Risk Management Behavior of a Forest Owner to Address Growth Risk

Marielle Brunette and Stéphane Couture

We analyze risk management behavior (financial savings *versus* physical savings) of a private forest owner who values amenities in relation to uncertainty about timber growth. In a two-period model, we study the properties of optimal current and future harvesting and risk management decisions. We show that the forest owner chooses the tool with the highest rate of return unless both risk management instruments are perfect substitutes. We prove that future harvesting is greater under physical savings than under financial savings. Comparative static results on amenity preferences, incomes, forest stocks, timber prices, and opportunity costs are investigated.

Key Words: amenities, financial savings, forest management, growth risk, harvesting decision, physical savings

In many European countries, forests are managed by small nonindustrial private forest (NIPF) owners who have specific characteristics that affect how they manage such forests. Two main characteristics are important. First, the primary objective of NIPF owners is to smooth consumption over time. They therefore face a savings-consumption problem linked with forest management. Second, NIPF owners have positive utility that results from amenity functions provided by the forests and revenue from timber sales. Indeed, forests provide a wide variety of nontimber services that include hiking opportunities, landscapes, and mushroom crops. These services are produced jointly with timber and vanish with the standing stock. Several studies have demonstrated that NIPF owners confer some private value on the amenity services of forest stock even when no financial incentive is linked to the functions (Birch 1994, Butler and Leatherberry 2005, Zhang, Zhang, and Schelhaas 2005). The resulting savings-consumption problem associated with a joint production property affects how NIPF owners manage their forests.

Furthermore, NIPF owners face risks associated with nature that affect the joint products of forests and their efforts to smooth consumption. The frequency and severity of extreme climate events appears to have increased in recent years, leading to increasing damage to forests (Schelhaas, Nabuurs, and Schuck 2003). Natural disasters directly affect timber production and, consequently, the amenity services obtained from standing stock. The amenity value, therefore, reinforces owners' interest in risk management measures. Despite of the availability of market insurance,[1] NIPF owners do not rely on insurance

[1] In Europe, NIPF owners rarely carry insurance to protect their forests against natural disturbances (Brunette and Couture 2008).

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in many cases; generally, they usually opt for financial savings as the primary means by which to smooth consumption across different states of nature (Puech 2009) or adopt alternative forest management strategies to reduce potential losses (Lindner, Lasch, and Erhard 2000, Spittlehouse and Stewart 2003). A major forest management practice is forest stock regeneration, which involves planting selected species that are more resilient to natural damage but less productive than traditional ones (Lindner, Lasch, and Erhard 2000). One can view the choice of resistant species as a way to protect the owner against risk using a physical method—a form of savings but with a physical component. Moreover, some programs implemented in Europe after the last exceptional natural disaster have moved NIPF owners to adopt risk management practices in an effort to reduce their level of risk.[2] Therefore, before one analyzes policy instruments, it is essential to understand the risk management behavior of NIPF owners. Such an examination raises many questions. Should NIPF owners use financial savings and physical risk management tools simultaneously? How do risk management strategies affect allocation within a forest to harvesting and amenity services and do any resulting differences in harvesting behavior depend on the risk management strategies selected by the forest owner? How can governments influence NIPF owners' behavior? We provide some answers to these questions.

Analytical economic studies in forest management typically have focused on the effects of risk and amenity preferences on timber supplies (Koskela and Ollikainen 1999, Amacher, Ollikainen, and Koskela 2009) or the effect of taxation of forest properties on harvesting and thinning (Ovaskainen 1992, Koskela and Ollikainen 1997, Barua, Kuuluvainen, and Uusivuori 2011, Barua et al. 2010). They have ignored the implications of risk management decisions. The effects of risk and amenity preferences were analyzed in a rotation model in Englin, Boxall, and Hauer (2000) and in a two-period model in Amacher, Ollikainen, and Koskela (2009). These two studies showed that the harvesting rule is defined by a tradeoff between harvesting revenue and amenity valuation. In addition, Amacher, Ollikainen, and Koskela (2009) analytically revealed that the current period's harvest depended positively on current timber prices and interest rates and negatively on future timber prices, whereas future harvests depended positively on future timber prices and negatively on current timber prices and interest rates. However, studies have not examined risk management decisions within a framework that combines risk and amenity preferences. In this study, we contribute to the literature concerning two-period models in two ways. First, we concentrate on analysis of savings decisions in an expected utility model with amenities and risks and without restrictions on risk and the utility function. Amacher, Ollikainen, and Koskela (2009) assumed that the random variable (forest growth) was normally distributed and that utility was described by an exponential utility function. We avoid such restrictions. Second, we introduce a second risk management instrument (referred to as physical savings) and analyze optimal harvesting decisions. Within this framework, our objective is to investigate decision-making by NIPF owners regarding managing risk posed by natural hazards and harvesting using a two-period framework. We provide a comparative analysis of alternative advantages produced by two risk management measures: financial savings and physical savings. We explore

[2] See, for example, the Commission of European Communities (2006) and the United Nation's Food and Agricultural Organization (2007) for information on prevention of storm risks in Europe.

harvesting and risk management behavior by forest owners when they value amenity services provided by forests and there is uncertainty about biomass growth. Our results show that, with any constraint on the forest's surface area, the owner chooses the tool that offers the greatest rate of return unless the two risk management instruments are perfect substitutes. However, an assumption that the forest surface size is fixed can lead owners to use the two risk management instruments jointly. We also demonstrate that more timber is harvested in the second period under physical savings than under financial savings. An increase in amenity preference decreases the optimal quantity of timber to harvest in the future but increases the degree of risk management measures that is optimal. We also use comparative static results to investigate incomes, forest stocks, timber prices, and opportunity costs. Finally, we show that public (governmental) intervention can affect risk management decisions made by NIPF owners.

