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INSTRUMENTS FOR FOREST HABITAT CONNECTIVITY[†]

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SUMMARY

In places such as the boreal forest of Northern Alberta, where demands for energy and forest products are growing, it is necessary to balance economic development activities on the land with the environmental services the land can provide. Wildlife habitat for species such as woodland caribou is one such service. If adequate habitat for species such as woodland caribou is to be maintained, both the quantity of habitat and its configuration matter. Woodland caribou are in decline partly due to habitat fragmentation. For that species, connections between patches of mature forest are crucial to sustaining viable populations. To ensure continued provision of woodland caribou habitat, it is necessary to develop and use some set of regulatory instruments that will limit overall disturbance and preserve a degree of connectivity among mature parcels. The purpose of this report is to present some economic experimental results on a regulatory mechanism that is a combination of tradable disturbance permits and a procurement auction for connectivity, and compare it with the alternative of a stricter cap on disturbance permits. The usual argument is that the latter approach is less costly. We show that, although the combination mechanism can create significant transaction costs, it is not necessarily the more costly approach.

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INTRODUCTION

On September 1, 2012, the first of the regional land-use plans falling under the Alberta Land Stewardship Act, The Lower Athabasca Regional Plan (LARP), came into force. A main purpose of the land-use plans is to balance economic development activities on the land with the environmental services the land can provide. Nowhere is the conflict between economic development and environmental services more immediate than in the lower Athabasca Region in northeastern Alberta, where oilsands development and forestry are important industries, and mature boreal forest provides the public good of habitat for a variety of species including dwindling populations of woodland caribou. When demands for energy and forest products are growing, some limit must be placed on the disturbance caused by these activities. If an adequate habitat for species such as woodland caribou is to be maintained, both the quantity of habitat, and its configuration, matter. Woodland caribou numbers are in decline, partly due to habitat fragmentation. For that species, connections between patches of mature forest are crucial to sustaining viable populations. To ensure continued provision of woodland caribou habitat, it is necessary to develop and use some set of regulatory instruments that will limit overall disturbance and preserve a degree of connectivity among mature parcels.

The purpose of this report is to present a regulatory mechanism that is a combination of tradable disturbance permits and a procurement auction. Tradable disturbance permits (TDPs) are often recommended as a way to limit development disturbance that reduces the amount of mature forest habitat, while allowing industry flexibility, which minimizes profit lost due to the limitation. However, the flexibility that TDPs allow for disturbance location will not necessarily prevent fragmentation. Either the aggregate disturbance limitation must be stricter, or an additional mechanism to encourage connectedness among undisturbed parcels is required. Both approaches will restrict development and impose costs. It has been suggested that it is less costly to place a stricter limit on total allowed disturbance than to manipulate the configuration of disturbance.[1] This may be true in some circumstances, due to the lower administrative or transaction costs of the stricter cap, but it is not always true.[2] Because it only indirectly regulates connectivity, the stricter cap has greater efficiency costs. Both efficiency and transaction costs matter in the comparison.[3] We consider the use of a procurement-auction mechanism that can be combined with TDPs to buy connectivity among undisturbed forest parcels. In a laboratory setting, we consider both whether sustained connectivity among mature forest parcels can be created using the mechanism, and how costly it is.

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[1] M. Weber and W. Adamowicz, "Tradable Land Use Rights for Cumulative Environmental Effects Management," *Canadian Public Policy* 28(4) (2002): 581-595.

[2] Transaction costs are the costs of participating in a market. There are various types of transaction costs including search and information costs, negotiation costs, and enforcement costs. See C.J. Dahlman, "The Problem of Externality," *Journal of Law and Economics* 21(2) (1979): 141-162.

[3] In a related area, there is a growing literature devoted to new ways of regulating the spatial effects of air and water pollution to achieve efficiency cost savings without incurring excessive transaction costs. For example, see M.F. Hung and D. Shaw, "A Trading-Ratio System for Trading Water Pollution Discharge Permits," *Journal of Environmental Economics and Management* 49(1) (2005):83-102; and M. Fowlie and N. Muller, "Designing Markets for Pollution when Damages Vary Across Sources," Department of Agricultural Economics, University of California Berkeley, 2010, http://are.berkeley.edu/~fowlie/Fowlie_draft_march_2012_correct.pdf.

