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Assessing Timber Value: a case study in the Italian Alps

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Abstract

In the Piedmont region, in North-West Italy, the abundance of unmanaged woods has led to negative environmental and economic consequences, generating a decrease in the ecosystem services supplied and in the provision of low-value timber products. In this context, increased logging activities could create new development opportunities for the rural areas in which most of the abandoned stands are situated.

This work analyses a forest harvest by creating a model to evaluate its Timber Value. The economic results were analysed to investigate the structural and logistic factors influencing the profitability of a harvest. The results obtained revealed that a small profit margin is achievable for small local logging companies, even if strongly influenced by the hourly costs of labourers.

To quantify the influence of each factor of the model on the timber value, a sensitivity analysis was performed. Then, to test the robustness of the results a Monte Carlo simulation was carried out simultaneously varying the factors involved. Finally, a scenario analysis was performed, in which the standard conditions referring to the most common private forest company typologies were examined.

Overall, these methods were found to be suitable for our aims and capable of supplying important results to analyse a forest harvest from an economic perspective.

Keywords

Timber value; sensitivity analysis; forest harvest; Monte Carlo simulation; Italian Alps

Highlights

- A model to compute the Timber Value of a harvest in chestnut coppice was built
- The model was statistically analysed to measure the influence of factors on its results
- Sensitivity Analysis, Monte Carlo simulation and Scenario analysis were performed
- Results support logging companies in improving their economic performance

30 Introduction

31 It is commonly accepted how the active management of forests can enhance the liveability of local
32 communities in rural areas both from a socio-economic and environmental perspective, supporting local
33 timber markets and ensuring the provision of several valuable Ecosystem Services, such as protection from
34 natural hazards, recreation and biodiversity (Frank et al., 2015, Fürst et al., 2010). Therefore, in some
35 European countries characterized by low rates of forest exploitation (as is the case in Italy, where the
36 harvest rate is 23% of the growth rate) (Secco et al., 2017), measures and instruments capable of assisting
37 forestry operations could play an important role in supporting the forestry sector at both policy and
38 economic levels. In this context of under-exploitation of forest resources, enhancing the value of the
39 existing coppice forests can represent a consistent opportunity, where these new measures and
40 instruments could be adopted.

41 Coppice forests, that cover more than 18M ha in Europe (19% of which are in Italy) (Angelini et al., 2013)
42 represent a paradigmatic example of a natural environment which has been profoundly shaped by human
43 intervention. Past management has modified the species composition and structure in order to mainly
44 provide small-sized fuelwood production (Fabbio, 2016). Due to this close relationship with the surrounding
45 human settlements, exploitation of coppices has followed the evolution of society. In Italy, over the last 70
46 years, these rural areas, where most of these forests are located, have suffered a vast depopulation (Pelleri
47 and Sulli, 1997), that has led to the abandonment of large areas of agricultural land and actively managed
48 forests, allowing secondary woodlands to proliferate (Bätzing et al., 1996, Coppini and Hermanin, 2007).
49 These phenomena, occurring mainly in the Alpine areas, consequently caused a decrease of the ability of
50 forests to cope with natural hazards (Vogt et al., 2006) and reduced the quality and quantity of the
51 harvested timber (Fonti and Giudici, 2001), which is still not sufficient to satisfy national demand (Secco et
52 al., 2017).

53 In order to support the development of the forestry sector in Italy, many political efforts have been
54 undertaken on both national and regional scales (Quatrini et al., 2017, Marchetti, 2018), with several
55 measures focusing on coppices (Mairota et al., 2016). In addition to these policy measures, the scientific
56 community produced several works addressing this topic, including among others: the benefits deriving
57 from the sustainable active management of coppices studied from the perspective of biodiversity (Mattioli
58 et al., 2016, Müllerová et al., 2015), natural risk reduction (Vogt et al., 2006), logging impacts (Venanzi et
59 al., 2016) and policy solutions (Fabbio, 2016). Nonetheless, this current discussion seems lacking in the
60 evaluation of economic aspects: for this reason, this paper is an attempt to rectify this shortcoming, by
61 establishing a model to analyse the harvesting operations in a coppice forest, in order to define the main
62 factors influencing their economic results.

63 The selected study area is a chestnut (*Castanea sativa* L.) coppice located in the Piedmont Region, in the
64 Western Italian Alps. In Italy, this typology of coppice covers almost 1M ha, equal to 27% of all Italian
65 coppices (Angelini et al., 2013) and represents a valuable example of the effects of the different societal
66 trends that influenced forest management over the last decades. In the past, thanks to the many different
67 products that chestnut stands were able to provide (Mariotti et al., 2008), society favoured their presence
68 throughout all the mountainous areas in the country, generating a veritable “Chestnut culture” (Conedera
69 et al., 2004). Then, from the Seventies onwards, the spread of some virulent pathogens, such as Ink Disease
70 (*Phytophthora cambivora* (Petri) Buisman) and Chestnut Blight (*Cryphonectria parasitica* (Murrill) Barr.)
71 (Turchetti and Maresi, 2006, Turchetti et al., 2008), and the related physiological problems, such as Ring
72 Shake, limited their use (Macchioni and Pividori, 1996, Fonti et al., 2002). Consequently, these limitations
73 provoked a clear change in their management, shifting from coppice to high forest, or frequently to
74 abandonment (Arnaud et al., 1997, Conedera et al., 2001). From an economic perspective, this change also
75 influenced the profitability of these stands: in fact, the lower value of the achievable wood products, made
76 the economic return of their exploitation uncertain. Currently, chestnut stands are the most common
77 forest type in the Piedmont Region, covering an area of 205,000 hectares, equal to 23% of the forests
78 covering the regional territory (Gottero et al., 2007), and also one of the most common in Italy, but their
79 fate is still uncertain. Therefore, the framework we developed aims to illustrate the potential revenues that
80 can be achieved through a return to the active management of these stands, by providing a reliable
81 economic analysis of the forest harvesting process, taking into consideration both the revenues that can be
82 obtained from the different timber products and the costs associated with logging operations.

