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Strategic Planning in a Forest Supply Chain: a multi-goal and multi-product approach

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Complete List of Authors:	Broz, Diego; UNaM CONICET, Facultad de Ciencias Forestales Durand, Guillermo; PLAPIQUI UNS CONICET, Departamento de Ingeniería Química Rossit, Daniel; INMABB UNS CONICET, Departamento de Matemática Frutos, Mariano; IIESS UNS CONICET, Departamento de Economía Tohmé, Fernando; INMABB UNS CONICET, Departamento de Matemática
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Diego Broz^{a*}, Guillermo Durand^b, Daniel Rossit^c, Fernando Tohmé^d, Mariano Frutos^e

^e IIESS UNS CONICET, Departamento de Ingeniería – Av. Alem 1253. Bahía Blanca, Argentina. Email: mfrutos@uns.edu.ar

* **Corresponding author:** Diego Broz, Universidad Nacional del Misiones, Facultad de Ciencias Forestales. Bertoni 124, Misiones, Argentina (AR3380). Email addresses: diego.broz@uns.edu.ar

17 **Abstract**

18 Supply chain management problems are widespread across all economic activities. We analyze here
19 how to address them in the case of the forest industry, which in emerging economies as Argentina is
20 subject to high logistic costs and faces problems of biological and economic sustainability. In this
21 work we analyze a management model covering from the schedule of harvesting activities and the
22 transportation of raw materials to the final transformation at several industrial plants. Since this
23 involves more than one objective, single-criterion mathematical programming methods are not
24 appropriate. Here, instead, we introduce an *extended goal programming* (EGP) formulation of the
25 problem, able to yield good solutions in a computationally efficient way. We consider four goals: the
26 maximization of the net present value of the production, the minimization of inter-annual variations in
27 harvests, the maximization of carbon capture in the form of forest biomass and the minimization of
28 variations in the mean annual distance covered in transportation to the industrial plants. We apply this
29 theoretical model to derive solutions for an actual Argentinean company. We show that the model
30 reaches the target levels of the different goals, except for carbon balance, which is negative in all the
31 scenarios under evaluation.

32 Keywords: forest management, goal programming, industrial forest plantations, multiple criteria
33 decision making, supply chain management.

34

1. Introduction

Forests and forest industries have a very important role in the economic and social development of North-East of Argentina. However, the management of their supply chains face problems, i.e., the integration of forest harvesting scheduling, log transportation and factory demands. The reach of this integration can be extended to encompass the larger problem of developing and managing efficient supply chains, which are known to promote the competitiveness of businesses in globalized markets (Boston, 2014). But in Argentina the costs of the export logistics of forest products accounts for 30% of the Free On Board (FOB) value, 3-5 times higher than those of its main competitors in the region, i.e. Chile, Brazil and Uruguay (AFOA, 2015). In addition to these high costs, the persistence of inflation leads to a scenario of low competitiveness that must be addressed using sound management practices underpinned by robust decision support tools.

It is well known that the application of supply chain management techniques has become increasingly important for the forest industry (Carlson and Rönnqvist, 2005; D'Amours *et al.*, 2008; Carlsson *et al.*, 2009 and Varas *et al.*, 2014, Rönnqvist *et al.*, 2015). This is especially relevant due to the high costs incurred during the transportation phase, covering up to 45% of the total costs (Weintraub *et al.*, 1996 and Broz, 2015). To ensure the efficient management of these resources, techniques based on mathematical programming are customarily applied (Rönnqvist *et al.*, 2015).

In this work we introduce an Extending Goal Programming (EGP) approach, integrating the maximization of certain objectives and the attainment of balances in certain activities in time. The objectives and activities include the schedule of harvesting operations, the transportation of raw materials and their transformation in several industrial plants. The model treats aspects of tactic and strategic planning in a single mathematical structure. Unlike the models in Silva *et al.* (2010), Gimenez *et al.* (2013) and Diaz-Balteiro *et al.* (2013), where the main issue is

the amount and timing of forest treatments, we seek an optimal harvesting and provision policy. We disregard all aspects of forest management other than the number of turnover periods. This makes our approach similar to Troncoso et al. (2015), where a single framework covers all the stages of this industry, although their choice of goals is not the same as ours. Models in this line tend to focus only on short, i.e. 5 year long horizons (Paradis et al., 2013 and Paradis et al., 2015) and seek the maximization of the net present value of production (Shabani and Sowlati, 2013; Shabani et al., 2014 and Troncoso et al., 2015). Such approaches tend also to discard goals related to environmental, logistic and sustainability aspects of the production process.

Our main contribution is the development of a planning approach for a long strategic horizon (18 years), addressing simultaneously various goals of the forest industry (of economic, environmental, logistic and silvicultural nature). It is intended as a model of decision-making of a vertically integrated firm supplying several products (veneer log, sawlog and pulpwood) to different production units (pulp mill, MDF factory, sawmill and plywood mill).

The paper is structured as follows. Section 2 is a review of the relevant literature. Section 3 presents the main features of the model and a description of the application case. We describe both the analytical model and its interpretation from the point of view of the preferences of potential decision-makers. Section 4 presents the results of applying the model to the particular case at hand. Section 5 discusses the result while section 6 summarizes the main conclusions derived from this research.

2. Literature review

While supply chain models have been widely discussed in several strands of the literature on production processes, we will focus on the main contributions in the specific field of forest management. Gunnarsson et al. (2007), for instance, present a mathematical model of the entire supply chain including a large number of continuous variables and a set of binary

variables to reflect different combinations of products and order selections. The model yields optimal decisions on the transportation of raw materials from harvest areas to pulp mills, the production mix and contents at pulp mills, the distribution of pulp products from mills to customers, and finally the selection of potential orders and their levels. Chauhan et al. (2009) minimize a combination of harvesting and transportation costs in mixed-integer optimization models under demand satisfaction constraints. These authors consider two-echelon timber procurement systems in which the first echelon consists of multiple harvesting blocks and the second of multiple mills. Their results show a good performance of the branch-and-price approach (implemented by the CPLEX solver) for large-scale problems. Shabani and Sowlati (2013) and Shabani et al. (2014) have approached a similar problem in the case in which wood biomass is destined to the production of electricity. These authors develop a mixed integer non-linear programming model of the optimization of the supply chain where the objective is improving cost competitiveness. The model is solved using the outer approximation algorithm provided by the AIMMS software package. This tool allows, additionally, finding the optimal scenario, assessing different configurations. Paradis *et al.* (2015) present a two-level formulation, based on a classical wood supply optimization model, which explicitly anticipates the consumption of industrial fibers. This model is NP-hard, non-linear and non-convex but can be decomposed into convex sub-problems yielding a global optimum. The corresponding solution exhibits a low risk of wood supply failure (Paradis et al., 2013 and Paradis et al., 2015). Troncoso et al. (2015) present a model of the supply chain of a vertically integrated firm. The goal is to determine which stand to cut and when and where to send each of its products. The analysis is carried out in the framework of two scenarios, one of independent management of the two sectors (forest and industry) and another, integrating them. Both scenarios are evaluated using the Mixed-Integer Linear Programming Model (MILP), where the maximization of Net Present Value (NPV)

determines the best practice. These authors show that NPV can increase up to 5.0% when management is integrated.