Procurement auctions for ecosystem preservation are already being used to reduce the cost of paying for preservation, but not in combination with TDPs or in a dynamic forest habitat. Because forests are dynamic, a disturbance need not permanently reduce the quantity of mature forest habitat, TDPs need not be held permanently, and the spatial pattern of mature forest patches on the landscape will change through time. We use economic experiments to investigate the workability of the combined auction-TDP mechanism in a dynamic forest environment. We find that it is possible for the regulator to use a procurement auction to sustain connectivity among mature patches, but that the mechanism does have substantial transaction costs. Uncertainty about permit prices, the potential for "winner's curse" in the auction, a lack of competition among auction bidders, and disputes among joint bidders all contribute to the transaction costs. Nevertheless, the auction-TDP system is not necessarily more costly than using a stricter TDP cap to achieve the same goal.

The paper is organized as follows. The next section provides some background on Alberta's boreal forest and the LARP. The following section reviews the literature on TDPs and payments for ecosystem services, and presents our combination of the two. We then present experiments on the combination instrument and provide conclusions.

ALBERTA'S BOREAL FOREST AND LARP

The Lower Athabasca Regional Plan (LARP) covers the northeastern part of Alberta, including numerous oilsands leases, the large Al-Pac Forest Products Forest Management Area (FMA), and much of Alberta's woodland caribou habitat.[4] Oil and gas and forestry developments have considerable impact on the boreal forest, creating concerns about ecological integrity.

Most of the productive forest resources are currently managed by large, integrated forest companies under long-term Forest Management Agreements (FMAs). FMAs are rights to the use of the land and are given for a 20-year term, renewable for a further 20. While the FMAs are often large, they are overlain by timber quotas and commercial timber permits. These add to the intensity of timber utilization. In addition, oil and gas companies are allocated leases on the same lands.[5] The multiplicity of uses on one tract of land, combined with the tendency to regulate them separately, increases the cumulative ecologic impact on that land.

A system of TDPs would set a cap on the number of hectares allowed to be disturbed (harvested or used for energy operations) within a given time period. To operate on the land, a timber harvester or energy company would have to have existing resource rights, plus disturbance permits to cover the area disturbed by its operations. When there are multiple

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[4] For a map of the area covered by the Lower Athabasca Region see LARP Lower Athabasca Regional Plan 2012-2022 Map (Schedule G), accessed August 30, 2012, https://www.landuse.alberta.ca/SiteCollectionDocuments/LARP%20Lower%20Athabasca%20Regional%20Plan%20 2012-2022%20Map%20-%202012-08.pdf.

[5] M. Ross, "Legal and Institutional Responses to Conflicts Involving the Oil and Gas and Forestry Sectors," CIRL Occasional Paper #10, January 2002, accessed August 22, 2012, http://dspace.ucalgary.ca/bitstream/1880/47199/1/OP10Conflicts.pdf.

disturbers on a given area of land, integrated planning might reduce the number of disturbance permits required. For example, a timber harvesting company could salvage timber from an energy operator holding disturbance permits.[6] Permit trading allows scarce permits to go to the highest valued use, with land that is less valuable for timber or energy left undisturbed. When a disturbance ends, the land can be rehabilitated, and can again be counted as mature (undisturbed) forest. The location of the disturbance is driven by use value. If it is the aggregate amount of mature land that is important, then trading simply maximizes the value obtained from the allowed amount of disturbance.

In its goals for establishing new conservation areas, the LARP makes it clear that connectivity of habitat matters, as well as the aggregate amount.[7] For woodland caribou, larger areas of contiguous mature forest are most desirable. Although the greater the quantity of mature forest preserved, the greater the likelihood of large contiguous patches, in fact, woodland caribou habitat is often a matrix of high-quality, mature patches embedded within areas of lesser-quality habitat, and the connectivity among the high-quality patches is crucial.[8] The conservation of remaining woodland caribou populations requires land management strategies that not only sustain larger areas of mature forest but also favour connectivity.[9]

The LARP addresses these concerns by creating six new conservation areas.[10] There is some overlap with oilsands projects in the region. While conventional oil and natural gas tenures will be honoured in the new conservation areas, no oilsands development will be allowed unless surface disturbance is avoided, and a number of energy companies will have their leases cancelled, with negotiated compensation promised for costs incurred. Energy companies have expressed concern about the compensation limit, and have suggested other approaches, such as trading one piece of land for another outside the conservation zone.[11] The LARP also states that a regional landscape-management plan, which could include biodiversity offsets (a mechanism very similar to TDPs) as a management tool, will be developed for the public land in the boreal forest area by the end of 2013. The LARP approach bears some similarity to our auction-TDP approach, except that the auction is replaced with negotiation, and the TDP system is unlikely to be in place before the buyout of leases occurs.

