\mu(R)]f(\epsilon)d\epsilon \tag{7}$$

where $\widehat{W_c} = R - (1-\widehat{\alpha}_c)L(R,\epsilon) - (1+\lambda)\widehat{\alpha}_c\mu(R)$ et $\widehat{W_{mc}} = \widehat{\alpha}_c R_m + R - (1-\alpha)L(R,\epsilon) - (1+\lambda)\widehat{\alpha}_c\mu(R)$.

By comparing condition (7) evaluated at $\widehat{\alpha}$ with condition (4) defining $\widehat{\alpha}$, we obtain the following result:

Proposition 3 *: Adapting public financial assistance programmes to insurance coverage makes insurance more attractive for forest owners. The existence of public compensation for disasters subject to coverage has the effect of increasing the optimal level of insurance, although the public programme reduces the forest owner's loss of damage, leading to lower efficiency in private insurance.*

The proof of Proposition 3 is given in Appendix A. In fact, the insurance demand is higher when the public programme is contingent on insurance coverage than when it is not the case.

3 Optimal forest management activity with a public programme

We consider forest management activities such as the installation of artificial firebreaks that mitigate the size of natural disaster losses. These coverage practices are self-insurance activities. We only consider the protection objective of forest management actions against natural hazards here, but there may be other ones such as the interest for non-timber services provided by the forest (fruit crops, leisure activities, etc). In the economic literature, self-insurance activities have been principally studied in a two-state model assuming an additive loss function (Ehrlich and Becker, 1972; Dionne and Eeckhoudt, 1985; Briys and Schlesinger, 1990; Schlesinger, 2000, among others). In Stenger (2004), forest owners' decisions of self-insurance toward natural risk are investigated through experiments. She shows that if the forest owner decides to invest in self-insurance activities, then the amount of money allocated to these expenses is high.

We propose a theoretical multiple-state model of forest management activities here where the loss is a function of stand value. We first analyse the forest management decision of a private forest owner without a public assistance programme. We then study this choice within the context of a public financial assistance programme. We use the same framework here as in the insurance case.

3.1 Optimal forest management decision without a public assistance programme

Let $L(R,q,\varepsilon)$ denote the size of loss, given forest management activity q, with $0 \leq L(R,q,\varepsilon) \leq R$. When the timber revenue increases, financial loss rises as well: $L_R(R,q,\varepsilon) \geq 0$. An increase in q reduces the size of loss at any given ε, so that $L_q(R,q,\varepsilon) \leq 0$ with strict inequality for some ε. The private forest owner's problem is to choose q to maximise her/his expected utility:

$$EU = \int_0^{\overline{\varepsilon}} U\left[R - L(R,q,\varepsilon) - cq\right] f(\varepsilon)\, d\varepsilon \tag{8}$$

where cq denotes the cost of forest practices q. Since $U' > 0$, an interior solution referred to as q^*, exists if $L_q(R,0,\epsilon) + c < 0$ for all possible values of ϵ and R. At the optimal level, q^*, the potential marginal benefit, $-L_q$, must be at least greater than the cost of the increase on q, c. q^* satisfies the first-order condition:

$$\frac{\partial EU}{\partial q} = \int_0^{\overline{\varepsilon}} U'\left[W^*\right]\left(-L_q(R,q^*,\varepsilon) - c\right) f(\varepsilon)\, d\varepsilon = 0 \tag{9}$$

where $W^* = R - L(R, q^*, \varepsilon) - cq^*$. For the rest of the paper, we assume that we have an interior solution.

The first-order condition given (9) has an immediate conventional interpretation in terms of cost and benefit; it states that, at the optimal level of forest management activity, the expected marginal benefit from the reduction in the size of a loss, $E\{U'[W^*](-L_q(R, q^*, \varepsilon))\}$, equals the expected marginal cost from the increase in forest practices, $E\{U'[W^*](c)\}$. The second-order condition is satisfied if the loss function is convex. This logical assumption means that a reduction in the size of loss becomes more difficult as forest management activities increase. These characteristics are assumed afterwards.

Optimal activity of forest management, q^*, depends on the marginal cost of this activity, c, on risk preferences, and on the value of the stand[5], R.