The next section presents the theoretical model of timber supply with amenity service valuation, uncertainty about forest growth, and two risk management instruments that are studied together. We then present harvesting rules for each risk management instrument and compare them. That section also presents the results of comparative static effects. We subsequently analyze how public intervention affects how NIPF owners manage their forests against natural risks. The final section provides concluding remarks.

Model with Financial and Physical Savings

Assumptions and Basic Setup

Consider an NIPF owner who is endowed with exogenous initial wealth at the beginning of each period (Y_1 and Y_2) and an initial forest stock (Q). The owner behaves as if s/he has maximized utility from consumption (c_1 and c_2) and nontimber services of the standing forest (k_1 and k_2) over two periods. We make the traditional assumption that the larger the forest stock, the greater the amenity services provided (Max and Lehman 1988). We consider an additive and separable utility function that is strictly concave in its arguments so that

$$(1) \qquad V = u(c_1) + v(k_1) + \delta\left[u(c_2) + v(k_2)\right]$$

where $\delta \in \left]0,1\right[$ is the discounting factor and $u(\cdot)$ and $v(\cdot)$ are temporal utility functions for consumption and amenities, respectively. We assume that u and v are increasing and concave ($u' > 0$, $u'' < 0$ and $v' > 0$, $v'' < 0$).

The problem for the forest owner is to maximize the expectation of equation 1 subject to

$$(2) \qquad c_1 = Y_1 + \pi(x_1) - s - eq \textit{ with } q \leq x_1,$$

$$(3) \qquad c_2 = Y_2 + Rs + \pi(x_2),$$

$$(4) \qquad k_1 = Q - x_1 \textit{ with } 0 \leq x_1 \leq Q, \text{ and}$$

$$(5) \qquad \tilde{k}_2(\tilde{\theta}) = \tilde{\theta}g(Q - x_1) - x_2 + q \textit{ with } 0 \leq x_2 \leq \tilde{\theta}g(Q - x_1) + q.$$

The forest owner's decision variables are quantity of timber to harvest at each period (x_1 and x_2) and the risk management tool(s) to employ. We consider two possible risk management instruments: financial savings[3] (s with $s > 0$) and physical savings (q with $q > 0$). The owner can decide to save money as a hedge against future damage or to plant species that have greater resistance to damage. This alternative forest management strategy leads to an outcome only in period 2—the implicit assumption is that young plantations produce no financial or ecological value as long as the trees have not yet reached sufficient size, which occurs only in the second period.[4] Consequently, the owner can save funds in the current period and consume more in the future based on the gross interest rate in the capital market (R). S/he can also decide to plant resistant species during the current period with an expenditure of $e(q)$ where $e(q) = eq$ and $e > 0$.

First-period consumption (equation 2) comprises the owner's initial wealth (Y_1) and net revenue from harvesting ($\pi(x_1)$) minus financial savings (s) and the cost of physical savings (eq). $\pi(x_i)$ is defined as the difference between harvest revenue, p_1x_1, and harvest cost, hx_1 with $h > 0$. p_1 corresponds to the first-period timber price. We impose a restriction on q because the area devoted to physical savings cannot be greater than the area that is harvested ($q \leq x_1$); in other words, we consider a fixed forest surface. Consumption in the second period (equation 3) originates from initial wealth (Y_2), net revenue from harvesting ($\pi(x_2) = p_2x_2 - hx_2$), and earnings on financial savings (Rs). p_2 corresponds to the second-period timber price. The volume of the forest stock at period 1, k_1 (equation 4), is the initial forest stock (Q) minus the first-period harvest (x_1). Thus, it may be useful to consider some natural restrictions, such as $0 \leq x_1 \leq Q$, that would introduce some obvious limits on the first-period harvesting decision; the owner may prefer either (i) not to harvest at all in the first period or (ii) to harvest all of the available timber in the first period. Both restrictions imply, given the forest owner's intrinsic preference for amenity services, that $k_1 \geq 0$.

The timber stock evolves between the two periods according to a process described by the growth function $g(k_1)$ satisfying $g(0) = 0$, and for any $k_1 > 0$, $g'(k_1) > 0$, and $g''(k_1) < 0$. However, the final outcome of this natural process depends on realization of a random variable, θ, that represents the multiplicative risk related to forest growth.[5] $\tilde{\theta}$ reflects the influence of natural risks (biological and/or climatic) that affect the volume of the forest stock at the beginning of the second period prior to the decision to harvest in the second period. Consequently, the volume of the forest stock at the end of the growth process and before harvesting takes place is $\tilde{\theta}g(k_1)$. Possible realizations for $\tilde{\theta}$ are described according to a probability distribution that is assumed to be known by the forest owner and is represented by a cumulative function referred to as $F(\tilde{\theta})$ that is defined on $[\underline{\theta}; \bar{\theta}] \subset [0,1]$ with a density $f(\tilde{\theta}) > 0$ throughout. We can also choose a value for $\underline{\theta}$ that is as close as possible to 0, which would represent realization of a catastrophic event in which the forest was fully destroyed.

