TOWARDS INTERGENERATIONAL EQUITY IN LP BASED LONG TERM FOREST PLANNING MODELS

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ABSTRACT.—Standard linear programming (LP) formulations of forest planning problems are not explicit enough in their treatment of time to address intergenerational equity (IE) concerns. A modified model, which includes present net worth (PNW) accounting rows from the perspective of future planners, is presented. These accounting rows are used to evaluate solutions from each planner's perspective. When these PNWs are used in a MAXMIN formulation, the model solution represents a form of intergenerational Rawlsian equity between planners, where the minimum PNW outcome is maximized.

INTRODUCTION

Intergenerational equity (IE) is a simple notion. Any one generation does not want to leave a future generation relatively worse off. IE requires a human concern for the future of the young or yet-to-be born human beings that will populate the planet. However, it is one thing to accept IE as a relevant goal for society and something else entirely to actually do something about it. The difficulty lies in defining what constitutes equity between generations, and, just as importantly, what this definition implies for the current generation. Forestry as a profession has been and continues to be concerned with future generations. This concern is evidenced by such concepts as long-term sustained yield (LTSY), and by such tools as long-term forest planning models. In this paper we argue that while linear programming (LP)-based long-term forest planning models include a time dimension and long-term timber supply constraints, the models do not explicitly address IE. The case for this claim is made in the first part of the paper, which includes interpretations of IE. The body of the paper investigates an initial approach for explicitly including IE in forest planning models. This initial approach is based on modifications of a traditional forest planning model formulation. We took this approach to answer the question of how to move from existing forest planning models towards models that can better address notions of IE. The intent at this time is not to re-define the problem, but to move current approaches in a meaningful direction with respect to IE.

INTERPRETATIONS OF EQUITY AND INTERGENERATIONAL EQUITY

Equity addresses relative distribution. Within the current generation, equity involves the relative distribution of resources, rights, and wealth amongst people (Young 1992). The neoclassical economic approaches to within generation equity focus on Pareto optimality. The intent is to find an aggregation of individual utilities that represent social welfare while avoiding interpersonal comparison of welfare. Since no such aggregation has been developed outside a perfect market, neoclassical economics continues to rely on the Pareto optimality concept, using the compensation principle (Young 1992). Pareto optimality describes an allocation of resources such that no other allocation would make at least one person better off and no one else worse off. When evaluating changes in allocation (e.g., public projects), one cannot determine if the reallocation is a Pareto improvement without evaluating the distributional changes and effects on individual utility (Scitovsky 1941). The compensation principle is an extension of Pareto optimality that attempts to avoid the difficulty with individual utility comparison by defining a potential Pareto improvement. Decisions or reallocations are a potential Pareto improvement if the gainers could compensate the losers such that no one is worse off (Kaldor 1939). Decisions are allowed under this criterion even if no compensation is required (Young 1992). By attempting to avoid distributional issues and individual utility comparisons, the potential Pareto improvement criterion fails to address equity. Mathematical

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decision models based on marginal analysis implicitly rely on the potential Pareto improvement criterion. When used for public planning, these models also fail to explicitly address distributional issues and within generation equity.

Addressing within generation equity requires qualitative interpersonal comparison of utility or preference. Rawls (1971) proposed a standard for equity based on people collectively allocating resources prior to knowing what share they would receive. The application of this standard results in the raising of the worse-off allocation to some minimum level. Intergenerational, or between generation, equity adds the dimension of time to equity consideration. IE addresses issues of equity between people from different time periods. The addition of time greatly influences equity and what it constitutes. The Rawlsian standard becomes more difficult to apply because future generations cannot sit at the current allocation table. The Rawlsian standard has been interpreted to mean leaving the next generation the same total level of conditionally renewable resource stocks. The limitation of this standard is that it requires assumptions about future generations' preferences for resources, which are most often assumed to be the same as the current generation's preference. We believe that IE is best addressed by evaluating options passed to the next generation, so that they can use the options to solve their own problems. This approach follows Brown-Weiss (1990), who examined IE from a policy-making perspective. She proposed a criterion of value independence between generations. A policy principle should not require one generation to predict the preferences of other generations. This criterion leads directly to one of her policy principles, the conservation of options. In this principle, each generation should conserve the diversity of the resource base so as to provide the flexibility to future generations to solve their own problems and make their own decisions. Under this approach IE addresses the relative distribution of options between generations. The issue of predicting preferences is avoided because one could evaluate decisions on the cardinality of options passed on, rather than on the value of the options. The problem becomes defining what constitutes an option.

