The determinants of adapting forest management practices to climate change: Lessons from a survey of French private forest owners

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October 22, 2021

Abstract

Climate change seriously impacts forest ecosystems. In order to maintain a healthy and sustainable forest cover, adaptation strategies should be implemented. This article proposes to deepen our understanding of the decision-making process of private forest owners in terms of adaptation decisions towards climate change. In particular, we question whether or not French private forest owners have already implemented adaptation strategies and if yes, we identify the determinants of this decision. ~~the aim is to identify determinants of adaptation decisions.~~ We focus on the identification of the determinants of the probability to adapt and on the determinants of adopting each strategy separately (early harvest, thinning, irregular silviculture). A survey of more than 900 French private forest owners was conducted for the purpose of collecting both (1) objective variables: characteristics of the owners and the property; and (2) subjective variables: perception of climate change and impacts. The results reveal that both types of variables ~~are complementary to~~ explain the adaptation decision. In addition, we show that the determinants are different from one adaptation strategy to another, meaning that the adaptation decision should not be thought of in general but, instead, strategy-by-strategy.

Keywords: adaptation, forest, survey, French private forest owners.

JEL codes: Q23 (Forestry); Q54 (Climate • Natural Disasters and Their Management • Global Warming)

DECLARATIONS

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1. Introduction

Climate change ~~will~~has serious impacts on forest ecosystems, altering the provision of goods and services worldwide. The increase in temperature and reduction in the precipitation regime affects growth and productivity (Ma et al. 2019) and will result in decline and mortality (Cohen et al. 2016; Send et al. 2020~~Bergh et al. 2003; Jump et al. 2006~~). In the same way, the increase in frequency and intensity of natural events (~~Flannigan et al. 2000; Fuhrer et al. 2006~~Seidl et al. 2020; Zscheischler et al. 2018) suggests large losses in future forest value (Hanewinkel et al. 2013) in the coming years. Forest disturbance damage in Europe has increased throughout the 20th century (Schelhaas et al. 2003) and has continued to rise in the first decade of the 21st century (Seidl et al. 2014), mainly due to climate change (Seidl et al. 2011). Damage from wind, bark beetles and forest fires is likely to increase even more in coming decades, and the rate of increase is estimated at $+0.91 \times 10^6$ m^3 of timber per year until 2030 (Seidl et al. 2014). In France, where the forest cover encompasses 31% of the territory with a total of 16.9 million hectares (IGN 2020), and where the forest sector directly employs 395,000 people, for an added value of €26.1 billion, representing 1.08% of the French GDP (VEM 2019), these impacts may be detrimental.

The speed of environmental changes is such that implementation of adaptation strategies by foresters is required to maintain a forest cover (Spittlehouse and Stewart 2003). In this context, a wide range of adaptation strategies are recommended: reduction of harvest rotation length, reduction of density at the time of plantation, adoption of species better adapted to the future climate, species mix, uneven-aged stands, etc. (Spittlehouse and Stewart 2003; Ogden and Innes 2009). These adaptation strategies are linked to mitigation strategies, especially since they favour tree growth and carbon storage (Verkerk et al. 2020). Indeed, a "successful mitigation strategy must consider adaptation measures to ensure the resilience of forest ecosystems (Schoene and Bernier 2012)". Millar et al. (2007) also insist on the fact that resource managers need to integrate both adaptation and mitigation strategies into forest management plans. Consequently, in this paper, we focus on adaptation strategies as a prerequisite to mitigation. However, to implement adaptation, foresters must be aware that climate change is actually occurring, they must perceive the threat that climate change represents for their forests, and they must be able to make often irreversible decisions.

In the framework of international negotiations about climate change, forests have a main role to play ~~in terms of mitigation~~. Public authorities are thus under pressure to implement policies and projects that facilitate adaptation (Van Aalst 2006; Hochrainer-Stigler et al. 2014). However, little information exists about the ~~French~~ private forest owner's adaptation decisions, which are the relevant decision unit in France because 75% of the forest area is privately owned by 3.3 million private forest owners. Exploring their choices in terms of adaptation with the aim to identify major determinants ~~the determinants of their adaptation choices~~ is thus critical for policy makers. Indeed, better knowledge of how these choices are made and why is essential to understand the triggers of adaptation strategies. Moreover, policy makers rely on such information to design public policies that aim at creating incentives for owners to adapt to climate change. A better understanding of the ~~drivers~~determinants of adaptation strategies will make it possible to increase the efficiency of public policies for both mitigation and adaptation.

In this context, many research questions have emerged: Are ~~French~~ private forest owners aware of climate change? How do they perceive the impact of climate change? Have they already modified their management practices in view of climate change? If yes, which adaptation strategies have they adopted and why? If not, why choose to not adapt?, etc. More generally, we address the question of the determinants of the adaptation decisions of French private forest owners in order to identify levers to encourage them to adapt. For that purpose, we ran a phone survey with 960 respondents, selected by plot size and region using a stratified sampling method among eight regions and four forest area classes. Descriptive statistics made it possible to characterise French private forest owners, their property, the way they perceive climate change and their adaptive capacity. We used probit regressions to identify the determinants of the adaptation choice. In addition, the high number of respondents allowed us to estimate the role of each determinant for every adaptation strategy considered, which allows us to identify strategy-dependent determinants.

2. Literature review

~~Private forest owners' adaptation decisions have been widely addressed in the literature.~~ An interesting literature review by Keenan (2015) inventories 1172 research articles on climate change impacts and management options for adaptation to climate change. He shows that only 12% of the papers considered adaptation options. He concludes that research to support adaptation to climate change is still heavily focused on assessing impacts and vulnerability. He underlines that "Knowledge gaps lie more in understanding the social and community attitudes and values that drive forest management and the decision making processes of forest managers". In this sense, our article directly contributes to filling in this gap.

Another literature review proposed by Brunette et al. (2018) is restricted to 89 articles, simultaneously dealing with climate, adaptation, risk and economy. The articles were categorised into three distinct groups that affect adaptive decisions: (i) profit and production; (ii) microeconomic risk-handling; and (iii) decision and behaviour. The third group is of particular interest since it includes social and behavioural variables that affect management decisions collected through questionnaires. In that third group, we can find, for example, articles dealing with forest owner's perceptions (Blennow and Sallnäs 2002 ; Eriksson 2014) and attitudes towards risk (Sauter et al. 2016 ; Brunette et al. 2017).

Our article is directly linked to this literature that focuses on the determinants of the forest owner's decisions. However, since we only focus on adaptation decisions, in the following literature review, we only selected articles that deal with the determinants of adaptation strategies among foresters, based on a survey. These articles make it possible to identify relevant determinants of adaptation and to justify our approach.

~~In particular, numerous articles focus on use surveys of private forest owners to analyse concerning their adaptation decisions, and making it possible to identify relevant determinants of adaptation.~~

Van Gameren and Zaccai (2015) carried out a qualitative survey with semi-structured interviews of 32 private forest owners in Wallonia, Belgium. They investigated climate change adaptation practices that had already been implemented or considered as well as the adaptive capacity of the owners. They showed that socio-cognitive variables related to personal representations about forest management, climate change risks and adaptation must not be neglected since they interact with more objective variables like the features of the forest property, forest owners' knowledge resources, and institutional incentives.

Through an online survey of 220 private forest owners (and 171 public managers) from Belgium, Sousa-Silva et al. (2016) studied how they perceive the role of their forest management in the context of climate change and the impediments that limit their ability to prepare and respond to these changes. They showed that most of the respondents are aware of climate change. They also indicate that private owners are, on average, less likely to have adapted their management practices than public managers. The main brake to this implementation is the lack of information.

Fischer (2019) implemented a qualitative analysis of 85 private forest owners involved in focus groups in the upper Midwest of the United States. The objective was to evaluate forest owner's responses to local forest stressors linked to climate change. She found that forest owners' responses were planned as well as autonomous, more proactive than reactive, incremental rather than transformational, and aimed at being resilient to change and transitioning to new conditions rather than resisting change alone. She also showed that many of the landowners' responses can be considered as forms of adaptation rather than coping mechanisms because they were aimed at moderating and avoiding harm on long-term horizons in anticipation of change.