Contemporary concerns with the protection of the environment together with the growing demand of natural resources are forcing the firms in the sector to change their business models. In particular, forest companies are focused on improving their supply chain management to ensure sustainability (Wu and Pagell, 2011). At the same time, worries about the emission of greenhouse gases have led to policies of reduction of environmental impacts (Dadhich et al., 2015; Colombo et al., 2012). According to Martí et al. (2015) the greenhouse gas emissions come from direct and indirect sources at the different stages of the supply chain. This is relevant for our purposes since it indicates that comprehensive supply chain approaches are essential to ensure the cost-effectiveness of carbon management strategies.

3. Goal Programming

The use of Multiple-Criteria Decision-Making (MCDM) tools has been recommended to deal with the management problems of the forest industry (Buongiorno and Gilles, 2003 and Bettinger, 2009). Several of these methods have been implemented as specialized decision-making software: the Analytic Hierarchy Process (AHP), the analytical network process, data envelopment analysis, multi-attribute utility theory, evolutionary multiobjective optimization, multiple objective mathematical programming, etc. One of the approaches most widely applied in the field is Goal Programming (GP), based on Herbert Simon's "satisficing" alternative to optimization. This idea, contrary to the usual multi-objective approaches, is not to find optimal levels of the variables but to attain some pre-specified target values. Each class of potentially conflicting goals is associated to an aspiration level. A weight is allocated to each goal, indicating its degree of priority. A solution would be an allocation of resources or a plan that "satisfies" the goals, i.e. that it get as closely as possible to their aspiration levels. (see, for instance, Silva *et al.*, 2010; Gimenez *et al.*, 2013 and Diaz-Balteiro *et al.*,

2013). GP was initially proposed by Charnes *et al.* (1955), Charnes and Cooper (1961) and later developed and extended within a "satisficing" logic by Lee (1972), Ignizio (1976), Romero (1991) and Jones and Tamiz (2010) among others. Pioneering applications of GP to forest management can be found for instance in Field (1973) and Diaz-Balteiro and Romero (1998). In particular, the approach known as Extended Goal Programming (EGP) provides a flexible analytical framework for these applications (Romero, 2004). This extension of GP is easy to postulate and facilitates the interaction between the model and actual decision-makers. Either priorities (lexicographical orderings) or preferences (weights) can be defined, striking a balance among the goals (Broz, 2015; Romero, 2004). While finding only "satisficing" solutions, instead of optimal ones, can be seen as a disadvantage, make the approach closer to real world decision-making processes. The steps towards the development of a EGP model involve finding the appropriate goals, define their target values and use as variables the *deviation* from the aspiration levels. The computational burden imposed by these extra variables can be, in most cases of interest, handled with relative ease by current software packages. An additional advantage of EGP stems from its origins as a variant of linear programming. Models based on this approach are easy to understand and their results can be interpreted in a natural way (Broz, 2015; Zeleny, 1981).

4. Materials and methods

In this section the main elements in our framework will be presented. This includes the structure of the decision making process, the case study, with its assumptions and parameters and the ensuing EGP model.

4.1. The decision-making process

Fig. 1 shows the sequence of steps leading to the decisions made according to our model. We apply it on a case study involving a vertically integrated firm in the forestry industry. In order

159 to do that, we have to consider the fundamentals of our model, like the forest management
160 goals, the preferential weights as well as the physical, environmental and silvicultural
161 constraints faced by the firm. Data obtained from surveying the forest structure together with
162 information about the industrial system provide the inputs for the simulation of the
163 production process. Once the targets for the goals are formulated, the EGP model is solved,
164 providing a plan and additional data for the decision makers.

165 **4.2.Selection of a forest system scenario**

166 The province of Misiones concentrates 85% of the forest plantations as well as 90% of the
167 forest industries in the whole country (MAGyP, 2013). It is thus highly relevant to optimize
168 the supply chains in this economic sector. Any gains in efficiency may constitute a
169 substantial contribution to the development of this region and of the entire Argentinean
170 economy.

171 We focus on the case of vertically integrated forest firms. The relevant data (dasometric,
172 silvicultural and geographical information) was provided by Arauco S.A., the main firm in
173 the region. In particular, dasometric data was obtained using field inventories and a
174 Geographic Information System (GIS) to determine spatial parameters. We consider a
175 compound of 100 stands of *Pinus taeda* L. aged from 1 to 14 years, with densities ranging
176 from 373 to 1,325 trees per hectare, a survival rate of 95% and a site index from 20 to 22
177 meters, with a base age index of 15 years. While in the past some parts of the stands were
178 trimmed, this is no longer done except for forest health considerations. Thus, the only
179 relevant prescriptions are determined by the earliest harvest age and the length of the
180 planning horizon. So, for instance, if the earliest harvest age were 13 years and the planning
181 horizon 18 years, we would face a scenario of 470 prescriptions. The area covered by the
182 harvest blocks ranges between 5.1 and 236.6 hectares, being the system's total surface of
183 8,319 hectares. On the other hand, the industrial sector consists of a pulp mill, a sawmill, a

184 MDF factory and a plywood mill (Fig. 2) distributed all along Misiones. These production
185 units consume logs of different lengths and diameters. The model should determine a harvest
186 schedule satisfying in the best possible way all the different goals in a 18 years period.

187 **4.3. Simulation of forest growth**

188 The production parameters were determined up from the bucking requirements of the
189 industry (Table 1). The plywood mill requires logs wider than 30 cm and lengths in the range
190 of 1.75 to 2.25 m –i.e. veneer logs-. On the other hand, the sawmill has two production lines
191 for logs of 2.4 m of length, one for diameters between 25 and 30 cm –sawlogs of large
192 diameters– and the other for diameters ranging from 18 to 25 cm, i.e. sawlogs of small
193 diameters. Finally, the pulp mill and the MDF Factory consume logs of diameters between 8
194 and 18 cm with a length of 2.6 m, known as pulpwood. While it is possible to degrade the
195 products, like using veneer logs as sawlogs, we will assume here that each quality is only
196 destined to its better use.

