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Abstract

The paper focuses on the choice of forest management strategies for natural hazards by nonindustrial owners, when forest provides nontimber services. We introduce a basic two-period model where the private owner hedges against natural hazards on his/her forest thanks to financial strategies (accumulation of savings) or to the adoption of sylvicultural practices. We show that: 1/ the harvesting rule, in the presence of amenity services and a random growth rate for forest, is smaller than the one predicted under the Faustmann's rule; 2/ savings and sylvicultural pratices may be seen as perfectly substitutable tools. However, our analysis predicts that, depending on whether forest owners opt for the financial strategy or undertake sylvicultural practices, the harvesting rule displays a specific sensitivity to price effects and/or changes in the distribution of natural hazards.

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1 Introduction

For several years, the frequency and the severity of extreme climatic events have seemed to increase and they have caused more and more damages in forestry management (Schelhaas and *al.*, 2003). Climate change may reinforce the traditional damages caused by natural risks in forest. Recent exceptional events such as forest fires and windstorms in Europe have focused attention on programs to incite nonindustrial private forest owners to reduce the risk of damage from natural events. Such natural disasters affect the timber production of forests and also amenity services one can get from standing stocks of forests. Forests provide a large variety of nontimber services, such as walk, landscape, mushroom crop, produced jointly with timber, and vanished with the standing stock and also with natural disasters. Recently it is proved that nonindustrial private forest owners confer some private value to the amenity services of forest stock even if there is no financial incentives to these functions (Birch, 1994 ; Butler and Leatherberry, 2005). This joint production property is now included in the forest owner's decision to harvest timber that affects automatically the flow of amenity services. These amenity relationships reinforce the importance of hedging strategies against natural risks. Forest owners can undertake risk management activities at the same time of stand management that are likely to reduce the potential financial losses due to natural disasters. Such an activity is insurance or savings; another one is sylvicultural practices. However, it is observed in Europe that forest insurance is an unusual practice and nonindustrial private forest owners favor sylvicultural practices, principally regeneration of forests, or financial tools to protect their forests against natural disasters (Picard *et al.*, 2002; Brunette and Couture, 2006). As a result, understanding nonindustrial private forest owners' hedging strategies is important to improve government prevention policy.

These hedging practices of nonindustrial private forest owners when standing stock has private value rise many questions. First, how does hedging strategies affect the allocation of forests into harvesting and amenity service purposes? Second, are these differences in harvesting behaviour depending on the hedging strategies selected by the forest owner? Third, what are the qualitative properties of timber supply and hedging strategies when amenity services have private value? The aim of this paper is to investigate decision making for nonindustrial private forest owners in terms of coverage against natural hazards, and thus to provide a comparative analysis of the alternative advantages produced by two different hedging strategies: savings *versus* sylvicultural practices. This paper explores harvesting and coverage behaviour of nonindustrial private forest owners when they value amenity services of forests and when there is uncertainty about biological timber. Despite the absence of data about the behaviour of hedging strategies, we adopt a normative approach designed to provide a basic dynamic framework.

The implications of biological risk for nonindustrial private forest owners' harvesting behaviour have been studied in many papers in a Faustmann-type framework when forest owners choose only stand rotation age (Reed, 1984; Reed and Clarke, 1989) and timber and nontimber services have private value (Englin and *al.*, 2000), and in a framework of a two-period model (Koskela and Ollikainen, 1999). They, however, considered no coverage measures. The question of hedging strategies have been subject only to relatively few studies. Within the Faustmann rotation framework, Reed (1987) and Amacher and *al.* (2005) analyzed how optimal rotation is affected by coverage measures which may take the form of fire protection expenditures and fuel management activities respectively. Reed (1987) does not consider nontimber benefits, and assume that fire protection only influences the probability of fire occurrence. Amacher and *al.* (2005) consider amenity services. They assume that nonindustrial forest owners can undertake sylvicultural practices such as intermediate fuel treatment and varying planting density. They show that, based on simulations, the standard result that fire reduces the optimal rotation age does not hold when landowners use fuel management. Indeed, the optimal rotation age rises as fire risk increases. They do not analyze the financial hedging strategy, and they adopt a Faustmann framework but not a basic two-period model.

