1999

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ANALYSIS

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Received 28 August 1998; received in revised form 10 May 1999; accepted 7 June 1999

Abstract

A forester and a conservation organization bargain over the commercial exploitation or preservation of a forested tract of land with unique ecological characteristics. The forester can improve its bargaining position by preparing a portion of the land for future timber production prior to negotiations between the two. However, doing so decreases the preservation value of the forest, as well as the compensation the conservation group is willing to pay to preserve the forest. The analysis suggests that the forester will begin preparing the land for timber production prior to negotiations only when the value of the land in timber production is significantly lower than the preservation values of the conservation group.

Keywords: Preservation; Bargaining; Threat positions

JEL classification: D62; Q20

1. Introduction

De-centralized bargaining to control environmental externalities is widespread. Negotiated agreements between non-profit organizations and landowners to preserve ecologically sensitive areas, debt-for-nature swaps, and international environmental agreements to control transboundary pollutants are only a few examples. Accordingly, there exists a very large literature that examines negotiated resolutions of environmental conflicts. A portion of this literature has examined the incentives parties to negotiations over the use of an environmental asset have to establish better bargaining positions by committing themselves to threat positions; that is, to actions to be taken in case negotiations break down. For example, Buchholz and Konrad (1994) identify an incentive

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PII: S0921-8009(99)00065-8

nations have to commit themselves to inferior pollution-control technologies prior to an agreement to control a transboundary pollutant. This investment commits a nation to a higher level of emissions in case of bargaining impasse, and this *threat* can give a nation a stronger bargaining position and ultimately more favorable terms from a successfully negotiated agreement. Copeland (1990) identifies a similar incentive in the context of international negotiations to limit over-exploitation of an open-ocean fishery.

Of course, a threat of any sort requires an initial irreversible action (investment) that makes it rational for the threat-maker to follow through on the threat if the need arises (Schelling, 1960, chapter 2). Simply put, any threat must be credible. Adopting the theory of rational threats that follows from the Nash bargaining solution, Richer and Stranlund (1997) have focused on the optimality and credibility of threats in the classic context of bargaining between a polluting firm and the victim of its pollution. Stranlund (1999) has extended this work to cases of bilateral externalities to focus on equilibrium threat strategies. Regardless of the approach or context, all of the existing literature on threat making prior to bargaining to control environmental externalities suggests that these investments can have significant adverse impacts on the health and value of environmental assets, as well as the efficiency of bargaining over the use of these assets.

This paper examines the role of threat making in the context of bargaining over the commercial exploitation and/or preservation of a unique ecosystem. To be concrete, we shall examine a situation in which a forester has the unrestricted right to place all or a portion of a tract of land into timber production. On the other hand, a conservation organization is interested in preserving the existing forest because it has unique ecological characteristics in its natural state. Bargaining between the forester and the conservation group is over how much of the forest will be converted to timber production and how much will be preserved in its existing state.

As in the contexts addressed in the earlier works, the forester may be able to improve its bargaining position by committing itself to converting a certain portion of the forest to timber production in case the two parties fail to negotiate a mutually agreeable harvest/preservation plan. Indeed, the forester has a natural commitment mechanism by which to make its harvest threat credible. Preparing the land for timber production by building logging roads into the forest prior to negotiations is a sunk, irreversible investment that gives credibility to a threat to harvest a certain portion of the forest in case of bargaining impasse. What distinguishes this exercise from earlier works is that building roads into the forest also diminishes its preservation value; hence, the compensation the conservation group would willingly offer to preserve the forest is less. In deciding upon an anticipatory investment to establish a harvest threat, the forester must then weigh the gain from improving its bargaining position against lower compensation from a negotiated agreement and the direct cost of establishing the threat.

The primary issue that this paper addresses has not been dealt with before: Under what circumstances will the owner of a natural asset try to establish a better bargaining position by preparing the asset for future commercial exploitation prior to negotiations to preserve the asset? The analysis of this paper suggests, somewhat paradoxically, that a property owner will make a preparatory investment only when the commercial value of the asset is significantly lower than the value of the asset in its natural state.

The answer to the question posed by this paper is likely to be an important consideration in a number of actual bargaining situations. For example, in the United States there are many nonprofit organizations whose sole purpose is to protect ecologically significant areas from development. Excluding large national conservation organizations like the Nature Conservancy, there are more than 1000 of these so-called land trusts, and these organizations protect more than five million acres of land nationwide. Through negotiations with landowners, these land trusts protect sensitive areas by purchasing them outright, or by purchasing conservation easements or mineral and grazing rights (Land Trust Alliance, 1995; Wiebe, 1994). A similar application involves debt-for-nature swaps in which a conservation organization agrees to retire a part of the debt of a national government in exchange for that government's commitment to preserve a unique ecosystem under its control. (Deacon and Murphy (1997) analyze the structure of actual debt-for-nature swaps, and Chambers et al. (1996) model these trades in non-cooperative and cooperative settings). In these and similar cases, it behooves a conservation organization to know when a property owner is likely to make an anticipatory investment to improve its bargaining position because this investment affects the terms of any agreement between the two, as well as the health of the ecosystem under consideration.

2. Harvest and preservation values

The bargaining game that we examine is between a forester and a conservation organization over the commercial exploitation or preservation of a forest consisting of A acres. The forester has the unrestricted right to harvest the forest, but the conservation group is willing to compensate the forester to preserve all or a portion of the forest.

The timber in the forest is of uniform density and quality. If a portion of the land is harvested, the forester will keep it in timber production for the foreseeable future with a sequence of re-plantings and harvests. Assume that the long run, per-acre value of the forest in timber production is p_f. To prepare a portion of the forest for timber production, the forester must build a logging road into the forest. Each mile of road prepares α acres for timber production. Let r denote the length of a logging road and h denote acres in timber production. Then, given a road of length r, the number of acres that can be harvested is $h \leq \alpha r$. The cost of road building is $c(r)$ with $c'(r) > 0$, $c''(r) > 0$, and $c(0) = c'(0) = 0$. Later in the analysis we shall assume that the cost function takes a quadratic form; however, this additional structure is not needed for most of the analysis. Assume that a logging road has no valuable alternative opportunities. Therefore, building one is an irreversible investment in timber production capacity, and the costs of road building are sunk.

