Ambiguity, value of information and forest rotation decision under storm risk

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Context I

Natural events in forest

- European scale : over the period 1950-2000, an annual average of 35 million m^3 of wood was damaged by disturbances in Europe, storms were responsible for 53% of the total damage, fire for 16%, snow for 3% and biotic factors for 16%.
  $\hookrightarrow$ **Storms are the most damageable natural event for European forests**.

Climate change

- Natural disturbances have increased over the period 1950-2000 and this increase will continue in the 21^{st} century.
  $\hookrightarrow$ CC is the main driver and it impacts both the frequency and the intensity.

Uncertainty / Ambiguity

- Frequency and intensity of natural events are thus uncertain : difficult to quantify.
- This imprecision translates into different climate scenarios.
  $\hookrightarrow$ Difficult to predict future scenario : **scenario ambiguity** (SA, 1st level).
  $\hookrightarrow$ Assessment of the storm risk based on expert opinion : **frequency ambiguity** (FA, 2nd level).

Context II

Forest management

- Private forest owners have to manage their forests : **optimal cutting age** (i.e., when to harvest) $\rightarrow$ The two levels of ambiguity will impact the optimal cutting age.
- The forest owners' **preferences towards risk and ambiguity** are important.

Information

- It is fundamental to improve our knowledge about the characteristics of natural disturbances to ensure better decision-making.
  $\hookrightarrow$ Key challenge : to provide **information** that will make it possible to reduce or eliminate ambiguity (Snow, 2020).
- This information has a **value** that is useful to know and to quantify.

Objective and method

Objective

We question the **impacts of the SA and FA on the optimal cutting age**.
$\hookrightarrow$ Does the optimal cutting age vary under SA and FA as compared to risk ?
$\hookrightarrow$ Does the optimal cutting age depend on the forest owner's preferences towards risk and ambiguity ?
$\hookrightarrow$ What is the value of information that will make it possible to resolve each level of ambiguity ?

Method

- We propose a **theoretical model** that extends the classical Faustmann framework under risk proposed by Reed (1984) to ambiguity.
  $\hookrightarrow$ The forest is threatened by a storm risk.
  $\hookrightarrow$ Decision criterion : smooth ambiguity model (Klibanoff et al. 2005).
- We solve the model numerically in a case study of a beech stand.

Literature review

Optimal cutting age in forest economics

- Initial model deterministic : optimal cutting age (Faustmann, 1849) $\rightarrow$ the variable which optimized the sum of net discounted revenues from forestry.
- Extension with risk : Reed (1984) in terms of “expected value” $\rightarrow$ the risk reduces the optimal cutting age.
- This framework was used to analyze the impact of different types of risks in forestry : disease (Macpherson et al. 2018) and storm (Haight et al. 1995 ; Loisel 2014 ; Rakotoarison and Loisel 2017 ; Loisel et al. 2020).

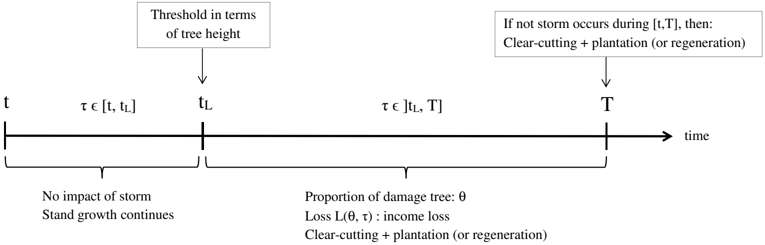
$\Rightarrow$ **Ambiguity has never been considered in such a framework.**

The value of information in decision theory

- Value of information under ambiguity has been analysed in theoretical literature. $\hookrightarrow$ Nocetti (2018), Hoy et al. (2014) and Snow (2010) : the effect of ambiguity aversion on the value of information, with non-unanimous results.
- Peysakhovich and Karmarkar (2015) : only empirical study. $\hookrightarrow$ They found that the value of information increases or not depending on its favorable or unfavorable nature.

$\Rightarrow$ **The value of information has never been considered in a forestry context.**

Storm risk



Sequence of events

Without storm, the forest stand grows from t to T, where T is the cutting age. The storm modifies the sequence of events as follows :

- If a storm occurs before the **threshold time** t_L, there is no impact, $L(.) = 0$ and stand growth continues.
- If a storm occurs after t_L but before T, the proportion of damaged trees is θ and the loss is $L(\theta, \tau)$; a clear-cutting and a regeneration (or plantation) of the stand take place.
- If no storm occurs before T, a clear-cutting and a regeneration (or plantation) of the stand take place at time T.

