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1 Determinants of forest owners attitudes towards wood ash recycling in Sweden
2 Can the nutrient cycle be closed?

3 Jens Abildtrup¹, Göran Bostedt², Benjamin Ouvrard³, Anne Stenger⁴

6 Abstract

7 The use of biomass, in particular wood, has increased this last decade as a result of the European
8 Union's objectives to reduce the use of fossil energies. This has amplified the use of whole-tree
9 harvesting and the exploitation of forest residues from traditional timber harvest. However, these
10 practices have some ecological consequences because they remove nutrients from the forest, thus
11 potentially reducing soil fertility. To compensate for this nutrient loss, it has been proposed to recycle
12 wood ash to reintroduce the exported nutrients. In this paper, we assess private forest owners'
13 willingness to pay to spread ash in Västmanland, Sweden, where ash recycling is not widely adopted,
14 though an increasing supply of wood ash. In particular, we take into account behavioural motives that
15 may explain forest owners' willingness to pay (Theory of Planned Behaviour and environmental
16 sensitivity). We conclude that Swedish forest owners generally have a positive willingness-to-pay for
17 wood ash application in their forests, but that this measure is highly dependent on their attitudes. We
18 also show that a forest owner's decision to apply ash to all or a portion of his/her forest is explained by
19 two different characteristics: the landowner's environmental sensitivity and his/her perceived control
20 of wood ash recycling.

21
22 **Keywords:** wood ash recycling; choice experiment; environmental sensitivity; Theory of Planned
23 Behaviour

24 **JEL classification:** C24; D91; Q57

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1. Introduction

The use of biomass, in particular wood, has increased this last decade as a consequence of the European Union’s renewable energy targets, and is explicitly mentioned in the EU’s target to reach a 20% share of energy derived from renewables by 2020 (EU 2009). The latest report on the European bioeconomy from the Standing Committee on Agricultural Research (SCAR) and the European Bioeconomy Panel (European Commission 2014) also identified sustainable biomass production as a main issue. With this demand for wood energy, new harvesting techniques such as whole-tree harvesting and the exploitation of harvest residues from traditional timber harvest have become more popular. However, these practices may have important ecological consequences since they remove nutrients from the forests (such as calcium, magnesium, potassium, nitrogen and phosphorus), thus reducing soil fertility. Compared to traditional harvesting techniques where only trunks are harvested, whole-tree harvesting and harvest residues also include small branches that contain relatively more nutrients than the trunks. A recent meta-study by Ranius et al. (2018) concludes that extraction of harvest residues (called “slash” in the article) is associated with risks for decreased biomass production. Achat et al. (2015) find in another meta-study the tree growth as overall negatively and significantly impacted by removing harvest residues in European countries.

To compensate for this nutrient loss, ash recycling in forests has been proposed in order to reintroduce the exported nutrients (Egnell 2011; Väättäinen et al. 2011). Experimental research shows that spreading wood ash may increase tree growth. However, the impacts depend very much on the soil and forest types (Huotari et al. 2015). Furthermore, it has also been shown that ash use on certain forest soils has positive environmental impacts, e.g., to improve the acidification of soils and surface waters caused by acid deposition (Ekvall et al. 2014). In comparison with chemical fertilisers, wood ash has the advantage of not necessarily inducing a decrease in soil pH (Jokinen et al. 2006; Molina et al. 2007; Saarsalmi et al. 2012). Moreover, applying wood ash could also be seen as a measure of sustainability since it returns nutrients to the forest (except nitrogen) that were removed during harvesting, and can therefore be considered as an environmentally-friendly measure. Furthermore, ash recycling reduces the demand for the deposit of wood ash in landfills. According to Väättäinen et al. (2011), the majority of the 150,000 tons of wood ash produced annually in Finland is deposited in landfills. Despite these positive aspects of ash recycling, forest owners have been reluctant to recycle ash (Bohlin and Roos 2002). First of all, spreading ash in forests implies the costs of raw ash treatment (e.g., granulation or enrichments), transport and spreading (Väättäinen et al. 2011). In a Canadian, study of barriers to ash recycling, Hannam et al. (2018) find that the cost of getting regulatory approval of ash recycling represents also an important barrier. These costs may be higher than the

66 value of the expected gains in productivity. Moreover, uncertainty about impacts on forest ecosystems
67 and the lack of knowledge about wood ash application, e.g., questions about quantities to be applied,
68 timing, expected impacts and spreading technologies, may be a barrier to the adoption of ash
69 recycling. However, the cost of wood ash disposal in forests is slightly higher than other options like
70 applying ash in producer-owner landfill, but these findings do not consider the potentially high value
71 of environmental services (Hope et al. 2017). It is also well-known that non-industrial forest owners
72 may have other management objectives than just profit maximisation (see, e.g., Petucco et al. 2015).
73 Therefore, we may also expect that forest owners considering the sustainability of their management
74 may be more prone to adopt ash recycling. Understanding private forest owners' preferences for ash
75 recycling and the factors underlying its adoption is crucial for closing the nutrient cycle in a future
76 with an increasing demand for biofuel. The present study was conducted in the county of Västmanland
77 (central Sweden) with the cooperation of the forest owners' association, Mellanskog. In this county,
78 forest owners have not yet adopted wood ash recycling on a large scale, whereas power and district
79 heating plants produce abundant quantities of ash, which they consider to be a waste product
80 (Rolfsson 2018).

81

82 *i) Wood ash recycling in Sweden*

83 Sweden has 23.2 million hectares of productive forests (representing a total of approximately 57% of
84 the total land area), with a total standing volume of 3.0 billion cubic meters (Swedish Forest Agency
85 2014). An increased demand for bioenergy in the last decades, resulting in nutrient export, has
86 contributed to the acidification of the soils in Sweden.

87 As a consequence of the requirements imposed by the Swedish national environmental objective,
88 *Reduced Climate Impact*,⁵ the power and district heating plants in Sweden, which tend to have good
89 fuel substitution possibilities, have largely switched to biomass-based sources. These district heating
90 plants are therefore the main source of ash. There are several alternatives when it comes to how ash
91 resulting from the combustion of wood can be utilized. A part of the ash is contaminated because it is
92 mixed with other types of fuels (e.g., waste wood from house renovations) and must be deposited at
93 waste disposal sites. However, the most common applications for the remaining ash is as cover
94 material for landfills, as improved frost-resistant material in gravel roads, or for ash recycling in
95 forests (Olsson et al. 2008).