[3] Indeed, as we are interested in the risk management characteristic of financial savings, we assume that the forest owner cannot borrow.

[4] Consequently, physical savings are not associated with the outcome in the first period. Rather, financial revenue and amenity services that are highly valued by private forest owners accrue in the second period (Birch 1994).

[5] Amacher, Ollikainen, and Koskela (2009) showed that, in a context involving random growth and amenities, an additive risk leads to results similar to those of a framework with certainty. Consequently, we opt for multiplicative risk.

In contrast, as $\tilde{\theta} \to 1$, the event corresponds to the best outcome for the NIPF owner when no natural risk damages the forest property.

According to equation 5,[6] the volume of the forest stock at the end of the second period consists of the volume of the available stock after realization of the risk, $\tilde{\theta}g(Q - x_1)$, up to the amount of physical savings, q, minus the second-period harvest ($x_2 \geq 0$). The second-period harvest decision is made after realization of $\tilde{\theta}$ and is constrained by $x_2 \leq \tilde{\theta}g(Q - x_1) + q$.

Optimal Rules of Risk Management Strategies

Each of the risk management instruments plays a specific role in the risk exchange. On the one hand, financial savings allow for reallocation of resources across dates to smooth consumption inter-temporally, possibly providing coverage against future risks (i.e., precautionary savings). Thus, the use of financial markets is a matter of an inter-temporal tradeoff. Physical savings, on the other hand, allow the owner to reallocate resources across different states of nature and reduce exposure to natural risks (i.e., mitigate the consequences of nature on the rate of forest growth). Thus, physical savings are a matter of risk tradeoff. However, both instruments are designed to fulfill the same objective, and both have perfectly foreseen outcomes in the second period. In particular, they have a deterministic influence in the sense that their use entails no additional source of uncertainty for the NIPF owner. The interest rate and cost of physical savings are known with certainty. As a result, the owner can use two instruments that are close to substitutes since they differ only in terms of the return/cost conditions. The issue, then, is whether forest owners should use both instruments. We show that owners generally should not.

The forest owner chooses x_1, x_2, q, and s to maximize the expectation of equation 1 under constraints 2 through 5 and of non-negativity constraints on q and s. We focus on the issue of the optimal mix (q,s). Let us introduce five Lagrange multipliers: (i) $\mu = 0$ if $s > 0$ and $\mu \geq 0$ otherwise; (ii) $\lambda = 0$ if $q > 0$ and $\lambda \geq 0$ otherwise; (iii) $\beta = 0$ if $q < x_1$ and $\beta \geq 0$ otherwise; (iv) $\sigma = 0$ if $x_1 < Q$ and $\sigma \geq 0$ otherwise; and (v) $\gamma = 0$ if $x_2 < \tilde{\theta}g(Q - x_1)+q$ and $\gamma \geq 0$ otherwise. The Lagrangian, L, is then as follows.

$$\mathrm{L} = u(c_1) + v(k_1) + \delta u(c_2) + \delta E\left[v(\tilde{k}_2)\right] + \mu s + \lambda q + \beta(x_1 - q) + \sigma k_1 + \gamma(-x_2 + E\left[\tilde{\theta}g(k_1)\right] + \mathrm{q})$$

The first-order conditions are[7]

$$(6) \quad L_{x1} = u'(c_1)\pi'(x_1) - v'(k_1) - \delta E\left[v'(\tilde{k}_2)\tilde{\theta}g'(k_1)\right] + \beta - \sigma - \gamma E\left[\tilde{\theta}g'(k_1)\right] = 0,$$

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[6] It is usually assumed that $k_2 = k_1 + h(k_1) - x_2 = k_1(1 + (h(k_1) / k_1)) - x_2$ where $h(\cdot)$ is an increasing and concave function (see Koskela and Ollikainen 1997, 1999, Ovaskainen et al. 2006) in which $h(k_1) / k_1$ corresponds to the net forest growth rate. One can see that the two specifications are equivalent to the extent that $g(k_1) / k_1 = 1 + h(k_1) / k_1$ corresponds to the gross forest growth rate. Our formulation simply allows for more tractable expressions for the first-order conditions.

[7] Given the large number of associated constraints that may potentially be involved, we introduced some simplifications to allow us to focus on the main issues of the model. We neglected the non-negativity constraints on x_1 and x_2; in other words, we assumed that $x_1 > 0$ and $x_2 > 0$. Intuitively, then, p_1 and p_2 must be large enough. Note that this also implies that $p_i - h > 0$ is not enough for x_i to be greater than 0 for all $i = 1,2$: p_1 and p_2 must be sufficiently greater than the

(7) $$L_{x2} = \delta u'(c_2)\pi'(x_2) - \delta E[v'(\tilde{k}_2)] - \gamma = 0,$$

(8) $$L_s = -u'(c_1) + \delta R u'(c_2) + \mu = 0, \text{ and}$$

(9) $$L_q = -eu'(c_1) + \delta E[v'(\tilde{k}_2)] + \lambda - \beta + \gamma = 0$$

where $\pi'(x_i) = p_i - h$ for $i = 1,2$. The second-order conditions are met due to the concavity of functions u, v, and g.