83 To reach this goal, we i) set up a model to evaluate, from an economic perspective, the most likely timber
84 value of a harvest and then tested it on a representative case study located in the Western Italian Alps; ii)
85 assessed the effect and intensity of the variation of the economic and technical factors on the results of the
86 model, through a sensitivity analysis of its parameters and the evaluation of their elasticity; iii) proved the
87 robustness of the results, by applying a reiterative probabilistic analysis based on a Monte Carlo simulation
88 model; and finally, iv) built a scenario analysis with the standard features of the two most common types of
89 private logging companies in the study area, whose characteristics are also well suited to the Italian
90 context. This set of analysis is intended to be employed to compare and analyse the drivers which most
91 profoundly affect the profitability of a harvest in different areas and when adopting different work
92 methods. Moreover, its application with real data from the standard logging companies in the area will also
93 be relevant for entrepreneurs, in order for them to evaluate the management of their logging operations
94 from an economic perspective and to support the definition of the most suitable business strategies to
95 implement their company performance.

96

97 **2 Materials and Method**

98 2.1 Case study

99 The data needed to build the timber value (TV) model was obtained from a case study conducted in the
100 Ormea territory of the Piedmont Region, a small municipality in the Western Italian Alps, 800 m above sea
101 level. The analysed chestnut stand is an over-mature coppice stand, with sporadic sycamore (*Acer*
102 *pseudoplatanus* L.), European ash (*Fraxinus excelsior* L.) and rowan (*Sorbus aucuparia* L.) trees, covering a
103 total area of 0.42 ha. A forest road, suitable for use as a bunching site, where the timber can be collected
104 before its extraction, constitutes the lower boundary of the stand. This area, whose features are consistent
105 with most of the privately-owned coppice forests of the Region (Gottero et al., 2007), can also be
106 considered as an example of the most common state of Italian coppices, where the lack of management
107 has negatively influenced the profitability of the harvest (Moscatelli et al., 2007). In Piedmont, at least 30%
108 of chestnut stands are either abandoned (Manetti et al., 2006) or over-aged and under-exploited (Gasparini
109 and Tabacchi, 2011). Moreover, 89% of these stands in this Region are privately-owned (Gottero et al.,
110 2007), and generally affected by a fragmentation of ownership that negatively influences harvesting
111 activities (Brun et al., 2009). This phenomenon is clearly evident in the statistical data collected from the
112 Italian Statistics Institute (ISTAT), which states that the average harvest area in the Western Alps is equal to
113 0.46 ha (Istat, 2015), while the area of forest operations in coppice forests, referring to the Piedmont
114 Region, varies from 0.43 to 0.78 ha (Brun et al., 2014a). Therefore, this study can be considered
115 representative of the current forestry situation in the area, securing validity to the results.

116 The dendrometric data was collected through field surveys with complete callipering of the trees and
117 measurement of a relevant number of tree heights. This data allowed us to employ the Italian Forest
118 National Inventory (IFNI) log rules (Castellani et al., 1984) to estimate the total wood volume of the area,
119 equal to 494 m³/ha.

120 The stand is an over-aged chestnut coppice stand; since the production of new sprouts for this species is
121 only marginally influenced by the age of the stump (Conedera et al., 2001), the current Regional Forest Law
122 defines specific rules for its management (art. 56; Law 8/r – 2011). In particular, for chestnut stands, no
123 maximum rotation period is defined by law, but a minimum crown cover percentage after harvesting, equal
124 to the 10% of the initial volume, is required. Moreover, it should be noted that pathogens such as ink
125 disease and chestnut blight resulted to be widespread in the stand, negatively influencing the quality of the
126 products.

127

128 2.2 Timber Value model

129 To understand how the structural and logistic features of logging companies operating in the Piedmont
130 Region influence the TV of a forestry operation, a model capable of describing and analysing the whole
131 process was developed. TV is the most common measure used to estimate the value of a mature forest

132 stand (Faustmann, 1995, Chang and Gadow, 2010, Navarrete and Bustos, 2013) and is defined as the value
133 of standing timber, as determined from the sales price at the landing location, minus all harvesting costs
134 (Armitage, 1998, Nieuwenhuis, 2000, Amacher et al., 2009). The model we created examines all the
135 positive and negative items in the economics of the logging operation. Regarding timber revenues, the
136 quantities and market values of the assortments were estimated. As for costs, all the segments of the
137 logging operations needed to perform the harvest were analytically considered, and subsequently
138 formalized into a framework able to take into account different harvest types. The TV per cubic meter was
139 then obtained by dividing this value by the extracted wood volume: this value was used as the reference
140 value in this study and in the following analyses. The data acquisition of all the information necessary to
141 build the TV model, e.g. wood volume, achievable products, hourly yields, machinery costs, manpower
142 costs and market prices, is a complex and accurate operation. In fact, all technical and economic data was
143 collected both in the field or by means of a literature review of relevant studies (Picchio et al., 2011, Brun
144 and Blanc, 2017). This data can be divided into three categories: a) ordinary objective data, namely the
145 organization of the logging operations; b) complex objective data, such as the collected and elaborated
146 dendrometric data; c) estimated information, such as the hourly yield and the opportunity costs from the
147 logging company internal data.

148

149 2.2.1 Revenues

150 The main data source concerning timber revenues is the timber market itself, pertaining to both the
151 features of the most common assortments and their price. According to the literature on chestnut timber
152 (Nosenzo, 2007), its products are usually divided into: i) first grade poles, which are straight logs without
153 knots and can be used for natural engineering works; ii) second grade poles, which are mostly straight logs
154 with a limited number of knots that do not affect their technical qualities and are generally used for
155 vineyards and other plantations; and iii) chipping wood for local biomass energy plants. Considering these
156 constraints, the overall amount of the revenues is derived from the product of the n product and its
157 respective price (Eq. (1)).