In the absence of a cooperative agreement to preserve a portion of the forest, the forester's long-run profit is $p_f h - c(r) = p_f \alpha r - c(r)$. To maximize the value of the forest in timber production, the forester chooses a road length that maximizes $p_f \alpha r - c(r)$ subject to $r \in [0, A/\alpha]$, where A/α is the length of the logging road needed to harvest the entire tract. The associated Kuhn–Tucker condition is $p_f \alpha - c'(r) \geq 0$, and if > 0, $r = A/\alpha$. Let the long-run, profit-maximizing number of acres in timber production be $h^\pi = \alpha r^\pi$. Since $c'(0) = 0$, the forester would choose to harvest at least some of the forest in the absence of an agreement to preserve part of the forest; that is, $h^\pi = \alpha r^\pi > 0$. Let us suppose for simplicity that $r^\pi < A/\alpha$; that is, simple profit-maximization would leave part of the tract undisturbed. Then, we have

$$p_f \alpha - c'(r^\pi) \equiv 0 \tag{1}$$

The conservation group values the preservation of the forest because it contains some unique ecological characteristics that are lost when the forest is harvested. In fact, the formal analysis assumes that the conservation group considers the tract to be truly unique in the sense that it does not feel that it has other preservation opportunities that are reasonably close substitutes. This assumption has two important effects on the forester's willingness to invest in improving its bargaining position prior to negotiations with the conservation group. First, because the group feels that it does not have comparable preservation opportunities, it will not be able to credibly walk away from negotiations with the forester to pursue another preservation opportunity. (Section 5 includes a discussion of how the presence of an outside option for the conservation group may limit the forester's ability to invest in improving its bargaining position). Second, the lack of substitute preservation opportunities likely implies that the conservation group places a relatively high value on preserving the forest.[1] We shall see

[1] Empirical evidence of higher valuations for environmental goods without close substitutes can be found in Whitehead and Blomquist (1991), Hoehn and Loomis (1993), Cummings et al. (1994), Boxall et al. (1996). An anonymous reviewer deserves credit for bringing this literature to my attention.

that high preservation values, relative to the commercial value of the forest, is the critical determinant of whether the forester will have sufficient incentive to make an anticipatory investment to improve its bargaining position.

Let us assume that the group's long-run, per-acre valuation of preserving a portion of the forest depends on whether this portion is completely undisturbed or it has been prepared for timber production, and that the group values undisturbed acreage more highly than preserved land that has been prepared for harvest. Assume that the group places a value of p_c^u per acre of completely undisturbed forest; $p_c^d < p_c^u$ per acre of land that has been prepared for timber production but is preserved instead, and it does not value land in timber production at all. Suppose for a moment that there is a road of length $\bar{r} < A/\alpha$ into the forest and $\tilde{h} < \alpha\bar{r}$ acres are in timber production. Then, the value the group places on the entire tract is $p_c^u(A - \alpha\bar{r}) + p_c^d(\alpha\bar{r} - \tilde{h})$, where $A - \alpha\bar{r}$ is the amount of land left undisturbed and $\alpha\bar{r} - \tilde{h}$ is the amount of land that is prepared for timber production but is preserved instead.

2.1. *Efficient preservation and harvest*

The efficient harvest plan for the forest is the number of acres h^* in timber production that maximizes the joint payoffs of the forester and the conservation group. Since it cannot be efficient to extend a road into land that will not be harvested, the efficient harvest plan is completely determined by the efficient length of a logging road. The efficient road length maximizes $p_c^u(A - \alpha r) + p_f\alpha r - c(r)$ subject to $r \in [0, A/\alpha]$. Again, A/α is the length of the road needed to harvest the entire tract. The Kuhn–Tucker condition is

$$\alpha(p_f - p_c^u) - c'(r)\begin{cases} \leq 0, \text{ if } < 0, \ r^* = 0 \\ \geq 0, \text{ if } > 0, \ r^* = A/\alpha \end{cases}$$

The Kuhn–Tucker condition and the assumptions about the cost of road-building imply that the efficient road length is such that

$$\begin{cases} r^* = 0, \text{ if } p_f - p_c^u \leq 0 \\ r^* > 0, \text{ if } p_f - p_c^u > 0. \end{cases} \tag{2}$$

Eq. (2) reveals that the efficient use of the forest is to leave it undisturbed if and only if the per-acre value of undisturbed forest is not less than the per-acre value of the land in timber production. Otherwise, it is efficient that some of the forest be used for timber production. Under the assumption that $r^\pi < A/\alpha$, $r^* < r^\pi$, and therefore $h^* < h^\pi$; that is, efficiency requires that less of the tract be placed in timber production than the forester would choose in the absence of a bargaining opportunity.[2]

2.2. *Nash bargaining*

Assume throughout that any agreement between the forester and the conservation group is characterized by the Nash bargaining solution. Denote the bargaining payoffs to the forester and the conservation group as v_f and v_c, respectively. The Nash bargaining solution is then the pair of payoffs (v_f, v_c) that maximize the product $[v_f - z_f][v_c - z_c]$ subject to $V \geq v_f + v_c$, where V is the maximal value of an agreement and (z_f, z_c) is the payoff allocation in the event that negotiations between the two players are unsuccessful. The necessary and sufficient conditions for a solution to the bargaining problem are $[v_f - z_f] = [v_c - z_c]$ and $V = v_f + v_c$, the explicit solution to which are the bargaining payoffs

$$v_f = (1/2)[V + z_f - z_c] \quad \text{and}$$
$$v_c = (1/2)[V + z_c - z_f]. \tag{3}$$

The disagreement payoffs in the Nash bargaining solution, (z_f, z_c), are often called threat positions because they specify the outcome of unsuccessful bargaining. The theory of *rational threats* recognizes that parties to an agreement have an incentive to manipulate these payoffs before the completion of an agreement to shift the terms of an agreement to their advantage.[3] To

[2] The efficient road length r^* is determined from the Kuhn-Tucker condition $p_f\alpha - p_c^u\alpha - c'(r) \leq 0$, and if < 0, $r^* = 0$. The profit-maximizing road length r^π is determined by $p_f\alpha - c'(r) = 0$. The presence of $p_c^u\alpha$ as an additional cost of harvest in the determination of the efficient road length implies $r^* < r^\pi$.

[3] Useful expositions of the theory of rational threats can be found in many game theory texts (e.g. Harsanyi, 1977; Myerson, 1991). Readers who seek an accessible introduction to the Nash bargaining solution might begin with Binmore et al. (1986).

establish a better bargaining position in this way, a player must be able to commit itself to an action (i.e. threat) before the completion of an agreement that will be taken in case of bargaining impasse.

In our context, the conservation group has no mechanism by which it can attempt to establish a better bargaining position by manipulating the disagreement payoffs, and it does not have a credible walk-away threat because it considers the tract to be truly unique. However, the forester may be able to improve its bargaining position by building a road into the forest before bargaining begins, because the existence of a road can establish a credible threat to harvest a certain number of acres should the two parties fail to reach an agreement. Whether the forester is actually motivated to undertake this anticipatory investment depends on its bargaining payoff when it builds a logging road prior to bargaining and its payoff when it refrains from doing so. Section 3 is devoted to deriving the forester's optimal anticipatory investment and its resulting bargaining payoff. We conclude this section by deriving the forester's bargaining payoff when it refrains from making this anticipatory investment.