Risk-neutral forest owners always reduce their optimal activity when the price of these measures increases. This result is not always verified when forest owners are risk averse. The sign of $\frac{dA[W^*]}{dW}$ and the sign of $L_{q\varepsilon}$ are important. Consideration of many states of nature enables us to define forest management activity as either a risky or a risk-reducing activity. The technology of protection is then described by the relationship between the marginal return to forest management activity, L_q, and the random severity of a natural disaster, ε. For example, if the forest owner exhibits constant absolute risk aversion, then $A[W]$ is positive and constant. When $L_{q\varepsilon} < 0$, expenditures on forest management practices are regarded by the private forest owner as being a "risk-reducing" investment. These include smoke detectors and auxiliary generators for use in blackouts, for example, because the marginal return to expenditure on forest management activity $(-L_q)$ varies directly with the severity

[5] A complete set of comparative statics is available from the authors upon request.

of the disaster since higher values of ε are assumed to correspond to relatively more severe disasters; therefore $L_\varepsilon > 0$. When $L_{q\varepsilon} > 0$, expenditure on forest management practices is a "risky" asset, for example the installation of fire retardants, because the marginal return of such an activity varies inversely with disaster severity. An increase in forest management activity cost induces a decrease in optimal forest management activity only: (a) if forest owners exhibit constant absolute risk aversion; (b) if they exhibit decreasing absolute risk aversion, and investment in forest management practice is a risky expenditure; (c) if they exhibit increasing absolute risk aversion, and investment in forest management practices is a risk-reducing expenditure. These results are consistent with the ones obtained by Mahul (1998). The result that an increase in self-insurance activity cost induces a decrease in optimal self-insurance activity depends on the absolute risk aversion and the investment features. When forest owners exhibit decreasing absolute risk aversion (that is generally accepted), they will reduce their coverage when the cost of coverage increases only if the marginal return of such activity is more important in the states of nature with low levels of damage.

If investment in forest management activity is a risk-reducing (risky) expenditure, more risk-averse private forest owners invest more (less) in coverage activity. In fact, when investment in forest management activity is a risk-reducing expenditure, the more unfavorable the states of nature are, the higher the marginal return of coverage expenses is. Therefore, a more risk-averse forest owner spends more on coverage activity. Inversely, when investment in forest management activity is a risky expenditure, the marginal return is then more important in the favourable states. Consequently, more risk-averse forest owners invest less in forest practices.

If the forest owner's stand value changes but the loss exposure remains the same, will she/he choose more or less forest management activities? Note that risk-neutral forest owners increase (decrease) their optimal forest management activity for a higher stand value if $L_{Rq} < 0$ (> 0). If forest management practices are more profitable for high revenues of timber production (that is, $L_{Rq} < 0$: if R increases, then L_q decreases; therefore, the marginal return of forest practices rises), then risk-neutral forest owners choose a higher level of forest management activities. This result has not been verified for risk-averse forest owners. If forest management activities are profitable at all the states of nature, then risk-averse forest owners only decrease their optimal level of forest practices for a higher stand value if $L_{Rq} > 0$; otherwise, their behaviour remains ambiguous.

The cost of forest management activities, the risk preferences of the private forest owner and the value of the stand are fundamental factors explaining the decision to self-insure against natural risks.

3.2 Optimal forest management activity with a public programme

We now assume that the same public assistance programme as the one defined in the case of insurance is implemented. This programme may or may not be implemented, depending on the optimal forest management activity, but the forest management decision depends on the knowledge of the existence of this programme. We therefore analyse these two cases.

First, the financial public compensation programme is independent of the optimal forest management activity chosen by the forest owner facing natural risk.

The private forest owner chooses the level of forest management activity to maximise her/his expected utility, taking the existence of the public compensation programme into account:

$$Max_{\{q\}}\ EU_s(q) = \int_0^{\widehat{\varepsilon}} U\left[R - L\left(R, q, \varepsilon\right) - cq\right] f\left(\varepsilon\right) d\varepsilon + \int_{\widehat{\varepsilon}}^{\overline{\varepsilon}} U\left[R_m + R - L\left(R, q, \varepsilon\right) - cq\right] f\left(\varepsilon\right) d\varepsilon \tag{10}$$

The first term in (10) reflects the forest owner's wealth with no compensation of loss, while the second term represents the level of revenue guaranteed to the forest owner by public compensation.