158

$$159 R_{ass} = \sum_{i=1}^n p_i \cdot q_i \quad (1)$$

160

161 where R_{ass} is the revenue originated by the trees equal to the sale of the assortment (€) at the landing site;
162 n is the number of the considered assortment; p_i is the price of the i assortment (€ m⁻³) and q_i is its volume
163 (m³).

164

165 2.2.2 Costs

166 In order to compute the costs of the harvest, it is first necessary to define the characteristics of the logging
167 operations and their organization, on which the hourly yield depends (Gautam et al., 2014). Despite recent
168 innovations in terms of harvest mechanization and the development of machines that are able to perform
169 different operations over a wide range of conditions (Cavalli, 2008), a traditional organization of harvesting
170 operations still prevails in Piedmont (Picchio et al., 2011). Therefore, a “Short Wood System” was adopted
171 for the harvest. This traditional system, characterized by low mechanization, low budget machinery, often
172 derived from agriculture, and a limited number of employees for each company (Spinelli et al., 2004,
173 Gautam et al., 2014), represents the standard method adopted in the area. In fact, most private companies
174 cannot afford to employ more than two workers, or buy highly mechanized machines, such as harvesters
175 and forwarders (Blanc et al., 2017).

176 In order to properly compute the costs of the harvest and since different hourly yields and timber volumes
177 were involved, it was necessary to consider the different phases of the logging operations separately,
178 because each phase requires different machinery and manpower. In addition, the wood volume is also
179 influenced by the considered phases. The extracted volume is often lower than the felled one, due to the
180 processing operations, which assume a certain percentage of wood waste. The wood waste value adopted
181 in this study was the 10% of the felled volume, a value consistent with other similar works (Giordano, 1981,
182 Carbone et al., 2013).

183 According to the Short Wood system employed, the required logging operations are: i) felling and
184 processing, where trees are cut, delimbed, topped and bucked in merchantable lengths; ii) bunching, when
185 poles are transported to the landing site; iii) extraction, when the trunks are hauled to a truck road. The
186 cost of each phase includes machinery and labour costs, where the work hours were computed in
187 consideration of the characteristics of the harvest and of the working strategy adopted (Picchio et al.,
188 2011). It should be pointed out that the number of machinery and labour work hours may not be identical,
189 since some operations can be performed without the need to employ machines. Moreover, as far as the
190 hourly labour costs are concerned, it is important to underline how this amount changes greatly in relation
191 to their source. In this context, two options were defined. The first option is when the workers’ wage is
192 considered as external to the company, the price is defined by national agreements, and considered as a
193 full cost for the company (Blanc, 2010). The second option is when it is internal to the company, e.g.
194 because it is performed by the entrepreneur himself or a member of his family, the workers’ wage can be
195 evaluated as an opportunity cost (Posnet and Ian, 1996, Brun and Mosso, 2014), that is, the salary of the
196 alternative activity the worker decides to forgo. By contrast, the hourly machinery costs were computed
197 analytically, considering both the fixed costs (capital recovery, interest and depreciation, taxes and
198 insurance) and the variable costs (fuel, lubricant, repair and maintenance costs) that contribute to the final
199 cost amount (Miyata, 1980, Sierra-Pérez et al., *in press*).

200 The harvesting costs of the general i phase were thus obtained by multiplying the number of hours of work
 201 of the j machines utilized by their cost per hour, then adding the hours of work of each worker multiplied
 202 by the respective unitary costs (2):

203

$$204 \quad C p_i = \sum_{j=1}^n q_j \cdot u c_j + \sum_{k=1}^m q_k \cdot u c_k \quad (2)$$

205

206 where $C p_i$ is the cost of a general i phase (€); q_j is the number of hours of employment of the general j
 207 machine (h); $u c_j$ is the average unitary cost of the j machine (€ h⁻¹); q_k is the number of hours of
 208 employment of the k typology of worker (h); $u c_k$ is the average unit cost of the k typology of worker (€ h⁻¹); i
 209 is the number of considered phases; j is the number of employed machines and k is the number of
 210 employed workers.

211 The number of the employed q_j and q_k factors is influenced by both the wood volume of the harvest and
 212 the productivity rate of each phase, namely (3):

213

$$214 \quad q = \frac{V}{r} \quad (3)$$

215

216 where q is the number of employed factors (h), V is the wood volume processed by a machine in a general i)
 217 phase (m³) and r is the productivity rate (m³ h⁻¹).

218 The volume is a complex objective datum, and its amount was obtained after processing the dendrometric
 219 data using volume tables, whereas the productivity rates were estimated following a literature review
 220 (Hippoliti and Fabiano, 1997, Hippoliti and Piegai, 2000, Blanc, 2010). This data was then adapted to the
 221 conditions of this study, including environmental adaptations such as slope, road network and terrain
 222 roughness, and logistic adaptations such as the extraction distance and harvest intensity, which are
 223 determined by features of the harvest site (Accastello and Brun, 2016).

224 The harvesting costs were computed by summing the amount of each phase, using equation [2]. According
 225 to other authors (Carbone, 2008, Picchio et al., 2011), the administrative costs, interest and earnings of the
 226 logging company were then added and subsequently evaluated as 5% of the cost of the operations. The TV
 227 is the difference between the revenues obtained from the sale of the timber and this sum of costs; the TV
 228 per cubic meter is then obtained by dividing this difference by the felled wood volume (4):

229

$$230 \quad TV = \frac{R_{ass} - C_{tot}}{V} \quad (4).$$

231

232 where TV is the Timber Value (€·m⁻³); R_{ass} is the revenues obtained from the sale of the assortments (€); C_{tot}
 233 is the overall amount of costs (€) and V is the felled wood volume (m³). This set of operations constitutes

234 the model to calculate the TV of the harvest. This constitutes the starting point for all the following
 235 statistical elaborations, which were performed by employing this model and its results.

236

237 2.2.3 The TV of the case study

238 Once the model had been built, it was used to estimate the TV of the case study. According to the
 239 environmental characteristics of the stand and the logistic features of the logging operations, all the values
 240 required for the model were measured or estimated, depending on the type of data. A market survey
 241 (Piedmont Region personal communication, 2017) was performed to define the type and price of each
 242 assortment; the collected data is reported in Table 1.