In contrast, in this paper our purpose is to focus on self-coverage activities which may be used by nonindustrial private forest owners in order to hedge against natural risks; we mainly consider financial strategies (accumulation of savings) and sylvicultural practices (regeneration of forest). Our paper builds on the literature that has explored self-insurance practices mostly in a static framework (Ehlrich and Becker, 1972 ; Lee, 1998 ; Jullien and *al.*, 1999). Although these static works are very helpful to understand agents' coverage behaviour, they cannot be used to address our questions that require a simple dynamic framework. The most important contributions in the literature in this context are by Gollier (2002), Gollier (2003), and Braun and Koeniger (2007) but they investigate the interaction between market insurance and accumulation of riskless asset except Gollier (2002). Here we propose, in an expected utility framework, a dynamic model with two periods to represent harvesting and hedging behaviour of a forest owner that derives utility from timber revenue and amenities provided by the standing forests. We assume that he/she is a nonindustrial private forest owner, in the sense that his/her main earnings do not come from forest harvestings. This is consistent with, on the one hand, the assumption according to which he/she is risk averse with respect to natural disasters; on the other hand, the fact that he/she does not buy marketable insurance coverage. Such an utility maximization framework with two-period has been used in many previous papers (Max and Lehman, 1989 ; Hyberg and Holthausen, 1989 ; Amacher and Brazee, 1997 ; Koskela and Ollikainen, 1997, 1999) to study forest management but not to analyze hedging strategies. The paper extends the earlier analyzes in these points. It is shown that accumulation of savings and sylvicultural practices may be seen as perfectly substitutable as hedging strategy by the nonindustrial private forest owners. It is also shown that the harvesting rule displays a specific sensitivity to price effects and/or changes in the distribution of natural hazards, depending on whether forest owners opt for the financial strategy or undertake sylvicultural practices.

The rest of the paper is organized as follows. Section 2 presents the theoretical model of timber supply when nonindustrial private forest owners value amenity services of forest stands and there is an uncertainty on production. Each hedging tool is separately studied. Section 3 derives results about the comparative statics by interpreting the differences between the two prevention tools. Finally, section 4 contains some concluding remarks.

2 Optimal hedging strategies in a risky context

There are two categories of decision variables given that forest, on the one hand is a productive asset for the owner (forest allows the owner to obtain earnings), and on the other hand, it is a risky asset with an uncertain value in the future (requiring that the forest owner undertakes protective investments). The first kind of decision variables is associated to the forest management strategies (harvesting at each date). The second type of decisions linked to the coverage of risks, is understood either as savings noted s or sylvicultural practices noted q.

We consider a nonindustrial private forest owner endowned with an exogenous initial wealth Y and an even-aged forest with an initial stock Q. The owner is assumed to have preferences over present and future consumption (c_1 and c_2) and over present and future amenity services provided by the forest stands (k_1 and k_2)[1]. For the sake of simplicity, we assume that preferences have a representation which is separable (at each date) between consumptions and amenities, and additively separable accross periods, which write as:

$$V = u(c_1) + v(k_1) + \delta E\Big[u(c_2) + v(k_2)\Big] \tag{1}$$

where δ denotes the discount rate and E the expectation operator, u being the utility value of consumption (supposed to be increasing and concave), v being the utility value of forest amenities (being increasing and concave). In order to rule out inessential difficulties, we assume that $v'(k_1) = v'(k_2) = m > 0$. As a result, the assumptions made on u ensure that the second order conditions are always satisfied.

The existence of the forest stocks k_i with $i = 1, 2$ procures amenity services to the forest owner. The value of the forest stock in the second period is uncertain because we assume that forest may be damaged by a natural hazard at the beginning of the second period, for example forest fire or windstorm. In our framework, this is captured as follows: the physical gross rate of forest growth γ is a random variable whose realizations belong to the interval

[1]There is a current substantial interest in evaluating and valuing various services provided by different ecosystems. Some of these studies deal with the amenity services in the forest sector (Zandersen and Tol (2003)). There is several methods in order to estimate the value of amenities. For example, the travel cost method and the contingent valuation one are used to assess tourism and recreation services. For more details on the methods, see Barbier and *al.* (1997) and for informations about categories of amenities, see Costanza and *al.* (1997).