197 In order to project the volumes of production we use the equations of the “Simulación
198 Forestal” module of FlorExel[®] 3.14 (<http://www.florexel.com.br>) implemented in MS Excel[®]
199 as a Visual Basic Application (VBA). In this case, we applied a fifth degree polynomial taper
200 function fitted with data from 315 *Pinus taeda* L. trees from Paraná, Brazil. By means of
201 these projections a table is generated, providing the inputs for the model.

202 **4.4. Goals and preferential weights**

203 In our analysis we also include classical aspects of forest management, related, on one hand,
204 to the sustainability and profitability of production as well as its carbon balance, and on the
205 other to supply chain concerns, e.g., transportation costs and balance, clients’ demands, etc. A
206 group of experts, constituted by a forest engineer, an industrial engineer and an economist,
207 under directives of the firm, established the goals. These experts were selected because of

208 their strong background in management science and their familiarity with the forest sector in
209 Misiones, Argentina. They carried out an analysis of both the firm's main objectives and the
210 constraints imposed by its environment. The first goal proposed by them is the improvement
211 of profitability measured by NPV. This implies that the discounted cash flow must be
212 maximized (Kuuluvainen, et al., 2012; Bettinger, 2009 and Clutter, 1992). Another goal is to
213 reach a positive carbon balance, in order to reduce the emission of greenhouse gases by
214 maximizing the difference between the amount of carbon sequestered in the forest biomass
215 and the quantity released by harvesting (Mäkipää *et al.*, 2014; Gimenez *et al.*, 2013, Diaz-
216 Balteiro *et al.*, 2013; Masera *et al.*, 2003 and Hoen and Solberg, 1994). Another goal is the
217 usual balance of production, i.e. the minimization of inter-annual fluctuation of the volume of
218 harvested wood. Ideally, each annual harvest should collect the same amount of wood
219 (Bettinger, 2009; Buongiorno and Gilles, 2003; Clutter, 1992). The experts suggested another
220 goal, little considered in the literature but highly relevant for firms, namely the balance of
221 transportation. That is, to minimize the inter-annual fluctuation of the distances covered by a
222 given fleet of (a fixed number of) trucks of the company (Broz, 2015). This allows a
223 reduction in the cost of transportation. Logistic costs affect significantly the competitiveness
224 of the forest sector in Argentina, Brazil and Uruguay. Its losses are mostly attributed to the
225 incidence of logistic costs in the final price of the products (Schwab, 2015; Arvis *et al.*,
226 2014).

227 **4.5. Formulation of the EGP model**

228 As said we have four goals, set by the group of experts: a) the maximization of the net
229 present value (NPV) of future flows; b) the maximization of carbon fixation; c) the
230 minimization of inter-annual variations in production and d) the minimization of the inter-
231 annual variations in the mean transportation length.

232 This problem combines classical aspects of forest management with features of the primary
233 and industrial production, including its economic, logistic and silvicultural aspects as well as
234 its carbon balance. The latter two aspects have, as far as we know, not been analyzed
235 previously in the literature on supply chain management. This integral approach, covering
236 from the stands to the industrial plants, allows the determination of which stands to harvest,
237 when to harvest and where to send the sub-products and, indirectly, in a post-optimization
238 assessment, which roads should be built or reconstructed.

239 With these results at hand, the firm can make sound decisions relating the supply of timber,
240 its transportation and the satisfaction of demands. Furthermore, thanks to the multi-objective
241 approach of the model, other aspects, of economic and environmental nature, can be also
242 addressed.

243 In Table 2 we list all the variables and parameters of the model, which can be seen as a sparse
244 transportation model for a time period (p), in which each stand (i) produces sub-products (k)
245 that have pre-assigned destinations (j). Fig. 3 represents a case for three stands, four sub-
246 products and four destinations. Notice that all the sub-products of a stand must be
247 simultaneously delivered at a given period p (we consider only 18 possible periods).

248 In this example $i = 1$ generates all four sub-products destined to the four industries. Stand $i =$
249 2 does not generate sub-product $k = 4$, and thus does not have to deliver to destination $j = 4$.
250 Finally, $i = 3$ generates sub-products 1 and 2, that can destined to industries 1, 2 and 3.

251 **4.5.1. Goals**

252 As said, the model has four goals, which can be formally presented as follows.

253 *Net present value*

$$\left\{ \sum_{i=1}^I \sum_{k=1}^K \sum_{p=1}^P \left[\frac{pr_{ikp} \times PV_{ikp} - pr_{ikp} \times CCC_{ikp} - CTK \sum_{j=1}^J \frac{vd_{ijkp}}{CC} \times d_{ij}}{(1+r)^p} \right] \right\} + n^{PV} - p^{PV} = g_{PV} \quad (1)$$

The condition given in (1) indicates that the goal is the maximization of the net present value of production. That is, the (discounted) sale of final products minus harvesting and transportation costs. Notice that, as prescribed originally by Simon (1955), what it is actually sought is a close approximation, satisficing a given goal or aspiration level g_{PV} minimizing the deviation n^{PV} . The aspiration level for this goal is fixed by the group of experts.

Carbon balance

$$\sum_{i=1}^I \left\{ \begin{aligned} & \gamma \delta \text{feb}(1+R) \times fd \left[\sum_{k=1}^K (s_i \times vol_{ikp} - s_i \times vol_{ik(p-1)}) \right] - \\ & \gamma \delta \text{feb}(1+F) \times fd \sum_{k=1}^K pr_{ikp} - \gamma \delta \times fd \left[\sum_{j=1}^J \sum_{k=1}^K vd_{ijkp} (1-\eta_j) \right] \end{aligned} \right\} + n_p^{CAR} - p_p^{CAR} = g_{BC} \quad \forall p > 1 \quad (2)$$

The second goal, represented by (2), intends to maximize the capture of carbon in the form of forest biomass, which is obtained from the difference between the forest growth and the losses due to harvesting, evaluated according to the Kyoto Protocol. This is a way of providing incentives for the sequestration of carbon as a way of reducing the emission of greenhouse gases (Manley and Maclaren, 2012). In this case, thus, we seek the closest possible value for n^{CAR} . Notice that we do not incorporate as possible causes of loss events like fire, plagues, and other natural sources, which have a minimal impact in the region on which we want to apply the model. The equations and parameters for this goal were determined according to Briggs (1994) and reports in Penman (2003).