Naturally, the definition of options is where things become complicated. For example, in forest planning models, how do we define the set of options to use in evaluating equity? In this paper we will leave the question of options unaddressed. Instead we will consider how to modify current planning models to include a Rawlsian standard. The modifications entail a more explicit consideration of time in forest planning models. The approach will still rely on the assumption that future generations will retain our preference ordering. We will use existing variables of the model as criteria for considering Rawlsian equity.

LP-BASED FOREST PLANNING MODELS AND TIME

The occurrence of future economic events is typically handled by discounting (Young 1992). All future values are discounted to present-day values using a given interest rate. However, discounting can discriminate against the interests of future generations by emphasizing the value of present day activities over those that may occur in the future (Young 1992). Discounting reduces time to a common denominator, rather than explicitly considering different time periods. Norgaard (1991) argues that it is inappropriate to use discounting to allocate resources through time. Discounting should be used to evaluate the efficiency of capital, and IE allocation should be addressed through explicit assignments of resource rights through time.

Since the mid-1970's, the USDA Forest Service has been required to include some form of efficiency analysis in forest planning. LP models have been prevalent, starting with FORPLAN Version 1 and continuing to the latest LP model generator, Spectrum (USDA Forest Service 1997). These models are used to optimize land allocation and schedule the occurrence of activities and outputs over time (USDA Forest Service 1997). The models use discrete time periods to represent the passage of time, and decision variables are indexed by the period in which they occur. Discounting of future costs and returns is common in such models, and the models often maximize present net worth (PNW). The needs of future generations are commonly addressed through harvest flow and LTSY constraints. These constraints can be viewed as the assignment of resource rights to future periods. Each period has the right to the same level of timber harvest, and no period may harvest more than the long-term sustainable level.

While these LP-based forest planning models include notions of equity between time periods, they are solved from the perspective of the current planner, and use discounting as a tool for allocating over time. The perspectives of

future planners are not explicitly included in the formulations. The models are solved as closed loop systems, with a focus on the current time period over future periods. Although we assign the rights to the same harvest level to future periods, we allow the current planner to optimize the allocation from the current generation's utility (i.e., maximizing PNW). A more explicit consideration of the future planner's perspective would better address IE concerns in forest planning models. The allocation of harvest rights over time should be based on the perspectives of future planners, as well as the current planner's perspective. This notion is the basis for our approaches to modeling the forest planning problem.

APPROACHES TO MODELING

Three approaches to modeling were used to generate outcomes for comparison. All approaches included the addition of accounting rows that represented the perspective of future planners. In a standard formulation, a planner would maximize the PNW of a schedule of activities over time, with the current (first) planning period viewed as time zero. Likewise, planners in subsequent periods would also be expected to do the same thing. From their perspective, their period would be the current period and activities from earlier periods would not count towards their PNW. Accounting rows were added to a standard 20-period forest planning model formulation to calculate the PNW from the perspective of the first 10 period planners. PNW was calculated for the activities of ten periods, starting with the period viewed as current by each planner. For example, the accounting row for the planner in period 1 would calculate the PNW of activities from periods 1 through 10. The row for the planner in period 2 would calculate the PNW of activities from periods 2 through 11, with all values discounted as though period 2 were period 1.