96 In addition to the combustion of logging residues in district heating plants, ash is also generated by the
97 forest industry through the combustion of spill from sawmills and as a by-product of pulp factories.
98 However, this ash usually has a lower nutrient content and a higher level of environmentally-

⁵ <https://www.miljomal.se/Environmental-Objectives-Portal/Undre-meny/About-the-Environmental-Objectives/1-Reduced-Climate-Impact/>, accessed May 29, 2018.

99 hazardous substances, which make it unsuitable for recycling on forest land (Swedish Forest Agency
100 2008).

101 Wood ash was spread on some 10,000 hectares of forests in 2013, mainly in the Götaland and
102 Svealand regions (south and central Sweden, respectively), wood ash fertilisation being most efficient
103 in the presence of organic soils. Indeed, studies have shown that wood ash fertilisation has the highest
104 positive effect on productivity on organic soils. On the mineral soils that are mainly present in the
105 north of Sweden, wood ash fertilisation has not been shown to have particularly strong effect on
106 productivity (Jacobson 2003; Ekvall et al. 2014). The volume of recycled ash distributed in the forests
107 in Svealand (where the county of Västmanland is located) in 2016 was approximately 2,725 tonnes,
108 corresponding to about 24% of all ash distributed in Swedish forests (Swedish Forest Agency). This
109 amount has been roughly constant for the last seven years. The majority of the ash, 75% in 2016, is
110 distributed in the southernmost region, Götaland, which is the region that was historically most
111 affected by acid rain. Practically, ash is applied either with a ground spreader, often a converted
112 tractor, or by helicopter. Both techniques are used, but ground application is considerably more
113 common.

114 As emphasized in Ekvall et al. (2014), ash has several alternative uses, whereas no explicit market for
115 forest ash exists in Sweden. One fundamental problem with the use of ash on forest land is the large
116 number of actors involved in the chain, from forest fuel extraction to the application of the stabilised
117 ash. A private forest owner usually contracts a forest company to conduct the extraction of forest
118 fuels. The forest company then sells the forest fuel to a forest fuel supplier, who has contracts with a
119 number of energy companies or individual district heating plants where the ash is produced. District
120 heating plants pay entrepreneurs to get rid of the ash. These entrepreneurs further refine and distribute
121 the ash. Finally, private forest owners pay to have the ash distributed on their land. In some areas, the
122 district heating plants themselves initiate ash recycling, whereas in other areas, it is the forest fuel
123 suppliers who do so. Due to the lack of wood ash markets, it was not possible to reveal forest owners'
124 demand for ash recycling on the basis of market prices and observed behaviour. Furthermore, in the
125 county of Västmanland ash recycling has hitherto only been sporadically adopted.

126

127 *ii) Objectives and hypotheses*

128 This paper contributes to the literature in three ways. We first assess the Swedish forest owners'
129 motivations to use wood ash. We estimate their willingness-to-pay (WTP) to spread wood ash in their
130 forest, applying a choice experiment (CE). Even though a sustainable use of wood for energy purposes
131 will depend on private forest owners' adoption of ash recycling, few studies have investigated their
132 willingness to apply such measures. Given that wood ash application is a rather new measure, it is

133 difficult to determine market adoption based on forest owners' real behaviour.⁶ A choice experiment
134 based on stated preferences is an approach to evaluate a hypothetical demand. Choice experiments
135 have also been used to analyse landowners' willingness to accept to participate in hypothetical agri-
136 environmental schemes or in the adoption of alternative management regimes (see Horne and Petäjistö
137 2003, Broch and Vedel 2012, Vedel et al. 2015a, Vedel et al. 2015b, Kuhfuss et al. 2016 and Vaissière
138 et al. 2018). In our choice experiment, we considered three attributes (increase in forest productivity,
139 free technical support and a cost attribute), for describing scenarios with ash recycling, and we wanted
140 to test the following hypothesis:

141 **Hypothesis 1 (H1):** The decision to adopt wood ash depends on its cost, the possibility to receive
142 technical help and the expected increase in forest productivity.

143

144 Second, and contrary to the previously quoted papers, we propose an original approach in which we
145 elicit the forest owners' preferences and intentions regarding the environment and ash recycling. In
146 this way our study is related to empirical works on the adoption of a new technology or product (see
147 McCluskey et al. 2003 for a study on the adoption of genetically modified food by Japanese
148 consumers or Ziegler 2012 for the determinants of car buyers to purchase green cars). In our study,
149 we used a questionnaire developed in the psychological literature (Milfont and Duckitt 2010). Indeed,
150 the adoption of wood ash recycling may be explained by different reasons that are not directly linked
151 to the expected impact on the profit of forest exploitation. It might be that forest owners are interested
152 in closing nutrient cycles by spreading ash in their forests because they are conscious of the impact of
153 their actions on the environment, and that they prefer this method over the use of chemical fertilisers.
154 In this paper, we refer to environmental sensitivity as the fact of taking the impact of one's actions on
155 environmental quality into account. We wanted to test the following hypotheses:

156 **Hypothesis 2 (H2):** Forest owners who are the least sensitive to environmental matters have a
157 preference not to engage in ash distribution.

158 **Hypothesis 3 (H3):** Those expressing a high sensitivity have less strong preferences for increases in
159 soil fertility.

160 The intuition is that the forest owners with a high environmental sensitivity give relative more weight
161 to the recycling aspect of ash spreading in forest than the impact on forest productivity. Therefore, the
162 forest productivity attribute will have less impact on the choice of scenarios with ash recycling for
163 environmental sensitive forest owners.

⁶ Wood ash recycling has been implemented in Nordic countries (such as Sweden and Finland) for two decades. However, ash recycling has only been extensively used in some regions and no markets for ash recycling have been developed.