243

Assortment	Price (€·m ⁻³)
1st grade poles	70
2nd grade poles	60
Chipping wood	45

244

Source: market survey, 2016.

245

Table 1 – The assortments and their price

246

247 The logging operations considered to calculate the harvesting costs were: i) felling and processing with
 248 chainsaw; ii) manual bunching along the slope; iii) extraction with a tractor and trailer along the existing
 249 road. These operations are summarized in Table 2, which also includes the employed machinery as well as
 250 its estimated hourly cost and productivity rate.

251

Phase	Adopted technique	Productivity (m ³ h ⁻¹)	Employed machine	Hourly cost of the machine (€ h ⁻¹)
Felling and processing	Processing at the felling site	1.3	Chainsaw	3.10
Bunching	Manual along the slope	1.4	-	0.00
Extraction	Forwarding with trailer	2.9	Tractor, grapple loader and trailer	31.90

252

Table 2 – Description of the features of the logging operations

253

254 The most common private logging company structure in the area was adopted for this evaluation: namely,
 255 a craftsman enterprise composed of the entrepreneur and one salaried worker. The hourly wage of the
 256 former was estimated as an opportunity cost for the company as 15€ h⁻¹, while the retribution of the latter
 257 was defined, according to national agreements, as a cost of 18.63€ h⁻¹. This value was considered the most

258 suitable in relation to the skills required to perform the harvest and the average characteristics of these
259 workers, in terms of years of employment and experience.

260

261 *2.3 Sensitivity analysis*

262 The Sensitivity Analysis (SA) allows the effects on the result to be evaluated in relation to fixed variations of
263 the variables (Grubbs, 1969, Sobol, 1990, Saltelli et al., 2004). This procedure is also known as a “what if”
264 analysis (Himmelblau and Bischoff, 1968), since it evaluates what happens when a default variation of a
265 factor is hypothesized. A specific SA methodology was developed, according to the features of the
266 variables, in order to measure the TV ranges. The results of the performed SA can supply useful information
267 to optimize the decision process of the harvest, to foster the robustness of the decisions that are made and
268 to highlight the main factors that influence the results of the model (Brainard et al., 2006, Navarrete and
269 Bustos, 2013). Consequently, these factors are also those on which it is appropriate to focus during the
270 estimation process (Koller, 1999).

271 A local SA has been performed in this study. This technique evaluates the effect of each single input
272 variable on the result through a “one factor at a time” approach (Saltelli et al., 2000). The factors were
273 made to vary singularly over a default range of values, while the other input values were kept fixed. The
274 reciprocal independence of the involved variables is a basic element that ensures the reliability of the
275 results, since they cannot influence each other (Zhang et al., 2012). For this reason, a relevant variable such
276 as the fuel price was excluded from the analysis: in fact, since its variation directly influences the hourly
277 costs of machinery, its inclusion would not have maintained the condition of independence of the variables.
278 The SA performed on the TV model included 6 independent variables: 3 related to the economic
279 parameters of the model (namely the hourly costs of the machines and the workers involved), and 3 related
280 to technical parameters (namely the productivity rates of the different logging operations) (Hanewinkel et
281 al., 2014). These parameters were made to vary over specific ranges, as defined in the literature (Hippoliti
282 and Fabiano, 1997, Hippoliti and Piegai, 2000, Blanc, 2010), and then adapted to the conditions of the
283 hypothesized harvest, that is, the conditions that were investigated during the field surveys (Moore et al.,
284 2011). The features of each variable are summarized in Table 3, together with their variation range, which
285 was defined following a literature review (Logan, 2011, Picchio et al., 2011).

286

Variable	Measurement unit	Minimum value	Maximum value
Worker's hourly cost	€ h ⁻¹	8.00	25.00
Hourly cost of the chainsaw	€ h ⁻¹	2.00	6.00
Hourly cost of the tractor	€ h ⁻¹	20.00	45.00
Felling and processing productivity rate	m ³ h ⁻¹	0.75	1.75
Bunching productivity rate	m ³ h ⁻¹	0.88	1.88

Extraction productivity rate	m ³ h ⁻¹	1.25	3.75
------------------------------	--------------------------------	------	------

Table 3– Input variables involved in the SA

287

288

289 The TV variations were then analysed using descriptive parameters to allow a comparison of the considered
 290 variables. More specifically, the results were analysed by: i) defining the Break Even Point (BEP) of the
 291 variable (Singh and Deshpande, 1982), that is, the value that is able to ensure equilibrium between the
 292 revenues and costs (where its position can supply important information about the trend of the variable
 293 and the possibility of achieving a profitable harvest); ii) comparing the gradient of the lines, which describes
 294 the trend of the relationship between the variables and the results (this elaboration was only possible for
 295 the variables that showed a linear trend); iii) calculating the elasticity of this relationship (Pannell, 1997),
 296 that is, a parameter that can be used to measure the influence of a variable on the TV (eq. [5]):

297

$$e = \frac{\Delta Y/Y}{\Delta x/x} \quad [5]$$

299

300 where $\Delta Y/Y$ is the variation of the result and $\Delta x/x$ is the variation of the parameter in relation to the value
 301 assumed in the estimation. Performing these elaborations on the results of the SA, allowed more
 302 information to be obtained about the typology and intensity of the influence of each variable on the TV.

303

304 *2.4 Monte Carlo Simulation*

305 The Monte Carlo Simulation (MCS) is a reiterative analysis of the results of a model in relation to random
 306 and simultaneous variations of its independent input factors, in which a normal distribution of the
 307 frequencies of the latter is hypothesized (Saltelli et al., 1999). It is commonly adopted to analyse a model
 308 and evaluate the robustness of the results (Confalonieri, 2010, Moore et al., 2011). This methodology
 309 allows a greater in-depth analysis of the results and the relationship of the model with the input variables,
 310 which are investigated together simultaneously. This technique allows the stability of the results of a
 311 model, including a stochastic element in its input variables, to be tested in order to simulate the intrinsic
 312 uncertainty of the operative conditions. Due to their characteristics of uncertainty, the productivity rates of
 313 the logging operations and the average price of the timber products were investigated. Their features were
 314 included in the model by defining a random variability, in terms of standard deviation, equal to 10% of the
 315 mean value of each considered variable. This analysis was reiterated 10,000 times to simulate the random
 316 variation of the variables.