Vulturius et al. (2018) looked at the adaptation process of 836 Swedish private forest owners. In particular, they assessed and compared the role of cognitive, experiential and structural factors on individuals' climate change adaptations. They showed that cognitive factors (i.e., personal level of trust in climate science, belief in the salience of climate change and risk assessment) are the only statistically significant factors explaining the forest owner's intention to adapt to climate change. The other factors (structural or socio-demographic) do not have a significant impact, like, for example, age, gender, education, forest size and income level.

Using data from online surveys of 1131 forest owners and managers from seven European countries (203 respondents from France), Sousa-Silva et al. (2018) assessed how they perceive their role in adapting forest management to climate change. The surveys deal, among other things, with the impacts of climate change and the way foresters consider climate change in their management decisions. Their main conclusion is that results are country-dependent with variability in terms of perceptions and actions. They identified some relevant actions such as changes in species mix and assistance in tree regeneration. They also found that forest owners and managers from France (along with the Slovakian ones) have the largest share of individuals who have undertaken adaptation strategies.

More recently, Eriksson and Fries (2020) collected 1251 Swedish private forest owners' answers to a postal questionnaire aimed at examining the current knowledge (objective knowledge), confidence (subjective knowledge) and value basis of forest management behaviours, including different management strategies (management for production, biodiversity, recreation, climate adaptation, climate mitigation) and management inactivity. The results revealed that different knowledge dimensions and value priorities both contributed to forest management behaviours. In addition, the importance of the role of the forest owner's identity (self-identity and social identity) on management behaviours was confirmed. They were able to show that variables related to forest and forest owners have an impact on the adaptation decision (significant and positive effect of forest size, significant and negative impact of gender).

Finally, Brunette et al. (2020) carried out an online survey of 88 forest managers from Germany and France. First, they measured their attitudes towards risk and uncertainty and collected socio-demographic information. Second, they observed the effect of these variables on the probability to adapt and on the intensity

of adaptation. They showed that the probability to adapt is negatively impacted by risk aversion, being French (as compared with being German) and the variable age, whereas the level of income has a significant and positive impact. They also observed that only two variables explain the intensity of the adaptation. Being French and being risk-averse have a significant and negative impact on the number of adaptation strategies selected by the individual.

On the basis of this ~~short~~ literature review, several comments can be made, making it possible to justify our approach.

~~First, it appears that several determinants of private forest owners' adaptation decisions are identified and classified. A first category of variables, referred to as "Objective variables" by Van Gameren and Zaccai (2015), "characteristics of respondents" by Sousa-Silva et al. (2016, 2018) and "socio-demographic" variables by Vulturius et al. (2018) and Brunette et al. (2020), deals with the characteristics of the forest owner (gender, age, etc.) and the forest property (surface area, management document, etc.). A second category, referred to as "socio-cognitive variables" by Van Gameren and Zaccai (2015), "beliefs" by Sousa-Silva et al. (2016, 2018) and "cognitive factors" by Vulturius et al. (2018), consists of variables related to climate change such as perception of climate change, expected impact of climate change, etc. We retained these two categories of variables and used them to build our questionnaire.~~

~~Second~~First, the literature converges towards the idea that some adaptation strategies seem to be prioritised or will be prioritised in the future by foresters, like the increase in the species mix and assistance in tree regeneration (Sousa-Silva et al. 2018). However, to our knowledge, no article has yet to explain what the determinants are that encourage foresters to adopt one of these strategies rather than another.

~~Third~~Second, only the ~~some articles focus on the adaptation practices in one country at a time, like Belgium, the USA and Sweden, and one paper proposes a~~ multi-country survey of Sousa-Silva et al. (2018) and Brunette et al. (2020) considered ~~with a sample of 203~~ French foresters. However, these samples are not focused on private forest owners and are rather "small". This means that understanding the adaptation decisions of French private forest owners is still a challenge that we attempt to tackle in this article.

In this context, we propose to analyse the French private forest owners' ~~revealed preferences~~ choices in terms of adaptation strategies when faced with climate change. We explore their adaptation choice (yes or no) and analyse the determinants of their choices (objective and subjective variables).

3. Conceptual framework

Based on the literature review, it appears that several determinants of private forest owners' adaptation decisions are identified and classified.

A first category of variables, referred to as "Objective variables" by Van Gameren and Zaccai (2015), "characteristics of respondents" by Sousa-Silva et al. (2016, 2018) and "socio-demographic" variables by Vulturius et al. (2018) and Brunette et al. (2020), deals with the characteristics of the forest owner (gender, age, education, profession) and the forest property (surface area, management document, location, income from forestry).

A second category, referred to as "socio-cognitive variables" by Van Gameren and Zaccai (2015), "beliefs" by Sousa-Silva et al. (2016, 2018) and "cognitive factors" by Vulturius et al. (2018), consists of variables related to climate change such as perception of climate change, expected impact of climate change, etc.

We retained these two categories of variables and we propose the conceptual framework in Fig. 1 to analyse their impact on the adaptation decision of French private forest owners and on the choice of the adaptation strategy to be implemented. Indeed, in a first step, we will identify the determinants of the probability to adapt, and, in a second step, among those who already adapt their management and choose to implement strategies, we propose to identify determinants of these strategies.

The choice of the questions in each category, objective and subjective variables, is based on the existing literature and is the result of a long process of discussions and negotiations with the stakeholders. Indeed, this questionnaire is part of a project involving different actors from the French forestry sector. The questionnaire had been extensively discussed and modified to reach a consensus. We present here the results for this consensual questionnaire. We do not try to be exhaustive in the variables considered. Our objective during the building of the questionnaire was to identify potential relevant variables that can explain the private forest

owner's adaptation choices in France, and to formulate the associated questions to capture these relevant variables.

For example, Brunette et al. (2020) found the variables that capture age and income to be significant and Eriksson and Fries (2020) found gender and forest size to be significant as well. Consequently, we consider that they can influence both the decision to adapt and the choice of adaptation strategy. Other more specific variables are considered. For example, income from hunting was identified during our discussions with stakeholders as an important variable to consider because this practice is very developed in France. The idea is that people who pay to hunt also pay for a hunting environment (with the landscape and amenities aspects) and, consequently, changing practices to adapt may affect this environment and represent a potential brake to adaptation.

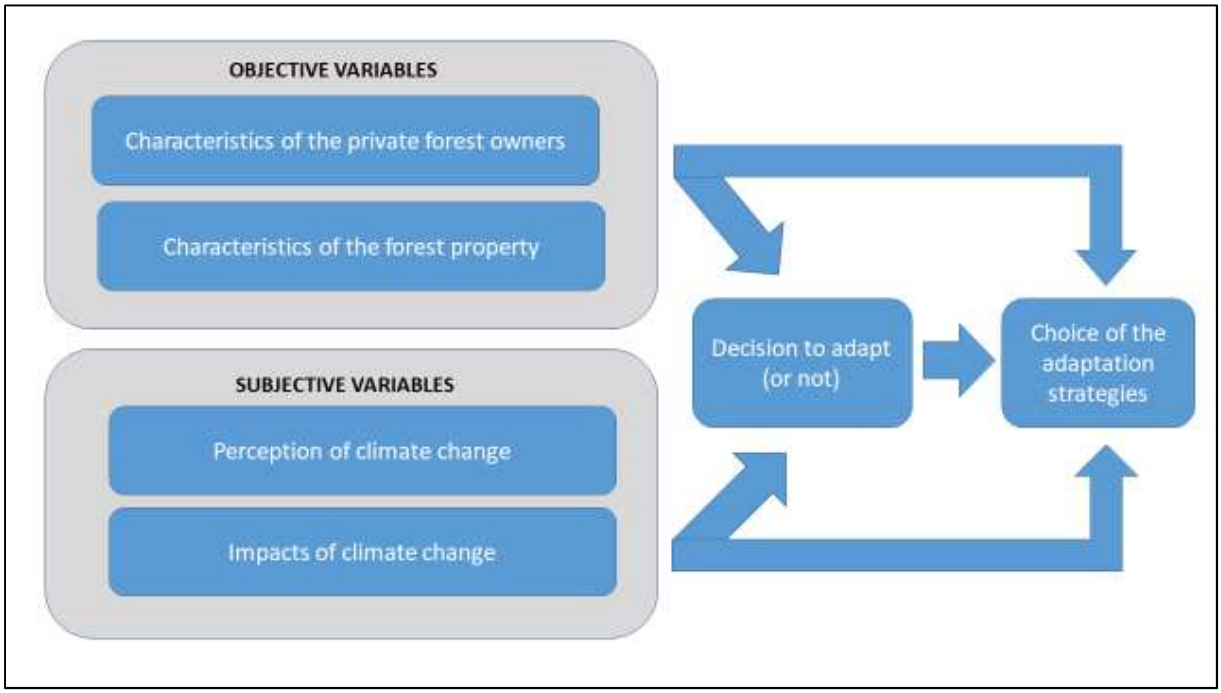

Figure 1. Conceptual framework of French private forest owners' adaptation decisions and choices.