Each of the three approaches used different objective functions to vary the perspective from which the model was solved. The first approach (MAXPNW) followed the standard approach of maximizing PNW over the 20 periods of the planning horizon from the first period planner perspective. The accounting rows represent the solution's PNW from the perspective of the first ten planners, if they followed the solutions schedule of activities. Next, the PNW from each planner's perspective was maximized. These outcomes represented the maximum outcome for each planner, if they controlled all activities, both past and present. These 10 model runs constituted the second approach to modeling (MAXPLANNER). The third approach to modeling (MAXMIN) used a modified maxmin formulation, which maximized the minimum PNW for the set of planners. From an equity viewpoint, the third approach represents a form of Rawlsian equity between planners, in which the worst outcome for the set of ten planners is raised. Each planners' PNW was also included in the objective function to allow individual planner's PNW to exceed the minimum. Weighting ensured that the minimum PNW was maximized first. The formulation was:

Maximize:

(1) $$100\ PNWMIN + \sum_{i=1}^{10} PNWPLANNER_i$$

Subject to:

(2) $$PNWPLANNER_i - PNWMIN \geq 0;\ \forall i,\ i = 1, \cdots, 10$$

(3) $$PNWPLANNER_i = \sum_{t=i}^{i+9} \left(Revenue - Cost\right)_t / \left(1 + r\right)^{10(t-i)+5};\ \forall i,\ i = 1, \cdots, 10$$

Where: $PNWMIN$ = the minimum of the present net worths from each planner's perspective; $PNWPLANNER_i$ = the present net worths from each planner's perspective; and r = the discount rate.

It should be noted that a true approach to maximizing the minimum would be an iterative process, with an objective function that just maximized the minimum PNW. Following each run, the minimum PNW from the run would be used as an absolute constraint for those planners whose PNW was at the minimum. The model would then be solved again, in order to raise the minimum PNW for the remaining planners. This process would continue until the minimum PNW could no longer be raised. We used the above formulation so that only one model run would be required, allowing such a change to be easily incorporated into current models.

The three approaches were run on three sets of initial conditions. Initial conditions were varied because they affect what the current generation can leave to future generations. Given the focus of this approach on the PNW from each planner's perspective, we used these PNW as the criteria for evaluating the equity of the three approaches. These criteria do not address the notion of options, and therefore do not fully address IE concerns. However, these criteria are easily developed and are relevant when comparing standard formulations of the forest planning problem to other formulations.

THE BASIC MODEL

In developing the model for this evaluation, we chose to create a simple hypothetical model for ease in applying the approaches outlined above, and especially in varying the initial conditions. The LP model was created using the SARA (Spreadsheet Assisted Resource Analysis) system (Scott 1991). An Australian forest example was chosen for variety. The timber yield information, based on a clear-felling system, was obtained from West and Mattay (1993), and the economic information from McKenney (1990). The single tree species used was *Eucalyptus regnans (F.Muell)*, or Mountain Ash. The model had 20 10-year periods. The land types were 14 age classes of Mountain Ash, from 0-10 years old through 130+ years old. Harvesting was not an option for age classes less than 50-60 years old. The primary output of the model was sawlog volume, which had yields by age class and revenue specified per unit volume. A fixed cost per hectare harvested was employed. The model included a nondeclining yield constraint for sawlog volume, along with a constraint that the final period sawlog volume must be less than or equal to LTSY. Ten accounting rows were included in the model, to represent the PNW of 10 periods of activities, from the perspective of the first 10 planners. In addition, an accounting row for the PNW of all activities over the 20 periods, from the first planner's perspective, was included. Twelve runs of the model were required for each set of initial conditions, one to maximize the PNW over all 20 periods, ten to maximize each planner's PNW, and one for the MAXMIN formulation. The initial hectares in each age class were varied to model 3 initial conditions, EVEN, YOUNG, and OLD, each with a total of 14,000 hectares. These conditions are presented in Table 1.