317

318 *2.5 Scenario analysis*

319 A Scenario analysis was the last investigation to be performed on the TV model. It consists of the
320 development of hypothetical conditions of interest, characterized by input variable values chosen by the
321 stakeholder, inserted into the model to study the corresponding result (Saltelli et al., 1999). Therefore, it
322 can be considered as a particular case of sensitivity analysis, since a predetermined modification of the
323 factors is established. The creation of these predefined situations can be useful to understand, for example,
324 which of a group of options is the most suitable for the aims of the stakeholder, in order to support his
325 decision-making processes with objective results supplied by the model (Hoogstra-Klein et al., 2016). Actual
326 data pertaining to the two most represented private forest company typologies in Piedmont were
327 introduced as parameters into the model to build the hypothesized scenarios. The comparison of these
328 scenarios makes it possible to highlight how the structural and logistic features of the logging companies
329 can affect the profitability of the harvest. The data necessary to accurately describe the standard conditions
330 of the private companies operating in the area were obtained from the Regional Register of Forest
331 Companies (<http://www.sistemapiemonte.it/aifo>), which includes organizational, economic and
332 management information about the enterprises operating in the regional territory (Blanc et al., 2017).
333 The craftsman logging company, which had previously been considered to estimate the TV, and a logging
334 company owned by a farmer are the two enterprises that were tested in the scenario analysis. These two
335 typologies of entrepreneurs constitute more than 90% of the logging companies operating in Piedmont
336 (Brun et al., 2014b). The differences in these two enterprise structures lie within the adopted machinery
337 and labour costs. As far as the farmer's enterprise is concerned, the agriculture sector is supported by fiscal
338 subsidies distributed to purchase fuel, which consequently costs much less, than fuel sold at the market
339 price (almost 50% less). Moreover, the annual number of hours of machine employment is generally higher
340 than the number reached by craftsman enterprises, leading to a lower hourly incidence of fixed costs. As
341 far as labourer's wages are concerned, workers employed in the agricultural sector have lower salaries than
342 those of qualified craftsman workers, as stated in their respective national agreement. Moreover, the
343 entrepreneur's wages have to be considered differently as it is viewed as an opportunity cost, which is
344 defined by comparing these activities with others they cannot accomplish. While harvesting is the main
345 employment of a craftsman, a farmer usually performs forest activities during the winter, when his
346 agricultural activities are less compelling and profitable. These conditions mean that the farmer should be
347 assigned a lower opportunity cost than the craftsman. Finally, because of the simple technical requirements
348 needed to perform the considered harvest, a delta in terms of productivity rate, cannot be precisely
349 defined for the enterprises. The characteristics of the two considered scenarios are described in Table 4,
350 where the differences between the craftsman enterprise (Scenario 1) and the farmer enterprise (Scenario
351 2) are listed and compared.

352

Cost of item	Scenario	Scenario	Measurement
---------------------	-----------------	-----------------	--------------------

	1	2	unit
Entrepreneur's wage (opportunity cost)	15.00	13.00	€ h ⁻¹
Employed worker's wage	18.63	14.98	€ h ⁻¹
Fuel price (11/2016)	1.06	0.65	€ l ⁻¹
Hourly cost of the tractor	31.90	21.30	€ h ⁻¹

Table 4 – Characteristics of the two scenarios

353

354

355 **3 Results**

356 *3.1. Timber value*

357 The revenues derived from the products sale are mainly obtained from the sale of chipping wood, which
 358 represents 72% of the wood volume and generates 64% of the revenues. This is because the characteristics
 359 of the main species of the stand are not suitable for more profitable utilization, such as construction
 360 beams, and pathogens present in the stand had depreciated the value of the majority of the stems. These
 361 conditions are, in fact, quite common in these stands, and only a local energy station, to which the chipping
 362 wood can be sold, can make the harvest profitable. In this harvest, 440 trees were felled, and a volume of
 363 187 m³ of processed wood was obtained, whose sale ensured the enterprise a total revenue of €9,533 (Tab.
 364 5).

365

Assortment	Volume		Revenue	
	m ³	%	€	%
1st choice poles	18.99	10	1329.30	14
2nd choice poles	34.17	18	2050.20	22
Chipping wood	136.74	72	6153.30	64
Total	187.00	100	9532.80	100

Table 5 – Assortments and their related revenues

366

367

368 The cost of the logging operations were computed according to the methodology illustrated in equations
 369 (2) and (3). Administrative costs, interest and earnings of the company were added, and the total cost of
 370 the harvest was obtained (Tab. 6).

371

Phase	Cost (€)
Felling and processing	3231.68
Bunching	2322.99
Extraction	3218.06
Cost of logging operations	8772.73
Administration cost (5%)	438.64
Overall harvesting cost	9211.37