164 Moreover, consistent with Börger and Hattam (2017), we also elicit the intention of forest owners to
165 apply ash according to the Theory of Planned Behavior (Ajzen 1991). The aim of this theory is to
166 identify individuals' determinants to adopt a given behaviour. We believe that this theory is adapted to
167 our study because the decision for a forest owner to recycle wood ash is a significant change in
168 management. In our study, we will test the following hypotheses:

169 **Hypothesis 4 (H4):** Those expressing confidence in being able to apply wood ash (high control)
170 choose an alternative other than the status quo alternative.

171 **Hypothesis 5 (H5):** Those expressing a high control are less interested in receiving technical help.
172

173 We show how this theory can help to explain why forest owners decide to apply wood ash. Our results
174 therefore provide important information for forest agency communication strategies with forest
175 owners.

176 Finally, similarly to Kuhfuss et al. (2016), each time a respondent chose an alternative different from
177 the status quo, we asked him/her to indicate the proportion of his/her forest that he/she would treat
178 with wood ash under the chosen scenario. The aim of this question is to quantitatively assess the
179 demand for wood ash as well as to more deeply investigate forest owners' motivations to apply wood
180 ash in their forests. Indeed, with this question, respondents are encouraged to consider the relevance of
181 ash recycling as a function of the specificities of their forests. In this sense, the choice experiment is
182 expected to get closer to the root of real behaviour. We therefore test the following hypothesis:

183 **Hypothesis 6 (H6):** The choice of the proportion of the forest to be treated with wood ash depends
184 negatively on the cost and positively on the forest owner's sensitivity and control.

185 The present study, and the econometric analysis that follows, are intended to test these different
186 hypotheses. The rest of the paper is organized as follows. We present the methodology of our study
187 and the survey in the following section. In Section 3, we present the results on forest owners'
188 preferences regarding wood ash, and discuss the results and provide a conclusion in Section 4.
189

190 **2. Methods**

191

192 *i) The discrete choice experiment (CE)*

193 To determine forest owners' willingness-to-pay for wood ash application, we designed a choice
194 experiment with three attributes. The first attribute, *Forest productivity*, describes the increase in
195 forest productivity as a result of spreading wood ash, measured in the percentage of increase of wood
196 production over a rotation period (0%, +10%, +15%, +20%). This attribute served to evaluate to what
197 degree the forest owners' demand for ash is determined by the expected impact on wood productivity.
198 Concerning this attribute, different results are found in the literature, depending on the type of soil and

199 on the quantity of ash used. Pérez-Cruzado et al. (2011) compared two quantities of ash (10 tonnes and
200 20 tonnes per hectare). They determined that, for both quantities, the diameter of trees increased, on
201 average, by +16%, and the height by +11%. In another study, Saarsalmi et al. (2014) determined that
202 the use of three tonnes of ash per hectare on Scots pine stands led to an increase in productivity of
203 +11% after four years of treatment. On peatland sites, they did not find any significant changes in
204 productivity during the six years after treatment. However, they did observe a significant increase in
205 productivity of +25% at seven to 16 years after treatment.

206 In the introduction to the CE, the owners were explained that the impact on productivity depends on a
207 number of factors, including type of ash, soil and forest type, and they were asked to imagine that
208 these proposed productivity levels would be possible on their land. The second attribute, *Free*
209 *technical support*, informed the forest owners whether they would obtain additional technical support,
210 taking the form of a free 2-hour visit from an expert, access to a list of ash producers, and advice on
211 how to apply wood ash. This attribute was added because the use of ash is a rather new measure in the
212 region we surveyed. Forest owners may want some advice on how to apply ash (questions about ash
213 quantities and qualities, and when and where to apply it). This attribute serves two purposes, firstly, to
214 reveal to what degree information and knowledge may be barriers to ash recycling and, secondly, to
215 provide important information to forest co-operatives about the demand for technical advice. Two
216 levels were considered (yes and no). The last attribute, *Cost*, informed the forest owners about the
217 additional cost per hectare that they would bear when applying ash in their forest. The cost includes
218 the price of ash, the transport to the forest and the spreading. Attributes and their levels are
219 summarized in Table 1.

220

221

[Table 1 here]

222

223 The levels of the cost attribute were based on estimations found in the literature. Väätäinen et al.
224 (2011) estimated that the total cost of wood ash (including its purchase, transportation and dispersal) is
225 €167/hectare if ground dispersal is chosen, and €241/hectare with helicopter dispersal. Pukkala (2017)
226 estimated a total cost of €370/hectare.⁷

227 Our study consisted of 16 choice tasks that we blocked into two different questionnaires (with eight
228 choice tasks per respondent, in random order). In each choice task, respondents were given three
229 options: “Situation 1”, “Situation 2” and “No wood ash” (corresponding to the status quo option). An
230 example is presented with Fig. 1. Using Ngene software, a D-efficient design was generated for a

⁷ These are only estimates given that a market for wood ash does not really exist at this time.

231 multinomial logit model with some priors based on expert knowledge.⁸ Before presenting the different
232 attributes of our choice experiment to the respondents, we explained to them that they would have to
233 make decisions between different options, in different scenarios, in which wood ash would be applied,
234 with some effects on the forest. We asked them to choose among the different options, considering
235 their own forest and their perspective of management for their forest in the next 10 years.

236

237 [Figure 1 here]

238

239 Once the respondents finished with their eight choice cards, those who always responded “No wood
240 ash” were asked the reason for this choice, making it possible to identify potential protesters.

241

242 *ii) Theory of Planned Behaviour*

243 In keeping with Börger and Hattam (2017), we asked questions intended to elicit the forest owner’s
244 intention to apply wood ash (the questions asked are given in the Appendix A). The Theory of Planned
245 Behavior (TPB) was initially proposed by Ajzen (1991). It measures the individual’s intention to
246 undertake a given task according to three dimensions: perceived behaviour *control* (i.e., whether
247 individuals think they can undertake the action easily or not), *subjective norms* (i.e., the way the
248 considered behaviour is generally perceived by others), and *attitudes* towards the considered
249 behaviour (i.e., the individual’s own evaluation of the behaviour).