Harvest volume balance

$$\sum_{i=1}^I \sum_{k=1}^K pr_{ikp} - \sum_{i=1}^I \sum_{k=1}^K pr_{ik(p+1)} + n_p^{VOL} - p_p^{VOL} = 0 \quad p=1, \dots, P-1 \quad (3)$$

In (3) we intend to minimize the fluctuation in the harvested amounts from period p to period $p+1$, for all relevant periods. The fluctuations are bounded by the aspiration level and thus we seek to make both n_p^{VOL} and p_p^{VOL} close to zero. The amount of production can reach a steady amount by planting immediately after harvesting, as to compensate the extraction. Here we follow closely Clutter (1992), Diaz-Balteiro and Romero (2003) and Giménez *et al.* (2013).

Transport balance

$$\sum_{i=1}^I \sum_{j=1}^J \sum_{k=1}^K d_{ij} \times \frac{vd_{ijkp}}{CC} - \frac{\sum_{i=1}^I \sum_{j=1}^J \sum_{k=1}^K \sum_{p=1}^P d_{ij} \times \frac{vd_{ijkp}}{CC}}{N_J} + n_p^{DIS} - p_p^{DIS} = 0 \quad \forall p \quad (4)$$

The goal in (4) is the minimization of the inter-annual variation in the distances covered by transportation and thus to balance the annual transportation budget. We thus seek that the distance covered in any period be close to the average transportation length. Here again n_p^{DIS} and p_p^{DIS} must be brought close to zero.

Minimax goals

Combining the goals we obtain the MINMAX (Chebyshev function) of the goal programming model:

$$\left. \begin{aligned} W_1 \left(\frac{n^{PV}}{PV^* - PV_*} \right) &\leq D \\ W_2 \left(\frac{n^{CAR}}{BC^* - BC_*} \right) &\leq D \\ W_3 \left(\frac{\sum_{p=1}^{P-1} \frac{n_p^{VOL} + p_p^{VOL}}{VOL_* - VOL^*}}{\sum_{p=1}^{P-1} \frac{n_p^{VOL} + p_p^{VOL}}{VOL_* - VOL^*}} \right) &\leq D \\ W_4 \left(\frac{\sum_{p=1}^P \frac{n_p^{DIS} + p_p^{DIS}}{DIS_* - DIS^*}}{\sum_{p=1}^P \frac{n_p^{DIS} + p_p^{DIS}}{DIS_* - DIS^*}} \right) &\leq D \end{aligned} \right\} \quad (5)$$

Then, the largest deviation D between the achievement of each goal and its target value is minimized, i.e. we seek to equilibrate the different goals. Here each W_q weights a goal $q=1, \dots, 4$. In our application we determine them in a pair-wise comparison process (Romero,

1991 and Jones and Tamiz, 2010). The information to run this analysis was obtained again from the group of experts, who built a comparisons matrix, evaluating by pairs the criteria, giving relative importance to them. Then, the matrix was normalized, yielding the weights and assessing the consistency: the deviation variables n and p are scaled to the difference between ideal and antideal values and thus becoming pure numbers.

4.5.2. Achievement function

Then, the achievement function subject to constraints and goals can be written as:

$$\text{Min } (1-\lambda)D + \lambda \left[W_1 \left(\frac{n^{PV}}{PV^* - PV_*} \right) + \left[W_2 \left(\frac{n^{CAR}}{BC^* - BC_*} \right) + \left[W_3 \left(\sum_{p=1}^{P-1} \frac{n_p^{VOL} + p_p^{VOL}}{VOL_* - VOL^*} \right) + \left[W_4 \left(\sum_{p=1}^P \frac{n_p^{DIS} + p_p^{DIS}}{DIS_* - DIS^*} \right) \right] \right] \right] \quad (6)$$

Expression (6) is intended to minimize the deviation of all four goals where λ is a control parameter that can take values within the closed interval $[0, 1]$. In this case λ weights the importance of the sum of the measures of the deviations described by (5). Then, if $\lambda=1$ we have a way to satisfy goals (1) to (4) but in an unbalanced fashion. On the other hand, if $\lambda=0$ we get balanced solutions but perhaps not very close to the aspiration levels. For $\lambda \in (0,1)$ we have a compromise between satisficing and balancing the goals. This approach reflects better the preferences of the expert group than any isolated goal.

4.5.3. Constraints

The constraints of the problem are formulated as follows:

$$pr_{ikp} = s_i \times vol_{ikp} \times x_{ip} \quad \forall i; \forall k; \forall p \quad (7)$$

$$\sum_{j=1}^J v d_{ijkp} \times A_{kj} = pr_{ikp} \quad \forall k; \forall i; \forall p \quad (8)$$

In equation (7), $x_{ip} \in \{0,1\}$ gets value 1 only at the period p at which stand i must be harvested. This expression also yields the partial volume of the harvest destined to become

sub-product k . Equation (8) ensures that each sub-product k is sent to a destination j and constraints the delivery of sub-products to the industries as determined by Table 3.

$$\sum_{p=1}^P x_{ip} = 1 \quad \forall i \quad (9)$$

$$x_{ip} + x_{yp} \leq 1 \quad \forall p, y \in \psi_i \quad (10)$$

$$M_i x_{ip} \leq a_{ip} \quad \forall i, \forall p \quad (11)$$

$$\left. \begin{aligned} \sum_{i=1}^I \sum_{k=1}^K v d_{ikp} &\geq D_{jp}^{\min} & \forall p, \forall j \\ \sum_{i=1}^I \sum_{k=1}^K v d_{ikp} &\leq D_{jp}^{\max} & \forall p, \forall j \end{aligned} \right\} \quad (12)$$

$$x_{ip} \in \{0, 1\}, Pr_{ikp} \in \square, v d_{ikp} \in \square \quad (13)$$

Equation (9) ensures that the stands will be harvested once in the planning horizon. Expression (10) indicates that no adjacent stands must be harvested at the same period p . This reflects the so-called *Unit Restriction Model* (URM) which, given the set ψ_i of stands adjacent to i , no $l \in \psi_i$ can be harvested in the same period as i . Constraint (11) establishes a minimal age for a tree to be harvested, according to either technological or economic criterion established by the expert group. This indicates that stand i will be harvested when it has an age a_{ip} in the time interval $[M_i, \dots, P]$. In the case of Misiones the experts indicate that no tree younger than 13 years old should be harvested, because it reaches its full potential with a few more years. Expression (12) establishes conditions on the demands from the industry, determined again by the experts. Finally, expression (13) indicates the types of the variables.

4.6. Analysis of Scenarios

331 Table 4 summarizes the scenarios drawn from the Misiones data, under different
332 combinations of three parameters: the discount rate (r), the weighted preference model (λ)
333 and the preferences for goals (W_q).