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[6] To reduce the cumulative petroleum and forestry impacts over its entire FMA, Al-Pac has integrated its harvesting with areas being used for bitumen development. See C. Aumann, D.Farr and S. Boutin, "Multiple Use, Overlapping Tenures, and the Challenge of Sustainable Forestry in Alberta," *Forestry Chronicle* 83 (2007): 642-650.

[7] Government of Alberta, *Lower Athabasca Regional Plan* 2012-2022. (https://www.landuse.alberta.ca/RegionalPlans/LowerAthabascaRegion/)

[8] D. O'Brien et al., "Testing the Importance of Spatial Configuration of Winter Habitat for Woodland Caribou: An Application of Graph Theory," *Biological Conservation* 130 (2006): 70-83.

[9] Wittmer et al. suggest that this is because young forest attracts alternate prey (e.g. moose and deer), which in turn attract more predators. Home ranges of caribou killed by predators had lower proportions of older forest. See H.U. Wittmer et al., "Changes in Landscape Composition Influence the Decline of a Threatened Woodland Caribou Population," *Journal of Animal Ecology* 76 (2007): 568-579.

[10] See Note 8 above, and Pembina Institute, *Lower Athabasca Regional Plan (LARP): Performance Backgrounder,* August 22, 2012. (http://www.pembina.org/pub/2367)

[11] See Canadian Association of Petroleum Producers, "Alberta's Lower Athabasca Regional Plan," April 5, 2011, accessed August 23,2012, http://www.capp.ca/aboutUs/mediaCentre/issues/Pages/LARP2011.aspx; and Keith Gerein, "Plan Could Cancel 19 Oilsands Leases: Compensation for Lost Profits a Complex Issue," *Calgary Herald*, August 23, 2012, http://www.calgaryherald.com/business/energy-resources/Plan+could+cancel+oilsands+leases/7132388/story.html

REVIEW OF INSTRUMENTS

Tradable Disturbance Permits

The purpose of biodiversity offsets, or tradable disturbance permits (TDPs), is to limit aggregate development disturbance on wildlife habitat and biodiversity. A TDP system has been explored for Alberta's boreal forests.[12] A cap would be placed on the amount of disturbance allowed. Disturbance permits, summing to that amount of disturbance, would be allocated, either by auction or gratis, and permit trading would be allowed. Trading allows the limited number of permits to be used in the locations where they generate the most profit for developers. If there is concern that not all habitat types are equivalent, it is possible to divide the cap into more than one habitat type with permits for each.[13] TDPs would have a limited duration, perhaps 20 years, to accommodate forestry and energy developments. As existing TDPs expire, they can be replaced by newly issued ones, although care must be taken to ensure that the disturbance cap is not violated. But, unless the TDP limit is sufficiently restricted, trade is restricted, or the system is supplemented by some other incentive mechanism, the spatial pattern of protection will not necessarily provide the desired degree of connectivity.[14]

Connectivity Instruments

Given that neighbouring undisturbed parcels promote connectivity better than an equivalent area of dispersed parcels, there needs to be some incentive associated with maintaining a set of neighbouring sites in a mature state. Sometimes it is recommended that this be done through trading rules, but these can become very complex. A disturbance permit for a parcel neighbouring other mature parcels should cost more than a disturbance permit for a parcel without such neighbours. This interdependence creates difficulties because it requires market co-ordination. Zoning, or set-aside preserves, are another alternative. Often, these are proposed as an alternative to TDPs and have a permanent location.

Some research has been done on payments for grouping together (agglomeration) of undisturbed sites, in absence of transferable disturbance permits. The problem is typically addressed as a static co-ordination problem.[15] In an experimental setting, landowners/agents are paid a flat fee to set aside land for conservation purposes. Parkhurst et al. introduced an agglomeration bonus for players setting aside contiguous plots in certain spatial arrangements.[16] An agent's payoff depended partly on other agents' choices. The experiment

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[12] J. Grant, S. Dyer, D. Droitsch and M. Huot, *Solving the Puzzle: Environmental Responsibility in Oilsands Development*, The Pembina Institute, http://www.pembina.org/pub/2210.