The optimal level of forest management activity, $\widehat{q}$, is defined by the following first-order condition:

$$\int_0^{\widehat{\varepsilon}} U'\left[\widehat{W}\right]\left(-L_q\left(R, \widehat{q}, \varepsilon\right) - c\right) f\left(\varepsilon\right) d\varepsilon + \int_{\widehat{\varepsilon}}^{\overline{\varepsilon}} U'\left[\widehat{W_m}\right]\left(-L_q\left(R, \widehat{q}, \varepsilon\right) - c\right) f\left(\varepsilon\right) d\varepsilon = 0 \tag{11}$$

where $\widehat{W} = R - L\left(R, \widehat{q}, \varepsilon\right) - c\widehat{q}$ and $\widehat{W_m} = R_m + R - L\left(R, \widehat{q}, \varepsilon\right) - c\widehat{q}$.

According to our assumptions, the second-order condition is verified. The private forest owner purchases forest management activity up to the point where the marginal utility obtained from such expenditures equals zero over all the states of nature.

We compare the optimal level of forest management activity obtained with public programme $\widehat{q}$ to the optimal level of forest management activity obtained without the public programme q^*. We evaluate the first-order condition (11), defining $\widehat{q}$ at q^*. We note that $EU_s(q)$ is concave in q. It is easy to show that $\frac{dEU_s(q)}{q}|_{q^*} < 0$ where the inequality follows from the concavity of U. This last expression equals zero by the first-order condition for q. Since $EU_s(q)$ is concave in q, the inequality implies that $q^* > \widehat{q}$. The existence of a public compensation programme has the effect of lowering the optimal level of forest management activity.

The public financial assistance programme is defined by the threshold of compensation $\widehat{\varepsilon}$ and the minimal value R_m. Therefore, these two parameters affect the optimal forest management decision of the forest owner. We can then analyse the effect of change in public programmes, through $\widehat{\varepsilon}$ or R_m, on optimal forest management activity, $\widehat{q}$. We obtain the two following sign conditions.

The sign of $\left(\frac{d\widehat{q}}{d\widehat{\varepsilon}}\right)$ is the same as the sign of the expression

$$\left(U'\left[\widehat{W}|_{\widehat{\varepsilon}}\right] - U'\left[\widehat{W_m}|_{\widehat{\varepsilon}}\right]\right)\left(-L_q\left(R, \widehat{q}, \widehat{\varepsilon}\right) - c\right)$$

where $\widehat{W}|_{\widehat{\varepsilon}} = R - L\left(R, \widehat{q}, \widehat{\varepsilon}\right) - c\widehat{q}$ and $\widehat{W_m}|_{\widehat{\varepsilon}} = R_m + R - L\left(R, \widehat{q}, \widehat{\varepsilon}\right) - c\widehat{q}$, that is, depending on the sign of the term $\left(-L_q\left(R, \widehat{q}, \widehat{\varepsilon}\right) - c\right)$ because U' is decreasing. For a given R, the sign of the term $\left(-L_q\left(R, \widehat{q}, \widehat{\varepsilon}\right) - c\right)$ directly depends on the comparison of the marginal benefit from the reduction in the size of a loss, $\left(-L_q\left(R, q, \varepsilon\right)\right)$, and the marginal cost from the increase in forest management activity, c, at the threshold state of nature $\widehat{\varepsilon}$.

If forest management activity is a risk-reducing activity, then for exceptional disasters ($\widehat{\varepsilon}$ high), the marginal benefit is greater than the marginal cost; we then have $\left(\frac{d\widehat{q}}{d\widehat{\varepsilon}}\right) > 0$. Otherwise, for small disasters ($\widehat{\varepsilon}$ low), we have $\left(\frac{d\widehat{q}}{d\widehat{\varepsilon}}\right) < 0$. If forest management activity is a risky activity then, for exceptional disasters, the marginal benefit is lower than the marginal cost; we then have $\left(\frac{d\widehat{q}}{d\widehat{\varepsilon}}\right) < 0$. Otherwise, for small disasters, we have $\left(\frac{d\widehat{q}}{d\widehat{\varepsilon}}\right) > 0$.

Proposition 4 *: If forest management activity is a risk-reducing (risky) activity, then a decrease in the threshold state of nature that limits public compensation has a direct effect* *on the forest owner's incentive to manage forest activity: since the government assumes less financial loss, the optimal level of forest management activity becomes higher (lower) for exceptional disasters and lower (higher) for small disasters.*

The sign of $\left(\frac{d\widehat{q}}{dR_m}\right)$ is the same as the sign of the expression

$$\int_{\widehat{\varepsilon}}^{\overline{\varepsilon}} U'' \left[\widehat{W_m}\right] \left(-L_q\left(R, \widehat{q}, \varepsilon\right) - c\right) f\left(\varepsilon\right) d\varepsilon$$

that can be positive or negative. We assume a given level for the stand value. We find that:

$$\left(\frac{d\widehat{q}}{dR_m}\right) < 0 \Leftrightarrow cov(A[\widehat{W_m}], -L_q(R, \widehat{q}, \varepsilon)) > 0$$

If forest management activity is a risk-reducing activity and the preferences of the forest owner exhibit DARA, then the covariance is positive and we therefore have $\left(\frac{d\widehat{q}}{dR_m}\right) < 0$. If forest management activity is a risky investment then, under IARA, we have
$cov(A[\widehat{W_m}], -L_q(R, \widehat{q}, \varepsilon)) > 0$.