$]0, \overline{\gamma}]$ with $\overline{\gamma} > 1$.

2.1 Financial strategy

If the forest owner opts for the financial tool in order to protect the forest stand against the consequences of a natural disaster, the decision variables are the harvesting in the first period and in the second one, denoted respectively x_1 and x_2, and the savings s.

The objective of the forest owner is the maximisation of (1) with respect to x_1, x_2 and s, under the following relationships for consumption flows and forest stocks:

$$c_1 = Y + p_1 x_1 - s \tag{2}$$

$$k_1 = Q - x_1 \tag{3}$$

$$c_2 = p_2 x_2 + Rs \tag{4}$$

$$k_2 = \gamma k_1 - x_2 \tag{5}$$

The equations (3) and (5) give the joint production of timber and amenities. By choosing current harvesting of the initial forest stand Q, the forest owner defines also k_1. This remaining stock will grow according to the stochastic growth rate γ. The choice of the second period harvesting x_2 determines also the future forest stock k_2 which gives terminal amenity services.

We consider that the timber price at date i is denoted by p_i with $i = 1, 2$ and $R = (1 + r)$ where r denotes the net interest rate on the capital market. Then the two equations (2) and (4) deal with the forest owner's consumption and savings decisions. In the first period, the consumption is defined by the sum of the initial wealth and the revenue from harvesting minus the savings. During the first period, the forest owner allocates the total revenue between current consumption and savings. In the second period, the consumption represents the sum of the revenue from harvesting and the capital income plus savings.

For an interior solution, the optimal first and second period harvesting $({x_1}_s^*, {x_2}_s^*)$, and the optimal accumulation of savings (s^*), are given by the following first order conditions:

$$p_1 u'({c_1}_s^*) - m(1 + \delta E[\gamma]) = 0 \tag{6}$$

$$p_2 u'({c_2}_s^*) - m = 0 \tag{7}$$

$$-u'({c_1}_s^*) + \delta R u'({c_2}_s^*) \quad = 0 \tag{8}$$

with ${c_1}_s^*$ $({c_2}_s^*)$ corresponding to the optimal first (second) period consumption and ${k_1}_s^*$ $({k_2}_s^*)$ representing the optimal timber stock at the first (second) period.

The equation (6) means that the optimal first period consumption (which is controled thanks to the optimal level of harvesting in first period) is reached when the marginal benefit of this consumption expressed in utility terms, $p_1 u'({c_1}_s^*)$, is equal to its marginal cost (which is constant) $m(1 + \delta E[\gamma])$. Remark that this marginal cost can be divided in two terms. The first effect comes from the existence of a tradeoff between consumption and amenity services in the first period: an increase in x_1 allows to increase the first period consumption but reduces the first period stock k_1, such as the value of amenity services decreases at a constant rate m. The second effect is explainable in terms of intertemporal substitution effects: the increase of x_1 reduces, all else held equal, the second period value of the forest stock k_2, and thus decreases the second period value of amenity services.

The first order condition (7) determines ${c_2}_s^*$ (which is now controled thanks to the optimal level of harvesting in second period) by equating the marginal benefit of harvestings expressed in utility terms $p_2 u'(c_{2_s}^*)$ and their marginal cost m.

Finally, the condition (8) means that the optimal savings is obtained when the marginal benefit of savings, expressed in utility terms, $\delta R u'(c_{2_s}^*)$ is equal to its marginal cost (also in utility terms) $u'(c_{1_s}^*)$. Remark that (8) can be rewritten as follows:

$$\frac{u'(c_{1_s}^*)}{u'(c_{2_s}^*)} = \delta R \tag{9}$$

This expression means that the optimal savings is reached when the marginal rate of substitution between consumptions is equal to the return of savings, which is a condition well-known in the literature on consumption/savings decision.