250 In the literature, the theory participated to explain different types of behaviors. Börger and Hattam
251 show that the respondents’ intentions are a strong predictor of choice behaviour. In another study,
252 Läßle and Kelley (2013) use this theory to elicit the intention of Irish farmers to adopt organic
253 farming. They show that farmers are influenced by social norms (the behaviour generally adopted by
254 their peers) and their own ability to adopt organic farming. The ability, or perceived control of the new
255 proposed method, is also found to be a determinant regarding the decision to grow biofuel sugar beet
256 in Mattison and Norris (2007).

257 In our case, it might be that respondents distribute ash on their soils because they have seen other
258 forest owners doing it. Another possibility to explain the adoption of wood ash recycling might be that
259 forest owners think that they are able to apply wood ash (it is not only beneficial but also tractable for
260 them), in order to ensure the future productivity of their soils. In this paper, we therefore attempt to
261 better understand forest owners’ decisions to adopt ash recycling. Indeed, as previously emphasized,
262 wood ash application is a form of recycling that may be of particular interest for individuals the most
263 sensitive to environmental matters.

⁸ We used only assumptions about the signs: productivity and free technical advice have positive signs and cost has a negative sign.

264

265 *iii) Environmental sensitivity questionnaire*

266 To determine the Swedish forest owners' environmental sensitivity, we used the ten questions
267 proposed in Milfont and Duckitt (2010) related to the implementation of a new environmental
268 measure. The objective of the set of questions is to elicit the forest owner's support for an intervention
269 aimed to protect the environment. It consists of ten affirmations (the questionnaire is presented in the
270 Appendix B), with five pro-environmental behaviours (positively framed sentences) and five anti-
271 environmental behaviours (negatively framed sentences). The respondents had to give their level of
272 agreement according to a 5-Likert scale between "I totally disagree", "I disagree", "Neutral", "I
273 agree" and "I totally agree". We recoded the answers to the pro-ecological behaviours from 1 for "I
274 totally disagree" to 5 for "I totally agree" (and conversely for the anti-ecological behaviours).

275

276 *iv) Choice modelling and willingness-to-pay*

277 The choice experiment is analysed based on the random utility model (McFadden 1973). The
278 (random) utility of choosing alternative j for individual n in choice situation t , with p_{jt} the price of
279 alternative j in scenario t and the other attributes included in the vector x_{jt} , is given by:

$$280 \quad U_{njt} = \alpha_n p_{jt} + \beta' x_{jt} + \varepsilon_{njt} \quad (1)$$

281 where α_n and β_n are the parameters to be estimated, and ε_{njt} is the random unobserved utility
282 component, with ε assumed to be identically and independently distributed according to an extreme
283 value distribution.

284 In addition to eliciting the forest owners' preferences regarding wood ash, we are interested in
285 determining their willingness-to-pay (WTP) for wood ash application. Thus, rearranging Eq. (1), we
286 obtain a representation of their preferences in the WTP space (Train and Weeks 2005):

$$287 \quad U_{njt} = \alpha(p_{jt} + c' x_{jt}) + \varepsilon_{njt} \quad (2)$$

288 where $c_n' = \frac{\beta_n}{\alpha_n}$ is the vector of marginal WTP estimates. An advantage of estimating the utility model
289 in WTP space is that the distribution of willingness to pay is directly defined by the researcher and
290 therefore often gives more reasonable values (Scarpa et al. 2008; Hole and Kolstad 2012). The
291 distribution of the WTP that applies to the preference space model implies taking the ratio of two
292 distributions and may result in arbitrary distributions.

293

294 **3. Results**

295 In this section, we present the results of the estimations we conducted. We begin with a description of
296 the obtained data. We then analyse the attitudes of the forest owners (environmental sensitivity and
297 Theory of Planned Behaviour), and finally conduct some econometric analyses.

298

299 *i) Data*

300 The questionnaire was developed in co-operation with and tested by the Swedish forest owners’
301 association, Mellanskog. Furthermore, the design of the choice experiment benefited from a previous
302 related choice experiment with French forest owners (Abildtrup et al. 2017). However, in the present
303 survey, the questionnaire and experimental design were modified to account for specific research
304 questions and the Swedish context. For example, compared to France, ash recycling is actually
305 permitted and applied in Sweden.⁹ In the county where the survey was carried out (Västmanland,
306 central Sweden), only a few forest owners currently recycle ash (only two out of the 89 participants in
307 the survey have applied ash before) but pressure to accept ash recycling on forest owners selling wood
308 for energy purposes implies that adoption of ash recycling in private forests in Västmanland is an
309 important question (Rolfsson 2018).

310 The data was collected through *Limesurvey*, an online survey platform. The invitation to participate to
311 this study, with a link, was emailed in October 2017 by Mellanskog. In total, 800 emails were sent to
312 the forest owners from Mellanskog. A total of 227 of them followed the link to participate, but only 92
313 completed the questionnaire (response rate of 11.50%). We excluded three respondents because they
314 stated in the follow-up questions that they did not understand the idea of our choice experiment.
315 Finally, our total sample is composed of 89 respondents, with a balance between the two blocks: 41
316 respondents in the first block and 48 in the second one.

317 The characteristics of the sample are presented in Table 2. We observed a relatively homogenous
318 distribution of forest sizes in the interval of 21 to 500 hectares. In our sample, 49.44% of forest owners
319 are less than 56 years old, and 42.69% of them have a master’s degree. Finally, most of the forests are
320 certified, at least partially.

321

322 [Table 2 here]

323

324 *ii) Theory of Planned Behaviour (TPB) and environmental sensitivity*

325 Three sets of questions were asked to elicit the forest owner’s *attitude, social perception* and *control*
326 regarding wood ash application (the questions are provided in Appendix A). We recoded the answers
327 from one to seven, and summed up the score per behaviour measured (*attitude, social perception,*
328 *control*). Mean scores per item and standard deviation are presented in Table 3.

329

330 [Table 3 here]

⁹ Wood ash recycling is not allowed by law in France, but the government is currently reconsidering this possibility.

331

332 Overall, these measurements seem to indicate that forest owners perceive that they have good control
333 (the mean score per item is higher than the midpoint of the Likert scale): they think that they are able
334 to apply wood ash in their forests. However, it seems that the social perception of the other forest
335 owners does not necessarily have an influence on their choice to apply wood ash (the score is below
336 the midpoint). Regarding attitude, since the mean score per item is close to the midpoint, we can
337 neither conclude a positive nor a negative attitude towards wood ash.