More precisely, the objective variables are the characteristics of the owners (age, gender, profession, education), and the characteristics of the forest property (area, location, management document, source of revenue and management objective). These variables were also part of the studies referred to in the literature review and are known to influence forest adaptation. The subjective variables are the perception of climate change, the origin of climate change, the impact of climate change, the timing of impact, the feeling about these impacts and the manifestations in the field. Beliefs, convictions and perceptions in the salience of climate change have been found to be the strongest determinants of adaptation decisions (Blennow et al. 2012).

4. Materials and Methods

4.1 Definition of adaptation strategies

As mentioned above, Fischer (2019) found that landowner responses were mainly planned, proactive and incremental. Proactive adaptation entails reorienting practices in anticipation of new conditions in order to reduce future damage, risk and vulnerability. Incremental adaptation refers to making small changes in current contexts to avoid disruptions and continue pursuing the same objectives. Planned adaptation involves intentional efforts to obtain information about present and future changes, taking the suitability of current and planned practices and policies into account.

In terms of forestry, many adaptation strategies have been proposed. In particular, we retained three of them from the 30 proposed by Ogden and Innes (2009) : "reduce the rotation age" (*Early harvest*), "modify thinning practices" (*Thinning*) and "apply silvicultural techniques that maintain a diversity of age stands and mix of species" (*Irregular*). All things considered, these three strategies seem to be relevant for our article, their effectiveness is not subject to discussion in terms of adaptation to climate change in the literature, and they are in

line with Fischer (2019) in the sense that they correspond to planned, proactive and incremental adaptation strategies. Moreover, they are relevant for French forestry, as discussed below.

Growing stock, old and large trees are expected to increase the vulnerability of forests (Seidl et al. 2011). In keeping with Lafond et al. (2014), we can say that limiting forest stocking through more intensive management (i.e., *Early harvest*) is assumed to be an adaptation strategy to lower forest vulnerability (Puettman 2011) by limiting competition for water (Sohn et al. 2012) and exposure time to risk (Loisel 2011), especially insect attacks and diseases (Gottschalk 1995). In addition, *Early harvest* also makes it possible to accelerate the establishment of better-adapted forest types and tree species (Ogden and Innes, 2009; Lindner et al. 2000; Parker et al. 2000). From an economic perspective, reducing the rotation length has already proved to be efficient to lessen the risk of forest decline (Bréda and Brunette 2019).

Modifying *Thinning* in timing or intensity makes it possible to increase growth and turnover of carbon (Ogden and Innes 2009). In addition, thinning improves the recovery of radial growth following drought and, to a lesser extent, growth resistance during a drought event (Sohn et al. 2016). Partial cutting or thinning also leads to increased stand vigour and lowers susceptibility to biotic attacks (Wargo and Harrington 1991; Gottschalk 1995). Finally, thinning makes it possible to increase solar radiation, water and nutrient availability to the remaining trees (Smith et al. 1997; Papadopol 2000).

The *Irregular* strategy makes it possible to diversify the stand in terms of species and age, to have a continuous cover and to then reduce the associated risks (Ogden and Innes 2009). In addition, and consistent with Lafond et al. (2014), uneven-aged structures allow the permanence of high regeneration cover in the stand (O'Hara 2006; Cordonnier et al. 2008) and create complementarities in species sensitivity or response to disturbance (DeClerck et al. 2006; Jactel and Brockerhoff 2007).

4.2 Questionnaire design

The survey ~~was conducted in 2018 on 944 private forest owners from metropolitan France by the Research Centre for the Study and Observation of Living Conditions (CREDOC). It~~ consisted of a phone survey with 37 questions that took an average of 10 minutes to answer.

The questionnaire was composed of different parts. These parts correspond to the categories of variables already identified in the literature. Indeed, the first part of the questionnaire is dedicated to “Objective variables” linked to the characteristics of the forest owner and forest and the second part deals with “Subjective variables” related to climate change (perception and cause, observation and impact). The last part consists of questions for the forest owners about potential changes of practices in order to adapt to climate change. Consequently, the answers provided by the private forest owners in the first two parts are then used to explain the adaptation choices expressed in the third part. The questions asked in each part of the questionnaire are presented in Appendix A.

4.3 Description of the sample

The survey was conducted in 2018 on private forest owners from metropolitan France by the Research Centre for the Study and Observation of Living Conditions (CREDOC). The CREDOC had the phone numbers of more than 6000 French private forest owners. Among them, 3827 owners could not be reached, 760 were contacted but turned out to be off-target (too small surface area, errors in the plot held, etc.), 789 simply refused to answer and 944 fully completed the questionnaire.

The sample was drawn up from a double stratification, by region and area class. Surveyed owners were selected, first, according to the location of their forest (region) and, second, according to the forest surface area they owned. All regions and forest area classes are represented in our final sample.

The stratification by large region was carried out in order to differentiate the various types of climates found in France (oceanic, continental, Mediterranean and mountain) and the type of associated stands with their own constraints and number of private forest owners. Results were presented per region to ease their incorporation into local public policies.

We randomly selected the same numbers of potential respondents for each region. We thus had eight regions (vs. 13 in the official sub-national divisions). Because some regions have similar climatic and settlement patterns, we decided to group them together and select eight large regions represented by roughly equal samples in each (compared to 13 in the official subnational divisions): (1) Auvergne-Rhône Alpes (119 respondents), (2) Corse-Provence-Alpes-Côte d’Azur-Occitanie (114), (3) Bourgogne-Franche Comté (119), (4) Grand-Est (119), (5)

Centre-Val de Loire-Ile de France (112), (6) Nouvelle Aquitaine (117), (7) Bretagne-Pays de Loire (123), (8) Hauts de France-Normandie (121).

The stratification by area class is explained by the presence of management documents specific to the area category, and required by law as of 25 ha of forest owned, which explains why the largest properties must have a management document validated by a forestry consultant. Another point, consistent with other surveys conducted in France by the National Centre of Private Property ("Centre National de la Propriété Forestière") and its partners revealed differences in owners' behaviours according to the surface area they own, particularly in terms of their attachment to their forests, but also, for example, in terms of their expectations and behaviour with regard to wood cutting.

The 2016-2026 National Forest and Timber Program initiated by the Minister of Agriculture and Food has announced that the priority of the action of the National Centre of Forest Property will focus on owners with at least 4 ha, or about 76% of the private forest area, in order to assist them in the management of their forest. In view of the limited public resources (human and financial), the government has agreed to prioritise action for this population, targeting properties with the most favourable criteria in terms of economic development. The choice was therefore to follow this directive and focus on owners with 4 ha or more.

We considered four forest area classes: from 4 to 10 ha, from 10 to 25 ha, from 25 to 100 ha, and more than 100 ha. The distribution was as follows: 314 owners in [4-10 ha], 161 in [10-25 ha], 399 in [25-100 ha] and 70 in >100 ha]. This makes it possible to reach national (or regional) level representativeness using weights.