Ambiguity context

Storm = the rate of storm return (the time between the beginning of the stand and the storm τ with a distribution $\mathbf{F\tau}$) ; **the proportion of damaged trees θ** (Loss $\mathbf{L(\theta,\tau)}$)

Risk context: known probability and damage $[F\tau;L(\theta,\tau)]$

Ambiguity context: probability and damage not precisely known

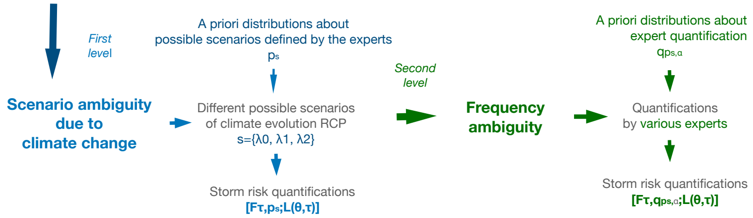


Figure – Risk, scenario ambiguity and frequency ambiguity

Forest rotation decision under risk

The decision problem

- The forest owner chooses the **optimal cutting age** that will maximize **expected utility** from the forestry activity.
- We assume a risk-averse private forest owner characterized by an utility function u where $u'(.) > 0$ and $u''(.) < 0$.
- Risky context : the probability of occurrence of the risk is known ($\lambda = \lambda_0$).

The decision criteria

- For a discount rate δ, the utility of the net economic return $\mathcal{Y}$, actualized at storm occurrence time τ or logging time T, is written as follows :

$$\mathcal{Y}(\tau) = \begin{cases} \mathcal{H}_\delta(\underline{t}, \tau) + u(V_1(\theta_\tau, \tau) - c_1 - C_n(\theta_\tau, \tau)) & \text{if } t_L < \tau < T \\ \mathcal{H}_\delta(\underline{t}, T) + u(V(T) - c_1) & \text{if } \tau = T \end{cases}$$

- The Faustmann value is $J(\lambda_i, T_i) = \frac{E[e^{-\delta\tau}\mathcal{Y}(\lambda_i, T_i)]}{1 - E[e^{-\delta\tau}]}$.
- We look for the max of the Faustmann value : $J(\lambda_i, T_i) = \max_T J(\lambda_i, T)$ where T_i is the optimal cutting age obtained under risk for a known and unique storm occurrence probability level, λ_i.

Forest rotation decision under ambiguity

The decision problem

- The forest owner finds the **optimal cutting age** that will maximize a **functional form over the expected utility** level.
- Forest owners characterized by an increasing and concave function $\phi(.)$, defined over the expectation of the utility function $u(.)$, representing ambiguity aversion. $\hookrightarrow$ Smooth ambiguity model of Klibanoff et al. (2005).
- For SA, we look for the max of the Faustmann value as follows :

$$\sum_i p_i \phi(J(\lambda_i, T_*)) = \max_T E[\phi(J(\lambda, T))]$$

- For FA, we look for the max of the Faustmann value as follows :

$$E\left[\phi\left(\sum_i q_i J(\lambda_i, T_*)\right)\right] = \max_T E\left[\phi\left(\sum_i q_i J(\lambda_i, T)\right)\right]$$

Value of information

Favorable information

- **Favorable information** that allows to go from ambiguity to risk.
- This information **fully resolves** the ambiguity : this value corresponds to the maximum amount of money the forest owner would be willing to pay to obtain information that would remove the ambiguity.
- The value of information is calculated as the value that makes the forest owner **indifferent** between two situations : Risk vs SA, SA vs FA.

Value

The value of information that eliminates the SA satisfies :

$$\phi(J(\lambda_0, T_0) - y_0^J) = \max_T \sum_i p_i \phi(J(\lambda_i, T))$$

The value of information that eliminates the FA satisfies :

$$\phi\left(\sum_i p_i J(\lambda_i, T_p) - y_\pi^J\right) = \max_T E\left[\phi(\sum_i q_i J(\lambda_i, T))\right]$$

The calibration

Case study

- Simulation of the model for a **beech stand** of one hectare exposed to a storm risk.
- Three possible **climate scenarios** : the current scenario, the scenario based on the so-called optimistic RCP 4.5, and the scenario based on the so-called pessimistic RCP 8.5.
- Estimates of the **rates of return** of storm are : 1/55 for the current period, 1/47 under the RCP 4.5 and 1/23 under the RCP 8.5 (Brèteau-Amores et al., 2020).