2.3. Bargaining without an anticipatory investment

Without a road in the forest when bargaining begins, in case the two parties fail to reach agreement, the forester will build a road of profit-maximizing length r^π and produce timber on $h^\pi = \alpha r^\pi$ acres after negotiations fail. In this case the disagreement payoffs are

$$z_{\mathrm{f}}^0(r^\pi) = p_{\mathrm{f}}\alpha r^\pi - c(r^\pi) \quad \text{and}$$
$$z_{\mathrm{c}}^0(r^\pi) = p_{\mathrm{c}}^{\mathrm{u}}(A - \alpha r^\pi). \tag{4}$$

(Throughout, the superscript '0' denote values when the forester does not build a road prior to bargaining). In case negotiations fail, the forester gets the value of the profit-maximizing timber production and the conservation group gets the preservation value of the portion of the forest that the forester finds unprofitable to harvest.

The disagreement payoffs Eq. (4) contain a key determinant of whether the forester will try to improve its bargaining position with an initial investment in a logging road. It is important to note that the forester has a credible harvest threat without preparing part of the forest for harvest – in case of bargaining impasse, it is clear that the forester will place $h^\pi = \alpha r^\pi$ acres into timber production. The purpose of building a logging road prior to negotiations is to improve on this bargaining position. Now, $h^\pi = \alpha r^\pi$ is increasing in the per-acre value of the forest in timber production, p_{f}.[4] Thus, when the timber value of the forest is low, the forester has a relatively weak bargaining position because, if the two parties fail to reach a cooperative agreement, the forester will harvest only a small portion of the forest and leave the rest in its natural state. Conversely, when the timber value of the forest is high, the forester has a stronger bargaining position. One might expect that the forester will be more likely to try and improve on its bargaining position with an anticipatory investment when its bargaining position is weak in the absence of such an investment. In Section 4 we shall see that this intuition is quite correct.

The maximal value of an agreement when the forester does not build a logging road prior to bargaining is the value of the efficient preservation/harvest plan,

$$V^0 = (A - \alpha r^*) + p_{\mathrm{f}}\alpha r^* - c(r^*), \tag{5}$$

where r^* is the efficient road length given by Eq. (2). Using Eqs. (3)–(5), the forester's bargaining payoff when it does not build a logging road prior to bargaining is

$$v_{\mathrm{f}}^0(r^\pi) = (1/2)[V^0 + p_{\mathrm{f}}\alpha r^\pi - c(r^\pi) - p_c^u(A - \alpha r^\pi)], \tag{6}$$

and the conservation group's payoff is

$$v_{\mathrm{c}}^0 = (1/2)[V^0 + p_{\mathrm{c}}^{\mathrm{u}}(A - \alpha r^\pi) - p_{\mathrm{f}}\alpha r^\pi + c(r^\pi)]. \tag{7}$$

[4] To show that $h^\pi = \alpha r^\pi$ is increasing in p_{f}, first recall from Eq. (1) that r^π is the solution to the first-order condition $p_{\mathrm{f}}\alpha - c'(r) = 0$. From the first-order condition we can obtain the comparative static $\partial r^\pi/\partial p_{\mathrm{f}} = \alpha/c''(r) > 0$, the sign of which follows because $c''(r) > 0$.

3. An anticipatory investment to establish a stronger bargaining position

To analyze the forester's motivation to prepare a portion of the forest for harvest before negotiating with the conservation group, we consider a two-stage game. In the first stage the forester may prepare a portion of the forest for future timber production by building a logging road of length r^{t} into the forest. (The superscript t denotes values when the forester makes an anticipatory investment to improve its bargaining position). In the second stage, the forester and the conservation group successfully negotiate an agreement about a harvest/preservation plan for the forest. The agreement and the resulting payoffs are determined by the Nash bargaining solution. Of course, the negotiated outcome will depend on the forester's first-stage choice.

Complete information is assumed so that the forester knows the conservation group's values for disturbed and undisturbed land, and the conservation group knows the value of timber production and the costs of road building. We shall also assume perfect information so that the conservation group observes the forester's anticipatory investment before the two enter into negotiations. Lastly, all information is common knowledge.

Since building a logging road is an irreversible investment in timber production capacity, the forester's first-stage investment may credibly commit it to put h^{t} acres into timber production in case the two fail to reach an agreement. Credibility of the forester's harvest threat h^{t} requires that, given a road of length r^{t} and bargaining impasse between the two parties, the forester does not extend the road to put additional land into timber production; that is, we require that the harvest threat be such that $h^{\mathrm{t}} \leq \alpha r^{\mathrm{t}}$. Credibility also requires that the forester not leave prepared land out of timber production in case of bargaining impasse. In fact, the forester will always harvest the prepared portion of the tract in case of bargaining impasse because the marginal value of prepared land in timber production, $p_{\mathrm{f}}\alpha$, is always positive. Therefore, a harvest threat is credible if and only if it is exactly equal to the acreage the forester prepares for timber production before negotiations begin; that is, $h^{\mathrm{t}} = \alpha r^{\mathrm{t}}$.

The existence of a road prior to bargaining affects all of the components of the Nash bargaining solution. Therefore, let the disagreement payoffs be $(z_{\mathrm{f}}, z_{\mathrm{c}}) = [z_{\mathrm{f}}^{\mathrm{t}}(r^{\mathrm{t}}), z_{\mathrm{c}}^{\mathrm{t}}(r^{\mathrm{t}})]$, and let the maximal value of the agreement be $V = V(r^{t})$. From Eq. (3), the bargaining payoffs are:

$$v_{\mathrm{f}}^{\mathrm{t}}(r^{\mathrm{t}}) = (1/2)[V^{\mathrm{t}}(r^{\mathrm{t}}) + z_{\mathrm{f}}^{\mathrm{t}}(r^{\mathrm{t}}) - z_{\mathrm{c}}^{\mathrm{t}}(r^{\mathrm{t}})];$$

$$v_{\mathrm{c}}^{\mathrm{t}}(r^{\mathrm{t}}) = (1/2)[V^{\mathrm{t}}(r^{\mathrm{t}}) + z_{\mathrm{c}}^{\mathrm{t}}(r^{\mathrm{t}}) - z_{\mathrm{f}}^{\mathrm{t}}(r^{\mathrm{t}})] \tag{8}$$

Since $h^{\mathrm{t}} = \alpha r^{\mathrm{t}}$ acres will be converted to timber production in case of bargaining impasse, the disagreement payoff to the forester is the value of timber production on the prepared portion of the tract, and the disagreement payoff to the conservation group is the preservation value of the forest that is left. Thus,

$$z_{\mathrm{f}}^{\mathrm{t}}(r^{\mathrm{t}}) = p_{\mathrm{f}}\alpha r^{\mathrm{t}} \quad \text{and} \quad z_{\mathrm{c}}^{\mathrm{t}}(r^{\mathrm{t}}) = p_{\mathrm{c}}^{\mathrm{u}}(A - \alpha r^{\mathrm{t}}). \tag{9}$$

Note that since the cost of building the road $c(r^{\mathrm{t}})$ is expended before bargaining begins, it is not part of the forester's disagreement payoff.