4.3.1 Objective and subjective variables: Parts 1 and 2 of the questionnaire

Table 1 presents the descriptive statistics related to the first part (objective variables) and the second part (subjective variables) of the questionnaire.

Objective variables. Our sample is mainly composed of middle-aged men (45 to 65 years old). They show very heterogeneous education levels, with well-represented extremes: a large proportion of the sample has an education level lower than A level and the second largest share reached a master's degree. The two most highly represented socio-professional categories (*SPC*) are farmers and executives.

Regarding the characteristics of the forest, we can say that the average forest area owned in our sample is about 40 hectares, with a large variability: minimal area of 4 hectares and a maximal area of 2300 hectares. Most of the forest owners have forests of between 4 and 100 hectares; very few (less than 1%) own more than 100 ha. Private forest owners mainly own their forests for leisure-related reasons (*Obj_Leisure*) and biodiversity conservation (*Obj_Biodiversity*), although the answer to such a question could be relatively sensitive. Among the seven possible main reasons for owning forests, owners selected 4.5 of them on average, confirming the multi-functional characteristics of French forests and the non-specialisation of French forestry.

Table 1. Descriptive statistics for objective (left) and subjective variables (right).

Objective variables	Freq.	N
FORESTER		
Gender (female = 1)	76	944
Age < 44 years	35	944
45-65 years	656	944
> 65 years	268	944
Education: No diploma	51	944
< A level	386	923
A level	125	923
2 to 3 years after A level	180	923
Master	196	923
SPC: Never worked	13	944
Farmer	312	944
Craftsman/Artisan	130	944
Superior (executive)	248	944
Intermediary	122	944
Employee	67	944
Worker (factory)	67	944
FOREST		
Area (Min = 4.012 ha; Max = 2300.48 ha)		944
4-10 ha	314	944
10-25 ha	161	944
25-100 ha	399	944
> 100 ha	70	944

Subjective variables	Freq.	N
Perception: Yes	287	944
Somewhat yes	406	944
Somewhat not	97	944
Not at all	74	944
Don't know	80	944
Anthropic: Yes	323	693
Somewhat yes	274	693
Somewhat not	37	693
Not at all	56	693
Don't know	3	693
Impact: Large impact	307	693
Small impact	252	693
No impact	34	693
Don't know	100	693
Timing: Today (already observable)	305	559
In 10 years	96	559
In 30 years	104	559
Don't know	54	559
Feeling: Very worried	38	364
Not very worried	272	364
Don't know	54	364
Manifestation: More drought	531	944
More winter rain	322	944

Objective: Obj_Emotion	5	944
Obj_Heritage	5	944
Obj_Fiscal/Tax	1	944
Obj_Hunting	8	944
Obj_Timber	46	944
Obj_Biodiversity	106	944
Obj_Leisure	788	944
Manag_document	460	922
Revenue_12months	409	913
Among which: Revenue_logging	211	398
Revenue_ hunting	146	398
Revenue_other	52	398
Regions: Auvergne-Rhône-Alpes	122	944
Bourgogne-Franche-Comté	121	944
Bretagne-Pays de la Loire	123	944
Centre-Val de Loire-Ile de France	114	944
Corse-PACA-Occitanie	115	944
Grand Est	122	944
Hauts de France-Normandie	122	944
Nouvelle Aquitaine	120	944

More storm	573	944
Less frost	412	944

Approximately half of the people in the sample own at least one formal document for forest management and public regulation (*Manag_document*). The three documents considered are: Simple Management Plan ("Plan simple de gestion"), Management regulation ("Règlement type de gestion"), and Codes of good silvicultural practices ("Codes des bonnes pratiques"). When owners own more than 25 hectares of forest, they have to provide a Simple Management Plan. It is required by law and well enforced.

Finally, the forest provided revenue over the last 12 months for 409 private forest owners (*Revenue_12months*), mainly from logging.

The number of respondents is almost identical in each of the eight regions considered, approximately 12% of the sample in each region.

Subjective variables. Approximately 73% of the private forest owners are aware of climate change (*Perception*) and most of them think that it is human-induced (*Anthropic*). Most of the respondents are persuaded that climate change will have an impact (either small or large), and they think that the impacts are already observable today (*Timing*). Generally, the respondents are not very concerned by climate change impacts on their own forest (*Not very worried*). We also questioned them about how climate change reveals itself in their forests and most of them mentioned the increase in frequency and intensity of drought as well as storm events.

4.3.2 Adaptation choices: Part 3 of the questionnaire

Table 2 presents the descriptive statistics in terms of adaptation choices, i.e., Part 3 of the questionnaire. We ask forest owners to indicate if they have changed their practices to address climate change for more than 5 years, in the past 5 years, if they plan to do so in the next 5 years, if they have no plan or if they do not know.

We focused on a 5-year period for several reasons. The standard rotation period in France for forest management is 10 years. This means that the forest owners attend to their stands approximately every ten years (with some exceptions) to carry out silvicultural operations (thinning, harvest, etc.). As a consequence, our questions to the forest owners concern the past five years and the next five years, in order to cover this 10-year rotation period, and to ensure that some management actions have taken place during the period. In addition, considering a longer time frame would create quality issues due to the impossibility of recalling certain details with precision. Indeed, people may forget older changes and, in the same vein, it may be difficult for them to represent themselves in the distant future. This 5-year time frame is commonly considered in the literature. For example, Vulturius et al. (2018) asked private forest owners to state their intention to take risk-mitigating actions in the coming 5 years. A 5-year period is also used to analyse harvesting decisions of private forest owners in Conway et al. (2003), Garcia et al. (2014) and Brunette et al. (2017), among others.

We created a variable *Change_practices* that encompassed all the forest owners who had adopted adaptation strategies in the past, both in the past five years and before. We chose to not consider those "who plan to adapt in the next 5 years" because future changes are what is really going to happen but may explain how the propensity to declare future changes can be fostered by a better understanding of individual behaviours and preferences (rather than the future projection of changes). We can see that 16.1% have already changed their practices (*Change_practices*). Among those who already adapt (*Past*), they mainly changed the way they thin (*Thinning*)

and have moved towards irregular stands (*Irregular*) as adaptation strategies. The factor that triggered the changes is specialised information in the forestry sector (*Specialised info*). The motivation to adapt is generally the desire to reduce the damage due to climate change (*Damage reduction*). To better assist them in their changes in practices, forest owners indicated that they were interested in specialised training (*Training*) on climate change and its regulations.

The forest owners who do not plan to adapt evoked the following reasons (*No change*): they think they can still wait (*Can wait*), current regulations limit their means of action (*Admin rules*), lack of money (*Money*) and other priorities regarding forest management (*Other priorities*).

Table 2. Adaptation decisions towards climate change.

Variable	Freq.	N
Change_practices	107	663
Past (for more than 5 years)	51	703
Past (in the past 5 years)	56	703
Plan (in the next 5 years)	127	703
No plan	429	703
Don't know	40	703
Among which "Past"		
Thinning	67	104
Early harvest	49	105
Irregular	66	104
Trigger: Professional advice	27	191
Friendly advice	13	191
Specialised info	101	191
Renewal_doc	50	191
Motivation: Ecosystem	1	225
Resilience	4	225
Productivity	12	225
Damage reduction	36	225
Support: Financial/tax	13	196
Technical assistance	17	196
Scientific answers	47	196
Training	119	196
No change: Limited info	4	382
Contradicting info	10	382
Can wait	130	382
Other priorities	56	382
Admin rules	71	382
User pressure	46	382
Money	65	382

When looking at effective (*Past*) management practices, heterogeneities by area owned and region are relatively limited.

4.4 Econometric strategy

In the first step, we ran a probit regression on the binary variable *Change_practices*, taking the value of 1 for forest owners who had already begun adaptation and 0 otherwise (no adaptation undertaken). This regression allowed us to identify the determinants of the private forest owner's decision to adapt.

In the second step, we ran a probit regression per adaptation strategy, among the three included in the survey. This regression aims to highlight potential strategy-dependent ~~drivers~~determinants that can only explain some strategies and not the general decision of adaptation.