From equations 6 through 9, we can define the optimal behavior of the NIPF owner in terms of risk management instruments (as summarized in proposition 1). We only consider interior solutions.

Proposition 1: All else held equal,

If $R < \pi'(x_2)/e$, then either (1) $q^* > 0$ and $s^* = 0$ or (2) $q^* > 0$ and $s^* > 0$. In the first case, the forest owner will choose only physical savings to cover against risk, which is defined by $-eu'(c_1) + \delta \mathrm{E}[v'(\tilde{k}_2)] = 0$. In the second case, the forest owner will choose both risk management instruments.[8]

If $R > \pi'(x_2)/e$, then $s^* > 0$ and $q^* = 0$. The forest owner will choose only financial savings to cover against risk, which is defined by $-u'(c_1) + \delta R u'(c_2) = 0$.

If $R = \pi'(x_2)/e$, then $q^* > 0$ and $s^* > 0$. The forest owner will choose both risk management instruments.

Proof

Combining equations 7 and 8 leads to

$$u'(c_1) = \left(\frac{R}{\pi'(x_2)}\right)\left(\delta E[v'(\tilde{k}_2)] + \gamma\right) + \mu$$

while equation 9 yields

$$u'(c_1) = \tfrac{1}{e}(\delta E[v'(\tilde{k}_2)] + \lambda - \beta + \gamma).$$

Combining both relationships and using equation 7 gives

$$\left(\frac{R}{\pi'(x_2)} - \frac{1}{e}\right)\delta u'(c_2)\pi'(x_2) = \frac{\lambda - \beta}{e} - \mu,$$

implying that, for any solution, $sign\,(R - \pi'(x_2)/e) = sign\,((\lambda - \beta/e) - \mu)$. There are three possibilities.

1. If $R - \pi'(x_2)/e < 0$, then $(\lambda - \beta)/e < \mu$, which requires that either $s = 0$ and $q > 0$ (case 1) or $s > 0$ and $q > 0$ (case 2). In the first case,

marginal cost, h. These conditions are maintained throughout the rest of the discussion.

[8] We also resolve the problem without the constraint on the forest surface ($q < x_1$). In the unconstrained model, we note that the owner will choose only physical savings if the rate of return of physical savings exceeds the rate of return of financial savings. In this scenario, the second case obtained in the constrained model disappears.

an assumption that $s > 0$ implies that $\mu = 0$, which requires that $\lambda - \beta < 0$. $\lambda - \beta$ could be equal to zero but then equations 7 and 8 would lead to a contradiction, $R - \pi'(x_2)/e = 0$. Thus, the solution is such that $s = 0$ and $q > 0$. In the second case, an assumption that $s = 0$ implies that μ is greater than 0, which requires that $\lambda - \beta < 0$. $\lambda - \beta$ could be equal to zero but then equations 7 and 8 would lead to a contradiction, $R - \pi'(x_2)/e = \mu$. Thus, the solution is such that $s > 0$ and $q > 0$.

2. If $R - \pi'(x_2)/e > 0$, then $(\lambda - \beta)/e > \mu$ and it is impossible for $q > 0$. Indeed, $q > 0$ implies that $\lambda = 0$, which requires that μ be less than 0, which is a contradiction. Consequently, the only solution is $s > 0$ and $q = 0$.

3. If $R - \pi'(x_2)/e = 0$, then $(\lambda - \beta)/e = \mu$, which requires that $s > 0$ and $q > 0$. However, intuitively, when $s > 0$ and $q > 0$, q and s are redundant because equations 8 and 9 with $R = \pi'(x_2)/e$ and $\mu = (\lambda - \beta)/e = 0$ give the following condition:

$$Ru'(c_2) = \frac{E[v'(\tilde{k}_2)]}{e} \Rightarrow \pi'(x_2)u'(c_2) = E[v'(\tilde{k}_2)],$$

which means that one of the conditions—7, 8, or 9—is redundant.

This proposition provides the optimal choice of risk management instrument. When the rates of return from financial and physical savings are the same, the forest owner will choose to use both instruments. Indeed, they are perfectly substitutable. When the rates of return are different and forest surface is not constrained, the owner will select the one tool with the highest rate of return. When the rate of return from financial savings is greater, the owner can choose only financial savings and the optimal risk management decision is defined by $-u'(c_1) + \delta Ru'(c_2) = 0$. The optimal amount of savings is obtained when the marginal benefit of savings ($\delta Ru'(c_2)$) equals the marginal cost ($u'(c_1)$). In other words, after we rewrite equation 8, the owner obtains the optimal level of savings when the marginal rate of substitution between c_1 and c_2 is equal to the interest rate, R. Consequently, the forest owner is confronted with a consumption substitution problem between the two periods. When the rate of return from physical savings exceeds the rate obtained from financial savings, the owner can choose only physical savings and the optimal risk management decision is defined by $-eu'(c_1) + \delta E[v'(\tilde{k}_2)] = 0$. The optimal amount of savings is obtained when the marginal benefit of savings ($\delta E[v'(\tilde{k}_2)]$) equals its marginal cost ($eu'(c_1)$). Equation 9 can be rewritten as $e = \delta E[v'(\tilde{k}_2)] / u'(c_1)$. The optimal amount of physical savings is obtained when the marginal rate of substitution between the second-period amenity value and the first-period consumption equals the constant marginal cost of the risk management tool. Consequently, the forest owner faces a problem of substitution between the amenity value and the consumption rate. When the rates of return from financial and physical savings are different and the amount of the forest surface is constrained ($q < x_1$), the owner will use both of the risk management instruments. The optimal amounts of financial savings and physical savings are defined by equations 8 and 9. Indeed, even if the rate of return from physical savings is greater, the constraint on forest surface leads the owner to include financial savings because s/he cannot plant as much land with resistant species as desired.