[13] See Note 2 above.

[14] S. Wissel and F. Wätzold, "A Conceptual Analysis of the Application of Tradable Permits to Biodiversity Conservation," *Conservation Biology*. 24(2) (2010): 404-411.

[15] G. M. Parkhurst et al., "Agglomeration Bonus: An Incentive Mechanism to Reunite Fragmented Habitat for Biodiversity Conservation," *Ecological Economics* 41 (2002): 305-328; G. M. Parkhurst and J. F. Shogren, "Spatial Incentives to Coordinate Habitat," *Ecological Economics* 64(2) (2007): 344-355; T. Warziniack, et al., "Creating Contiguous Forest Habitat: An Experimental Examination on Incentives and Communication," *Journal of Forest Economics* 13 (2-3) (2007): 191–207.

[16] See Note 16 above.

was static in that there was only one decision point. Iteration and pre-play communication were used as mechanisms to provide the information that private landowners need to co-ordinate their actions. The agglomeration bonus worked well in a static environment, with repeated play and/or pre-play communication. Communication among landholders resulted in higher levels of efficiency sooner than those prohibited from communicating.

While most studies have simply used a fixed payment with an agglomeration bonus for set-aside land, some recent ones have introduced scored procurement (or reverse) auctions. Greater connectivity gives a greater score, and the score helps determine the winners. The scored reverse auction has been used in Australia to encourage the preservation of native vegetation and wetlands.[17] Rolfe, Windle and McCosker used a scored reverse auction with multiple bidding rounds to maintain remnant vegetation patches with connectivity among the patches.[18] There was an opportunity for communication among bidders between rounds. Their results suggest that multiple bidding rounds have potential to deliver efficiency gains (reduced cost per unit of environmental benefit) in conservation auctions. Reeson et al. also used a scored reverse auction with multiple bidding rounds.[19] At the end of a round, the participants were shown the results and given the opportunity to modify their bids by changing the price and/or the particular parcel of land offered. The auctions were run for up to four rounds. The purpose of multiple rounds was to allow landowners to gain information that would enable them to more easily co-ordinate the land parcels offered. On the other hand, acquiring information enables bidders to engage in rent-seeking. Hence, the price to the regulatory authority may rise with repeated rounds. They did find rent-seeking to be a problem in repeated auctions when landholders were able to benefit from knowledge of the actions of their neighbours, but they countered this by preventing provisionally successful bids from being altered between rounds. In a similar experiment, Banerjee, Shortle and Kwasnica use a reverse auction approach with multiple rounds, and show that rent-seeking increases with information.[20]

A related literature exists in the use of incentive mechanisms for the control of non-point source pollution. The problem with non-point source pollution is that an individual agent's emissions cannot be observed. Hence, instruments such as a group fine, which has each agent pay a tax based on an aggregate measure of ambient environmental quality, are used. The overall tax paid by an agent will depend on the pollution caused by all agents. Much of the experimental literature in this area has been based on a non-co-operative model with no communication among agents. This was largely because the theory was based on such a model.[21]

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[17] G. Stoneham et al., "Auctions for Conservation Contracts: An Empirical Examination of Victoria's Bush Tender Trial," *Australian Journal of Agricultural and Resource Economics* 47 (4) (2003): 477-500; M. Hill et al., "A Reverse Auction for Wetland Restoration in the Assiniboine River Watershed, Saskatchewan," *Canadian Journal of Agricultural Economics* 59(2) (2011): 245-258; T. Cason and L. Gangadharan, "A Laboratory Comparison of Uniform and Discriminative Price Auctions for Reducing Non-point Source Pollution," *Land Economics* 81 (1) (2005): 51-70.

[18] J. Rolfe et al., "Testing and Implementing the Use of Multiple Bidding Rounds in Conservation Auctions: A case Study Application," *Canadian Journal of Agricultural Economics* 57 (2009): 287-303.

[19] A. F. Reeson et al., "Adaption Auctions for the Provision of Ecosystem Services at the Landscape Scale," *Ecological Economics* 70 (2011): 1621-1627.