Since each owner has to make binary choices, we have the following typical cross-section regression:

$$x_i^* = \alpha_i + Z_i\beta + \mu_i \quad \text{avec } i \in 1, N$$

$$x_i = 1\ (x_i^* > 0)$$

where x_i^* is the latent variable of the adoption of adaptation strategies of owner *i*, and x_i is the binary variable of adoption (adaptation strategies); α_i is a dummy indicating the spatial unity (department/region) and Z_i is the

vector of explanatory variables. The explanatory variables are the objective and subjective variables presented in Table 1 and represent the potential determinants of the adaptation decision.

Let $\Phi(\cdot)$ be the cumulative distribution function of observations: $PR(x_i = 1 \,|Z_i, \alpha_i) = \Phi(\alpha_i + Z_i\beta)$

Three models were run for each regression: a regression with a clustering of the standard errors at the department level[1] (Model 1), a regression with a clustering at the department level and regional fixed effects (Model 2), and a regression considering a clustering at the inter-regional level and regional fixed effects (Model 3). Standard errors are more robust when clusters are large, and coefficients more precise with a lower level of fixed effects, which makes the third regression the most robust. Consequently, we present the results of Model (3) in the manuscript and the results associated with the other two models in Appendix B.

For each regression, we controlled for individual, property and location characteristics. We tested standard individual controls such as age, education level and socio-economic status (socio-professional categories) of the owners, as well as administrative variables (documents provided related to forest management). In addition, we looked at the relationship between the reasons stated for owning woods and the climate change-related beliefs of owners and their propensity to adapt.

5. Results

5.1 Adaptation vs. non-adaptation: the determinants

Table 3 presents the results of the regression for Model (3). The variable regressed is binary: *Change_practices.* These regressions allow us to compare the determinants of those owners who have already adopted adaptation *(Past)* and the others *(Plan, No plan, Don't know).*

The results are almost the same regardless of the model (Table 3 below and Table B1 in the Appendix present the three models). Since education level and owner's age were not found to be significant ~~drivers~~determinants in any specifications, they were dropped from the result tables. It should be noted that the absence of a significant impact of these two variables is in line with the results of Vulturius et al. (2020).

Some characteristics of the private forest owner and the forest are significant. Being a woman has a significant and negative effect on the adaptation decision. This result is in line with Eriksson and Fries (2020). All of the SPC also have a significant and positive effect compared to the category *Never worked*. Regarding the forest, the area has a significant and positive impact, as in Eriksson and Fries (2020). The fact of having received revenue from hunting is negative and has a significant impact with respect to *Other objectives*. This means that if owners perceived revenue from hunting then they are less encouraged to adopt adaptation strategies. Indeed, changing practices, with what this can generate in forest work and change in environment, has a negative impact. Moreover, a change of setting can be associated with a loss of game, which, for example, would be less present if the tree species on the spot are modified by better-adapted species. Some objectives indicated by the forest owners for their forests appeared to always be positive and highly significant: *Biodiversity, Heritage, Leisure* and *Timber*. Being able to provide a management document (*Manag_document*) has a significant and positive impact on the decision. The location of the forest somewhere other than in NOUVELLE-AQUITAINE generally has a significant and negative impact on the adaptation decision. One exception is BOURGOGNE-FRANCHE-COMTE where the impact, although negative, is not significant.

Concerning the subjective variables, we observed that replying "Yes" to the question "Do you think the climate is changing?" (*Perception_Yes*) has a significant and positive impact on the adaptation decision. We can observe that respondents who think that climate change will have an impact (*Impact*) have a greater chance of adapting their management. Regarding the way climate change manifests itself among the respondents indicates negative and significant impact for *Less_frost* and *More_winter_rain*. Finally, people who consider that climate change has an anthropic origin (*Anthropic*) have a lower chance to adapt than the others.

[1] The department is the second sub-national administrative boundary in France, after the region.

Table 3. The determinants of the change in practices, inter-regional clusters and regional fixed effects.

	Model (3)
Area	0.00208* (0.00109)
Revenue_12 months	-0.0367 (0.415)
Gender	-1.020** (0.473)
Farmer	4.144*** (0.240)
Craftsman/Artisan	3.624*** (0.293)
Superior	4.203*** (0.253)
Intermediary	4.155*** (0.281)
Employee	3.840*** (0.362)
Worker	4.745*** (0.241)
Manag_document	0.453** (0.200)
Revenue_logging	-0.529 (0.361)
Revenue_hunting	-0.377* (0.180)
Obj_Biodiversity	3.917*** (0.384)
Obj_Heritage	4.107*** (0.863)
Obj_Leisure	4.216*** (0.441)
Obj_Timber	4.014*** (0.742)
Impact[2]	0.334* (0.168)
More_drought	0.269 (0.201)
Less_frost	-0.17** (0.0816)
More_winter_rain	-0.150* (0.0849)
Perception_Yes	0.418*** (0.165)
Anthropic[3]	-0.319*** (0.123)
AUVERGNE-RHONE-ALPES	-0.686*** (0.0487)
BOURGOGNE - FRANCHE-COMTE	-0.0404 (0.0351)
BRETAGNE - PAYS de la LOIRE	-0.484*** (0.0915)
CENTRE -VAL de LOIRE - ILE de F	-0.872*** (0.0832)
CORSE - PACA - OCCITANIE	-0.332*** (0.0516)
GRAND EST	-0.254*** (0.0820)
HAUTS de FRANCE - NORMANDIE	-0.167*** (0.0628)
Constant	-8.049*** (0.586)
Observations	629
Department-level clustering	No
Regional-level clustering	Yes
Adjusted R^2	0.2101

Standard errors in parentheses; *p < 0.1; **p < 0.05; ***p < 0.01

Respondents who had not changed their practices and did not wish to do so in the next five years (N = 429) were asked about the reasons for this refusal. These reasons are presented in Table 4.

Table 4. Reasons for "no adaptation", N=429.

Variable	Freq
Reasons for not adapting	
Not enough information	60
Contradictory information	57
Prefer to wait	138
Other priorities	45
Money	48
Administrative rules	40
User pressure	21
Incentives to change	
Climate change assessment	49
Need insurance	18
Sanitary assessment	48
Experimental plot (impact evaluation) tests	46
Money	61

The answer "Prefer to wait" was the most frequently given. The notion of information is also very important - it is cited by many respondents as either absent or contradictory. This idea of "lack of information" to explain the absence of adaptation is in line with Sousa-Silva et al. (2016). For those respondents who do not plan to change their practices, would certain tools or accompaniment encourage them to do so? Approximately 50% of the

[2] Impact has been coded as follows: Impact = 1 for "Large impact" and "Small impact"; Impact = 0 for "No impact" and "Don't know".

[3] Anthropic has been coded as follows: Anthropic = 1 for "Yes" and "Somewhat yes"; Anthropic = 0 for "Somewhat not", "Not at all" and "Don't know".

owners who do not wish to change their practices in the next 5 years are not interested (and/or do not know) in the proposals we have made to them (climate change assessment, insurance, sanitary assessment, experimental plots or money to assist them in adaptation). This may mean that our proposals were not varied enough or that these owners do not identify with the policies promoted by the forest and wood industry.

5.2 ~~Drivers~~Determinants of the adaptation strategies

We first present bilateral correlations between the three adaptation strategies in Table 5. We observe that the correlations between strategies are low, meaning they are generally exclusive.

Table 5. Bilateral correlations between the adaptation strategies.

	Thinning	Early harvest	Irregular
Thinning	1.0000		
Early harvest	0.0753	1.0000	
Irregular	0.1465	0.0759	1.0000

Table 6 presents the regressions per adaptation strategy for Model (3).

Table 6. ~~Drivers~~Determinants by strategy, inter-regional clusters and regional fixed effects.