Now, given an existing road of length r^{t}, the forester and the conservation group will negotiate the number of acres to be placed in timber production, $h^{\mathrm{a}} \leq \alpha r^{\mathrm{t}}$, to maximize their joint payoffs.[5] The value to the conservation group of h^{a} is $p_{\mathrm{c}}^{\mathrm{u}}(A - \alpha r^{\mathrm{t}}) + p_{\mathrm{c}}^{\mathrm{d}}(\alpha r^{\mathrm{t}} - h^{\mathrm{a}})$, where $(A - \alpha r^{\mathrm{t}})$ is the number of undisturbed acres and $(\alpha r^{\mathrm{t}} - h^{\mathrm{a}})$ is the amount of land that has been prepared for harvest but that will be preserved instead. The value to the forester of h^{a} is $p_{\mathrm{f}}h^{\mathrm{a}}$. The harvest plan the two negotiate maximizes $p_{\mathrm{c}}^{\mathrm{u}}(A - \alpha r^{\mathrm{t}}) + p_{\mathrm{c}}^{\mathrm{d}}(\alpha r^{\mathrm{t}} - h^{\mathrm{a}}) + p_{\mathrm{f}}h^{\mathrm{a}}$ subject to $h^{\mathrm{a}} \in [0, \alpha r^{\mathrm{t}}]$. Ignoring the case of $p_{\mathrm{f}} - p_{\mathrm{c}}^{\mathrm{d}} = 0$, the appropriate Kuhn–Tucker condition implies

[5] Credibility of a harvest threat implies that an agreement will not specify $h^{\mathrm{a}} > \alpha r^{\mathrm{t}}$. To see this, recall from Eq. (1) that $p_f\alpha - c'(r^{\pi}) \equiv 0$. If $r^{\mathrm{t}} < r^{\pi}$, then $p_{\mathrm{f}}\alpha - c'(r^{\mathrm{t}}) > 0$; that is, the value of extending the road beyond r^{t} is strictly positive. This implies that if $r^{\mathrm{t}} < r^{\pi}$, the forester will extend the road to r^{π} in case of impasse; hence, $r^{\mathrm{t}} < r^{\pi}$, does not signal a credible threat. To see why an agreement will not specify $h^{\mathrm{a}} > \alpha r^{\mathrm{t}}$, note that $r^{t} \geq r^{\pi}$ implies $p_{\mathrm{f}}\alpha \leq c'(r^{\mathrm{t}})$; hence, an extension of the logging road beyond r^{t} cannot be justified on the grounds of the value of additional harvest. Furthermore, extending the road will only decrease the preservation value of the tract.

$$h^{\mathrm{a}}(r^{\mathrm{t}}) = \begin{cases} \alpha r^{\mathrm{t}} \text{ if } p_{\mathrm{f}} - p_{\mathrm{c}}^{\mathrm{d}} > 0 \\ 0 \text{ if } p_{\mathrm{f}} - p_{\mathrm{c}}^{\mathrm{d}} < 0. \end{cases} \tag{10}$$

The welfare-maximizing harvest plan, given that a portion of the forest has already been prepared for harvest, depends on the value of the land in timber production relative to the value of preserving land that has been prepared for harvest. If the per-acre value of the land in timber production is greater, the parties will agree to harvest the prepared portion of the forest. If the preservation value of prepared land is greater, the prepared portion will be preserved. Note two sources of inefficiency associated with this latter outcome: an ultimately unproductive logging road is built and the existence of the road diminishes the preservation value of the forest.

Now, the maximal value of the harvest agreement is $V^{\mathrm{t}}(r^{\mathrm{t}}) = p_{\mathrm{c}}^{\mathrm{u}}(A - \alpha r^{\mathrm{t}}) + p_{\mathrm{c}}^{\mathrm{d}}(\alpha r^{\mathrm{t}} - h^{\mathrm{a}}(r^{\mathrm{t}})) + p_{\mathrm{f}} h^{\mathrm{a}}(r^{\mathrm{t}})$. Using Eq. (10),

$$V^{\mathrm{t}}(r^{\mathrm{t}}) = \begin{cases} p_{\mathrm{c}}^{\mathrm{u}}(A - \alpha r^{\mathrm{t}}) + p_{\mathrm{f}}\alpha r^{\mathrm{t}} \text{ if } p_{\mathrm{f}} - p_{\mathrm{c}}^{\mathrm{d}} > 0 \\ p_{\mathrm{c}}^{\mathrm{u}}(A - \alpha r^{\mathrm{t}}) + p_{\mathrm{c}}^{\mathrm{d}}\alpha r^{\mathrm{t}} \text{ if } p_{\mathrm{f}} - p_{\mathrm{c}}^{\mathrm{d}} < 0. \end{cases} \tag{11}$$

We are now ready to characterize the optimal anticipatory investment. Using the forester's bargaining payoff from Eq. (8), its disagreement payoffs from Eq. (9), and the maximal value of the agreement Eq. (11), the forester's bargaining payoff when it builds a logging road prior to negotiations is

$$v_{\mathrm{f}}^{\mathrm{t}}(r^{\mathrm{t}}) = \begin{cases} p_{\mathrm{f}}\alpha r^{\mathrm{t}} \text{ if } p_{\mathrm{f}} - p_{\mathrm{c}}^{\mathrm{d}} > 0 \\ \frac{1}{2}(p_{\mathrm{c}}^{\mathrm{d}} + p_{\mathrm{f}})\alpha r^{\mathrm{t}} \text{ if } p_{\mathrm{f}} - p_{\mathrm{c}}^{\mathrm{d}} < 0. \end{cases} \tag{12}$$

The optimal choice of r^{t} maximizes

$$v_{\mathrm{f}}^{\mathrm{t}}(r^{\mathrm{t}}) - c(r^{\mathrm{t}}) \text{ s.t. } r^{\mathrm{t}} \in [0, A/\alpha]. \tag{13}$$

4. When will the forester invest in improving its bargaining position?

We are now ready to characterize all of the possible outcomes of the game. There are three cases to consider. In the first, the per-acre timber value exceeds the conservation group's per-acre valuation of both undisturbed and prepared land; that is, $p_{\mathrm{f}} > p_{\mathrm{c}}^{\mathrm{u}} > p_{\mathrm{c}}^{\mathrm{d}}$. In the second case, the timber value exceeds the conservation group's valuation of prepared land, but not its valuation of undisturbed land; that is $p_{\mathrm{c}}^{\mathrm{u}} \geq p_{\mathrm{f}} > p_{\mathrm{c}}^{\mathrm{d}}$. Finally in the third case, the timber value is less than the conservation group's valuation of both undisturbed and prepared land; that is, $p_{\mathrm{f}} < p_{\mathrm{c}}^{\mathrm{d}} < p_{\mathrm{c}}^{\mathrm{u}}$. The outcomes of the game in each of these situations are specified in a series of lemmas. All lemmas and corollaries are proved in the appendix.