Table 1.—Initial conditions, in hectares, by age class

Condition	Age Class													
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110	110-120	120-130	130+
EVEN	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
YOUNG	1867	1733	1600	1467	1333	1200	1067	933	800	667	533	400	267	133
OLD	133	267	400	533	667	800	933	1067	1200	1333	1467	1600	1733	1867

The EVEN initial condition represented a balanced forest structure with equal areas in all 14 age classes. The YOUNG and OLD initial conditions represented skewed forest structures with the majority of hectares at either end of the age class distribution.

MODELING RESULTS

The MAXPLANNER approach resulted in PNW's for each planner that were roughly equal to the first period planner's PNW. All planners could obtain a PNW comparable to the first period planner's PNW if they could control the allocation. Future planners restricted harvest in earlier periods to enable them to maximize PNW from their perspective. Results from this approach are not presented in detail. The remaining results refer to the MAXPNW and MAXMIN approaches. The sawlog volume harvested per period showed little variation by approach or by initial condition. In the MAXPNW approach, volume harvested was at the maximum allowed by

the LTSY constraint in every period, for all the initial conditions. For the MAXMIN approach, virtually all periods were at the maximum allowed, those that were not were at 98 percent or higher of the maximum.

The PNW's from each planner's perspective for the MAXPNW and MAXMIN approaches are presented in Figures 1, 2, and 3 for each of the initial conditions. The MAXPNW approach represents the standard approach of maximizing the PNW over the planning horizon. For all three initial conditions, this approach led to the first period planner receiving the highest PNW, with subsequent planners receiving a lower PNW. The EVEN (Fig. 1) and OLD (Fig. 2) initial conditions exhibited a declining PNW for all subsequent planners. This decline in PNW occurred even though harvest volume was non-declining. In the YOUNG (Fig. 3) initial condition, PNW declined rapidly for the first six planners and then rose for the last four, although not to the level obtained by the first period planner. The PNW's from the MAXMIN approach showed a more uniform distribution than the MAXPNW approach. For all three initial conditions, the PNW's for early period planners are lowered to allow the raising of the later period planner's PNW. Under the EVEN initial conditions (Fig. 1), the first eight planners PNW's are lowered to benefit the last two planners, with the greatest decrease occurring in period one. In the OLD initial condition (Fig. 2) the PNW's of the first nine planners are lowered to benefit the tenth planner, resulting in an even-flow pattern of PNW. In the YOUNG initial condition, the first three planners' PNW is lowered for the benefit of planners four through seven.