338 Using a Spearman correlation test, we find that the attitude toward wood ash and the forest owner's
339 social perception are positively correlated ($\rho = 0.710, p < 0.01$). This is also the case for the attitude
340 and the control ($\rho = 0.209, p = 0.049$) and the control and social perception ($\rho = 0.281, p < 0.01$).

341 Regarding the questions on individual environmental sensitivity, we obtained a Cronbach's α equal to
342 0.86, meaning that our ten questions measure only one dimension, as expected (environmental
343 sensitivity in our case).¹⁰

344 Using a Spearman correlation test, we found that environmental sensitivity is not significantly
345 correlated with the control behaviour of the TPB ($\rho = 0.055, p = 0.606$), whereas it is with the
346 attitude ($\rho = 0.289, p < 0.01$) and the social perception ($\rho = 0.233, p = 0.028$). Thus, in our
347 econometric analysis, we included a variable for individual environmental sensitivity and one for
348 individual control regarding wood ash application.

349

350 *iii) Willingness-to-pay*

351 We estimated the utility model (1) using conditional logit, with a variable for the productivity increase
352 due to wood ash application (*prod*, modelled as a continuous variable), one for technical help (*tech*
353 modelled as a dummy variable equal to 1 if there is free technical help), one for the *cost* (modelled as
354 a continuous variable) and one for the status quo (*SQ*, modelled as a dummy equal to 1 if the status
355 quo is chosen). To test our hypotheses (discussed in the introduction), we also included crossed
356 variables in a second model: *SQ*control* and *SQ*sensi*, to capture the effect of choosing the status quo
357 alternative while expressing more control and having a higher environmental sensitivity,
358 respectively.¹¹ Finally, in a third model, we included two other variables to account for the effect of
359 receiving technical help when an individual expresses a high control over wood ash application
360 (*Control*tech*), and another one to account for the effect of obtaining higher productivity while being
361 more sensitive to environmental matters (*Sensi*prod*). According to H5, we expect that an individual
362 who expresses a high control over wood ash application (he/she perceives herself as someone who is
363 able to apply wood ash) would not need to receive technical help (the coefficient of the variable

¹⁰ The mean score per item is 3.88, with a standard deviation of 1.16.

¹¹ Both the variables *control* and *sensitivity* are modelled as continuous variables.

364 *Control*tech* should be negative). Secondly, according to H3, an individual who is highly sensitive to
365 environmental matters may not necessarily be interested in an increase in soil fertility: the protection
366 of the environment might be the priority (the coefficient of the variable *Sensi*prod* should be negative
367 as well). The results of the conditional logit regression are presented in Table 4.

368

369

[Table 4 here]

370

371 As expected, in the three models, we observe that the forest owner's utility increases with a positive
372 impact on forest productivity and with free technical help. On the contrary, the forest owner's utility
373 decreases when the cost of applying wood ash increases. Therefore, we cannot reject hypothesis **H1**.

374 The significant positive coefficient associated with the SQ variable indicates that forest owners, in
375 average, prefer no ash in a scenario with wood ash application, compared to a scenario where wood
376 ash is free (zero costs) but in which there is no productivity effect and no free technical help.
377 However, taking the psychological variables into account, we also determined that those owners
378 expressing a higher control over wood ash application, and those with a higher environmental
379 sensitivity were less likely to choose the SQ alternative (in the second model). Therefore, we cannot
380 reject hypotheses **H2** and **H4**. Our intuition regarding an individual expressing high control over
381 wood ash application is also verified with our third model: he/she would be less interested in receiving
382 technical help (third model). We cannot reject hypothesis **H5**. However, we did not find any
383 significant negative effect of being more sensitive to environmental matters on the preferences for
384 productivity increase. Being environmentally sensitive may also include a concern for future fertility
385 of the soil, which may be represented by the productivity variable. Environmentally-sensitive forest
386 owners have the same preferences for fertility as the other ones. We therefore rejected hypothesis **H3**.
387 We found that the pseudo R-squared is on an acceptable level for choice experiments.¹²

388

389 To account for heterogeneity of preferences and to obtain monetary values, we estimated model (2)
390 using simulated maximum likelihood methods (GMNL procedure in Stata; Gu et al. 2013), with 750
391 Halton draws and assuming normal distributed coefficient distributions. The results are reported in
392 Table 5. We determined that all the estimated means of the coefficient distributions are significant. It
393 appears that forest owners are willing to pay 45 SEK/hectare for a one percent increase in forest
394 productivity, and 184 SEK to receive two hours of technical help to apply wood ash in their forest.¹³

395

396

[Table 5 here]

¹² We propose latent class estimations with class membership function in the Appendix C. We obtain similar results.

¹³ These amounts correspond to €4.56 and €18.66, respectively (as of January 17th, 2018).

397

398 Note, however, that the most environmentally sensitive forest owners, and those expressing a higher
399 control regarding wood ash application would pay less for having the SQ alternative, i.e., not having
400 ash in their forests. Another way to interpret the SQ value is the willingness-to-accept (WTA) ash in
401 their forest given no effect on productivity, no technical help and no costs. This means that forest
402 owners should be compensated for using ash in their forests. However, this WTA is sensitive to
403 owners' feelings of control and their environmental sensitivity. Even then, accounting for the impact
404 of environmental sensitivity and feelings of control, we found a significant heterogeneity in
405 preferences over forest owners. All of the attributes have a significant standard deviation (Table 5)
406 with the exception of technical help.

407 On the basis of these results, we carried out simulations regarding forest owners' willingness-to-pay
408 for wood ash application in their forests with 2 hours of technical help, varying the increase in forest
409 productivity and the environmental sensitivity (ES) score. The results are presented in Table 6.

410

411

[Table 6 here]

412

413 These simulations highlight the fact that the median forest owner (in terms of environmental
414 sensitivity and expressed control) has a positive willingness-to-pay for wood ash application in his/her
415 forest. However, varying the total environmental sensitivity score, the willingness-to-pay becomes
416 negative for forest owners with the lowest sensitivity to environmental matters: they would require to
417 be paid to apply wood ash in their forests, even in the most optimistic scenario (corresponding to a
418 15% increase in soil fertility). Environmental sensitivity is therefore a key determinant of forest
419 owners' willingness-to-pay for wood ash application, as expected (**H2**).