Lemma 1. Suppose that $p_{\mathrm{f}} > p_{\mathrm{c}}^{\mathrm{u}} > p_{\mathrm{c}}^{\mathrm{d}}$. Then, the forester does not prepare a portion of the forest for future timber production prior to the bargaining agreement. The agreement that the two parties negotiate specifies that $h^* = \alpha r^* > 0$ acres of the forest be used for timber production and the rest preserved in its original state.

Lemma 2. Suppose instead that $p_{\mathrm{c}}^{\mathrm{u}} \geq p_{\mathrm{f}} > p_{\mathrm{c}}^{\mathrm{d}}$. As in Lemma 1, the forester does not prepare a portion of the forest for future timber production prior to the bargaining agreement. However, the agreement between the two parties specifies that the entire tract be preserved.

The outcomes outlined in the two lemmas are similar in that the forester does not try to improve its bargaining position by preparing a part of the forest for harvest. However, in the situation considered in Lemma 1 the agreement the two parties negotiate allocates a portion of the tract to timber production, while in the case that Lemma 2 considers the parties agree to preserve the entire forest.

In the situations addressed by Lemmas 1 and 2, the forester refrains from an anticipatory investment. The reason for this is quite simple. The proofs of the lemmas indicate that if the forester prepared a part of the forest for harvest, it would prepare exactly that acreage that it would convert to timber production in the absence of any agreement. But, doing so implies that the joint welfare-maximizing use of the forest is to produce timber on the prepared portion and preserve the rest. Since this is exactly what would occur in the absence of bargaining, there is no longer a gain from negotiating a cooperative agreement. Thus, the forester decides to refrain from its anticipatory investment and the parties are able to negotiate an agreement that specifies the efficient use of the forest.

The remaining case — the case in which the timber value is below the conservation group's valuations of both undisturbed and prepared land — is difficult to analyze without additional structure on the road-building cost function. Therefore, from here on we shall assume that this function takes on a quadratic form.

Lemma 3. Suppose that $p_{\mathrm{f}} < p_{\mathrm{c}}^{\mathrm{d}} < p_{\mathrm{c}}^{\mathrm{u}}$, and that the cost of road building is $c(r) = (\eta/2)(r)^2$, where η is a positive constant. Then there exists a timber value $\bar{p}_{\mathrm{f}}$ that is strictly between zero and $p_{\mathrm{c}}^{\mathrm{d}}$ such that if the actual timber value falls below $\bar{p}_{\mathrm{f}}$, the forester will build a road into the forest prior to bargaining. If the actual timber value is above $\bar{p}_{\mathrm{f}}$, the forester will refrain from building a road into the forest prior to bargaining. In both cases, the agreement that the parties come to specifies that no portion of the forest be used for timber production.

It is interesting that the forester finds it individually rational to attempt to strengthen its bargaining position only when the value of timber production is significantly below the preservation values of the forest. And remember that the preservation values of the forest are likely to be high because the conservation group considers the tract unique. Unfortunately, therefore, the forester is more likely to make a harmful threat-motivated investment when preservation is most valuable.

To see the intuition that drives Lemma 3, recall that an anticipatory investment decreases the preservation value of the forest, and is therefore costly for the forester because it decreases the amount of compensation the conservation group pays for the preservation of the forest. The forester must weigh this cost and the cost of building the road to establish its threat against the value of establishing a stronger threat position. When the per-acre timber value of the forest is relatively low, without an anticipatory investment in harvest capacity the forester's threat position is rather weak because, in case of bargaining impasse, the forester will harvest only a small portion of the forest and leave the rest in its natural state. When the forester has a weak bargaining position, it has a strong motivation to improve its bargaining position with an anticipatory investment despite the costs associated with devaluing the agreement the two parties come to and building the road to establish its threat. On the other hand, when the timber value of the forest is relatively high the forester has a strong credible threat to harvest a large portion of the forest in case of bargaining impasse. Thus, its incentive to improve its bargaining position with an anticipatory investment is low when the timber value of the forest is high.

To gain additional insight into how the forest values work together to determine whether the forester will invest in improving its bargaining position, let us examine how the cut-off timber value depends on the values of the conservation group.

Corollary 1. The cut-off timber value, $\bar{p}_{\mathrm{f}}$, is decreasing in $p_{\mathrm{c}}^{\mathrm{u}}$ and increasing in $p_{\mathrm{c}}^{\mathrm{d}}$.

Under the conditions of Lemma 3, the forester prepares a portion of the forest for timber production to improve its bargaining position, but the parties agree that this portion of the forest will never be harvested. Preparation of a portion of the forest for harvest diminishes the per acre preservation value of the prepared portion by $p_{\mathrm{c}}^{\mathrm{u}} - p_{\mathrm{c}}^{\mathrm{d}}$. This implies that the loss associated with an anticipatory investment is increasing in the value of undisturbed land ($p_{\mathrm{c}}^{\mathrm{u}}$) and decreasing in the value of preserved land that has been prepared for harvest ($p_{\mathrm{c}}^{\mathrm{d}}$). Thus, $\partial\bar{p}_{\mathrm{f}}/\partial p_{\mathrm{c}}^{\mathrm{d}} < 0$ reveals that the forester is less likely to invest in improving its bargaining position — in the sense that the range of p_{f} for which it is individually rational for the forester to do so is smaller — when the lost preservation value associated with this investment is high. Similarly, $\partial\bar{p}_{\mathrm{f}}/\partial p_{\mathrm{c}}^{\mathrm{d}} > 0$ reveals that the forester is more likely to invest in improving its bargaining position when the foregone preservation value of doing so is low.

Further insight is obtained by considering the forester's decision to make an anticipatory investment at the endpoints of the range of the conservation group's valuation of preserved land that has been prepared for harvest.

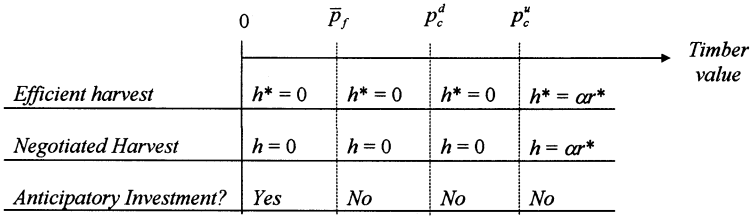

Fig. 1. The effects of timber and preservation values on bargaining outcomes.

Corollary 2. Suppose that $p_c^d = 0$ so that the conservation group does not value land that has been prepared for timber production. Then, the forester will never prepare a part of the land for timber production before negotiations.

Corollary 3. Suppose that $p_c^d = p_c^u$ so that the conservation group values land that has been prepared for harvest the same as completely undisturbed land. Then, as in Lemma 3, the cutoff timber value, $\bar{p}_f$, is still strictly between zero and p_c^d.