372

Table 6– Overall harvesting costs

373

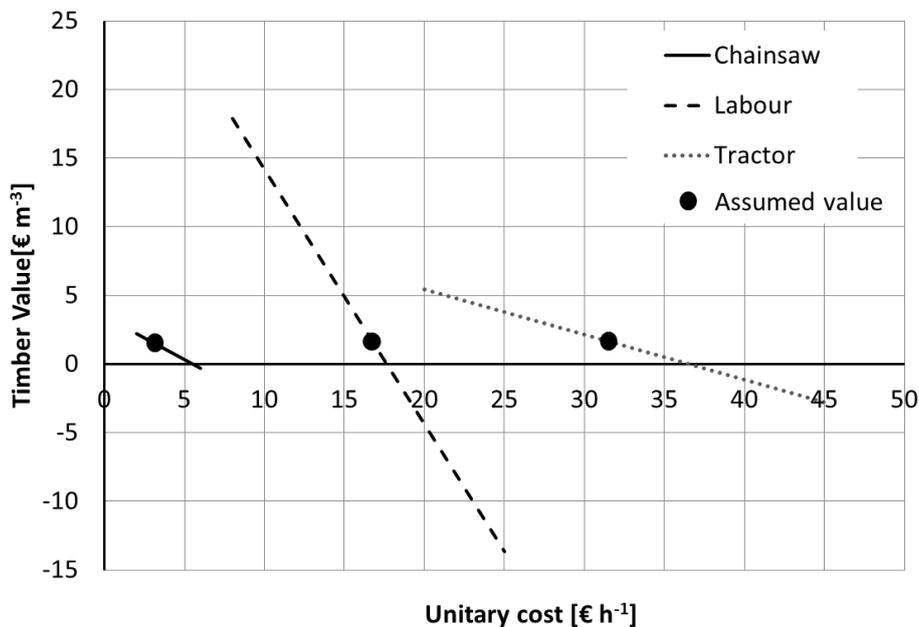
374 The difference between the revenues (€9532.80) and the overall harvesting costs (€9211.37) led to a
375 positive value of €321.43, for a TV of 1.72 € m⁻³. This demonstrates that the harvest resulted in a positive
376 outcome even though its profit margin is somewhat limited. In this sense, the robustness of the estimation
377 and its sensitivity to the variables that compose it become fundamentally important information to be
378 acquired, as this enables an in-depth evaluation of the achieved economic results.

379

380 *3.2 Sensitivity analysis*

381 The six variables listed in Table 3 were analysed one by one by means of a local SA. The variables were
382 inserted into the model according to the previously described default ranges of variation. Given the
383 different nature of the relationship between the variables and the result of the model, they were divided
384 into two groups. The first group was formed by the 3 variables related to costs. In fact, they all generate a
385 linear relation to the result of the model, which steadily grows as they increase. The trend that these
386 variables originate is shown in Figure 1. The black dots in Figures 1 and 2 represent the values that were
387 assumed in the economic estimation of the hypothesized harvest. As is evident, they are generally close to
388 the negative values of the y-axes, with each variable ensuring wide improvement margins to its
389 performance.

390



391

Figure 1 –The relationship between the hourly operation costs and the TV

392

393

394 The graph clearly shows the influence of each variable on the outcome. In fact, there is a noticeable
 395 different width of variation and the gradient they assume. The results of Figure 1 are expressed in terms of
 396 BEP, gradient and elasticity in Table 7.

397

Variable	Break-even point (€ h ⁻¹)	Gradient	Elasticity (%)
Hourly cost of the chainsaw	4.27	-0.63	-0.7
Hourly cost of the worker	17.22	-1.86	-22.8
Hourly cost of the tractor	36.54	-0.33	-6.8

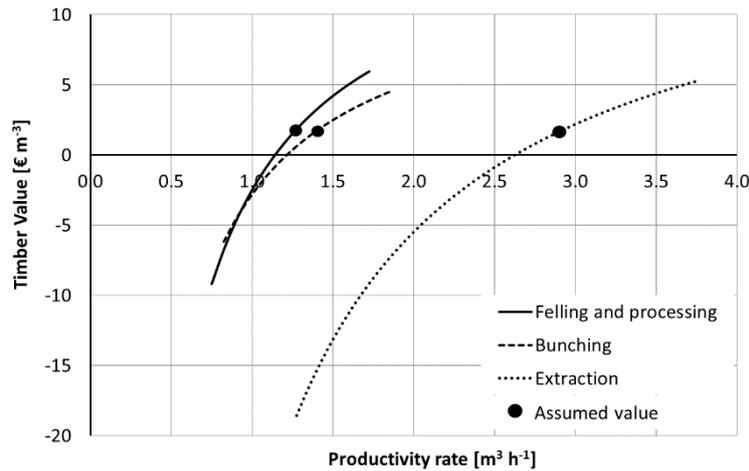
398 **Table 7** – Analysis of the results achieved with the SA for the three linear variables

399

400 In relation to the chainsaw hourly cost, it is apparent how its limited width does not allow the TV to vary
 401 extensively, even if, due to its gradient, it has already an influence on the profitability of the harvest,
 402 making it vary between positive and negative values. An opposite situation can be observed for the labour
 403 cost factor, whose high trend slope and wide range influence the TV to a greater extent, and allow very
 404 positive (17 € m⁻³) to very negative (-14 € m⁻³) monetary results to be reached. Finally, the hourly costs of a
 405 tractor represent an average situation, since the effects of its wide range are softened by its low slope,
 406 which greatly limits the variations of the TV.

407 The break-even point, whose values are influenced to a great extent by the range width and the unit of
 408 measure of each variable, varies between 4.27 and 36.54 € h⁻¹. The gradient always resulted in negative
 409 values, as also evidenced in Fig. 2. Since the slope of the hourly cost of a worker is the lowest negative
 410 value (-1.86), it can be hypothesized to have a greater influence on the result, while the hourly cost of a
 411 tractor assumes the highest value (-0.63). This situation is confirmed by the elasticity, where the decrease
 412 in the TV as a consequence of a 1% growth in the considered variable, ranges from very low (-22.8%) to
 413 nearly zero (-0.7%), in relation to the nature of the relationship between the variables and the results.
 414 Therefore, we can assume the results depict a close bond between labour costs, which represent 68% of
 415 the overall harvesting costs, and the TV of the intervention, as shown by elasticity values higher than 20%.
 416 The variables related to productivity rates, whose trend is shown in Figure 2, are linked to the result of the
 417 model by a non-linear relation, in which steady variations of the variables generate a more than
 418 proportional increase in the result before the inflection point, and a less than proportional increase after it.

419



420
421 **Figure 2** – Relationship between productivity rates and TV
422

423 The significant influence of the extraction phase on the final result clearly emerges in Figure 2. In fact, the
424 width of its variation range and the trend of the curve can be seen to clearly affect the TV, which varies
425 from 5 to -18 € m⁻³. The other two variables regarding the felling, processing and bunching phase, assume a
426 similar trend, whose influence on the TV is limited and mostly ensures positive TV values.