420 In contrast, the estimated willingness-to-pay measurements appear to be less affected by changes in
421 the control score because, contrary to changes in the environmental sensitivity score, the measured
422 willingness-to-pay is always positive, except for the case of a 5% increase in forest productivity.¹⁴

423

424 *iv) Surface area of forest treated with wood ash*

425 Consistent with Kuhfuss et al. (2016), we now explain forest owners' decisions to treat a proportion of
426 their forest. Indeed, when choosing one of the two alternatives different from the status quo, forest
427 owners had to decide what percentage of their forest they would treat with wood ash.

428 Out of the 89 respondents, 62 chose an alternative different from the status quo at least once
429 (corresponding to a total of 345 alternatives different from the status quo (minimum value of 2.22%).

430 These forest owners would treat, on average, 40.09% of their forest.¹⁵

¹⁴ Even though control has the highest standard deviation per item (see Table 3).

431 As in Kuhfuss et al. (2016), we estimated a one-inflated beta regression, i.e., a specific econometric
 432 method to explain proportions (Cook et al. 2008). This model separately estimates the fact that a forest
 433 owner decides to treat his/her entire forest, or a part of it. The assumption is that the determinants to
 434 fully treat the forest are different from those of treating a part of the forest only. Thus, the density
 435 function $g(\cdot)$ for this model is given by:

436

$$437 \quad g(y; \pi; \mu; \varphi) = \begin{cases} (1 - \pi)f(y; \mu; \varphi), & \text{if } y < 1 \\ \pi & \text{if } y = 1 \end{cases}$$

438

439 where $f(\cdot)$ is the beta distribution with mean μ , φ is the precision parameter and π is the parameter
 440 accounting for the probability of having observations at one. The model is estimated by maximum
 441 likelihood.

442

[Table 7 here]

443

444 The results are presented in Table 7. It seems that the decision to fully treat the forest or to treat a part
 445 of it corresponds to two different behaviours. In the latter treatment, it is the environmental sensitivity
 446 that explains the decision to treat the forest with wood ash (positive and significant coefficient at the
 447 5% level). The cost has a significant negative effect (significant at the 1% level). This is normal since
 448 a decreasing marginal productivity of ash with an increasing share of land where ash is applied can be
 449 expected. The results also correspond to what we obtained in the discrete choice model: higher
 450 productivity and lower costs increase the likelihood of applying wood ash. Contrary to the previous
 451 results, there is no effect due to the expression of a higher control on wood ash application or of being
 452 offered free technical assistance.

453

454 Regarding the decision to fully treat the forest, it seems to correspond to a different behaviour: the
 455 coefficient associated with environmental sensitivity is now significantly negative (at the 10% level),
 456 while the one associated with the control that a forest owner has over wood ash application is
 457 significantly positive (at the 10% level). This could indicate that a forest owner who is
 458 environmentally sensitive will generally be more prone to use ash recycling and a larger share of land
 459 – but less prone to applying it to all of the land. It could be hypothesized that an environmentally
 460 sensitive owner will apply only ash recycling on her/his land where ash spreading is ecologically
 461 feasible. On the other hand, an owner who feels that he/she is in control will be less likely to make
 462 such considerations.

462

¹⁵ The maximum value (100%) was chosen 28 times (7.67%).

463 We also estimated these proportions with a fixed effect panel data model. Still in keeping with
464 Kuhfuss et al. (2016), when analysing the decision to apply wood ash to a part or all of an individual's
465 forest, there may be a selection bias due to the fact that some unobserved factors influencing the
466 choice of an alternative (different from the status quo) may be correlated with unobserved factors
467 affecting the decision to treat a part (or all) of the forest. A fixed effect panel model avoids this
468 potential bias. The results are reported in Table 8.

469

470

[Table 8 here]

471

472 Contrary to the previous model, the coefficient associated with technical help is significantly positive
473 (at the 5% level), thus indicating that the forest owners who receive technical help accept to treat more
474 of their land with ash. This result may be due to the fact that, contrary to the previous model, the
475 proportions of forests treated are pooled (we do not disentangle the decisions to fully treat the forest
476 and those regarding a treatment of a part of the forest). Moreover, in the previous model, there were
477 few observations regarding the decision to fully treat a forest. Considering these two estimations, we
478 conclude that we cannot totally reject hypothesis **H6**.

479

480 **4. Discussion and conclusion**

481

482 Given the increasing demand for biofuel, ash recycling may represent an important measure to close
483 the nutrient cycle and ensure sustainable use of the forest. This paper focuses on the importance of
484 understanding the factors that influence forest owners to adopt ash recycling and, in particular, the
485 types of forest owners that are most likely to spread ash in their forests. This approach provides
486 important information for forest organisations and regulators in Sweden and other countries where
487 biofuel demand from forests is increasing.

488 We therefore assess forest owners' attitudes to and willingness-to-pay for wood ash application in
489 their forest. To do this, we have proposed an original approach that combines a choice experiment
490 with psychological questionnaires to better explain the factors that motivate forest owners' to adopt
491 wood ash.