Corollary 2 reveals that the forester will never invest in improving its bargaining position when doing so yields the prepared portion of the forest worthless from the conservation group's point of view. Corollaries 1 and 2 together suggest that a critical determinant of the forester's decision to undertake an anticipatory investment is the fact that such an investment diminishes the preservation value of the forest. However, Corollary 3 reveals that even when the forester's investment has no effect on the preservation value of the forest, the forester will refrain from investing in improving its bargaining position if the timber value of the forest is high enough.

5. Summary and discussion

Fig. 1 summarizes our results about how the timber and preservation values determine whether or not the forester makes an anticipatory investment to improve its bargaining position, as well as the efficient and negotiated levels of timber production. When the per-acre timber value exceeds the conservation group's valuation of completely undisturbed forest, it is efficient to use a portion of the forest for timber production and preserve the rest. Bargaining between the two parties results in an agreement that specifies this outcome. When the timber value falls below the conservation group's valuation of undisturbed forest, it is efficient to leave the entire forest in its natural state, and again, bargaining between the two parties leads to this outcome. However, when the timber value is significantly below the conservation group's values, the forester's weak bargaining position motivates it to improve its bargaining position by preparing a part of the forest for harvest.

When the forester makes a preparatory investment to improve its bargaining position, two kinds of inefficiency result. First, although the forester expends resources to prepare a part of the forest for harvest, no harvesting ever takes place; hence, from a social welfare point of view, the forester's initial investment is wasted. Second, the forester's initial investment reduces the preservation value of the tract even though it is efficient to leave the entire forest undisturbed.

If the two parties fail to reach an agreement — an aspect of real negotiations that is not dealt with by most bargaining games, including Nash bargaining — a third type of inefficiency may result from the forester's attempt to improve its bargaining position. Recall that the forester's investment establishes a credible threat to harvest a part of the forest in case of bargaining impasse. Then, if impasse occurs, the forester will produce timber on the prepared portion of the tract in spite of the fact that when the forester is actually motivated to make an anticipatory investment, it is efficient to leave the entire forest in its original state. In fact, when the forester invests in improving its bargaining position, it will prepare a larger portion of the forest for timber production than it would in the complete absence of a bargaining opportunity.[6] Thus, it is possible that a failed bargaining opportunity can result in even less efficient exploitation of the forest than in a completely non-cooperative setting.

The forester's attempt to improve its bargaining position may even be the reason that negotiations break down. In order to focus the analysis clearly on the motivations of the forester, we have not given the conservation group an opportunity to establish a threat position for itself. In reality, however, a conservation group may have a strong motivation to walk away from negotiations with a landowner, particularly if it has opportunities to negotiate agreements to preserve other comparable properties. The model of this paper implies that the payoff to the conservation group of a successfully negotiated agreement is reduced by the forester's attempt to improve its bargaining position. Thus, the forester's harvest threat could induce the conservation group to simply walk away and focus its resources elsewhere. If a conservation group has this walk-away power, a landowner will take this into account and, therefore, its incentive to improve its bargaining position with an anticipatory investment may be limited.

Of course, an effective walk-away threat must be credible, and credibility of such a threat in a particular bargaining situation likely depends on the supply of other preservation opportunities and the extent to which the conservation group feels that at least some of these other opportunities represent relatively close substitutes. Without comparable preservation opportunities, a threat to walk away in response to an attempt by a property owner to improve its bargaining position will not be credible. However, the results of this paper suggest that a conservation group may have a strategic incentive to develop credible walk-away threats to limit its vulnerability to harmful anticipatory threats. Perhaps by widening its geographic scope and becoming reasonably well informed about the ecological characteristics of the properties within this area, a conservation group may build an inventory of preservation opportunities that gives it credible walk-away power.[7]

However, it bears emphasizing that when a conservation group is interested in preserving a unique ecosystem that has no close substitutes, a threat to walk away and devote its efforts to preserving other properties is severely limited. And, of course, many conservation groups are likely to be much more interested in preserving properties with truly unique ecological characteristics. Furthermore, the preservation of these properties will be highly valued, which the analysis of this paper suggests may make harmful anticipatory threats more likely. Unfortunately, it appears that conservation groups may be most vulnerable to harmful anticipatory investments when preservation is most valuable.

6. Conclusion

In a straightforward and stylized model of bargaining between the owner of a environmental asset and a conservation group that is interested in preserving the asset in its natural state, we have examined the asset owner's motivation to improve its bargaining position by making an preparatory investment in the commercial exploitation of the asset. The primary result of the analysis suggests

[6] This conclusion follows from a comparison of r^{π} and the choice of r^{t} when $p_{f} < p_{c}^{d}$. Using Eqs. (12) and (13), the optimal choice of r^{t} in this case maximizes $(1/2)(p_{c}^{d} + p_{f})\alpha r^{t} - c(r^{t})$, subject to $r^{t} \in [0, A/\alpha]$. The associated Kuhn–Tucker condition is $(1/2)(p_{c}^{d} + p_{f})\alpha - c'(r^{t}) \geq 0$, and if > 0, $r^{t} = A/\alpha$ ($r^{t} = 0$ is not a possible solution). Recall from Eq. (1) that r^{π} is the solution to $p_{f}\alpha - c'(r) = 0$. Since $p_{f} < p_{c}^{d}$, $(1/2)(p_{c}^{d} + p_{f})\alpha > p_{f}\alpha$, which indicates that the marginal benefit of building the road to signal a harvest threat (r^{t}) is greater than the marginal benefit of building the simple profit maximizing road (r^{π}). This inequality implies $r^{t} > r^{\pi}$.

[7] Lobbying for political action, or building public support for the preservation of a particular property, may also be useful strategies for improving a group's bargaining power. Extending the model of this paper to examine the consequences of strategies like these may be a fruitful exercise for future research.

that the asset owner will make such an investment only when the commercial value of the asset is significantly lower than its preservation values. Although seemingly paradoxical, the result is quite intuitive. When the commercial value of an asset is low, its owner has a very weak bargaining position in negotiations with a conservation group, and hence, the asset owner has a strong motivation to improve its bargaining position by preparing the asset for commercial exploitation. Unfortunately, when this occurs, the initial commercial investment is completely wasted, and a part of the value associated with preserving the asset is destroyed.

Perhaps the primary message of this paper is best viewed as a cautionary note for entities that are devoted to protecting environmental assets from commercial development, and that must pursue their objectives through decentralized negotiations with property owners. The anticipation of such bargaining may induce a property owner to take actions that reduce the preservation value of the asset that is the focus of negotiations. This is most likely to occur when the commercial value of the asset is low relative to the value of preserving the asset in its natural state; when the lost preservation value associated with a preparatory investment is also low, and when the asset has truly unique (and consequently, highly valued) ecological characteristics so that its preservation has no close substitutes. When the commercial value of an asset is high enough, its owner already has a strong bargaining position and may not feel compelled to try and improve this position. Furthermore, since the property owner's compensation will be reduced if its anticipatory investment diminishes the preservation value of the asset, in some situations the property owner will find that investing in a stronger bargaining position actually reduces the compensation a conservation group would offer for preserving the asset. Lastly, when the preservation of a particular asset is viewed as a close substitute for the preservation of another, a conservation group is likely to have a credible walk-away threat that limits the ability of a property owner to improve its bargaining position.