Owner's behavior

- **Risk** : power utility function $u(x) = \frac{x^{1-r}}{1-r}$ where r is the relative risk aversion coefficient fixed at $r = 0.59$ (Brunette et al. 2020).
- **Ambiguity** : power function $\phi(x) = x^s$ where s is the coefficient of ambiguity aversion fixed at $s = 0.729$ (Brunette et al. 2020).
- Discount rate of 2% : classical for beech stands in forest economics (Loisel, 2014).

Scenario ambiguity vs. Risk

Table – Simulation results for scenario ambiguity.

RISK			
Risk rate	Opt. cutting age		
1/55	79		
1/47	78.5		
1/23	76		
SCENARIO AMBIGUITY			
	Opt. cutting age	Value of info.	
ϕ	78	1.57	0.341

Summary

- Result 1.1 : The higher the risk is, the lower the optimal cutting age will be.
- Result 1.2 : SA reduces the optimal cutting age.
- Result 1.3 : The value of information to eliminate SA is positive but low.

Frequency ambiguity vs. Scenario ambiguity

Table – Simulation results for frequency ambiguity.

SCENARIO AMBIGUITY		
Opt. cutting age		
78		
FREQUENCY AMBIGUITY		
Opt. cutting age	Value of info.	
78	0.009	0.100

Summary

- Result 2.1 : FA has no impact on the optimal cutting age.
- Result 2.2 : The value of information to eliminate FA is positive but close to zero.

Sensitivity analysis

Other aversion coefficients

- Risk (benchmark $r = 0.59$) : $r = -0.5$ (loving), $r = 0$ (neutrality), $r = 0.9$ (high aversion).
- Ambiguity (benchmark $s = 0.729$) : $s = 0.1$ (high aversion), $s = 0.9$ (close to neutrality) and $s = 1.5$ (loving).

Risk vs. SA

- **Result 3.1** : Under risk, the higher the risk aversion is, the lower the optimal cutting age will be.
- **Result 3.2** : Under SA, risk aversion $\searrow$ the optimal cutting age, and ambiguity aversion has no impact.
- **Result 3.3** : The value of information that resolves SA $\nearrow$ with risk aversion, but ambiguity aversion has no impact.

FA vs. SA

- **Result 4.1** : Under FA, risk aversion $\searrow$ the optimal cutting age, whereas ambiguity aversion has no impact.
- **Result 4.2** : The value of information that resolves FA $\nearrow$ with risk and ambiguity aversion.

Summary of the results

Risk and ambiguity

We confirm the result of Reed (1984) that risk $\searrow$ the optimal cutting age.
We complement this result by showing that :

- the higher the risk level is, the lower the optimal cutting age will be (**Result 1.1**)
- the higher the risk aversion is, the lower the optimal cutting age will be (**Results 3.1 and 3.2**).
- SA also $\searrow$ the optimal cutting age (**Result 1.2**), and FA has no effect (**Result 2.1**).
- ambiguity preferences have no effect on the optimal cutting age for both ambiguities (**Results 3.2 and 4.1**) $\rightarrow$ in line with Brunette et al. (2020).

Value of information

- The value of information is positive but low for both ambiguities (**Results 1.2 and 2.1**).
- The value of information that resolves both ambiguities $\nearrow$ with risk aversion (**Results 3.3 and 4.2**).
- Only the value of information to remove the FA $\nearrow$ with ambiguity aversion (**Results 3.3 and 4.2**) $\rightarrow$ in line with Snow (2010).

The following...

Experimental test

Online experiment is forecasted on private forest owners with three parts :

- Elicitation of risk and ambiguity preferences.
- Forestry decisions : owner of one hectare of beech stand, and we ask them to decide the cutting age under risk, SA and FA.
- Individuals' characteristics (age, gender, etc.).

Potential extension

- We assume that probability is ambiguous $\rightarrow$ ambiguity may also characterize the amount of the damage (outcome level).
- Du and Budescu (2005) : individuals prefer to $\nearrow$ the precision of the outcomes rather than the precision of the probabilities.
  $\hookrightarrow$ Result 2.1 : the value of information is very low, meaning that individuals are not ready to pay to increase the precision of the probabilities.
  Perhaps they are more willing to pay to reduce the imprecision of the outcome ? Further research in this direction is necessary.

Thank you

BETA lab :
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