[20] S. Banerjee et al., "Agglomeration Bonus in Local Networks: A Laboratory Examination of Spatial Coordination Failure," Stirling Economics Discussion Paper, 2011-18 (2011) https://dspace.stir.ac.uk/handle/1893/3477.

[21] K. Segerson, "Uncertainty and Incentives for Non-Point Source Pollution," *Journal of Environmental Economics and Management* 15 (1988): 87-98.

However, recently there have been a couple of papers that have introduced communication and co-operation. Vossler et al. tested two instruments with and without communication: a fixed group fine and a marginal tax-subsidy instrument.[22] The group fine comes into effect when aggregate pollution exceeds some specified level. With communication, agents were able to co-ordinate their actions to keep the aggregate pollution just under the level at which the fixed fine would be applied. Without communication, pollution frequently exceeded the standard. The marginal tax/subsidy instrument was a fixed tax per unit of pollution and the marginal tax paid by each agent was not affected by the actions of other agents. Since the optimal amount of pollution can be attained by agents making independent decisions, communication is not needed to avoid excess pollution. However, in this case there was collusion in the output market, resulting in less than the optimal amount of pollution. Suter et al. also introduced communication, with a fixed, competitive market price.[23] They conclude that when firms cannot collude to influence price, communication promotes the achievement of the social optimum, and the regulator can treat the regulation problem as one in which only one agent (the group of polluters) is being regulated.

Tradable Disturbance Permits plus an Auction for Connectivity

The problem we address is a bit different from much of the earlier literature on auctions involving bonuses for agglomeration of preserved or rehabilitated parcels. Our problem is one of co-ordination in a dynamic framework. It is motivated by the need to manage landscape disturbances in a forested area like the lower Athabasca region. In a stylized version of the problem, a larger forested landscape is made up of a set of parcels owned (or under long-term lease) and managed by different private forest owners/managers. There are two possible ages for the stand of trees on each parcel, young and mature. Harvesting timber is assumed to be the only possible disturbance activity. Mature forest is treated as undisturbed, harvesting is the disturbance, and a parcel of young forest is treated as disturbed forest. Forest harvested (disturbed) in the current time period will be young (disturbed) in the next time period, but, if not harvested, will grow to be mature (undisturbed) by the end of that time period (or equivalently the beginning of the next time period). In our stylized example, disturbance permits are harvest permits. The length of a time period is taken to be about 20 years. Harvesting takes place at the end of a time period. If harvesting takes place at the end of the first time period, the land will still be young forest in the second time period, but will be mature by the end of the second time period or the beginning of the third time period, at 20 years.[24] Similarly, if harvest takes place at the end of the fifth time period, the forest will again be mature at the end of the sixth time period, when the land is sold. The regulator's goal is to maintain a specified number of parcels of unharvested mature forest (greater than 20 years) for at least one period, with some of this mature forest being spatially arranged to provide connectivity in the form of a wildlife corridor. The regulator requires that the corridor be permanent in the sense that a corridor must exist in all of the six time periods, although it need not been in the same location.

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[22] C. A. Vossler et al., "Communication and Incentive Mechanisms Based on Group Performance: An Experimental Study of Nonpoint Pollution Control," *Economic Inquiry* 44 (2006): 599-613.

[23] J.F. Suter et al., "Experiments on Damage-Based Ambient Taxes for Nonpoint Source Polluters," *American Journal of Agricultural Economics* 90(1) (2008): 86-201.

[24] For a range of possible rotation ages for the boreal forest see C. G. van Kooten, C. S. Binkley and G. Delcourt, "Effect of Carbon taxes and Subsidies on Optimal Forest rotation Age and Supply of Carbon Services," *American Journal of Agricultural Economics* 77(2) (1995): 365-374.

The first part of this goal is achieved by issuing a limited number of TDPs. The second is achieved through the regulator paying a group of three parcel owners to enter into a contract to provide a wildlife corridor consisting of a column of three parcels of mature forest left unharvested for one time period. The payment is determined through a reverse auction, with a pre-specified split of the winning bid among group members. There is a penalty if an awarded contract is not honoured.