Optimal Harvesting Rules for Financial Savings and Physical Savings

We now focus on situations in which the owner chooses a single risk management tool and concentrate on an analysis of optimal harvesting decisions in the first and second periods for interior solutions.

Harvesting Decisions in the Financial Savings Model

Let us assume that financial saving has a greater return/cost ratio than physical saving so that the owner uses only financial saving to reallocate resources between the two periods. In this case, the optimal choices (x_1^*, x_2^*, s^*)[9] are easily deduced from conditions 6, 7, and 8 for $\mu = \gamma = \sigma = \beta = 0$. We then have

$$(6') \qquad u'(c_1)\pi'(x_1) = v'(k_1) + \delta E\left[v'(\tilde{k}_2)\tilde{\theta}g'(k_1)\right],$$

$$(7') \qquad u'(c_2)\pi'(x_2) = E\left[v'(\tilde{k}_2)\right],$$

$$(8') \qquad u'(c_1) = \delta R u'(c_2).$$

As previously discussed, condition 8′ defines the optimal decision for financial savings so that the marginal rate of substitution between current and future consumption equals the interest rate. Conditions 6′ and 7′ determine the optimal first-period and second-period harvest decisions. In terms of utility, the first-period harvest rule makes the value of the marginal benefit ($u'(c_1)\pi'(x_1)$) associated with the proceeds of the harvest equal to the value of the (composite) marginal cost ($v'(k_1) + \delta E\left[v'(\tilde{k}_2)\tilde{\theta}g'(k_1)\right]$).[10] Harvesting more in the present period reduces the value of the first-period amenity services and the expected outcome of the natural growth process for the forest between the two periods. The optimal second-period harvest rule is reached when the marginal benefit of the harvest expressed in utility terms ($u'(c_2)\pi'(x_2)$) equals its marginal cost, which corresponds to the decrease in amenity services, $E\left[v'(\tilde{k}_2)\right]$. In other words, harvesting in the second period ceases at the point at which the marginal increase in timber value expressed in expected utility terms if one additional unit of the forest stock is cut equals the marginal utility in terms of amenity services if the stock is not cut.

Plugging 7′ and 8′ into 6′ and rearranging the equation yields the current harvest rule:

$$(10) \qquad \frac{v'(k_1)}{\delta u'(c_2)} = R\pi'(x_1) - \pi'(x_2)E\left[\tilde{\theta}g'(k_1)\right]$$

[9] We focus on solutions where $s > 0$, which requires that the conditions for $\partial EV / \partial s > 0$ are satisfied for $s = 0$. Basically, this is the case if we introduce the restriction that $R > u'(c_1) / \delta u'(c_2)$, which is common in savings models.

[10] We assume that the marginal valuation of the amenity ($E\left[v'(\tilde{k}_2)\right]$) is independent of the growth stochasticity ($E\left[\tilde{\theta}g'(k_1)\right]$). Without such an assumption, the RHS of the optimal harvest rule should include a covariance term.

with $-\tilde{\theta}g'(k_1) = \partial\tilde{k}_2(\tilde{\theta}) / \partial x_1$. The righthand side (RHS) of the optimal current harvesting rule represents a tradeoff between current and future expected harvesting revenue. The RHS is positive because the lefthand side (LHS) is the marginal rate of substitution between preferences for consumption and for the amenity value. The forest owner chooses a level of harvest in the current period so that the difference between the marginal return and the expected opportunity cost of the current harvest equals the marginal rate of substitution between the preference for consumption and for the amenity value. Note that the forest owner's preferences for consumption and the amenity value affect the amount of timber harvested. This result is in line with the current-harvest rule obtained by Amacher, Ollikainen, and Koskela (2009).

The quantity harvested in the current period reflects a tradeoff between harvest revenue, the preference for amenity, and the utility of consumption. The role of amenity and consumption preferences can be seen by comparing the harvest rule (equation 10) with the behavior of a risk-neutral owner who harvests up to the point where the difference between the marginal return from harvesting and the expected cost of the current harvest equals the ratio of the marginal return from the amenity to the discount factor. That is,

$$\frac{v'(k_1)}{\delta} = R\pi'(x_1) - \pi'(x_2)E\left[\tilde{\theta}g'(k_1)\right]. \tag{10'}$$

The RHS of 10′ is familiar from equation 10 and the only difference between the LHSs of 10′ and 10 concerns the inverse of the marginal utility of second-period consumption ($1 / u'(c_2)$). The impact of this positive term depends on whether it is greater or smaller than unity. If $u'(c_2) < 1$, a risk-averse forest owner will reduce the current harvest; $u'(c_2) > 1$ implies an increase in the current harvest.