334 For each scenario we analyze the behavior both under the balanced goals setting ($\lambda = 0$), the
335 aggregate goals ($\lambda = 1$) and a mixed setting ($\lambda = 0.5$). We also study the outcomes under
336 heterogeneous weights given by the experts ($W_1 \neq \dots \neq W_q \neq 1$) as well as the case in which
337 they are given homogeneous weights ($W_1 = \dots = W_q = 1$). Finally, we studied the typical
338 behavior of the discount rate (r) for the forest sector in Argentina, according with previous
339 results in Broz (2015) and the data drawn from the national statistics reported in INDEC
340 (2013).

341 4.7. Solving the EGP problem

342 The overall model is implemented in GAMS® 24.1.4 with the optimization package CPLEX
343 12.1. The model was run on a PC with an Intel Core i3-2310M, CPU@ 2.10 GHz processor,
344 4 GB of RAM memory and a 64 bits operating system. The input (volume, age, prices, etc.)
345 and output data is summarized in two MS Excel spreadsheets connected through the
346 exchange of GDX (GAMS Data Exchange) files. We obtain different outputs by varying the
347 parameters of the model, yielding alternative harvest programs. The final decision on which
348 plan to implement is made on the basis of the analysis of those alternative scenarios.

349 5. Results

350 This section presents the scenarios under analysis as well as the ensuing results from the
351 Trade-off Matrix and the outcomes of the EGP model.

352 5.1. Trade-offs between ideal and anti-ideal values.

353 The *Trade-off Matrix* (Table 5) presents ideal and anti-ideal values for each of the goals
354 analyzed in this paper. The ideal values are obtained solving the problem just for the
355 corresponding goal. The anti-ideal values arise from the solution of the entire problem just
356 for all the other goals. In bold typeface we represent the ideal values while in italics the anti-
357 ideal ones. The volume control and the transport balance are captured by the sum of
358 deviations, which ideally should be null.

359 An important conclusion can be drawn from these tradeoff matrices: there are conflicts
360 between all criteria involved in each model, i.e. the ideal values of different goals cannot be
361 simultaneously achieved. Therefore, we can conclude that an acceptable harvest schedule
362 depends critically on the weights given by the experts.

363 **5.2. The Extended Goal Programming Approach**

364 Given the importance of trade-offs, we implemented a pair-wise comparison method to find
365 the weights of the different goals in both scenarios. For this, we used Expert Choice[®] version
366 11.1. Table 6 presents the results for 18 scenarios analyzed. The running times ranged
367 between 12.2 and 151.5 seconds.

368 **5.2.1. Example of a scenario**

369 Just to clarify how the results of these exercises must be read, let us consider a particular
370 instance. Here the discount rate (r) is 15%, $\lambda=0$ and $w=1$ (scen1). Here the NPV is USD
371 16,331,298 and the CO₂ balance fell -278,160 tons for the entire period. In average 204,946
372 tons of wood and 627,227 km are, respectively, harvested and covered, per year. Fig. 4
373 presents the yearly levels of provision for all the scenarios. In some cases kinks in the
374 trajectories can be detected, which cannot be avoided to not generate infeasible solutions.

375

5.2.2. The effect of the discount rate

We can see that the discount rate has a significant effect on the PV. As expected, PV has an inverse relation with r : an increase of 15% to 25 and 35% in the discount rate yields a decrease of PV between 60 and 80%, falling from 16 millions for $r=15\%$, to just slightly more than 3 millions for $r=35\%$. Besides, we found that a lower r improves the other goals, the balance of carbon, production and transportation. This is because the ensuing increase in PV closes the gap with g_{pv} , allowing a better distribution among the other goals.

5.2.3. Behavior under the different settings

The average performance of the aggregate ($\lambda = 1$), mixed ($\lambda = 0.5$) and balanced ($\lambda = 0$) settings shows that the mixed one yields a PV (USD 8,709,923) that is up to 3.6% larger than in the balanced one and a 1.3% larger than the aggregate case. Even if in all the scenarios carbon balance is negative, in the aggregate setting it improved over the other two cases: an average of -250,961 t, a 5.6 and a 10.3% better than the mixed and the balanced setting, respectively. The balanced setting, in turn, lead to a slightly larger mean annual production (204,898 t/year), up to a 1.3% over the two others but with a larger deviation. The aggregate setting lead to a more homogeneous production, with a standard deviation and variation coefficient up to 19.5% and 18.1% less than the other settings, respectively. It also yields a lower transportation length (615,821 km/year), 2.6% less than the balanced setting and 0.3% less than the mixed one. The standard deviation and the variation coefficient is, in the aggregate setting, lower in 68.6 and 64.2%, respectively, than in the balanced one, while the corresponding differences are not larger than 1.8% with the mixed setting.

5.2.4. The effect of the weights

Analyzing the weights of the different goals (w), we can see that there are not significant differences among the results in the cases of inhomogeneous ($w \neq 1$) and homogeneous ($w=1$)

400 weights with respect to PV, carbon sequestering, mean production, transportation length and
401 total production. Nevertheless, inhomogeneous weights increase up to a 16.2% the balance of
402 production, and a 30.0% the balance of transportation.

403 **5.2.5. The Joint effect of settings and preferences**

404 The homogeneous mixed setting ($\lambda=0.5$ and $w=1$) yields a PV (USD 8,736,615), up to 3.9%
405 larger than the other cases, being the balanced ones the worst no matter the weights. In all
406 scenarios, the aggregate approach with homogeneous preferences ($\lambda=1$ and $w=1$) leads to the
407 best carbon balance (-249,515 t), in average 11.4% superior to the other combinations. For
408 forest production, the balanced setting with homogeneous preferences ($\lambda=0$ and $w=1$) was
409 slightly better in a 1.5%, with a mean production of 204,893 t/year. Nevertheless, the
410 aggregate setting with homogeneous preferences ($\lambda=1$ and $w=1$) balanced production better,
411 since its standard deviation and the variation coefficient are 10.0 and 36.9%, respectively,
412 lower than in the other cases. The case of $\lambda=1$ and $w \neq 1$ yields the lowest mean transportation
413 distance (612,228 km/year) while in the case of $\lambda=0.5$ and $w=1$ we have a large reduction of
414 variation, 59.6% less than in the other cases. For this goal, as said, the worst cases were those
415 of $\lambda=0$ followed by the mixed setting with inhomogeneous weights ($\lambda=0.5$ and $w \neq 1$).
416 Production, in the $\lambda=0$ and $w \neq 1$ case was 1.5% larger than in the other cases, with a mean
417 amount of 3,688,247 t.