In the auction literature, joint bidding has a positive and a negative aspect. The positive aspect reflects complementarities among bidders. The negative aspects are the transaction costs associated with negotiating a joint bid, and the potential for collusion. Parcel owners have the goal of maximizing their individual profit, where profit can come from harvesting timber, selling a harvesting/disturbance permit, or being part of a group that obtains a contract to provide a wildlife corridor. Since the harvested timber is sold on a perfectly competitive market, there is no possibility of collusion to restrict output to raise price. Since it is difficult to know who will be buying or selling permits at any given time, collusion in that market is also difficult. On the other hand, there is some evidence of a lack of competition pushing up bids for the corridor. But, as the three parcels are perfect complements and co-ordination along the three parcel owners is necessary to produce a wildlife corridor, we expect the co-ordination benefit of communication to offset the cost of reduced competition.

EXPERIMENTS USING THE COMBINATION INSTRUMENT

The Greater Forest Landscape

The greater forest landscape at the beginning of the initial time period contains 12 to 18 parcels of land, all containing mature forest. The 12-parcel version is shown in Figure 1. Parcels in the middle row are of high quality (H) and produce timber that, when mature, has a harvest value of \$35. The parcels in the second and third columns and the first and third rows grow average-quality timber (A) with a mature harvest value of \$30. The remaining mature parcels grow low-quality timber (L) with a mature harvest value of \$25.[25] The harvest value of all young timber is \$10. There are six rounds in which parcels can be harvested or not. At the end of the sixth round, or the beginning of the seventh, the land is sold to the regulator, with the sale price paid to the plot owner being larger for mature forest than for immature forest. For H parcels, the mature and young sale values are \$85.70 and \$65.90; for A parcels they are \$73.46 and \$56.49; and for L parcels they are \$61.10 and \$47.10.[26]

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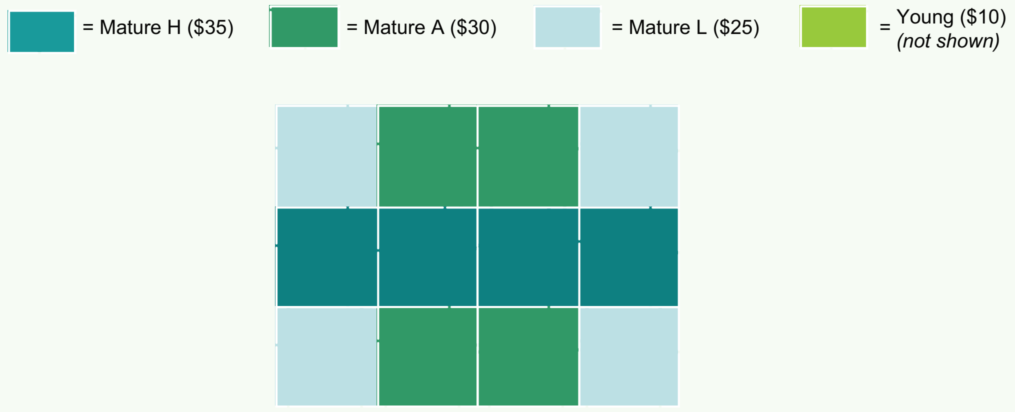
[25] In some experiments the number of parcels was 15 or 18. The 15-parcel landscape was achieved by adding a middle column to the 12-parcel landscape, with the middle column having the same harvest values as those on either side of it. The 18-parcel landscape was achieved by adding two columns to the 12-parcel landscape, one on the far left and one on the far right. These two columns had the same harvest values as their immediate neighbours.

[26] The final land-sale values are the present discounted value of the land used only for optimally timed forest harvests. A high discount rate of 30 per cent is used to prevent the final land-sale values from completely dominating harvest or corridor payments within the first six rounds. Although subjects may use their own discount rates in the first six rounds, no mention is made of discounting in the treatments.

First, consider the optimal harvest plans in an unrestricted regulatory environment. In the absence of any restrictions on harvesting, all 12 parcels would be harvested initially (in the first round), and again in the third and fifth rounds. All parcels would contain mature trees at the end of the sixth round. The unrestricted harvest value of the 12-parcel landscape is V_{HU} = \$1961.04. For a 15-parcel landscape it is V_{HU} = \$2476.66 and, for an 18-parcel landscape, it is V_{HU} = \$2886.84.

FIGURE 1: THE GREATER FOREST LANDSCAPE AT THE BEGINNING OF THE INITIAL ROUND



* A potential corridor is a mature column in the current time period that is maintained for an additional time period.