Proposition 5 *:*

An increase in the revenue guaranteed by public compensation R_m decreases the optimal level of forest management activity:

- *if forest management activity is a risk-reducing activity and forest owners exhibit decreasing absolute risk aversion*
- **or** *if forest management activity is a risky expenditure and the preferences of the forest owners increase absolute risk aversion.*

Indeed, forest owners observe that the government increases its assistance, leading them to reduce their forest management activities, since a larger part of the damage expenditures is assumed by a public programme. Consequently, if a public compensation programme exists, private forest owners may reduce their forest management expenditures. This conclusion can explain why so little forest management behaviour against natural disaster is observed.

We now consider that the public compensation level depends on the owner's forest management activity. In this context, forest owners decide to adopt forest management activity if their expected utility with such a practice and public programme is greater than their expected utility without forest management activity: $q > 0$ if:

$$\int_0^{\widehat{\varepsilon}} U\left[R - L\left(R, q, \varepsilon\right) - cq\right] f\left(\varepsilon\right) d\varepsilon + \int_{\widehat{\varepsilon}}^{\overline{\varepsilon}} U\left[R_m + R - L\left(R, q, \varepsilon\right) - cq\right] f\left(\varepsilon\right) d\varepsilon \tag{12}$$

$$> \int_0^{\overline{\varepsilon}} U\left[R - L\left(R, 0, \varepsilon\right)\right] f\left(\varepsilon\right) d\varepsilon$$

Since it is very difficult to directly verify if this inequality (12) is satisfied without function specification, we assume that the public assistance programme depends on the forest management activities as follows: $R_p(q)$ with $R' > 0$ and $R_p(q) \leq R_m \forall q$. Moreover, we assume that when q increases, public assistance increases as well. This type of public programme requires monitoring, but it is possible to oberve the forest management activities undertaken by non-industrial private forest owners. As an example, the preparation of the forest path to make access easier in the event of a fire is an easily observable action.

The objective of the private forest owner is to maximise her/his expected utility:

$$Max_{\{\alpha\}} \int_0^{\widehat{\epsilon}} U[R - L(R,q,\epsilon) - cq] f(\epsilon) d\epsilon + \int_{\widehat{\epsilon}}^{\overline{\epsilon}} U[R_p(q) + R - L(R,q,\epsilon) - cq] f(\epsilon) d\epsilon \quad (13)$$

The optimal level of forest management activities, $\widehat{q}_c$, is given by the following first-order condition:

$$\int_0^{\widehat{\epsilon}} U'[\widehat{W}_c][-L_q(R,\widehat{q}_c,\epsilon) - c] f(\epsilon) d\epsilon + \int_{\widehat{\epsilon}}^{\overline{\epsilon}} U'[\widehat{W_{mc}}][R_p'(\widehat{q}_c) - L_q(R,\widehat{q}_c,\epsilon) - c] f(\epsilon) d\epsilon \quad (14)$$

with $\widehat{W}_c = R - L(R,\widehat{q}_c,\epsilon) - c\widehat{q}_c$ and $\widehat{W_{mc}} = R_p(\widehat{q}_c) + R - L(R,\widehat{q}_c,\epsilon) - c\widehat{q}_c$.

By comparing this first-order condition evaluated at $\widehat{q}$ defined by (11), we obtain the following proposition:

Proposition 6 *: The existence of public financial assistance programmes based on forest management activities has the effect of changing the optimal level of forest management activities. Forest owners respond to the measure of adapting public assistance to coverage decisions by increasing their expenditures on forest management activities. This adaptation compensates the reduction of the forest owners' resulting damage due to the presence of public compensation.*

The optimal level of forest management activities when the public programme depends on these practices is greater than the optimal one when the public post-disaster compensation programme is independent of forest management activity[6].

[6] The demonstration of this result uses the same methodology as the one exposed in Appendix A; please refer to it for more details.