Acknowledgements

This research was supported by the Cooperative State Research, Extension, and Education Service, U.S. Department of Agriculture, Massachusetts Agricultural Experiment Station, under Project No. MAS00777. Manuscript No. 3247. The author gratefully acknowledges the comments of two anonymous reviewers, as well as constructive input from Jerrell Richer during the early stages of this project.

Appendix A

Proof of Lemmas 1 and 2. First, let us consider whether the forester will build a road prior to bargaining. By assumption of both lemmas, $p_f > p_c^d$. Then, Eq. (12) and Eq. (13) imply that the forester chooses to build a road of the length that maximizes $p_f \alpha r - c(r)$ subject to $r \in [0, A/\alpha]$. The solution is the simple profit-maximizing road, r^π (recall Eq. (1)). Furthermore, the harvest agreement Eq. (10) allows the forester to harvest the prepared portion of the tract. But then, there is no point to bargaining because the forester and the conservation group end up receiving the values they would have received in the absence of a bargaining opportunity. Since, the externality associated with timber production implies that both parties would be better off with a cooperative agreement than without one, the forester decides to refrain from preparing a portion of the forest for timber production prior to negotiations.

Under the condition of Lemma 1 that $p_c^d < p_f$, from Eq. (2) and Eq. (5), a bargaining agreement between the two parties will specify that a road of length $r^* > 0$ will be built into the forest and $h^* = \alpha r^*$ acres will be put into timber production. Under the condition of Lemma 2 that $p_c^u \geq p_f$, the parties will agree to leave the entire forest undisturbed

Note: more direct (and longer) proofs of Lemmas 1 and 2 would compare the forester's payoffs when it does and does not build a logging road prior to bargaining. These proofs are available from the author upon request.

Proof of Lemma 3. Let us suppose at first that the forester refrains from building a road prior to bargaining. Then, from Eq. *(2)*, $p_{\mathrm{f}} < p_{\mathrm{c}}^{\mathrm{u}}$ implies that the parties will agree to leave the entire forest undisturbed. From Eq. (5), the total value of an agreement in this case is $V^0(r^*) = p_{\mathrm{c}}^{\mathrm{u}}A$. Using this and Eq. (6), the forester's payoff is

$$v_{\mathrm{f}}^0(r^\pi) = (1/2)[(p_{\mathrm{f}} + p_{\mathrm{c}}^{\mathrm{u}})\alpha r^\pi - c(r^\pi)]. \tag{A1}$$

If the forester builds a road prior to bargaining, since $p_{\mathrm{f}} < p_{\mathrm{c}}^{\mathrm{d}}$, Eq. (12) and Eq. (13) imply that the forester will choose the road length r^{t} to maximize $(1/2)[p_{\mathrm{c}}^{\mathrm{d}} + p_{\mathrm{f}}]\alpha r^{\mathrm{t}} - c(r^{\mathrm{t}})$ subject to $r^{\mathrm{t}} \in [0, \ A/\alpha]$. Thus, r^{t} is determined by the Kuhn–Tucker condition

$$(1/2)[p_{\mathrm{c}}^{\mathrm{d}} + p_{\mathrm{f}}]\alpha r^{\mathrm{t}} - c'(r^{\mathrm{t}}) \geq 0, \text{ if } > 0, \ r^{\mathrm{t}} = A/\alpha. \tag{A2}$$

The road has positive length because at $r^{\mathrm{t}} = 0$, $(1/2)[p_{\mathrm{c}}^{\mathrm{d}} + p_{\mathrm{f}}]\alpha r - c'(0) = (1/2)[p_{\mathrm{c}}^{\mathrm{d}} + p_{\mathrm{f}}]\alpha r > 0$. Although the forester builds a road of r^{t} length prior to bargaining, the harvest agreement that the parties come to, which is given by Eq. (10), does not allow it to harvest any timber. Thus, whether the forester builds a road prior to bargaining or not, no part of the forest will be used for timber production once an agreement is completed.

From Eq. (12), the forester's bargaining payoff when it builds a road prior to bargaining is $(1/2)[p_{\mathrm{c}}^{\mathrm{d}} + p_{\mathrm{f}}]\alpha r^{\mathrm{t}}$. Taking into account the cost of building the road, the forester's net payoff is

$$v_{\mathrm{f}}^{\mathrm{t}}(r^{\mathrm{t}}) - c(r^{\mathrm{t}}) = (1/2)[p_{\mathrm{c}}^{\mathrm{d}} + p_{\mathrm{f}}]\alpha r^{\mathrm{t}} - c(r^{\mathrm{t}}). \tag{A3}$$

Subtract Eq. (A1) from Eq. (A3) to obtain

$$v_{\mathrm{f}}^{\mathrm{t}}(r^{\mathrm{t}}) - c(r^{\mathrm{t}}) - v_{\mathrm{f}}^0(r^\pi) = \frac{(p_{\mathrm{f}} + p_{\mathrm{c}}^{\mathrm{d}})\alpha r^{\mathrm{t}}}{2} - \frac{(p_{\mathrm{f}} + p_{\mathrm{c}}^{\mathrm{u}})\alpha r^\pi}{2} - c(r^{\mathrm{t}}) + \frac{1}{2}c(r^\pi) \tag{A4}$$

The forester will build a road into the forest prior to bargaining if and only if Eq. (A4) is positive, and will refrain from doing so if it is negative.

Now, assuming interior values for the road lengths specified in Eq. (A4), use the quadratic cost function $c(r) = (\eta/2)(r)^2$ and the marginal conditions Eq. (1) and Eq. (A2) to obtain

$$r^\pi = \frac{\alpha p_{\mathrm{f}}}{\eta} \quad \text{and} \quad r^{\mathrm{t}} = \frac{\alpha(p_{\mathrm{f}} + p_{\mathrm{c}}^{\mathrm{d}})}{2\eta} \tag{A5}$$

Substitute r^π and r^{t} into Eq. (A4) to obtain

$$v_{\mathrm{f}}^{\mathrm{t}}(r^{\mathrm{t}}) - c(r^\pi) - v_{\mathrm{f}}^0(r^\pi) = \frac{(p_{\mathrm{f}} + p_{\mathrm{c}}^{\mathrm{d}})^2\alpha^2}{4\eta} - \frac{(p_{\mathrm{f}} + p_{\mathrm{c}}^{\mathrm{u}})^2\alpha^2}{2\eta} - \frac{p_{\mathrm{f}}(p_{\mathrm{f}} + p_{\mathrm{c}}^{\mathrm{d}})^2\alpha^2}{8\eta} + \frac{p_{\mathrm{f}}^2\alpha^2}{4\eta} = \frac{\alpha^2}{8\eta}[-p_{\mathrm{f}}^2 + p_{\mathrm{f}}(2p_{\mathrm{c}}^{\mathrm{d}} - 4p_{\mathrm{c}}^{\mathrm{u}}) + (p_{\mathrm{c}}^{\mathrm{d}})^2] \tag{A6}$$