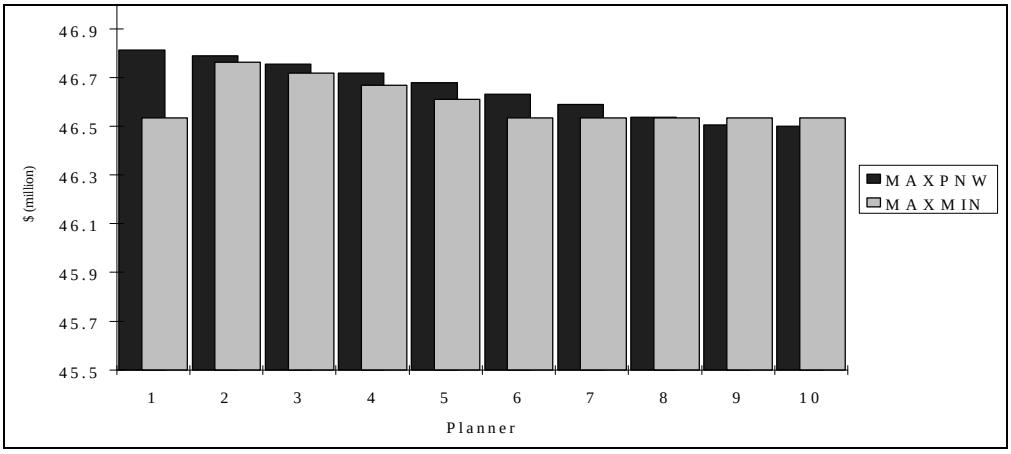

Figure 1.—Comparison of PNW by Planner—EVEN Initial Condition

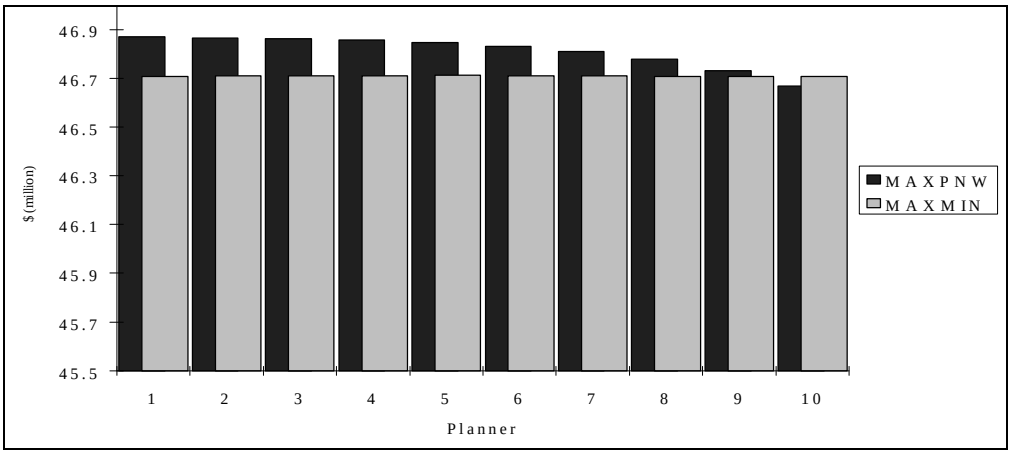

Figure 2.—Comparison of PNW by Planner—OLD Initial Condition

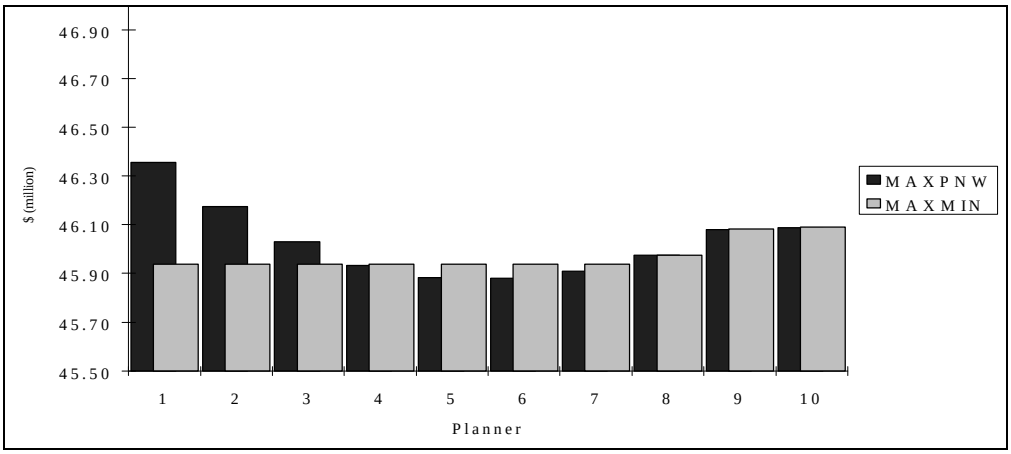

Figure 3.—Comparison of PNW by Planner—YOUNG Initial Condition

The hectares harvested by period for the MAXPNW and MAXMIN approaches are presented in Figures 4, 5, and 6. The hectares harvested do not vary by approach for the first five periods for the EVEN initial condition (Fig. 4), for the first seven periods for the OLD initial condition (Fig. 5), and for the first two periods for the YOUNG initial condition (Fig. 6). All three initial conditions exhibit a similar pattern in regard to the first peak in amount of hectares harvested. The MAXMIN approach shifts the first peak in hectares harvested to earlier periods, relative to the MAXPNW approach.