Mixing the first order conditions (6), (7) and (8), allows us to obtain the fundamental intertemporal harvesting rule, for current harvest, defined by:

$$\frac{p_1}{p_2}\delta R = 1 + \delta E[\gamma] \tag{10}$$

Condition (10) may be understood as the Faustmann's rule (1849) which is a result well-known in the literature on forestry management. The Faustmann's rule, which is written as $p_1 R = p_2 E[\gamma]$, states that at the optimal cut period, the forest owner is indifferent between harvesting in the first period and saving the revenue, and harvesting in the second period. Thus several comments can be made on the basis of equation (10). On the one hand, to the extent that it relies on exogenous parameters of the model, it is a necessary condition for an interior equilibrium to exist; more specifically, the interior equilibrium in our model is supported by the condition that $\frac{p_1}{p_2}R - E[\gamma] > 0$, i.e. the real interest rate must exceed the expected growth rate of forest. It implies that, when amenity services are introduced (given that $v'(.) = m$, the uncertainty on γ has no influence on this result), the level of harvesting in the first period is smaller than the one predicted by the Faustmann's rule.

2.2 Sylvicultural Practices

The sylvicultural practices consist, for the forest owner, in a regeneration of a part of the forest in the first period. This regenerated part of the forest procures an outcome only in the second period - the implicit assumption is that the young plantations produce no financial and no ecological value as soon as they have not yet reached a sufficient size which occurs only in the second period. The investment in the regeneration process will be represented through a constitution cost at the first period, denoted cq where c is the marginal cost (let us assume it is constant), and q represents the amount of the stock of regenerated trees (for example, a physical reserve of trees) choosen by the forest owner.
To the extent that the forest owner opts, now, for the sylvicultural practices (rather than for the accumulation of savings) the decision variables are the harvesting in the first and in the second period, denoted respectively x_1 and x_2, and the stock of regeneration q.

The objective of the forest owner is the maximisation of (1) with respect to x_1, x_2 and q

and under the following relationships:

$$c_1 = Y + p_1 x_1 - cq \tag{11}$$

$$k_1 = Q - x_1 \tag{12}$$

$$c_2 = p_2 x_2 \tag{13}$$

$$k_2 = \gamma k_1 + q - x_2 \tag{14}$$

The cost of the sylvicultural practices is deducted from the initial wealth Y plus the revenue of the first period harvesting $p_1 x_1$. The forest stock in the first period k_1 is the same whatever the coverage strategy adopted by the forest owner. We can see that the sylvicultural practices act on the forest stock of the second period by increasing it, whereas, as we have seen previously, the savings acts on the consumption of the second period by increasing it. Thus the forest owner removes cq to the first period consumption to set up a stock of regeneration which increases the forest stock in the second period.

Once more, the optimal first and second period harvesting $(x_{1_q}^*, x_{2_q}^*)$, and the optimal stock of regeneration (q^*), are determined, for an interior solution, through the following first order conditions :

$$p_1 u'(c_{1_q}^*) - m(1 + \delta E[\gamma]) = 0 \tag{15}$$

$$p_2 u'(c_{2_q}^*) - m = 0 \tag{16}$$

$$-cu'(c_{1_q}^*) + \delta m = 0 \tag{17}$$

with $c_{1_q}^*$ $(c_{2_q}^*)$ corresponding to the optimal first (second) period consumption and $k_{1_q}^*$ $(k_{2_q}^*)$

representing the optimal timber stock at the first (second) period.

The conditions (15) and (16) are the same as the ones (6) and (7). The condition (17) means that the optimal stock of regeneration is reached when the actual value of the marginal benefit of this stock (which is constant) δm is equal to its marginal cost $cu'({c_1}_q^*)$ (expressed in utility terms).

Using (16) and (17), we have the following simplified condition:

$$\frac{u'({c_1}_q^*)}{u'({c_2}_q^*)} = \delta \frac{p_2}{c} \tag{18}$$

This expression means that the equilibrium value for q is reached when the rate of return of sylvicultural practices is equal to the marginal rate of substitution between consumptions at each date. This also shows that sylvicultural practices mimic the functionning of financial markets and the accumulation of savings, in the sense that they play the role of a technology of intertemporal transfers of ressources: the forest owner has the opportunity to choose a consumption path along which the rate of return of the physical asset equals his/her personal marginal rate of intertemporal substitution.