Harvesting Decisions in the Physical Savings Model

Now let us assume that the higher return-cost ratio is for physical savings. The NIPF owner will plant resistant species. In this case, the optimal choices (x_1^*, x_2^*, q^*)[11] are given by equations 6, 7, and 9 for $\lambda = \gamma = \sigma = 0$. We then have

$$u'(c_1)\pi'(x_1) = v'(k_1) + \delta E\left[v'(\tilde{k}_2)\tilde{\theta}g'(k_1)\right], \tag{6''}$$

$$u'(c_2)\pi'(x_2) = E\left[v'(\tilde{k}_2)\right], \tag{7''}$$

$$eu'(c_1) = \delta E\left[v'(\tilde{k}_2)\right]. \tag{9''}$$

Condition 9″ defines the optimal physical savings decision by equalizing the marginal cost of the risk management tool with the marginal rate of substitution between current consumption and the amenity preference. Conditions 6″ and 7″ determine optimal current and future harvest decisions. These conditions have the same interpretations as conditions 6′ and 7′.

[11] Once more, we focus on solutions where $q > 0$, thus requiring that the conditions for $\partial EV / \partial q > 0$ are satisfied for $q = 0$. Basically, this is the case if we assume that the marginal cost of physical savings is low enough that $e < \delta v'(k_1) / u'(c_1)$. Note that, more generally, any model with self-protection activities usually assumes such a restriction.

We can use 7″ and 9″ in 6″ to obtain the following current-harvest rule.

$$\text{(11)} \qquad \frac{v'(k_1)}{\delta u'(c_2)} = \frac{\pi'(x_1)\pi'(x_2)}{e} - \pi'(x_2)E\left[\tilde{\theta}g'(k_1)\right]$$

with

$$-\tilde{\theta}g'(k_1) = \frac{\partial \tilde{k}_2(\tilde{\theta})}{\partial x_1}.$$

The LHS of the optimal current-harvest rule represents the marginal rate of substitution between the consumption and amenity preferences in the second period. Given the assumption about preferences, this term is positive. The RHS-term is the difference between the marginal return from the current harvest and the opportunity cost of that harvest (corrected by a positive covariance term). It is interesting that the harvest rules for the first and second periods both determine the level of harvest at which the forest owner is indifferent between harvesting and not harvesting. These levels are dependent on the forest owner's preferences about consumption and amenity.

It is worth noting that the current harvest is affected by the owner's preferences for both amenity and consumption. For a risk-neutral owner, equation 11 reduces to

$$\text{(11′)} \qquad \frac{v'(k_1)}{\delta} = \frac{\pi'(x_1)\pi'(x_2)}{e} - \pi'(x_2)E\left[\tilde{\theta}g'(k_1)\right].$$

The risk-neutral owner decreases or increases the current harvest based on the marginal utility of second-period consumption. We observe that the LHS of 11′ is different from the LHS of 11 only by the term $1 / u'(c_2)$. If $u'(c_2) < 1$, a risk-averse forest owner will reduce the current harvest. If $u'(c_2) > 1$, the owner will harvest a larger quantity of timber in the current period.

Comparison of the Optimal Harvest Rules in the Two Models

A comparison of the optimal harvest decisions obtained in the financial savings and physical savings models yields a first consequence: the amount harvested in the second period is larger with physical savings than with financial savings, all else held equal. A direct comparison of the first-period harvest decisions for the two models is not useful.

The conditions of the optimal future harvest rules for both models can be rewritten as

$$\pi'(x_2)u'(Y_2 + Rs^* + \pi(x_2^*)) - E\left[v'(\tilde{k}_2)\right] = 0,$$

$$\pi'(x_2)u'(Y_2 + \pi(x_2^*)) - E\left[v'(\tilde{k}_2)\right] = 0.$$

The optimal condition obtained for financial savings evaluated for the amount of the optimal future harvest obtained for physical savings is positive due to the concavity of u and v. Thus, one can conclude that the optimal amount of the future harvest is larger under physical savings than under financial savings, all else held equal.

A comparison of both conditions for the current harvest depends on the sign of $R = \pi'(x_2) / e$. The sign of this term determines the choice of the risk

Table 1. Comparative Static Results

	Financial Savings			Physical Savings		
	x_1*	x_2*	s*	x_1*	x_2*	q*
Initial wealth, period 1: Y_1	0	–	+	0	0	+
Initial wealth, period 2: Y_2	0	–	0	0	–	0
Initial forest stock: Q	+	–	+	+	0	+
Timber price, period 1: p_1	+	–	+	+	0	+
Timber price, period 2: p_2	–	A	-	0	A	0
Marginal utility of amenities: m	0	–	+	0	–	+
Rate of return on financial savings: R	+	–	+			
Marginal cost of physical savings: e				–	0	–

A: Ambiguous result without assumption. Assuming that the partial risk-aversion coefficient is less than 1 leads to a positive result. The partial risk aversion coefficient is

$$A_p = -\frac{w_0''}{w_0} w_0 \frac{u''(w_0)}{u'(w_0)}$$

where $w_0 = w_0' + w_0''$ is the global wealth, which is composed of two elements, w_0', which is certain, and w_0'', which is exposed to a multiplicative risk that is assumed to be actuarially neutral (Eeckhoudt and Gollier 1992). A reasonable assumption is to consider that the partial risk-aversion coefficient is less than 1 (Cayatte 2004, Reynaud et al. 2010).

management tool. Therefore, such a comparison makes no sense. Our results simply suggest that the NIPF owner will make decisions that yield the most efficient strategy in terms of smoothing consumption. By associating the results of proposition 1 and the harvest rules for both risk management instruments, we obtain an interesting consequence: both instruments may have equivalent consequences in terms of smoothing consumption. Consider two economies with the same characteristics in terms of values of δ, p_1, and p_2 and technological parameters such as the forest growth process (g), probability distribution ($F(\tilde{\theta})$), and cost function (h). In the first economy, forest owners have access to a perfect financial market that pays a gross interest rate of R. In the second, forest owners have no access to a capital market but invest in an expensive physical savings method at marginal cost e. If the ratio of the second-period marginal profit to the marginal cost of implementing physical savings is constant and satisfies $R = \pi'(x_2) / e$, then forest owners reach the same intertemporal consumption profile in both economies, choose the same harvest rule, and obtain the same value for amenity services.