4 Implications of public policy

After an exceptional natural disaster, governments provide some financial assistance to facilitate the recovery of unprotected or protected victim-forest owners. The existence of such public financial compensation influences forest owners' activities to protect their forest from natural damage. Providing assistance after a catastrophe reduces the incentives of forest owners to invest in protective measures prior to a disaster. The inefficiency of government assistance as a form of insurance following a major disaster is due to the fact that the government defines such a programme regardless of the disincentives created by this compensation for efficient insurance or forest management activities. Expectation of financial assistance after a natural disaster has occurred affects the forest owner's interest in voluntarily purchasing insurance or forest management activities prior to a catastrophe. Since the government assumes more financial loss, optimal private expenditures on insurance or forest management activity are reduced. An increase in forest value, the cost of protective measures, and risk aversion are also found to exacerbate this divergence.

We will now examine four types of government policies: (1) direct monitoring of private expenditures on protective measures; (2) a tax on each forest owner; (3) a per-unit subsidy for insurance or forest management activity; and (4) a combination of public/private measures. Our previous analysis provides the necessary information to evaluate each of these policies.

4.1 Direct monitoring

Indemnities paid by public programmes must be based on the prevention and coverage efforts that forest owners undertake. This means that forest owners who adopt insurance or forest management measures will be indemnified or they will at least receive more than those who do not. It is entirely possible to monitor the efforts provided by forest owners. Indeed, if forest owners are insured, they have a forest insurance contract. For example, in Denmark, after a natural catastrophe occurrs, private forest owners receive subsidies for clearing and replanting new forests only if they have subscribed to a basic windstorm-type insurance. Replanting has to be with wind-resistant tree species and overall replanting should also aim at making a wind-resistant forest. This type of behaviour encourages private forest owners to adopt insurance coverage. In the same way, if forest owners engage in forest management activities, then activities of this type that facilitate the intervention in case of fire or windstorm are easy to observe ex-ante and ex-post. Thus, when the government decides to attribute compensations, an expert can be sent to see the forest owners in order to evaluate the damage and the prevention efforts made. Of course, monitoring and enforcement are relatively expensive. Coverage is assumed to be voluntary. The government can also require that forest owners who receive disaster assistance purchase coverage. Receiving public assistance following a disaster forces forest owners to invest in protective measures.

4.2 Taxation

The government can implement a tax on each stand value. Taxation may increase forest owners' incentives to purchase private insurance or to increase forest management activities. Such a tax reduces the wealth of the forest owners. We have previously shown that when a reduction in initial wealth occurs, forest owners then increase their insurance demand (under the generally accepted DARA assumption), and their forest management activities only if forest management activity is less profitable when the stand value is high. Otherwise, the tax may have a perverse effect on forest management activity. Therefore, it is not obvious that financing the public assistance programme by taxing forest owners' stands induces incentives to protect against natural disasters. Only the money collected via the tax could allow the government to create a fund intended to finance public programmes.

4.3 Subsidies

The risk that a major catastrophe will lead to more government compensation requires insurers to charge even higher prices. A factor that limits the demand for private disaster coverage is the high cost of coverage that substantially reduces the remaining revenue of some low-income forest owners. The public sector may pay direct subsidies as a percentage of insurance premiums, that is, the greater the risk, the greater the subsidy, or of the cost of forest management activities in the form of low-interest loans or grants. The government can implement a per-unit subsidy for insurance or forest management activity in order to influence the behaviour of the forest owner. For example, in Germany, Länders pay 50% of the fire insurance premium and the public decision-maker can grant financial aid to forest owners that subscribe to an insurance contract. This measure decreases the cost of insurance. As previously found, in the case of DARA, a decrease of the price of insurance induces a decrease of insurance demand. Such a means can have perverse effects. In the same way, the government can bear a part of the forest management activity cost. For example, the government can subsidise forest owners who maintain their access roads in good condition in case of natural disasters. In such a context, forest owners will increase their forest management activity only if they present decreasing absolute risk aversion and if this activity is risk-reducing; these conditions are generally verified. However, a resulting problem may appear. Forest owners choose not to invest in coverage even when their rates are highly subsidised because they perceive the likehood of a natural catastrophe to be very low.