	Thinning	Early harvest	Irregular
Area	0.000650	0.00213	-.000272
	(0.00107)	(0.00167)	(0.00124)
Revenue_12 months	-1.380*	0.0316	0.0327
	(0.719)	(0.590)	(0.782)
Farmer	-0.459	0.709	-0.0152
	(0.548)	(0.604)	(0.506)
Craftsman/Artisan	-0.666	1.322*	0.0940
	(0.768)	(0.777)	(0.797)
Superior	-0.250	0.588	-0.263
	(0.522)	(0.572)	(0.498)
Intermediary	-0.101	1.359*	-0.398
	(0.611)	(0.697)	(0.706)
Employee	-2.003***	0.465	-0.219
	(0.647)	(0.690)	(0.836)
Manag_document	0.238	1.117***	0.962***
	(0.367)	(0.410)	(0.340)
Revenue_logging	-0.959	0.242	0.128
	(0.650)	(0.547)	(0.739)
Revenue_hunting	-0.122	-0.0438	0.188
	(0.308)	(0.362)	(0.321)
Obj_Biodiversity	1.201	1.537*	0.106
	(0.837)	(0.870)	(0.506)
Obj_Leisure	1.417*	1.436*	0
	(0.753)	(0.775)	(.)
Impact	-0.291	-0.615	0.612
	(0.535)	(0.633)	(0.413)
More drought	-0.455	-0.510	0.0478
	(0.466)	(0.412)	(0.388)
Less frost	0.362	-0.492*	0.346
	(0.307)	(0.264)	(0.273)
More winter rain	0.102	-0.240	0.393
	(0.258)	(0.312)	(0.259)
Perception Yes	-0.127	-0.130	-0.103
	(0.255)	(0.310)	(0.362)
Anthropic	-0.769*	0.481	-0.430
	(0.447)	(0.434)	(0.441)
Constant	2.933	-2.381	-1.127
	(2.021)	(1.664)	(1.751)
Observations	97	98	93
Adjusted R^2	0.1333	0.3029	0.1978

Standard errors in parentheses; *p < 0.1; **p < 0.05; ***p < 0.01

Many of the variables have a significant impact on the strategy *Early harvest*. Belonging to the SCP *Intermediary* or *Craftsman/Artisan* encourages the French private forest owners to harvest earlier. In the same

way, owning a forest mainly for biodiversity conservation (*Obj_Biodiversity*) and leisure-related reasons (*Obj_Leisure*) has a significant and positive impact on *Early Harvest*. Having a forest management document acts like a high incentive to adopt *Early harvest*. Finally, respondents who consider that the impact of climate change will be real (either *Large* or *Small*) are discouraged to harvest earlier.

Only one variable has a significant impact on *Irregular*. Indeed, having a forest management document encourages French private forest owners to implement the adaptation strategy *Irregular*. This is also true for *Early harvest*, showing a potential effect of public policies requiring a management document.

Having collected revenue from the forest over the last 12 months significantly and negatively affects the *Thinning* strategy. Being an *Employee* has a significant and negative effect on *Thinning*. Being sure that the origin of climate change is anthropic has a significant and negative effect on *Thinning*.

To conclude, we observe that: (i) adoption of the three adaptation strategies is not sensitive to the same drivers; and (ii) there are significant variables in both the objective and subjective categories. We will address these two results in the discussion.

6. Discussion

We first discuss our two main conclusions that deal with the strategy-dependent ~~drivers~~determinants and the complementarity between the categories of variables and, second, we discuss some potential limitations of the article and prospects for future research.

6.1 Strategy-dependent ~~drivers~~determinants

The intuition that the determinants of the adaptation decision are strategy-dependent turns out to be true since none of the variables has the same significant impact on the three adaptation strategies considered. This means that talking about adaptation in general may make no sense and that the incentives and design of public policies should probably be dependent on the strategy. This also suggests that specific populations may be targeted for the purpose of encouraging adaptation practices. For example, individuals belonging to the SCP *Intermediary* or *Craftsman/Artisan* categories, who own a forest mainly for biodiversity conservation (*Obj_Biodiversity*) and leisure-related reasons (*Obj_Leisure*), seem to be more prone to adopt *Early harvest*. Encouragement/incentive policies may attempt to target those categories, or consider that having a forest management document and questioning the impacts of climate change may also increase the probability of adoption.

The variable related to the management document increases the forest owner's propensity to adopt both *Irregular* and *Early harvest* strategies, whereas it does not interfere (very small and insignificant coefficient) with the adoption of *Thinning*. Although we cannot discuss the channels behind those relationships as they are beyond the scope of this paper, it seems that owners who were able to provide a document to certify their forest management (half of the people in the sample were able to provide either a simple or more detailed forest management plan or at least a list of good practices) are more inclined to adopt these adaptation strategies. The forest management documents thus represent a relevant vector for potential public policy dedicated to the implementation of an adaptation strategy.

We also identified a large number of significant ~~drivers~~determinants for the adaptation strategies based on harvest management (*Early harvest*). Advancing the final harvest has been a classical risk management strategy in forestry for a long time now and it is easy to implement throughout the rotation process. Moreover, this strategy offers flexibility compared to the *Irregular* strategy. This result is in line with Brunette et al. (2020) who observed that forestry professionals are afraid of changing routines and that current forest management practices are characterised by inertia. In order to reduce this inertia, the improvement and clarification of the information available to owners concerning climate change and its impact on forest management is an issue, as highlighted by Sousa-Silva et al. (2016). Moreover, knowing that the climate is changing is not sufficient to initiate an adaptation process. Indeed, private forest owners have to be convinced that the impacts of climate change will be real, either small or large, to make the decision to adapt. This result confirms anecdotal evidence based on descriptive statistics that show that private forest owners are in need of specialised information in the forestry sector as well as training on climate change and its regulations. This result is also in line with Yousefpour and Hanewinkel (2015) who show that "*forest decision-makers must be aware of the nature and implications of climate change in order to develop management strategies that may help to reduce adverse effects and sustain productive forests*".
Finally, when looking at the propensity of specific owners to adapt to climate change per region, we observed a higher propensity in NOUVELLE-AQUITAINE (where pines, in majority, are grown intensively for paper pulp

production and related products) and in BOURGOGNE-FRANCHE-COMTE. Alternatively, CENTRE-VAL-DE-LOIRE-Ile de FRANCE (the region encompassing Paris, the capitol) and AUVERGNE-RHONE-ALPES (the region with the second biggest city in France: Lyon) seem to be the two regions with the lowest propensity to adapt. This regional heterogeneity shows that our results should be interpreted with caution (also, because we do not have owner fixed effects that would make it possible to more robustly control for individual and especially unobservable specific characteristics). This is also in line with Spathef et al. (2014) who said that it is "of utmost importance to implement regionally-based adaptation measures that are accepted by the stakeholders involved".

6.2 Complementarity between categories of variables

The ~~two first parts of our questionnaire were built in reaction to the existing~~ literature~~,~~ shows~~ing~~ that two types of categories of variables seem to have an effect on private forest owners' adaptation decisions: objective and subjective variables.

Our results reveal that the variables that have a significant impact in Table 3, presenting the determinants of the change in practices, and Table 6, presenting the determinants by adaptation strategy, are from both categories of variables. Indeed, we observed that variables like forest area, region or management objective have a significant impact on the propensity to adapt (objective variables), as well as variables like the perception of climate change and the origin of climate change (subjective variables). In the same vein, significant variables from both categories appeared in Table 6. This result suggests that the variables in the two categories are complementary to explain adaptation decisions, including the strategy-by-strategy adaptation decision.

Our conclusion is in line with Van Gameren and Zaccai (2015) who said that these two categories of variables are complementary in the understanding of the private forest owner's adaptation decision in Belgium, and contrary to the results of Vulturius et al. (2018) who reported that only the "cognitive variables" (i.e., those related to climate change) have a significant impact, whereas the socio-demographic variables do not in Sweden. However, our results go a little bit further by revealing that this complementarity is also relevant when dealing with adaptation strategies on an individual basis.