492 Our results indicate that, overall, Swedish forest owners would agree to pay 45 SEK/hectare for a one
493 percent increase in forest productivity under wood ash application. We also show that the forest
494 owners who are most sensitive to environmental matters, as well as those who express a high control
495 over the way to apply wood ash, are willing to pay more for wood ash. Furthermore, forest owners
496 will pay an average of 184 SEK for two hours of technical help with wood ash application. In
497 particular, owners who do not feel in control will pay a higher value for technical help. Our result

498 regarding the link between environmental preferences and the willingness-to-pay corroborates the
499 findings of Taye et al. (2018) who also highlight such a relationship. In accordance with Läßle and
500 Kelley (2013), we found that the Theory of Planned Behaviour and, in particular, the perceived control
501 regarding a new management practice, explains the decision to adopt wood ash application.
502 From a public policy point of view, these results seem to indicate that a regulator or ash-producing
503 company seeking to promote wood ash adoption should target specific forest owners, e.g., those who
504 are the most sensitive to environmental matters. As emphasized in the simulations in the previous
505 section, the measured willingness-to-pay is less sensitive to a forest owner's control score regarding
506 wood ash application, than when we vary his/her environmental sensitivity score. We could therefore
507 recommend raising forest owners' awareness about environmental matters even more.
508 The fact that Sweden has been an early adopter of ash recycling also means that the research results
509 will be potentially important for other countries (Hannam et al 2018), notably France where ash
510 recycling is currently only allowed on agricultural land. However, ash recycling in forests features
511 prominently in the policy debate and the French Environmental and Energy Management Agency
512 (Agence de l'environnement et de la maîtrise de l'énergie) in particular is funding research
513 underpinning potential new regulation allowing wood ash use in forest (ADEME 2019). Our results
514 will, in particular provide useful information for the design of potential subsidy schemes including
515 providing an approach that can be useful in testing such schemes before implementation. As our
516 results are based on forest owners' stated behaviour, one could ask if the results could be prone to
517 hypothetical bias. Therefore, future research should survey adopters and non-adopters in regions
518 where ash recycling is more widely adopted and where markets exist for it with the purpose of
519 replicating our results observing forest owners' real behavior.
520 A limitation of our study comes from a relatively low responses rate and, consequently, a relatively
521 small sample size. Note that previous surveys targeting forest owners also often have a low response
522 rate (Petucco et al, 2015). It should also be noted that the main objective of this study is not to
523 estimate a national or regional demand for wood ash but to obtain insights into the factors that
524 influence forest owners' adoption of wood ash application. In this way, we believe that our results
525 may still provide useful information for policymakers since we were able to test our initial hypotheses.
526 The number of observations does not allow for an application of latent variable models that account
527 for potential endogeneity of environmental sensitivity and a feeling of control (Hess and Beharry-Borg
528 2012). Therefore, one should be careful when interpreting the significant impact of the attitudinal
529 variables on choices as causal relationships. However, it is still an important result for policymakers
530 that we found a statistically significant relationship between environmental sensitivity and choices
531 about ash recycling.
532

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534

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541

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Appendix A – Theory of Planned Behavior

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The respondents read the following sentences and selected the behaviour that best characterized the way they behave. The recoding is given in parentheses.

Attitude towards wood ash recycling:

• For you, to use ash in your forest during the next 10 years is:

Worthless _ _ _ _ _ Valuable
(+1) (+7)

• For you, to use ash in your forest during the next 10 years is:

Harmful _ _ _ _ _ Beneficial
(+1) (+7)

Social perception regarding wood ash recycling:

• The forest owners that I know whose opinions I value

Will not use ash _ _ _ _ _ Will use ash
in their forest during the 10 next years
(+1) (+7)

• Most forest owners I know will use ash in their forest during the next 10 years

Extremely unlikely _ _ _ _ _ Extremely likely
(+1) (+7)

Control regarding wood ash recycling:

• If I wanted to, I could use ash in my forest during the next 10 years

Definitely false _ _ _ _ _ Definitely true
(+1) (+7)

• It is mostly up to me whether or not I use ash in my forest during the next 10 years

Strongly disagree _ _ _ _ _ Strongly agree
(+1) (+7)

724
725
726

Appendix B – Environmental sensitivity questionnaire

727

728 • Industry should be required to use recycled materials even when this costs more than making the
729 products from new raw materials.

730 I totally disagree

731 I disagree

732 Neutral

733 I agree

734 I totally agree

735

736 • Governments should control the rate at which raw materials are used to ensure that they last as long
737 as possible.

738 I totally disagree

739 I disagree

740 Neutral

741 I agree

742 I totally agree

743

744 • Controls should be placed on industry to protect the environment from pollution, even if it means
745 that things will cost more.

746 I totally disagree

747 I disagree

748 Neutral

749 I agree

750 I totally agree

751

752 • People in developed societies are going to have to adopt a more energy-conserving life-style in the
753 future.

754 I totally disagree

755 I disagree

756 Neutral

757 I agree

758 I totally agree

759

760 • The government should give generous financial support to research related to the development of
761 alternative energy sources such as solar energy.

762 I totally disagree

763 I disagree

764 Neutral

765 I agree

766 I totally agree

767

768 • I don't think people in developed societies are going to have to adopt a more energy-conserving life-
769 style in the future.

770 I totally disagree

771 I disagree

772 Neutral

773 I agree

774 I totally agree

775 • Industries should be able to use raw materials rather than recycled ones if this leads to lower prices
776 and costs, even if it means the raw materials will eventually be used up.

777 I totally disagree

778 I disagree

779 Neutral

780 I agree

781 I totally agree

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783 • It is wrong for governments to try to compel business and industry to put conservation before
784 producing goods in the most efficient and cost-effective manner.

785 I totally disagree

786 I disagree

787 Neutral

788 I agree

789 I totally agree

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791 • I am completely opposed to measures that would force industry to use recycled materials if this
792 would make products more expensive.

793 I totally disagree

794 I disagree

- 795 Neutral
- 796 I agree
- 797 I totally agree
- 798
- 799 • I am opposed to governments controlling and regulating the way raw materials are used in order to
- 800 try to make them last longer.
- 801 I totally disagree
- 802 I disagree
- 803 Neutral
- 804 I agree
- 805 I totally agree
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Appendix C – Latent class estimation with class membership function

	Class 1 – Low expressed control on wood ash recycling		Class 2 – High expressed control on wood ash recycling	
Attributes	Coefficient	(Stand. Err.)	Coefficient	(Stand. Err.)
One percent increase in productivity	0.276*	(0.152)	3.436***	(0.124)
Technical help	0.048*	(0.027)	0.282***	(0.021)
Cost (in hundreds of euros)	-0.002*	(0.001)	-0.019***	(0.001)
SQ	0.920***	(0.022)	0.206***	(0.017)
Fixed effects in the class membership model				
Sensitivity	-0.048	(0.033)		
Control	-0.317***	(0.100)		
89 forest owners, 712 choices				
LL	-862.28			
AIC	1748.56			
BIC	1778.42			

Significance levels: * p < 0.10; ** p < 0.05; *** p < 0.01.