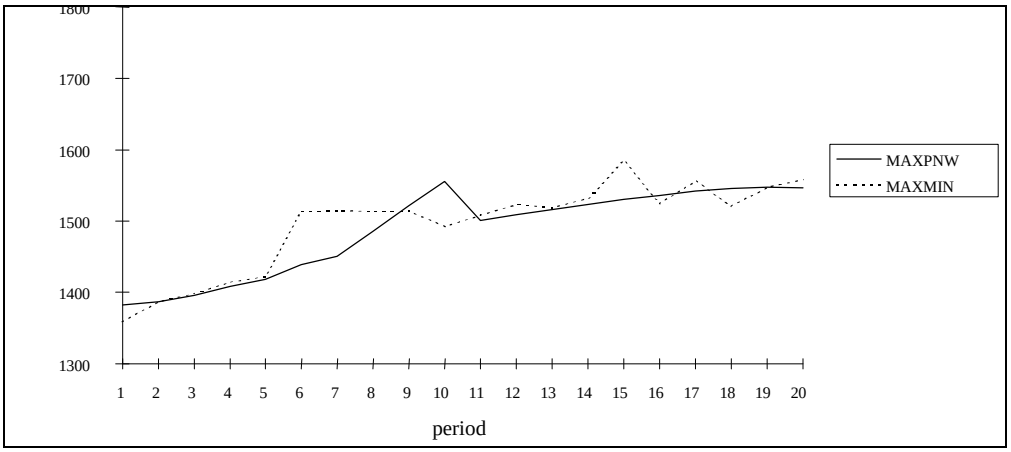

Figure 4.—Comparison of Harvested Area per Period—EVEN Initial Condition

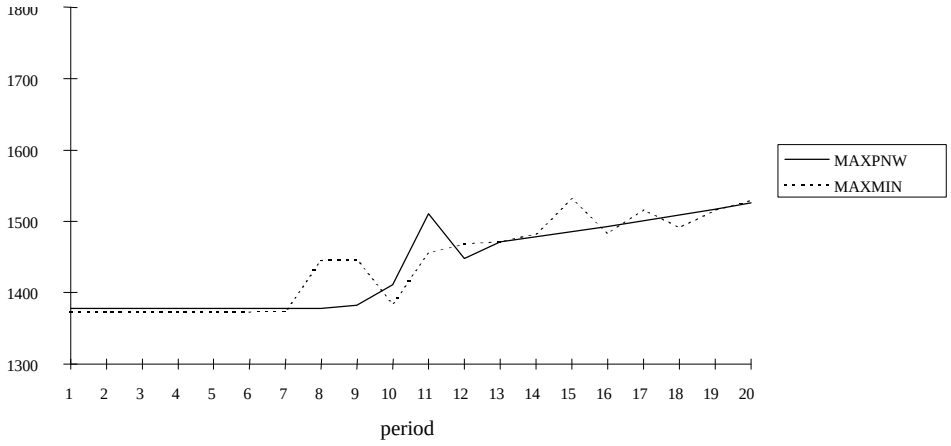

Figure 5.—Comparison of Harvested Area per Period—OLD Initial Condition

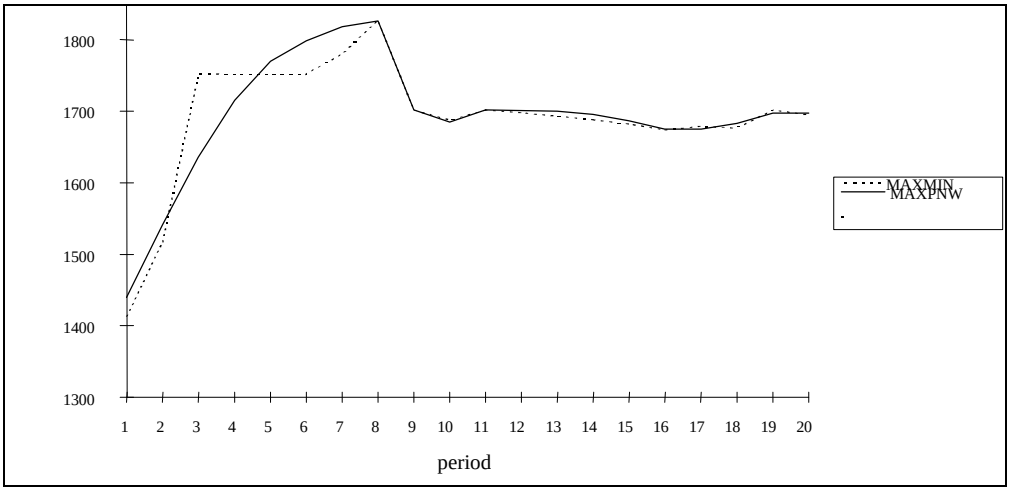

Figure 6.— Comparison of Harvested Area per Period—YOUNG Initial Condition

DISCUSSION

The PNW results exhibit a pattern consistent with a Rawlsian equity approach. The MAXMIN approach required early period planners to accept a lower PNW to benefit later period planners. For two of the initial conditions (EVEN and OLD), the MAXMIN approach required the majority of planners to lower their PNW for the benefit of one or two planners. The amount of PNW given up exceeds that gained by the late period planners. The results suggest that in these cases early planners have limited ability to transfer PNW to future planners by changing activity patterns. In a Rawlsian bargaining situation where all planners select the alternative, it is not clear that future planners would prefer the MAXMIN approach over the MAXPNW approach for the EVEN and OLD conditions. The results for the YOUNG initial condition more clearly represent a reasonable Rawlsian solution. In this case, only the first three planners are required to lower their PNW in order to benefit the next four planners. The remaining three planners would be indifferent to the approaches.

The pattern in hectares harvested by period explains the PNW results. There is a set of periods in which the area harvested under MAXMIN is greater than under MAXPNW, followed immediately by a set of periods where area harvested is lower under MAXMIN. The volume removed for these periods is constant, so that the net revenue in any period is lower the larger the area harvested**,** since revenue depends on volume and costs depend on area