418 Tables 7 and 8 summarize the behavior of forest production and transportation length,
419 respectively, along the planning horizon, depending on the settings and the weights given by
420 the experts. The lowest variation is obtained with the aggregate setting (43.4%), followed by
421 the balanced and the mixed one, the latter departing up to 11.1% from the mean production.
422 Inhomogeneous weights lead to an accumulated variation of 65.5%, while with
423 homogeneities rises to 71.9%, up to a 9.8% over the mean. The aggregate setting with
424 homogeneous preferences leads to the lowest accumulated deviation (42.4%). It is followed

425 by the mixed setting, also with homogeneous weights, which yields a deviation of 72.5%. In
426 these latter cases, the extreme cases do not depart more than 6.3% from the mean value. The
427 balanced setting, instead, leads to an accumulated deviation of 69.8%, with extreme
428 variations of up 12.2%.

429 Table 8 shows that the accumulated variations in transportation length are 69.4, 76.1% and
430 135.5%, in the aggregate, mixed and balanced setting, respectively. The latter case even
431 yields a period with a 20% variation with respect to the mean length. Homogeneous
432 preferences led to a lower variation of 77.8% as well as lower extreme annual variations. The
433 combination of mixed setting and homogeneous weights yields the lowest accumulated
434 variation (59.6%), followed by the aggregate setting also with homogeneous preferences
435 (66.7%). The extreme variations in these cases are lower than 11.4%. The worst performance
436 is that of the balanced setting with both inhomogeneous and homogeneous preferences,
437 yielding accumulated variations of 163.7 and 140.2% respectively. The corresponding
438 extreme cases were 17.3 and 22.9% with respect to the mean length.

439 With a scale of (increasing) shades of gray we show in both tables cases of variations of 5, 10
440 and 20% with respect to the mean. We can see that forest production (Table 7) is significantly
441 stable, since 77% of the annual variations are below 5%, while 21% of those values are in the
442 range 5-10% and only a 2% has a variation over 10%. The mean length of transportation
443 (Table 8) instead, shows more dispersion, with a 61% of the cases under 5%, a 25% between
444 5 and 10%, a 13% between 10 and 20% and 2% larger than 20%. The more extreme cases are
445 more frequent at the start and the end of the planning horizon. Both tables also show that the
446 largest variations are obtained in the balanced setting.

447 6. Discussion

448 The resulting program covers at least one forest rotation, discarding the potential of settling
449 on suboptimal solutions. We ran the model on information provided by the largest forest-
450 industrial compound in northeastern Argentina.

451 Among the main findings of this paper we have to mention the negative impact of
452 emphasizing the maximization of the present value over the achievement of the other goals.
453 In particular, in agreement with the results in Silva *et al.* (2010) and Diaz- Balteiro *et al.*
454 (2014), carbon balance can be achieved only at the price of a lower present value. This shows
455 that single-objective optimization may lead to a poor satisfaction of other potential goals
456 yielding a rigid and unsatisfactory model (Buongiorno and Gilles, 2003).

457 We also found that the discount rate has a strong impact on the present value of the system
458 while the balance of carbon is negative in all scenarios, with a deficit over 14,000 t per year.
459 Furthermore, the rather uncommon characteristics of the Argentinean economy make the
460 discount rate the most sensitive parameter of the model, determining the main features of the
461 supply chain. Future work involves, instead, using a stochastic model in which the effects of
462 an erroneous assessment of the discount rate in a volatile economy are less detrimental for the
463 firms in the sector.

464 On the other hand, comparing different scenarios we see that aggregate settings have the best
465 performances while mixed settings have the worst behavior. That is, the focus on just the
466 specific goals, instead on adding their balance as an extra objective yields better results. In
467 turn, homogeneous preferences had a slightly better performance but inhomogeneous ones
468 contributed more to reducing fluctuations in forest production and the length of inter-annual
469 transportation. The combination of a mixed setting with homogeneous preferences gave the
470 best performances. That is, it seems that the setting is much more relevant than the
471 information on the weights of the goals, provided by the experts. Furthermore, this latter

information seems to add rather little to the optimum, since equally weighted goals seem to yield better results than diversified weights, except than for balancing each of the goals.

7. Conclusions

We can conclude that the EGP approach yields valuable solutions to the planning problem of an integrated firm in the forest industry when several (somewhat conflicting) goals are postulated. This method achieves an equilibrium between the different objectives, which becomes advantageous for a firm that has to balance so many and different components of its production activities.

We found that NPV runs contrary the other goals. Its maximization worsens the others. This indicates that our multi-objective approach is better than single-objective ones, since it allows to avoid unintended consequences in other aspects of the activity of the firm.

The consideration of several products and processing units allows forces the incorporation of logistic goals, in particular the need to balance transportation and thus the resources devoted to the fleet of trucks of the company.

On the other hand, the economic and logistic goals impose environmentally negative solutions. In each scenario carbon balance is negative, indicating the release of an amount of greenhouse gases that is not compensated by sequestration.

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Fig. 1: Flowchart of the framework of analysis.

Fig. 2: An instance of the forest system constituted by a group of stands, an industrial complex and roads connecting the components.

Fig. 3: Assignment rule at a given period p .

Fig. 4: Evolution of supply levels by industry (Scen 1).

Table 1: Log bucking parameters.

Products	Min LD	Max LD	LongMin	LongMax
Veneer log	30	99	1.75	2.25
Sawlog - large diameter-	25	30	2.4	2.4
Sawlog -small diameter-	18	25	2.4	2.4
Pulpwood	8	18	2.6	2.6

LD: log diameter [in centimeters]. LongMin: minimum length of log [in meters]. LongMax: maximum length of log [in meters].

Table 2: indexes, variables and parameters of the model.