Finally, mixing the three conditions (15), (16) and (17) enables us to characterize the optimal harvesting rule as follows:

$$\delta \frac{p_1}{c} = 1 + \delta E[\gamma] \tag{19}$$

This last equation (19) leads to the same qualitative results as those suggested for the condition (10): thus the similar comments apply as regard to the role of uncertainty and amenity services.

Finally, comparing (8) to (17) and (10) to (19) suggest the following fundamental result:

Proposition 1: Consider an economy (its basic parameters are p_1, p_2, δ), where forest owners have access to perfect financial markets paying a non risky (gross) rate of interest denoted R in order to manage natural hazards associated to the random growth rate of forest γ. Then, there always exists an alternative economy (with the same basic parameters and natural hazards) where forest owners invest in costly sylvicultural practices (the marginal cost being c) which enable them to regenerate a part of their forest, such as forest owners have the same intertemporal consumption rule and adopt the same harvesting rule.

The intuition of this "equivalence theorem" is obvious, coming back to (17): consider that $\frac{p_2}{c} = R$, meaning that the gross interest rate of savings is equal to the rate of return of sylvicultural practices - (8) and (17) are thus identical, implying that, whatever the instrument at the disposal of forest owners to manage natural hazards, they will be induce to choose the same intertemporal consumption rule. By the same token, if $\frac{p_2}{c} = R$, then (10) and (19) are identical, meaning that in both economies, forest owners also undertake the same harvesting activities. Consequently , as soon as $\frac{p_2}{c} = R$, savings and sylvicultural practices are perfectly substitutable tools. In other words, $\frac{p_2}{c} = R$ implies that the forest owner is indifferent between accumulation of savings or the use of sylvicultural practices in order to protect his/her forest against natural hazards. Therefore we did not address the issue of the joint use of savings and sylvicultural practices because, if $\frac{p_2}{c} \neq R$, they are no more perfectly substitutable and so (given that uncertainty bears only on γ) forest owners will use the most efficient or less costly tool. For example, when $R > \frac{p_2}{c}$, forest owners will accumulate savings while when $\frac{p_2}{c} > R$, owners will invest in sylvicultural practices.

3 Analytics of timber supply under risk and multiple-use of forests

This section develops the comparative statics of the model, for both instruments of risk management. Although the savings and the sylvicultural practices may be seen as perfectly substitutable tools (proposition 1), the harvesting rules in the two cases have a different sensitivity to the parameters of the model, especially to price shocks and to a shift in risk[2]. The comparative statics results are divided in four categories. The first one deals with the impact of an increase in initial wealth or initial forest stock on the three decision variables for both savings and sylvicultural practices. The second one bears on the effect of a rise in the timber prices on the forest owner's hedging strategies. The third category takes an interest in the effect of an increase in the savings rate for the savings case and in the marginal cost of the regeneration process for the sylvicultural practices one. The last category deals with the effect of an increase in the expected forest growth rate on the decision variables for both instruments (an increase in $E(\gamma)$ may be the result of a first or second stochastic dominance shift in the probability distribution of γ). Now, we analyse with more details each of these categories.

3.1 Change in initial wealth and initial forest stock

RESULT 1. *For both the financial strategy and the sylvicultural practices an increase in the initial wealth Y or in the initial forest stock Q has no effect.*

[2]Derivations of all the following results are available from the authors upon request.

The model predicts that stock variables, Y and Q have no impact on the decision variables for both instruments, but this result is not a surprise because it is explainable by our assumption of a constant marginal utility for amenity services which implies risk neutrality to forest growth risk.

3.2 Change in timber prices

RESULT 2.

A) Financial strategy : i) an increase in p_1 leads to a rise in current harvesting and savings and to a decrease in the future harvesting. ii) an increase in p_2 leads to a rise in the future harvesting and to a decrease in current harvesting and savings.
B) Sylvicultural practices : i) an increase in p_1 generates a rise in current harvesting and sylvicultural practices while it has no effect on the future harvesting. ii) an increase in p_2 has no effect.