Let $H(p_{\mathrm{f}}) = -p_{\mathrm{f}}^2 + p_{\mathrm{f}}(2p_{\mathrm{c}}^{\mathrm{d}} - 4p_{\mathrm{c}}^{\mathrm{u}}) + (p_{\mathrm{c}}^{\mathrm{d}})^2$ and note that

$$\mathrm{sign}[v_{\mathrm{f}}^{\mathrm{t}}(r^{\mathrm{t}}) - c(r^\pi) - v_{\mathrm{f}}^0(r^\pi)] = \mathrm{sign} H(p_{\mathrm{f}}) \tag{A7}$$

$H(p_{\mathrm{f}}) = -p_{\mathrm{f}}^2 + p_{\mathrm{f}}(2p_{\mathrm{c}}^{\mathrm{d}} - 4p_{\mathrm{c}}^{\mathrm{u}}) + (p_{\mathrm{c}}^{\mathrm{d}})^2$ has the following characteristics:

1. $H'(p_{\mathrm{f}}) = -2p_{\mathrm{f}} + (2p_{\mathrm{c}}^{\mathrm{d}} - 4p_{\mathrm{c}}^{\mathrm{u}}) < 0$ (recall that $p_{\mathrm{c}}^{\mathrm{u}} > p_{\mathrm{c}}^{\mathrm{d}}$);
2. $H(0) = (p_{\mathrm{c}}^{\mathrm{d}})^2 > 0$;
3. $H(p_{\mathrm{f}} = p_{\mathrm{c}}^{\mathrm{d}}) = p_{\mathrm{c}}^{\mathrm{d}}(2p_{\mathrm{c}}^{\mathrm{d}} - 4p_{\mathrm{c}}^{\mathrm{u}}) < 0$

Since the relevant domain of $H(p_{\mathrm{f}})$ is the closed interval $[0, \ p_{\mathrm{c}}^{\mathrm{d}}]$, these characteristics state that $H(p_{\mathrm{f}})$ is monotonically decreasing in p_{f}, its vertical intercept is positive and when $p_{\mathrm{f}} = p_{\mathrm{c}}^{\mathrm{d}}$, $H(p_{\mathrm{f}})$ is negative. These characteristics imply that there exists $\bar{p}_{\mathrm{f}}$ such that $H(\bar{p}_{\mathrm{f}}) = 0$; in fact, $\bar{p}_{\mathrm{f}}$ is the positive root of $H(p_{\mathrm{f}}) = -p_{\mathrm{f}}^2 + p_{\mathrm{f}}(2p_{\mathrm{c}}^{\mathrm{d}} - 4p_{\mathrm{c}}^{\mathrm{u}}) + (p_{\mathrm{c}}^{\mathrm{d}})^2$. Most significantly, the sign of $H(p_{\mathrm{f}})$ is the same as the sign of $(\bar{p}_{\mathrm{f}} - p_{\mathrm{f}})$, and hence, the sign of Eq. (A6) is the same as the sign of $(\bar{p}_{\mathrm{f}} - p_{\mathrm{f}})$. We conclude that the forester will build a road of length r^{t} prior to bargaining if and only if the per-acre timber value of the forest is less than $\bar{p}_{\mathrm{f}}$.

Proof of Corollary 1. From the proof of Lemma *3*, $\bar{p}_{\mathrm{f}}$ is the positive root of $H(p_{\mathrm{f}}) = -p_{\mathrm{f}}^2 + p_{\mathrm{f}}(2p_{\mathrm{c}}^{\mathrm{d}} - 4p_{\mathrm{c}}^{\mathrm{u}}) + (p_{\mathrm{c}}^{\mathrm{d}})^2 = 0$, and therefore, we can write $\bar{p}_{\mathrm{f}}$ as a function of $p_{\mathrm{c}}^{\mathrm{u}}$ and $p_{\mathrm{c}}^{\mathrm{d}}$; that is $= p_{\mathrm{f}}(p_{\mathrm{c}}^{\mathrm{u}}, p_{\mathrm{c}}^{\mathrm{d}})$. Note that $H(\bar{p}_{\mathrm{f}}) = -(\bar{p}_{\mathrm{f}})^2 + \bar{p}_{\mathrm{f}}(2p_{\mathrm{c}}^{\mathrm{d}} - 4p_{\mathrm{c}}^{\mathrm{u}}) + (p_{\mathrm{c}}^{\mathrm{d}})^2 \equiv 0$. Differentiate $H(\bar{p}_{\mathrm{f}})$ with respect to $p_{\mathrm{c}}^{\mathrm{u}}$ and rearrange the result to obtain $\partial\bar{p}_{\mathrm{f}}/\partial p_{\mathrm{c}}^{\mathrm{u}} = 4\bar{p}_{\mathrm{f}}/(2p_{\mathrm{c}}^{\mathrm{d}} - 4p_{\mathrm{c}}^{\mathrm{u}} - 2\bar{p}_{\mathrm{f}}) < 0$, the sign of which follows because $p_{\mathrm{c}}^{\mathrm{u}} > p_{\mathrm{c}}^{\mathrm{d}}$. Now, differentiate $H(\bar{p}_{\mathrm{f}})$ with respect to $p_{\mathrm{c}}^{\mathrm{d}}$ and rearrange the result to obtain $\partial\bar{p}_{\mathrm{f}}/\partial p_{\mathrm{c}}^{\mathrm{u}} = -2(\bar{p}_{\mathrm{f}} + p_{\mathrm{c}}^{\mathrm{d}})/(2p_{\mathrm{c}}^{\mathrm{d}} - 4p_{\mathrm{c}}^{\mathrm{u}} - 2\bar{p}_{\mathrm{f}}) > 0$. Again, the sign of $\partial\bar{p}_{\mathrm{f}}/\partial p_{\mathrm{c}}^{\mathrm{u}}$ follows because $p_{\mathrm{c}}^{\mathrm{u}} > p_{\mathrm{c}}^{\mathrm{d}}$.

Proof of Corollaries 2 and 3. When $p_{\mathrm{c}}^{\mathrm{d}} = 0$, $H(p_{\mathrm{f}}) = -p_{\mathrm{f}}^2 - 4p_{\mathrm{f}}p_{\mathrm{c}}^{\mathrm{u}} < 0$, and $H'(p_{\mathrm{f}}) = -2p_{\mathrm{f}} -$

$4p_c^u < 0$. Therefore, when $p_c^d = 0$, the forester will never prepare a portion of the forest for harvest prior to negotiations. On the other hand, when $p_c^d = p_c^u$, $H(p_f)$ has exactly the same characteristics as when $p_c^d \in (0, p_c^u)$. Therefore, when $p_c^d = p_c^u$, the existence of $\bar{p}_f \in (0, p_c^u)$ is guaranteed.

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