Indexes	
i	Stands, $i = 1, \dots, I$.
j	Destinations, $j = 1, \dots, J$.
k	Products, $k = 1, \dots, K$.
p	Years, $p = 1, \dots, P$.
q	Goals, $q = 1, \dots, Q$.
Variable	
x_{ip}	Binary variable: 1 if stand i is harvested (and replanted) at period p ; 0 otherwise
pr_{ikp}	Amount of product k obtained from stand i at period p [t].
vd_{ijkp}	Amount of product k from stand i destined to industry j at p [t].
D	Maximal admissible deviation from the goals.
n^q	Negative deviation down from the optimal level when the goal q is to be maximized.
p^q	Positive deviation up from the optimal level when the goal q is to be minimized.
Parameters	
vol_{ikp}	Amount of product k from stand i at period p [t/ha], determined from the simulation.
γ	Carbon/biomass conversion rate [t per cubic meters (m^3)].
δ	Basic density.
feb	Biomass expansion factor, from tree to final product.
R	Root to tip relation between diameters.
F	Fraction of biomass that is left in the forest for decomposition.
fd	Dimensional factor [m^3/t].
η_j	Yield at destination j .
d_{ij}	Distance from stand i to destination j [in kilometers].
N_J	Length of the planning horizon.
s_i	Surface of stand i [in hectares].
M_i	Minimum harvest age of stand i [in years].
a_{ip}	Age of stand i at period p [in years].
r	Discount rate, yielding the present value of future yields adjusted by

	risk.
PV_{ikp}	Market price of product k from stand i at period p [\$/t].
CTK	Average transportation cost, assuming 80% on asphalt roads and 20% on dirt roads [\$/km].
CCC_{ikp}	Cost of elaborating and loading product k of stand i at p [\$/t].
CC	Load capacity of a truck [30 t].
D_{jp}^{min}	Minimal demand of industry j at period p [t/year].
D_{jp}^{max}	Maximal demand of industry j at p [t/year].
λ	Weight of the sum of deviation variables.
PV	Present value [\$/t]. PV^* is the ideal level; PV_* is the anti-ideal.
BC	Carbon balance [t]. BC^* is the ideal; BC_* the anti-ideal.
VOL	Volume control [t]. VOL^* is the ideal; VOL_* is the anti-ideal.
DIS	Equilibrium distance of inter-annual transport [km]. DIS^* is the ideal; DIS_* is the anti-ideal.
W_q	Weight of goal q .
g_q	Aspiration level of goal q .
A_{jk}	Binary: 1 if product k is sent to the destination j ; 0 otherwise.

Table 3. Sub-product destination rule. (×) indicates that sub-product k is destined to j .

Destinations	Products			
	Pulp logs	Fine sawn logs	Thick sawn logs	Veneer logs
	$k1$	$k2$	$k3$	$k4$
Pulp mill	$j1$	(×)		
MDF factory	$j2$	(×)		
Sawmill	$j3$	(×)	(×)	
Plywood mill	$j4$			(×)

Table 4: 18 scenarios analyzed.

EGP approach (λ) and goal weight (w)	Discount rate (r)	Scenario
$\lambda=0$ and $w1=w2=w3=w4=1$	15%	scen1
$\lambda=0$ and $w1=0.166$; $w2=0.151$; $w3=0.621$; $w4=0.062$	15%	scen2
$\lambda=0.5$ and $w1=w2=w3=w4=1$	15%	scen3
$\lambda=0.5$ and $w1=0.166$; $w2=0.151$; $w3=0.621$; $w4=0.062$	15%	scen4
$\lambda=1$ and $w1=w2=w3=w4=1$	15%	scen5
$\lambda=1$ and $w1=0.166$; $w2=0.151$; $w3=0.621$; $w4=0.062$	15%	scen6
$\lambda=0$ and $w1=w2=w3=w4=1$	25%	scen7
$\lambda=0$ and $w1=0.166$; $w2=0.151$; $w3=0.621$; $w4=0.062$	25%	scen8
$\lambda=0.5$ and $w1=w2=w3=w4=1$	25%	scen9
$\lambda=0.5$ and $w1=0.166$; $w2=0.151$; $w3=0.621$; $w4=0.062$	25%	scen10
$\lambda=1$ and $w1=w2=w3=w4=1$	25%	scen11
$\lambda=1$ and $w1=0.166$; $w2=0.151$; $w3=0.621$; $w4=0.062$	25%	scen12
$\lambda=0$ and $w1=w2=w3=w4=1$	35%	scen13
$\lambda=0$ and $w1=0.166$; $w2=0.151$; $w3=0.621$; $w4=0.062$	35%	scen14
$\lambda=0.5$ and $w1=w2=w3=w4=1$	35%	scen15
$\lambda=0.5$ and $w1=0.166$; $w2=0.151$; $w3=0.621$; $w4=0.062$	35%	scen16
$\lambda=1$ and $w1=w2=w3=w4=1$	35%	scen17

$\lambda=1$ and $w1=0.166$; $w2=0.151$; $w3=0.621$; $w4=0.062$ 35% scen18

Table 5: Trade-off Matrix for four goals with discount rate of 25%.

	Max. PV [USD]	CO ₂ balance [t]	Volume control [t]	Transport balance [km]
Max. PV	6,968,698	-318,866	273,659	1,863,610
CO ₂ balance	5,844,569	-131,047	54,584	905,912
Volume control	6,557,085	-302,008	11,053	859,338
Transport balance	6,508,283	-310,380	52,581	29,211

Table 6: EGP results for 18 supply chain scenarios analyzed.

Scenario	PV	Carbon	Balance of forest production			Balance of forest transportation			TFH	CPU
			A-F	SD-F	CV-F	A-T	SD-T	CV-T		
scen1	16,331,299	-278,160	204,946	17,172	8.38%	627,227	88,373	14.09%	3,689,031	36.0
scen2	16,070,897	-276,062	204,526	13,032	6.37%	628,247	90,122	14.34%	3,681,460	17.5
scen3	16,257,451	-246,260	200,989	10,743	5.35%	619,883	32,538	5.25%	3,617,804	151.5
scen4	16,265,801	-257,549	202,569	12,482	6.16%	615,998	55,078	8.94%	3,646,247	18.7
scen5	15,858,316	-236,515	199,581	9,877	4.95%	616,329	39,488	6.41%	3,592,455	38.2
scen6	16,011,428	-243,361	200,875	12,036	5.99%	606,070	56,054	9.25%	3,615,744	12.2
scen7	5,911,752	-264,334	202,997	14,498	7.14%	627,621	79,255	12.63%	3,653,942	26.4
scen8	6,089,906	-263,666	204,093	15,645	7.67%	629,828	81,829	12.99%	3,673,669	25.9
scen9	6,624,871	-268,819	204,097	13,681	6.70%	624,790	36,487	5.84%	3,673,744	26.2
scen10	6,534,475	-280,492	206,137	24,212	11.75%	609,977	90,571	14.85%	3,710,475	22.4
scen11	6,602,265	-256,026	202,488	12,549	6.20%	618,503	41,469	6.70%	3,644,793	37.8
scen12	6,556,248	-256,067	203,598	14,115	6.93%	616,575	52,139	8.46%	3,664,767	30.5
scen13	2,946,326	-291,551	206,735	15,178	7.34%	641,138	87,761	13.69%	3,721,234	36.7
scen14	3,030,932	-286,399	206,090	19,631	9.53%	636,387	94,510	14.85%	3,709,613	27.5
scen15	3,327,523	-271,738	204,678	14,940	7.30%	619,072	52,579	8.49%	3,684,211	21.2
scen16	3,249,418	-264,847	203,782	11,871	5.83%	614,892	47,928	7.79%	3,668,067	37.2
scen17	3,305,571	-256,005	203,445	12,869	6.33%	623,406	43,141	6.92%	3,662,012	30.5
scen18	3,227,959	-257,792	203,888	18,154	8.90%	614,040	77,179	12.57%	3,669,982	18.2

PV: present value (USD); Carbon: CO₂ balance (t); A-F: average annual forest production (t/year); SD-F: Standard deviation of forest production (t); CV-F: Coefficient of variation of forest production (%); A-T: average transport distance (km/year); SD-T: Standard deviation of transport (km/year); CV-T: Coefficient of variation of transportation (%); TFH: total forest harvesting production (t); CPU: process time (seg).