427 Further analysis was performed in order to quantify the relationship between the variables and the TV, as
428 shown in table 8. The values of the break-even point and the elasticity of the relation are listed for each
429 variable, whereas it was not possible to compute the gradient for them.

430

Variable	Break-even point (m ³ h ⁻¹)	Elasticity (%)
Felling and processing productivity rate	1.14	10.1
Bunching productivity rate	1.21	7.6
Extraction productivity rate	2.63	10.1

431

Table 8 – Analysis of the results achieved through the SA for the three non-linear variables

432

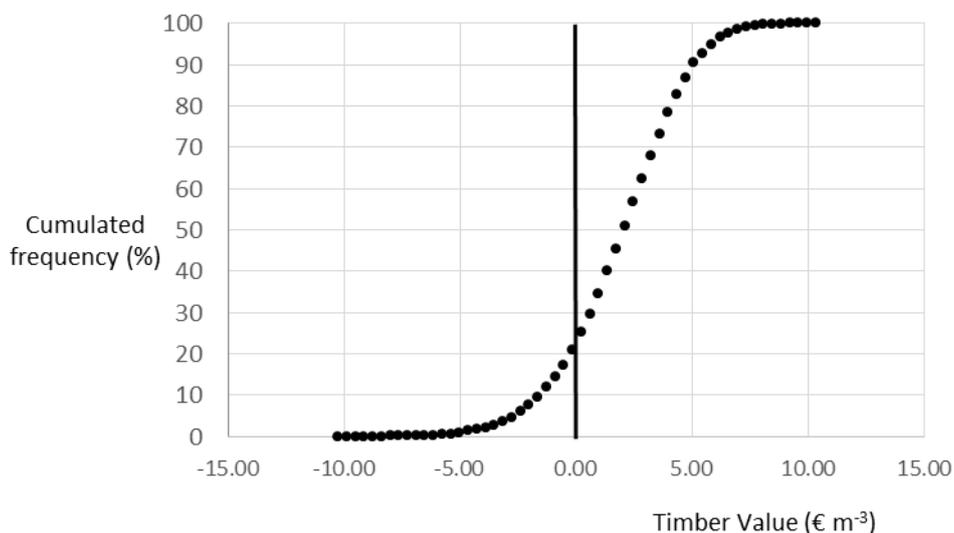
433 The break-even point is very similar for the first two variables, close to 1 m³ h⁻¹, while the productivity rate
434 of the extraction phase assumes a value of 2.63 m³ h⁻¹; in any case, it results much lower than the values
435 reported in table 7. Concerning elasticity, the bunching phase has the lowest value, at 7.6%, while the other
436 two factors report the same percentage; all of them have a positive influence on the result, allowing it to
437 increase substantially even with 1% variations.

438

439 3.3 Monte Carlo simulation

440 The Monte Carlo simulation took into consideration the simultaneous variation of the three productivity
441 variables of the logging operations and the mean price of the products. While the former were left free to

442 range over a delta of 10% of the standard deviation of their mean value, precise boundaries were fixed for
 443 the prices. In fact, the minimum value was set at the price of the least valuable assortment, that is, chipping
 444 wood, in order to simulate realistic market conditions, while the maximum was set at the price of the
 445 second grade poles. The results of the 10,000 simulations performed are shown in Figure 3, which shows
 446 the trend of the function on the cumulated frequency percentage of the TV.



447

448

449

Figure 3 – Distribution of the cumulated frequency (F%) of the TV

450

451 As can be noticed, the TV varies from -12 to 10 €m⁻³, due to the simultaneous variation of the productivity
 452 factor, thus confirming its great dependence on the input variables of the model. The graph supports the
 453 robustness of the results of our estimation, since the most frequent output is a positive economic result. In
 454 the MCS, 68% of the cases led to a profitable harvest.

455

456 3.4 Scenario analysis

457 The economic results of the harvest were computed for the two hypothesized scenarios based on the
 458 values reported in Table 4, which lists the differences between the two types of enterprises considered
 459 (Table 9).

460

Scenario	Enterprise typology	Overall unitary harvesting cost (€ m ⁻³)	TV (€ m ⁻³)
1	Craftsman	49.26	1.72
2	Farmer	35.87	9.31

461

Table 9 – Comparison of the main economic parameters achieved for the two scenarios

462

463 As shown in table 8, the enterprise run by the farming entrepreneur achieves better results in terms of
464 economic profitability of the harvest, with a lower harvesting cost of 7.59 € m⁻³. This positive result is also
465 evident when compared to the craftsman, when the TV value is approximately six-fold. This favourable
466 situation, as previously mentioned, is mainly due to the lower hourly costs of the machinery and of labour.
467 Moreover, it can be hypothesized that the results achieved for the farm enterprise are much more robust
468 than the ones represented in Figure 3, since the Monte Carlo simulation performed on the values of
469 scenario 2 led to a probability of obtaining negative economic results close to 0%.

470

471 **4 Discussion and Conclusions**

472 In this study, a model was developed to estimate the Timber Value of a forest harvest in a chestnut stand
473 under standard operative conditions. Each phase of the logging operations has been analysed and included
474 in the model in relation to the standard working protocols of the local companies (Spinelli et al., 2004,
475 Picchio et al., 2011, Gautam et al., 2014). Our case study, characterized by easy accessibility of the stand
476 and organization of the harvest operations, has allowed all the relevant technical and economic factors to
477 be defined and analysed. Even though the analysis only focused on one harvest, given the
478 representativeness of its features, we believe the results of this economic and statistical analysis can be
479 considered to be relevant at Regional and Alpine level and useful to provide some insights related to the
480 management of most of the over-aged chestnut stands in these areas, also thanks to the simulations and to
481 scenario analysis performed. Moreover, since the framework of the model is versatile and able to employ
482 input data that reflects the standard conditions of new study areas (e.g. with further market timber price
483 surveys, or collection of data regarding the most common working organizations and technologies for the
484 area,) it could be used to a great extent for other case studies, allowing the comparison between multiple
485 scenarios.