4.4 A combination of public/private measures

Another public instrument is to offer a potentially susbidised insurance and to then provide disaster assistance to most of the forest owners who decline coverage. Natural disaster losses can be covered by a combination of public and private sectors as described in the following system. Forest management practices and private insurance are chosen by the forest owners to avoid moral hazard problems that might otherwise occur if they behaved more carelessly because they knew they were fully protected against natural risks. The government can heavily subsidise these coverage measures. Private insurance is administrated by private insurers that define the amounts of coverage according to their surplus, their current portfolio, and their ability to diversify risks. The private sector risk transfer mechanism corresponds to government reinsurance that would only serve to make the initial insurance premium lower or the availibility of coverage greater. The different levels of this coverage system are administrated by the private sector. The role of the government would be limited to helping with the supply and demand for insurance.

5 Conclusion

In Europe, the occurrence of natural disasters has frequently elicited public financial assistance to compensate private forest owners, victims of these disasters. The limited financial loss created by such programmes may have an influence on the optimal levels of expenditure on market insurance and forest management activities. The relationships existing between market insurance or forest management activity, and public relief programmes are analysed in a simple expected utility model of private forest owner decisions in relation to the many states of nature. We find that the existence of public post-disaster programmes discourages private forest owners from adopting efficient insurance or forest management measures aimed at protecting their forest.

The possibility for the forest owner to jointly insure and achieve forest management activity is not analysed here. It could be interesting to show if the result obtained by Ehrlich and Becker (1972) under a two-state model, that market insurance and self-insurance are substitutes, can be extended to a multiple-state framework and to the existence of a public post-disaster compensation programme. Data on forest owners' decisions would yield more accurate information about insurance and forest management activities and would allow us to validate our theoretical conclusions. Such an analysis would help to quantify the potential effect of public assistance in the forest owner's insurance and forest management programme.

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A Proof of proposition 3

We evaluate the first-order condition (7) at $\widehat{\alpha}$, defined by the condition (4):

$$\int_0^{\widehat{\epsilon}} U'[R-(1-\widehat{\alpha})L(R,\epsilon)-(1+\lambda)\widehat{\alpha}\mu(R)][L(R,\epsilon)-(1+\lambda)\mu(R)]f(\epsilon)d\epsilon+ \quad (15)$$

$$\int_{\widehat{\epsilon}}^{\overline{\epsilon}} U'[\widehat{\alpha}R_m+R-(1-\widehat{\alpha})L(R,\epsilon)-(1+\lambda)\widehat{\alpha}\mu(R)][R_m+L(R,\epsilon)-(1+\lambda)\mu(R)]f(\epsilon)d\epsilon$$

We note that:

$$R_m+L(R,\epsilon)-(1+\lambda)\mu(R)\geq L(R,\epsilon)-(1+\lambda)\mu(R)$$

and

$$R_m+R-(1-\widehat{\alpha})L(R,\epsilon)-(1+\lambda)\widehat{\alpha}\mu(R)\geq\widehat{\alpha}R_m+R-(1-\widehat{\alpha})L(R,\epsilon)-(1+\lambda)\widehat{\alpha}\mu(R)$$

and, since $U'(.)>0$:

$$U'[R_m+R-(1-\widehat{\alpha})L(R,\epsilon)-(1+\lambda)\widehat{\alpha}\mu(R)]\leq U'[\widehat{\alpha}R_m+R-(1-\widehat{\alpha})L(R,\epsilon)-(1+\lambda)\widehat{\alpha}\mu(R)]$$

Therefore, we have:

$$\int_0^{\widehat{\epsilon}} U'[R-(1-\widehat{\alpha})L(R,\epsilon)-(1+\lambda)\widehat{\alpha}\mu(R)][L(R,\epsilon)-(1+\lambda)\mu(R)]f(\epsilon)d\epsilon+$$

$$\int_{\widehat{\epsilon}}^{\overline{\epsilon}} U'[\widehat{\alpha}R_m + R - (1-\widehat{\alpha})L(R,\epsilon) - (1+\lambda)\widehat{\alpha}\mu(R)][R_m + L(R,\epsilon) - (1+\lambda)\mu(R)]f(\epsilon)d\epsilon \geq$$

$$\int_0^{\widehat{\varepsilon}} U'\left[\widehat{W}\right](L(R,\varepsilon)-(1+\lambda)\mu(R))f(\varepsilon)\,d\varepsilon + \int_{\widehat{\varepsilon}}^{\overline{\varepsilon}} U'\left[\widehat{W_m}\right](L(R,\varepsilon)-(1+\lambda)\mu(R))f(\varepsilon)\,d\varepsilon = 0$$

We then conclude that $\widehat{\alpha}_c \geq \widehat{\alpha}$.