6.3 Some limitations of the article and prospects for future research

The article is based on a phone survey. In reality, such surveys face a number of problems. First, people may mistrust calls from unknown individuals, especially in terms of security issues (Tourangeau 2004). Second, innovations such as caller identification and answering machines make it possible to select the calls and to avoid survey requests (Tuckel and O'Neill 2002). Third, the general increase in cellular phones instead of landlines is another issue (Tourangeau 2004). Indeed, the phone numbers for landlines are easy to obtain and public, whereas it is not the case for cellular phones. Concerning this last point, the CREDOC tried to contact owners through landline and cellular phones. In our sample of 944 French private forest owners, 103 answered the questionnaire via cellular phones and 841 through landline phones. The risk is an under-coverage bias (i.e., under-representation of some sub-samples/population categories in the overall sample). This may be the case, for example, if French private forest owners with only a cellular phone (younger ones?) were not well represented in our sample. However, such an under-coverage is not relevant for our sample. We can try to find another way to contact private forest owners in the future. For example, Web questionnaires are currently quite popular. However, they may present problems for our population that is elderly. Indeed, only 35 owners are less than 44 years old, whereas 656 of the 944 respondents are between 45 and 65 years old, and 268 are over 65 years old. This last segment of the population is not as connected. The risk is an over-representation of the younger respondents in the sample. Since it is possible that different biases may impact the representativity of our sample (and thus reduce the external validity of our results) in different ways, it is not easy to tell/assess/estimate to what extent our results may be biased by such issues.

~~The questionnaire focuses on objective and subjective questions independently from any theoretical economic framework.~~ An idea for future research would be to include behavioural items ~~that assume such a framework~~ in the questionnaire. For example, the literature has already shown that the forest owner's attitude towards risk is a ~~drivers~~determinant for the adaptation decision, whereas uncertainty aversion is not (Brunette et al. 2020), so that including such an aversion measurement in the questionnaire may appear relevant. To do that, the multiple price list methodology of Holt and Laury (2002) offers an interesting tool based on expected utility theory. Another line of thought would be, for example, to consider a more sophisticated framework based on the cumulative prospect theory (Kanheman and Tversky 1992). This theory considers psychological processes such as loss aversion, subjective values of gains and losses and subjective probabilities. The experimental methodology based

on lottery choices and proposed by Tanaka et al. (2018) makes it possible to measure each of the parameters associated with this theory. Introducing such behavioural considerations will bring new insights to this literature on private forest owners' adaptation decisions. In addition, the complementarity or substitutability of these behavioural variables with the categories of variables analysed in the current article may be interesting to focus on.

The article is based on three adaptation strategies, whereas more than 30 have been suggested (Ogden and Innes 2009). However, it must be recalled that our objective is to deepen the analysis of the adaptation decision by proposing to identify the determinants strategy-by-strategy. This means carrying out a regression per adaptation strategy considered. Consequently, we focused on three strategies that are unanimous in the literature, in the sense that their capacity to cope with climate change is recognised. Our results reveal that our intuition is true: the determinants of the adaptation decision are different from one strategy to another. The analysis developed in this article may then be reproduced for any adaptation strategy that appears interesting, especially to identify relevant levers for public policy intervention.

The survey data mobilised in this study used a stratification sampling strategy so as to be representative in terms of the forest area owned at the national level in order to provide results with an external validity. This choice means that our results could be used for French forest adaptation policy design aimed at reaching a maximum number of forest areas. However, it could be argued that reaching a maximum number of forest owners may also matter, including the lowest decile of owners in terms of forest area owned. We focus on owners with at least 4 ha or about 76% of the private forest area. Indeed, in view of the limited public resources (human and financial), the government has agreed to prioritise action for this population, targeting properties with the most favourable criteria in terms of economic development. The choice was therefore to take this into account and focus on owners with 4 ha or more.

Finally, some unobserved variables ~~that were not taken into account~~ may have an impact on the adaptation decision. For example, we show that having a management document influences both the propensity to adapt and the choice of the strategy. An interesting piece of information connected with the latter would be to know if the forest owner has a certification or not. In addition, the questionnaire deals with risks, climate change and adaptation, so that it may be interesting to know if the forest is insured or not. In particular, we wonder if insurance contracts and adaptation strategies are complements or substitutes. This information should be included in future questionnaires.

7. Conclusion

This paper focuses on the determinants of the French private forest owners' adaptation decisions through a questionnaire. In particular, we tackled two main research questions about the determinants of the adaptation decision ~~as a whole~~, and concerning the ~~drivers~~determinants of the adoption of one strategy as opposed to another. Our results reveal that both the objective and subjective variables ~~are complementary to~~ explain the French private forest owners' adaptation decisions. Indeed, objective variables like gender, the owner's SPC, the forest area, the revenue from hunting, the management document, the management objectives and the region where the forest is located are on the same level as subjective variables such as the perception of climate change and its impact, the way climate change manifests itself and its origin, to explain the probability to implement adaptation strategies. In addition, we show that the determinants of the adaptation strategies are strategy-dependent. For example, the implementation of the strategy *Early harvest* is influenced by the *SCPs Artisan* and *Intermediary*, the management objective *Biodiversity* and *Leisure*, and possession of a management document. The strategy *Irregular* is only impacted positively by the management document. The strategy *Thinning* is affected by having perceived revenue in the last 12 months, the *SCP Employee*, the management objective *Leisure*, and the anthropic origin of climate change. The fact that the determinants are dependent on the adaptation strategy means that dealing with adaptation decisions in general may lead to wrong decisions, for example, in terms of designing public policy to incentivise adaptation, and that the reflection should be conducted at the level of the strategy itself. Consequently, a specific population associated with a specific adaptation strategy should be targeted to increase adaptation policy implementation and efficiency.

These scientific results have practical implications. Indeed, the questionnaire was developed with forestry organisations (advisors and managers), and the results are used to train new forestry advisors at the National Centre of Forest Property. The results are presented to the technicians within the framework of the accompaniment strategy of the forest owners. The key message is that expectations, needs and behaviours differ from one owner to another and that it is important to take them into account in order to best assist the owners in

their efforts and provide advice that will allow them to remain interested and involved in the management of their forest. Finally, the results also make it possible to design local public policies that incorporate our results into their territorial reflection rather than a single policy, which is not the best option given the differences in the profiles and expectations of the owners.

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Appendix A. Description of the questionnaire

Hello, I am [First and last name of the investigator] from CREDOC and I would like to speak to [First name Last name of the contact provided], the person who takes care of the woodlands in the department [Department of the contact provided] please. I am calling on behalf of the National Forest Property Centre and I would like to hear your opinion on climate change and the impact it may have on your management practices and adaptation strategies. This survey is anonymous and confidential. Do you agree to answer a few questions as a forest owner?

This questionnaire lasts approximately 10 minutes and is composed of three parts.

For information, as part of our quality approach, this call can be recorded.

PART 1: Objective variables

Characteristics of the forest owner

1.1 Gender (variable *Gender* in Table 1).
☐ Male
☐ Female

1.2 How old are you? (variable *Age* in Table 1 recoded with three categories: < 44 years, 45-65 years, > 65 years).
☐ Under 25
☐ 5-34 years
☐ 35-44 years
☐ 45-54 years
☐ 55-64 years
☐ 65-74 years
☐75 years and over

1.3 What is the highest level of diploma that you have obtained? (variable *Education* in Table 1 recoded with five categories: No diploma, < A level, A level, 2 to 3 years after A level, Master).
☐ No diploma
☐ Certificate of primary studies
☐ CAP, BEPC, BEP, college certificate
☐ General, vocational or technical baccalaureate (A level)
☐ BTS, DUT, DEUG (A level + 2 years)
☐ License, master's degree, higher studies (A level + 3 years)
☐ Master's, doctorate, engineer, higher studies (A level + 5 years and more)
☐ Refused or no answer

1.4 What is/was your profession? (variable *SPC* in Table 1).
☐ Farmer
☐ Craftsman/Artisan
☐ Superior (executive)
☐ Intermediary
☐ Employee
☐ Worker
☐ Never worked

Characteristics of the forest

1.5 Select the region where your forest is located (variable *Region* in Table 1).
☐ Auvergne - Rhône-Alpes
☐ Bourgogne -Franche-Comté
☐ Bretagne - Pays de la Loire
☐ Centre - Val de Loire - Ile de France
☐ Corse - Provence-Alpes-Côte d´Azur - Occitanie