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



Table 1 Attributes and their levels of the discrete choice experiment.

Attribute	Levels
Productivity	+0% +10% +15% +20%
Free technical support	Yes, free technical support No free technical support
Cost	0 SEK/hectare* 100 SEK/hectare 250 SEK/hectare 500 SEK/hectare 1000 SEK/hectare 1500 SEK/hectare 2000 SEK/hectare 3000 SEK/hectare

*These costs correspond to approximately €0, €10, €26, €51, €102, €153.44, €205 and €307, respectively (January 2018).

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Figure 1- Example of a choice card.

Attribute	Situation 1	Situation 2	No wood ash
Productivity	 +15%	 +10%	-
Free technical advice	 Support Yes	 Support No	-
Cost	1500 SEK/hectare	500 SEK/hectare	0

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Table 2 Characteristics of the sample.

Characteristic	Interval	%
Size of forest	0-5 ha	3.37
	6-20 ha	8.99
	21-50 ha	28.09
	51-100 ha	28.09
	101-500 ha	30.34
	> 500 ha	1.12
Age	18-40	14.61
	41-55	34.83
	56-70	42.70
	> 70	7.87
Gender	Male	87.64
	Female	12.36
Main activity	Forester	5.62
	Farmer	21.35
	Self-employed	10.11
	Employed	43.82
	Retired	15.73
	Other	3.37
Level of education	No diploma	1.12
	Secondary school/High school (professional)	26.97
	Short education	28.09
	Master's or higher	42.69
	Other	1.12
Certification (FSC, PEFC)	All of the forest	58.43
	Part of the forest	1.12
	No	40.45

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871 **Table 3 Mean scores per item and standard deviation of the behaviours measured by the TPB**

Behaviour measured	Mean score per item	Standard deviation
Attitude	4.13	1.73
Social perception	3.43	1.70
Control	4.81	1.91

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876 **Table 4 Conditional logit estimation.**

Variable		Model 1		Model 2		Model 3	
		Coef.	Stand. Err.	Coef.	Stand. Err.	Coef.	Stand. Err.
One percent increase in productivity	<i>prod</i>	8.065***	1.013	8.394***	1.045	11.055*	6.049
Technical help	<i>tech</i>	0.422***	0.131	0.393***	0.134	1.843**	0.579
Cost	<i>cost</i>	-0.001***	0.000	-0.001***	0.000	-0.001***	0.000
SQ	SQ	0.993***	0.160	5.777***	0.593	7.024***	1.083
	<i>SQ*control</i>	-	-	-0.214***	0.032	-0.302***	0.048
	<i>SQ*sensi</i>	-	-	-0.069***	0.012	-0.078***	0.023
	<i>Sensi*prod</i>	-	-	-	-	-0.057	0.148
	<i>Control*Tech</i>	-	-	-	-	-0.142**	0.055
89 forest owners, 712 choices							
LL		-604.106		-557.835		-554.323	
Pseudo R-squared		0.228		0.287		0.291	

Significance levels: * p < 0.10; ** p < 0.05; *** p < 0.01.

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Table 5 - Willingness-to-pay space.

Variable	Coefficient (Marginal WTP in 1000 SEK)	Stand. Err.
One percent increase in productivity	0.045***	0.005
Technical help	0.184***	0.053
SQ	3.407***	0.395
SQ*control	-0.072***	0.017
SQ*sensi	-0.059***	0.009
Price	1.43	
SD		
One percent increase in productivity	-3.756***	0.359
Technical help	0.018	0.046
SQ	0.519***	0.078
SQ*control	0.059***	0.006
SQ*sensi	0.013***	0.001
Price	1.750***	0.299
89 forest owners, 712 choices		
LL	-391.392	
Prob > chi ²	<0.001	

Significance levels: * p < 0.10; ** p < 0.05; *** p < 0.01.

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896 **Table 6 - Simulations of willingness-to-pay for wood ash application.**

Increase in forest productivity	Forest owner with median environmental sensitivity and control (TPB) score	Forest owner with median control score and 10% of the lowest ES score	Forest owner with median control score and 10% of the highest ES score	Forest owner with median ES score and 10% of the lowest control score	Forest owner with median ES score and 10% of the highest control score
+5%	89.55 SEK/hectare (€9.08)	-515.31 SEK/hectare (-€52.24)	575.81 SEK/hectare (€58.38)	-147.06 SEK/hectare (-€15.03)	304,65 SEK/hectare (€31.14)
+10%	313 SEK/hectare (€31.74)	-291.86 SEK/hectare (-€29.59)	799.26 SEK/hectare (€81.04€)	76.39 SEK/hectare (€7.81)	528.10 SEK/hectare (€53.99)
+15%	536.45 SEK/hectare (€54.40)	-68.41 SEK/hectare (-€6.94)	1022.71 SEK/hectare (€103.70)	299.84 SEK/hectare (€30.65)	751,55 SEK/hectare (€76.83)

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898 **Table 7 One-inflated beta model estimation.**

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Variable	Coefficient	Standard error
<i>Proportion 0 <y<1 (n=317)</i>		
One percent increase in productivity	1.021	0.981
Technical help	0.102	0.116
Cost (per hundred euros)	-0.028***	0.010
Sensitivity	0.025**	0.010
Control	-0.041	0.029
Constant	-1.216*	0.653
<i>One inflate (y =1) (n=28)</i>		
One percent increase in productivity	2.482	4.079
Technical help	0.288	0.482
Cost (per hundred euros)	-0.049	0.057
Sensitivity	-0.090*	0.051
Control	0.175*	0.106
Constant	-1.130	2.768
Ln_phi intercept	1.207***	0.066

Significance levels: * p < 0.10; ** p < 0.05; *** p < 0.01.

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Table 8 Panel model with fixed effects.

Variable	Coefficient	Standard error
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One percent increase in productivity	0.103	0.119
Technical help	0.028***	0.010
Cost (per hundred euros)	-0.004*	0.002
Constant	0.398***	0.041

62 forest owners.

Significance levels: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Bootstrapped standard errors (1000 replications).