Given that the model captures no stock effect (wealth effect), it is not surprising to find that a change in a price entails only a pure substitution effect.
For the savings context, as the timber price in the first period increases, the forest owner rises the harvesting in order to have a more important return. This larger return obtained at the end of the first period allows the owner to diminish the second period harvesting while maintaining the consumption of the second period constant. As a result, the amenity services provided by the forest stock in the second period increase. Moreover, a rise in p_1 pushes the owner to increase the savings.
For the sylvicultural practices context, from (16), we observe that p_1 has no effect on c_2 and

thus no one on x_2. Nevertheless, as the timber price in the first period increases, the first period return increases too and by rising x_1, the forest owner can face to higher regeneration costs and can increase his/her sylvicultural practices.

For the savings case, a rise in p_2 decreases x_1 and s while it rises x_2. Actually, as p_2 increases, the forest owner lowers the first period harvesting in order to harvest more in the second period and to have a higher return. However, we observe that an increase in the second period timber price encourages the forest owner to decrease the savings.
For the sylvicultural practices case, we see that from equations (13) and (16), the forest owner can increase the consumption of the second period, when p_2 rises, without any change in x_2. Moreover, from (15), we note that c_1 is independent of p_2 and as the marginal utility of amenity services is constant, the forest owner has no incentives to change k_1 and k_2 so that when the timber price in the second period increases, the only one effect is a rise in c_2.

3.3 Change in the parameters of hedging strategies

RESULT 3.

A) Financial strategy: an increase in R leads to a rise in current harvesting and savings and to a decrease in the future harvesting.

B) Sylvicultural practices: an increase in c generates a decrease in current harvesting and sylvicultural practices while it has no effect on future harvesting.

Facing an increase in R, we note the presence of a pure substitution effect. Therefore, as the rate of return on savings rises, the forest owner increases the first period harvesting so as to save more and to have more money in the second period. This larger amount of

money allows the forest owner to reduce the harvesting in the second period while keeping the consumption of the second period constant. Moreover, as x_2 decreases, the forest stock in the second period rises and the amenities too. We also observe that an increase in R leads the forest owner to increase his/her savings in order to be wealthier.
As the marginal cost of the regeneration process increases, the forest owner diminishes q, i.e the stock of the regenerated trees, because it becomes more and more expensive for the owner to regenerate a part of his/her forest.

3.4 Change in the expected forest growth rate

RESULT 4.

A) Financial strategy: an increase in $E(\gamma)$ leads to an increase in the future harvesting and to a decrease in current harvesting and savings.
B) Sylvicultural practices: an increase in $E(\gamma)$ generates a decrease in current harvesting and sylvicultural practices and has no effect on future harvesting.

We observe that for the savings case, an increase in $E(\gamma)$ rises the second period harvesting and reduces the first period harvesting and the savings. Therefore, from (6) we observe that if $E(\gamma)$ increases, the marginal cost of the first period harvesting rises so that the forest owner lowers x_1. The impact of an increase in $E(\gamma)$ on x_2 can be explained by two conflicting effects. The first one generates a decrease in x_2. In this case, the forest owner does not need to increase x_2 because, as the expected forest growth rate rises, his/her consumption in the second period increases. The second effect implies an increase in the second period harvesting. Indeed, the forest owner rises x_2 jointly to the increase in $E(\gamma)$ so as to increase his/her consumption in the second period. Thus, as an increase in $E(\gamma)$ generates an increase in x_2, we can notice that the second effect dominates. Finally, in the first period, the forest owner, anticipating an increase in $E(\gamma)$, reduces his/her savings because as $E(\gamma)$ rises, he/she can satisfy a higher consumption in the second period with less savings.

For the sylvicultural practices case, an increase in the expected forest growth rate reduces the first period harvesting and the regenerated trees while it has a null impact on the second period harvesting. From (15), we note that an increase in $E(\gamma)$ implies a rise in the marginal cost of the first period harvesting. This result leads the forest owner to decrease the first period harvesting. The impact of an increase in $E(\gamma)$ on x_2 can be explained by the two conflicting effects previously mentionned. In this case, we observe that an increase in the expected forest growth rate has no impact on x_2, meaning that the two effects offset each other. In the end, the decrease in q due to a rise in $E(\gamma)$ can be explained as follows: the owner needs a less important stock of regenerated trees when the expected forest growth increases because the rise in $E(\gamma)$ ensures the forest owner a larger stock of trees in the second period.