harvested. The same periods where the MAXPNW harvested area is higher than the MAXMIN harvested area, is where the PNW for the planners under MAXPNW is lower. The MAXPNW formulation raises PNW for early planners by scheduling the most valuable forest for harvest in the early periods, and delaying the harvest of less valuable forest to later periods. In order for the MAXMIN formulation to increase the PNW for the later planners, less value can be removed in the early periods, particularly period one. The MAXMIN formulation schedules the harvest of younger, less valuable forest in earlier time periods, in order to raise the PNW for later planners. The result is that no one future planner is sacrificed in order to raise an earlier planner's PNW.

CONCLUSIONS

IE is about the passing on of options to the next generation, so that they have sufficient resources and flexibility to solve their own problems and cater to their own needs. We did not attempt to meet this ideal in this paper. Rather, we started with a standard formulation of an LP-based forest planning problem and varied the perspective from which it was solved to modify the distribution of PNW. The intent was to consider ways of modifying a standard formulation to more explicitly address the time dimension. Such a modification was accomplished by simply including accounting rows that model the perspective of future planners. This formulation allowed consideration of a form of Rawlsian equity, which focuses on making the worst planner better off. For two of the three initial conditions examined in this paper, the IE trade off involved raising the PNW outcomes for a small number of planners at the expense of all other planners. From an equity viewpoint, one could argue either way as to whether this trade off is good or bad. The important point is that the model formulation allows this type of trade off to be explicitly examined in the first place.

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