☐ Grand Est
☐ Hauts de France - Normandie
☐ Nouvelle Aquitaine
☐ None of these regions

1.6 What is the total forest area that you own? (variable *Area* in Table 1 recoded in four categories: 4-10 ha, 10-25 ha, 25-100 ha, > 100 ha).
☐ Less than 4 ha (in that case, the participant was thanked and the interview was stopped)
☐ Between 4 and 10 ha
☐ Between 10 and 25 ha
☐ Between 25 and 100 ha
☐ More than 100 ha
☐ Don't know

1.7 Do your properties have one or more management documents for all or part of their forest area? (variable *Manag_document* in Table 1).
☐ Simple Management Plan ("Plan simple de gestion")
☐ Management regulations ("Règlement type de gestion")
☐ Code of good silvicultural practices ("Code de bonnes pratiques sylvicoles")

1.8 Personally, what interest(s) do you have in your forest? Is it for ... (variable *Objective* in Table 1).
☐ Emotional attachment
☐ Heritage
☐ Fiscality / Tax system
☐ Hunting
☐ Timber production
☐ Biodiversity preservation
☐ Leisure

1.9 During the past 12 months, have you earned income from your timber thanks to…? (variable *Revenue_12 months* in Table 1).
☐ Timber logging
☐ Hunting rental
☐ Another activity

PART 2: Subjective variables

<u>Perception and cause of climate change</u>

2.1 Do you think the climate is changing? (variable *Perception* in Table 2).
☐ Yes
☐ Somewhat yes
☐ Somewhat not
☐ Not at all
☐ Don't know

2.2 Climate change depends on human actions? (variable *Anthropic* in Table 2).
☐ Yes
☐ Somewhat yes
☐ Somewhat not
☐ Not at all
☐ Don't know

<u>Observation and impact of climate change</u>

2.3 What do you think will be the impact of climate change on your forest? Please choose only one of the following proposals (variable *Impact* in Table 2).
☐ Large impact
☐ Small impact

☐ No impact
☐ Don't know

2.4 Would you say that this impact…? (variable *Timing* in Table 2).
☐ Is already observable today
☐ Will be observed in 10 years
☐ Will be observed in 30 years
☐ Don't know

2.5 Regarding the impact of the change on your forest, would you say that you are ...? (variable *Feeling* in Table 2).
☐ Very worried
☐ Not very worried
☐ Don't know

2.6 In your opinion, climate change can be seen in your forest by…? (variable *Manifestation* in Table 2).

	Yes	No	Don' t know
More pronounced and more frequent droughts			
An increase in winter rains			
An increase in storms			
A reduction in frost periods			

PART 3: Adaptation decisions towards climate change

Changes of practices: strategies, triggers, motivations

3.1 In terms of forest management, would you say that…? (variable *Change_practices* in Table 3).
☐ You have changed your practices for more than 5 years
☐ You have changed your practices over the past 5 years
☐ You plan to change your practices over the next 5 years
☐ You do not plan to change your practices in the next 5 years
☐ Don't know

Questions for those having selected one of the first three possible answers in the previous question (changed your practices for more than 5 years, changed your practices over the past 5 years, plan to change your practices over the next 5 years).

3.2 How do you plan to change or how have you already changed your practices? (variables *Thinning*, *Early harvest* and *Irregular* in Table 2).

	Yes	No	Don' t know
Change the way you thin			
Harvest your trees earlier			
Harvest your trees later*			
Move towards irregular stands			
Move towards regular stands*			

** These two variables are not considered as adaptation strategies and are thus not included in our analysis.*

3.3 What triggered this change in practices? Is it…? (variable *Trigger* in Table 3).

	Yes	No	Don' t know
Professional advice			
Advice from a loved one, a family member			
Specialised information in the forestry sector (review, conference)			
Renewal of the management document			

3.4 Did the following reasons motivate you to adapt your practices? (variable *Motivation* in Table 3).

	Yes	No	Don' t know
Promote ecosystem services (water, carbon, biodiversity)			
Increase the capacity of your timber to resist climate change (resilience)			
Maintain or increase the productivity of your timber			
Limit potential damage			

Questions for those having selected "Do not plan to change" in the question related to change in practices.

<u>No changes of practices: reasons for inaction, potential supports</u>

3.5 Why do you not plan to change your forest management practices in the next 5 years? Is it because…? (variable *No change* in Table 3).

	Yes	No	Don' t know
Your information is too limited			
The information available is contradictory			
You think you can still wait			
You have other priorities concerning the management of your forest			
You lack money or financial support			
Current regulations or administrative rules limit your means of action			
You are constrained by pressure from forest users (hikers, hunters)			

3.6 To better help you with your changes in practices, would you be interested in…? (variable *Support* in Table 3).

	Yes	No	Don' t know
Financial or tax assistance			
Technical assistance on climate change			
Scientific answers about the future climate of your region			
Specific training on climate change			

3.7 Regarding climate change, would the following incentives encourage you to modify your management practices in the next 5 years? (variable *Incentives to change* in Table 5).

	Yes	No	Don’ t know
Benefit from a diagnosis linked to climate change			
Take out insurance (storm, fire)			
Benefit from a diagnosis of the health status of your forest			
Benefit from the establishment of experimental plots to test new techniques			
Obtain financial assistance to implement adaptation strategies			

The questionnaire is now finished. Do you have any comments or remarks to add?

Appendix B. Results of the regression for Models (1) and (2).

Table B.1. The determinants of the change in practices for Models (1) and (2).

	Model (1)	Model (2)
Area	0.00224 *	0.00211*
	(0.00117)	(0.00116)
Revenue_12 months	-0.0521	-0.0401
	(0.288)	(0.290)
Gender	-1.407**	-1.026**
	(0.427)	(0.440)
Farmer	4.229***	4.148***
	(0.253)	(0.281)
Craftsman/Artisan	3.660***	3.629***
	(0.296)	(0.327)
Superior	4.259***	4.209***
	(0.255)	(0.285)
Intermediary	4.239***	4.160***
	(0.270)	(0.309)
Employee	3.929***	3.868***
	(0.404)	(0.408)
Worker	4.831***	4.750***
	(0.366)	(0.385)
Manag_document	0.436**	0.450**
	(0.171)	(0.185)
Revenue_logging	-0.565**	-0.530*
	(0.267)	(0.272)
Revenue_hunting	-0.327*	-0.379*
	(0.195)	(0.211)
Obj_Biodiversity	3.718***	3.909***
	(0.394)	(0.486)
Obj_Heritage	4.067***	4.099***
	(0.694)	(0.823)
Obj_Leisure	4.029***	4.209***
	(0.377)	(0.487)
Obj_Timber	3.821***	4.006***
	(0.543)	(0.626)
Impact	0.292	0.336*
	(0.188)	(0.196)
More_drought	0.281*	0.271
	(0.170)	(0.179)
Less_frost	-0.128	-0.175
	(0.126)	(0.129)
More_winter_rain	-0.133	-0.152
	(0.143)	(0.138)
Perception_Yes	0.398***	0.420***
	(0.129)	(0.135)
Anthropic	-0.264	-0.318*
	(0.174)	(0.175)
AUVERGNE-RHONE-ALPES		-0.685**
		(0.272)
BOURGOGNE - FRANCHE-COMTE		-0.0379
		(0.210)
BRETAGNE - PAYS de la LOIRE		-0.481
		(0.300)
CENTRE -VAL de LOIRE - ILE de F		-0.871***
		(0.330)
CORSE - PACA - OCCITANIE		-0.321
		(0.261)
GRAND EST		-0.251
		(0.304)
HAUTS de FRANCE - NORMANDIE		-0.164
		(0.264)
Constant	-8.296*** (0.978)	-8.044***
		(1.039)
Observations	628	628
Department-level clustering	Yes	Yes
Regional-level clustering	No	No
Adjusted R^2	0.1836	0.2101

Standard errors in parentheses; *p < 0.1; **p < 0.05; ***p < 0.01