486 The approach we adopted to evaluate the TV of the harvest is classic, however, to our knowledge, the
487 manner in which we analysed it from a statistical point of view is innovative and could be adopted in other
488 contexts. Other previous Italian studies (Magagnotti and Spinelli, 2011, Picchio et al., 2011, Spinelli et al.,
489 2012), performed an economic analysis of forest interventions, but the reasons underlying those results
490 were in general little investigated. On the other hand, in this paper the computed TV is a stepping-stone for
491 further analysis that leads to both theoretical and operational insights on their influence on the final result.
492 More specifically, the sensitivity analysis we conducted, in which all the variables included in our economic
493 model have been considered, enabled the measurement of their influence on the TV (O'Neill et al., 1980,
494 Koller, 1999). This technique has already been adopted in several papers starting from Grubbs (1969) and
495 Sobol (1990) who were the first to focus on this aspect and to define its main framework and rules. More
496 recently, similar research was published by Saltelli (1999) and Saltelli, et al (2004), who focused on
497 describing the different analysis typologies that can be used in relation to the aims of the research and the

498 available data. Similarly, the Monte Carlo simulation also allowed more information to be gained on the
499 profitability of the harvest and on the robustness of our evaluation (Dieter, 2001, Maarit and Kallio, 2010),
500 even though negative economic results were observed for 32% of all the evaluated cases.

501 At international level, some other studies adopted similar approaches. Among these Whittock et al. (2004)
502 and Oliveira et al. (2012) evaluated the influence of some variables on the incomes derived from
503 plantations by performing a reiterative analysis, while Yoshioka et al. (2002) studied the variation of the
504 cost of biomass production in different harvesting sites. More related to our research are Van Gardingen, et
505 al. (2003), who studied the causes of the variations of the incomes derived from harvesting in relation to
506 different silvicultural management procedures, while other authors have studied the parameters that have
507 the highest influence on the harvest operations, and their effects on productivity (Vangansbeke et al.,
508 2015). This latter work is the most interesting because it adopts a similar approach, combining SA with
509 different scenarios; in our study however, a different scale was considered in order to better reflect the
510 current Italian conditions of the forestry sector and in particular the features of its logging companies.

511 These aspects were then specifically investigated in the scenario analysis conducted on the data taken from
512 the Regional Register of the Forest Companies, allowing the two most common types of private enterprises
513 in the forest harvest sector to be analysed. This data clearly highlighted the specific features of each of
514 these companies, whose characteristics influence the profitability of the performed harvests to a great
515 extent. In fact, farming enterprises that are able to harvest forest stands clearly emerge to be supported by
516 favourable conditions in terms of labour and fuel costs, which are two elements that do not depend on the
517 personal entrepreneurship skills of the owners. More favourable conditions are also derived from the
518 opportunity of employing the same machines for both the agricultural and forestry activities of these
519 companies, which results in a significant decrease in their fixed costs. On the other hand, this situation
520 entails strong limitations due to the peculiar features of the forestry operations performed in the Alps.

521 While the farmer's enterprise proved to be very well adapted to a context made of small forest blocks of
522 low quality products situated in favourable orographic conditions, we can assume that on higher slopes
523 with fewer available roads, the lack of professional skills and proper forestry machinery would strongly
524 decrease their economic competitiveness. In those cases, the skills of the craftsman enterprise would
525 represent a decisive aspect in ensuring a positive economic outcome from the harvest.

526 At policy level, even if this research has illustrated the economic potential ensured by the Chestnut stands
527 of the Italian Alps for harvests on small forest stands, several limitations still remain for this sector. They
528 are mainly related to a weak connection with the wood industry, where the demand of Italian wood
529 products is lacking, or even absent, due to their low quality (Cicarese et al., 2015), and to the territorial
530 governance guidelines, which over previous years have resulted to be confused and discontinuous
531 (Carbone and Savelli, 2009, Secco et al., 2017). While different governance addresses were pursued in the
532 last decades, causing inefficient resource management, in more recent years, some positive initiatives have

533 addressed the forestry sector, promising to deliver a positive outlook for harvest rates and profitability
534 trends. In the Piedmont Region, an innovative law was passed in 2017 to promote the establishment of
535 associations of forest owners, supporting the shared management of private forest areas (Marandola and
536 Romano, 2012, Beltramo et al., 2018). Similarly, within the application of the last period of the Rural
537 Development Fund, 15 Italian Regions out of 20 funded measures to improve the management of coppiced
538 forests (Quatrini et al., 2017) and a new National Forest Law was recently issued (Marchetti, 2018). Finally,
539 decisive progress was made in the development of management guidelines for coppices in order to reduce
540 the influence of the diseases affecting the chestnut in the achievable assortments (Spinelli et al., 2017,
541 Fabbio, 2016).

542 Overall, the methodologies included in this study can be considered suitable for our aims and capable of
543 supplying important results to analyse a forest harvest from an economic perspective. The model we built
544 considers all the logging operations and makes it possible to simulate variations of its input factors, whose
545 influence on the TV has been evaluated through SA, MCS and scenario analyses. The latter can be
546 particularly useful to support the evaluation of forest entrepreneurs, since they often operate in very
547 heterogeneous contexts, in which there is a lack of predetermined parameters, and often suffer wide
548 profitability variations due to the variation of single factors. The novelty of this study is represented by both
549 the adopted workflow, combining different economic and statistical analyses, and the study area: to our
550 knowledge, other examples of this kind of analysis in the Alpine area have not yet been undertaken.

551 In the future, our aim is to further develop the model in order to increase the complexity of the harvests
552 examined so more options can be evaluated and compared. This would include the organization of the
553 logging operations and the machinery involved, allowing more useful information about the profitability of
554 the harvest to be supplied to forest entrepreneurs.

555

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558

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562

563 **7 Conflict of interest statement**

564 None declared.

565

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