Comparative Static Analysis

The optimal amount of current and future harvests and the optimal choice of risk management instruments can be used to define a representative forest owner's behavior in response to risk. We can study the properties of that representative behavior using comparative static results obtained from the optimal harvest levels and risk management decisions. In general terms, comparative static results assuming concave utility functions are not only difficult to obtain but also are not very informative or helpful. To make this analysis instructive, we assume, as in Koskela and Ollikainen (1997, 1999), that the forest owner's utility function for the amenity value is quasi-linear so that $v'(k_i) = m$ for $i = 1,2$. This assumption applies for many amenity services (e.g., campsites and recreational facilities). We generate the comparative static results by completely differentiating the first-order conditions with all of the variables and using Cramer's rule. Table 1 provides a summary of the results (see the Appendix, available from the authors, for details for the financial savings model).[12]

From a general point of view, many of the comparative static results for the two risk management tools are identical. When differences do occur, the effect of the analyzed parameter on the optimal variable decision is null in the physical savings model but not in the financial savings model. These null effects come from the components of physical savings. By assumption, that risk management instrument affects the utility of the amenity in the second period in a constant manner. Moreover, for an increase in the second-period timber price (p_2) to affect the second-period harvest decision (x_2^*), one must impose an additional assumption about forest owners' preferences to determine the sign of the impact on optimal decisions. The comparative static results can be decomposed into substitution and income effects. For both instruments, the substitution and income effects have opposite signs. Additional assumptions on the partial risk-aversion coefficient are thus required. Assuming that the risk-aversion coefficient is less than 1 allows us to sign what initially were ambiguous results. We subsequently focused our analysis on the results related to risk management instruments.

Income and stock effects. The first-period income (Y_1) effect for both risk management tools is positive. Therefore, financial savings and physical savings are both superior goods. If first-period income increases, all else being equal, first-period consumption increases at the initial optimal level of financial savings. To guarantee that the first-order condition (equation 8′) is always valid, it is optimal to increase savings in response to decreasing marginal utility. On the other hand, the second-period income (Y_2) effect for both risk management tools is null. Since the risk management decisions occur in the first period, it is intuitive that second-period income does not affect them. The effect of the initial forest stock (Q) is positive for both risk management tools. If the forest stock increases, all else being equal, additional potential risk of damage incites the forest owner to increase the optimal investment in risk management.

Price effects. The total effect of an increase in the first-period price (p_1) reflects two factors—a substitution effect and an income effect. Decomposition of the total effect is useful and important (Koskela and Ollikainen 1997). The substitution effect reflects the distortionary effect of the price increase at the margin. The income effect reflects the fact that a change in the price acts like a change in the forest owner's income. These two effects are positive and encourage the owner to increase both financial and physical savings. For an increase in the second-period timber price, the substitution effect is negative while the income effect is null, which explains why the forest owner reduces

12 Proofs for the physical savings model are available from the authors upon request.

the amount of financial savings. The optimal level of physical savings is not affected by a change in the second-period price because physical savings have no impact on second-period consumption.

Amenities effects. All else being equal, the larger the marginal utility of the amenity services (m), the smaller the future harvest and the larger the financial or physical savings. Indeed, as the amenity utility increases, the forest owner reduces future harvests and increases savings to take advantage of the amenities. In fact, as the amenity utility increases, the marginal second-period utility of consumption increases because of the first-order condition (equation 7′). Then, as marginal utility decreases, second-period consumption decreases. To guarantee that the first-order condition (8′) is valid, the marginal first-period utility of consumption increases, inducing an increase in savings.

Opportunity cost effects. The total effect of the rate of return on financial savings (R) is positive. Indeed, as the rate of return is raised, the owner is encouraged to increase the amount of financial savings so s/he can benefit from the higher return. Similarly, the forest owner reduces savings as the marginal cost of physical savings (e) rises because it becomes more and more expensive to plant resistant species.

Comparative static results demonstrate the role of the forest owner's preferences for consumption and amenities. Those preferences strongly condition the optimal decision regarding choices of risk management instruments.

The Impact of Government Intervention on Risk Management Decisions

NIPF owners are viewed as generally underinvesting in risk management strategies (Picard, Robert, and Toppan 2002, Størdal, Lien, and Hardaker 2007). Therefore, government bodies are interested in intervening to induce forest owners to increase their level of protection from risk. Here we present a positive analysis of government intervention in the sense that we study how a policy instrument is likely to affect the NIPF owner's risk management decisions by considering a change in one variable at a time. We analyze two types of government intervention: (i) a direct instrument through a per-unit subsidy for risk management investments and (ii) an indirect instrument involving implementation of a threshold timber price or lump sum payment for amenity services provided by private forests.