Table 7: Behavior (%) of production levels with respect to the mean.

	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11	p12	p13	p14	p15	p16	p17	p18	Σ Cum.
$\lambda=0$	4.3	7.4	-1.1	1.0	-4.1	-1.1	-9.1	0.9	4.6	1.1	-0.1	7.3	-2.0	-1.6	-4.6	4.7	2.4	-10.3	67.8
$\lambda=0.5$	7.7	1.0	3.1	-5.3	-5.5	-0.7	-1.5	-3.3	3.7	11.1	2.4	-1.5	5.6	-1.5	-4.3	0.1	-2.4	-8.9	69.7
$\lambda=1$	5.2	1.9	2.1	2.9	-4.9	0.5	-4.0	0.0	4.9	0.9	-1.7	-0.7	2.3	1.0	-3.1	-0.4	-6.9	43.4	
$w=1$	4.7	1.8	1.5	-3.2	-4.0	1.9	-3.4	1.4	4.8	-3.1	1.9	-3.7	0.1	9.8	-5.5	8.1	-5.2	-7.9	71.9
$w\neq 1$	9.3	1.0	-0.3	0.8	6.4	1.0	-1.3	8.1	0.9	0.0	-2.7	0.7	4.5	-4.1	-6.3	-5.1	-6.7	-6.2	65.5
$\lambda=0$ and $w=1$	12.2	4.7	0.0	-0.9	-5.5	2.4	-3.9	-0.2	0.5	4.7	1.3	-0.1	3.6	5.3	-8.2	-1.4	-5.6	-9.1	69.8
$\lambda=0$ and $w\neq 1$	6.0	4.2	1.0	-2.2	-4.8	-0.9	-5.3	-1.2	4.2	6.1	1.2	2.9	1.8	-1.5	-4.4	2.4	0.0	-9.6	59.8
$\lambda=0.5$ and $w=1$	5.0	1.9	1.8	-0.1	-4.4	1.2	-3.7	0.7	2.4	0.9	1.4	-2.7	-0.3	6.1	-2.3	2.5	-2.8	-7.4	47.5
$\lambda=0.5$ and $w\neq 1$	10.8	2.9	-0.1	0.0	0.5	1.7	-2.6	3.9	0.7	2.3	-0.7	0.3	4.1	0.6	-7.3	-3.3	-6.2	-7.6	55.7
$\lambda=1$ and $w=1$	6.3	3.5	0.2	1.6	-0.9	0.1	-4.8	3.0	1.8	2.0	-0.6	2.1	0.6	-1.1	-3.3	-1.1	-1.5	-7.8	42.4
$\lambda=1$ and $w\neq 1$	8.2	2.5	1.5	-3.1	-5.0	1.2	-2.9	-0.7	3.0	4.3	1.9	-1.8	3.1	4.5	-6.0	2.3	-4.4	-8.6	65.1

Table 8: Behavior (%) of the average transport distance with respect to the mean.

	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11	p12	p13	p14	p15	p16	p17	p18	Σ Cum.
$\lambda=0$	14.4	17.1	15.0	2.9	-1.3	4.6	-1.0	-1.4	4.1	9.2	0.4	-0.2	-0.9	-9.4	-14.0	-9.4	-10.0	-20.1	135.5
$\lambda=0.5$	8.4	6.6	7.1	0.8	0.4	3.3	-1.5	-6.2	3.6	-1.6	0.6	-7.4	-2.3	4.8	-5.6	2.4	-9.1	-4.4	76.1
$\lambda=1$	13.6	8.6	5.5	0.8	0.3	1.3	-1.7	-1.3	0.6	4.0	-1.3	-1.5	-2.0	-0.4	-3.2	-7.3	-4.6	-11.5	69.4
$w=1$	10.5	10.4	8.0	2.0	1.0	1.4	-0.9	-0.5	3.2	2.3	-0.2	-0.9	-3.4	-4.0	-6.6	-6.4	-4.9	-11.1	77.8
$w\neq 1$	13.8	11.3	10.4	1.0	-1.4	4.7	-1.8	-5.4	2.3	5.6	0.0	-5.2	-0.1	0.6	-8.8	-3.3	-10.9	-12.9	99.6
$\lambda=0$ and $w=1$	12.4	22.0	13.2	3.8	0.6	2.6	-3.5	3.2	6.0	0.4	0.8	5.1	-7.9	-7.4	-12.3	-9.5	-6.7	-22.9	140.2
$\lambda=0$ and $w\neq 1$	16.4	12.3	16.7	2.0	-3.1	6.6	1.4	-6.0	2.1	18.1	0.1	-5.6	6.1	-11.3	-15.7	-9.4	-13.3	-17.3	163.7

$\lambda=0.5$ and $w=1$	7.8	4.2	6.3	2.6	-1.4	1.3	-0.9	-3.4	1.1	2.8	-1.7	-7.0	0.7	1.2	-5.0	1.8	-8.3	-2.0	59.6
$\lambda=0.5$ and $w\neq 1$	9.1	9.0	8.0	-1.1	2.1	5.4	-2.0	-8.9	6.1	-6.0	3.0	-7.8	-5.3	8.5	-6.3	2.9	-10.0	-6.7	108.3
$\lambda=1$ and $w=1$	11.3	4.8	4.5	-0.5	3.7	0.5	1.6	-1.2	2.5	3.8	0.4	-0.8	-2.9	-5.8	-2.4	-11.4	0.2	-8.3	66.7
$\lambda=1$ and $w\neq 1$	15.9	12.5	6.4	2.1	-3.1	2.2	-5.0	-1.3	-1.3	4.1	-3.0	-2.2	-1.1	5.0	-4.1	-3.0	-9.4	-14.7	96.5

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