In order to conclude (see Table 1 where is reported all previous comparative statics results), we observe that harvesting rules for the two risk management instruments have not the same sensitivity to price shocks and, to some extent, to risk shock.

4 Concluding Comments

In this article, we develop a dynamic theoretical model in order to analyse the forest owner's behaviour in a risky forest management. We compare two coverage activities that the forest owner can undertake to protect the forest against natural hazards, the savings and the sylvicultural practices. In this work, there is several contributions. First, we develop the comparative statics of harvesting and hedging strategies by studying the effect of each parameter on the optimal decisions. Second, we compare two different hedging strategies in terms of harvesting when forest owners value amenity services of forest. Third, our approach is original in the sense that the risk bears on the forest growth rate while it usually bears on future timber price. Finally, we analyse the savings in a context where the financial tools are more and more considered in order to cover the important risk. In this framework, we demonstrate that, the harvesting rule, in the presence of amenity services and a random growth rate for forest, is smaller than the one predicted under the Faustmann's rule. We also show that under some assumptions, accumulation of savings and sylvicultural practices may be seen as perfectly substitutable for the forest owners. Finally, we show that the harvesting rule displays a specific sensitivity to price effects and/or changes in the distribution of natural hazards, depending on whether forest owners opt for the financial strategy or undertake sylvicultural practices.

Several extensions are worth to be discussed for this research. First, our assumption of a constant marginal utility for amenity services could be seen as a limit of this paper. In fact, our result can be easily generalized assuming that v has a Constant Absolute Risk Aversion specification - given that wealth effects are also neutralized under the CARA assumption. Moreover, the same results still hold when we consider that v displays Decreasing Absolute Risk Aversion : in this last case, it is well-known in the literature that the pure substitution effects exhibited in our paper are amplified by the wealth effects. However, in the opposite case where v satisfies the Increasing Absolute Risk Aversion assumption, we know that we can expect to obtain ambiguous results since pure substitution effects and wealth effects have opposite signs.

Nevertheless, each of these alternative assumptions for v is consistent with the central result of the paper (proposition 1). This one cannot be challenged without introducing some frictions or imperfections in the model. For example, the basic two-period model we use implies that both financial decisions (savings) and sylvicultural pratices are held for the same (short term) horizon. However, due to imperfections in the financial markets on the one hand (asymmetrical information, borrowing constraints, different interest rates for lenders and borrowers), and on the other hand, given the existence of a natural delay between the plantation of the trees and their harvesting, the horizon of decisions in financial markets may be shorter than for decisions connected to the sylvicultural practices. Moreover, the production process in forestry may be more or less lengthy, depending on the choice of trees species. Remark that our analysis is still relevant for forests having a unique specie and/or homogenous trees in age, at least in the absence of financial imperfections. But more generally, dealing with market imperfections and non homogenous stands in forestry would require to introduce a n-period model. In such a framework, financial strategies and sylvicultural practices should appear as no more perfectly substitutable, and the study of the optimal mix of both instruments would become a relevant issue. In the same spirit, a last extension consists in the possibility for the forest owners to learn the state of the world (to gather informations on the weather, and thus on γ). We can expect that when information has a positive value, it will be used by forest owners in order to plan both their harvesting decisions and their risk management decisions. These important extensions are left out for future researches.

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Table 1: Comparative statics results

	Savings			Sylvicultural practices		
	x^*_{1s}	x^*_{2s}	s^*	x^*_{1q}	x^*_{2q}	q^*
Initial wealth Y	0	0	0	0	0	0
Initial forest stock Q	0	0	0	0	0	0
Timber price at first period p_1	+	−	+	+	0	+
Timber price at second period p_2	−	+	−	0	0	0
Rate of return on savings R	+	−	+			
Cost of sylvicultural practices c				−	0	−
Expected forest growth rate $E(\gamma)$	−	+	−	−	0	−