Direct Intervention: A Per-unit Subsidy for Risk Management Investments

Many in France have argued that the government should encourage NIPF owners to save money as a hedge against damage from natural events, especially events of low intensity (Picard, Robert, and Toppan 2002, Puech 2009). One approach the government can use to encourage NIPF owners to adopt financial savings is to guarantee a higher rate of interest, and we have demonstrated that such a practice can effectively increase forest owners' financial savings. Currently, there is no program to subsidize physical savings, but we have shown that this government intervention can reduce the cost of physical savings and thus increase the degree to which that risk management tool is used. It seems that subsidies for financial and physical savings would systematically induce forest owners to make greater use of risk management tools.

Moreover, the government can influence which risk management strategies are used. Proposition 1 reveals that, when $R = \pi'(x_2)/e$, the physical and financial risk management strategies have the same return/cost conditions. Consequently, the NIPF owner does not distinguish between them. To favor physical savings (when forest surface is not constrained), the government can implement a subsidy of that strategy so that the cost of physical savings drops below $\pi'(x_2)/R$. In that case, the NIPF owner will prefer physical savings. If, on the other hand, the government favors financial savings, providing an interest rate that exceeds $\pi'(x_2)/e$ will induce NIPF owners to choose financial savings.

Indirect Intervention

Threshold timber price. In the face of damage from a natural event, many forest owners harvest the damaged trees rapidly so that the quantity of timber available on the market rises, leading to a shift in price (Prestemon, Pye, and Holmes 2000). The shift in price is indicative of the financial damage suffered by the owner due to production losses. After windstorm "Klaus" in 2009, for example, the Union of South-Western French Foresters created an association to negotiate minimum timber prices within the industry to ensure sales of damaged timber and to smooth timber price shifts.[13] Consequently, it seems relevant to observe the role of a threshold timber price on NIPF owners' risk management behavior. In the current period, an increase in the price of timber has no effect on the choice of risk management strategies; instead, it affects the degree of investment in risk management. Such an increase in the price of timber will always increase the use of financial and/or physical savings. Consequently, the government's implementation of a threshold timber price in the first period could encourage NIPF owners to adopt additional risk management instruments. In contrast, implementation of a threshold timber price in the second period would influence both the choice of strategies and the level of investment in them. If the government implemented a minimum timber market price in the second period, the effect of that minimum price on the choice of risk management strategies would depend on the level of the threshold price, referred to as $\hat{p}_2$. Proposition 1 can help us to determine the consequence of the level of the threshold timber price in period 2 on the choice of risk management instruments. In proposition 1, we can rewrite $R = \pi'(x_2) / e$ as $p_2 / R = (h / r) + e$. Let us define $\widehat{p_2}$ as equal to $h + Re$. Then, if the regulator sets $p_2 > \widehat{p_2}$, all forest owners will invest in physical rather than in financial savings. If, on the other hand, the regulator sets $p_2 < \widehat{p_2}$, all forest owners will accumulate financial savings rather than invest in planting species that are more resistant to damage. That intervention, considered an increase in price, reduces the level of financial savings and has no effect on physical savings.

Lump sum for amenities. The government can also indirectly influence risk management decisions by giving a lump sum subsidy to NIPF owners for amenity services provided by private forests (Hartman 1976). NIPF owners produce amenities while producing timber. The amenity services of private forests may or may not be public goods. In general, private forests produce public goods in terms of amenities so a lump sum awarded by the government for provision of amenity services makes sense. This type of government

[13] See the website *www.gpbs.fr* for more details about the services of this union (accessed August 2011).

intervention is equivalent to additional exogenous revenue. The effect of the lump sum depends on the period in which it is delivered. If the NIPF owner receives the payment in the current period, this indirect intervention will encourage the owner to adopt risk management measures of some kind. If the payment is received in the second period, it will have no effect on financial savings or on physical savings.

Conclusion

Natural hazards, which we modeled as a risk to forest growth, affect the way NIPF owners manage their forests. The joint production of timber and amenity services reinforces the need for NIPF owners to invest in risk management. We concentrate on two types of risk management instruments, financial savings and physical savings, and contribute to the literature of risky forest management using two-period models in two ways. First, we propose a general model of expected utility that includes amenities and does not restrict risk or the utility function. Second, we integrate an alternative risk management tool, referred to as physical savings, in the two-period model. We demonstrate that the accumulation of financial and physical savings may be seen as perfectly substitutable for forest owners under some assumptions. We also demonstrate the importance of the forest owner's preferences regarding consumption and amenities.

Our work can be extended to other situations. In fact, our results cannot be challenged without introducing some friction or imperfections in the model. For example, the basic two-period model we use assumes that the financial and physical savings are maintained over the same (short-term) horizon. However, due to imperfections in financial markets (asymmetrical information, borrowing constraints, varying interest rates for lenders and borrowers) and the natural delay between planting and harvesting of trees, the horizon of decisions in financial markets may be more limited than the horizon for decisions connected to tree planting. Moreover, the forestry production process may be more or less lengthy according to the species of tree. The consequences of some variations for optimal decisions depend on forest owners' preferences. This conclusion underscores the need to develop methods that can measure forest owners' preferences. These extensions will be the subject of future research.

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