Tradable Disturbance Permits

Now consider a TDP system with fewer parcels having the right to harvest. Suppose we have a landscape of 12 parcels and a TDP system in which four harvest permits are allocated randomly in each of six rounds.[27] Regardless of the initial allocation of TDPs, with efficient trading the after-trade allocation of the permits would be to the middle row of H parcels where they generate the most harvest value, \$35 in each of the four parcels. These plots are then harvested, generating a total harvest value of \$140 for the round. At the beginning of the second round, all plots harvested in the initial round will contain young forest. Harvest permits are again allocated randomly, and the after-trade allocation should see four permits go to mature A parcels, each with a \$30 harvest value. The total harvest value in this round is \$120. In the third round, the after-trade allocation will again go to the four H parcels, and in the fourth round to four A parcels. These after-trade allocations and harvest patterns repeat for the fifth and sixth rounds. At the end of the sixth round all H and L plots will be mature, and all A plots will be young. The maximum harvest value that can be generated is three rounds of \$140, three rounds of \$120, plus the final sale value of all 12 plots. With efficient trading, the maximum harvest value is V_{HTDP} = \$1593.16, and the loss due to the four harvest permit restriction is $V_{HU} - V_{HTDP}$ = \$367.88. For the 15-parcel landscape with five permits, the loss is $V_{HU} - V_{HDP}$ = 2476.66 - 2003.80 = \$472.86, and for 18-parcel landscape and six permits, it is $V_{HU} - V_{HDP}$ = 2886.64 - 2340.96 = \$545.86.[28]

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[27] Four harvest permits were issued for the 12-parcel landscape, and six for the 18-parcel landscape.

[28] There were no corridor experiments for the 15-parcel landscape, so it is not discussed further.

Connectivity: A Wildlife Corridor

Now suppose the regulator wants to ensure connectivity through a wildlife corridor consisting of one column of mature forest. In our stylized model, it is assumed that there is high-quality caribou habitat both north and south of the landscape, and the purpose of the corridor is to connect the north and south habitats. In Figure 1, the four columns provide four possible locations for the corridor. All four locations are equivalent in terms of habitat benefits, but the costs to the landowners who supply them can differ.

One way to achieve this is to reduce the number of permits for the 12-parcel landscape to three. With only three permits, all four columns cannot be harvested at once, and, as only one time period is required for a parcel to return to mature forest, there will always be a column of mature forest. The harvest value becomes $V_{HTDP3} = 3\big(4(35) + 2(30)\big) + 3(86.7) + 65.9 + 2(56.49) + 2(73.46) + 4(61.1) = \$1427.30$. It will be either the rightmost or leftmost column that is left unharvested, minimizing the cost of restricting the number of permits. The total loss from the three-permit restriction on the 12-parcel landscape is $V_{HU} - V_{HTDP3} = 1961.04 - 1477.30 = \$533.74$. On an 18-parcel landscape, a five-permit restriction is required to maintain a corridor. In this case the loss is $V_{HU} - V_{HTDP3} = 2886.84 - 2199.19 = \$687.65$.

Alternatively, suppose that on the 12-parcel landscape we leave the number of permits at four, and instead restrict the locations where the permits may be used. There will still be an after-trade harvesting pattern in which four parcels are harvested each round. However, the pattern of harvest will be changed by the corridor. The best locations for the corridor are the ones that reduce the value of harvest the least; the leftmost or rightmost columns of the landscape.[29] If the corridor is in one of these two columns, the harvesting pattern will be: three H parcels and one A parcel in rounds one, three and five; and three A parcels and one L parcel in rounds two, four and six. This pattern generates a maximum harvest value of three rounds of \$135, three rounds of \$120, plus the land sale value of all 12 plots, giving a total value of $V_{HTDPC} = 3\big(3(35) + 4(30) + 25\big) + 4(85.7) + 73.46 + 3(56.49) + 47.1 + 61.1 = \$1566.13$. Subtracting this from the harvest-plus-land-sale-value of the landscape, with no restrictions, gives the loss from the TDP-corridor combination as $V_{HU} - V_{HTDPC} = 1961.04 - 1566.13 = \$394.91$.[30] With an 18-parcel landscape, the restriction is six permits and a corridor. The loss for the larger landscape is $V_{HU} - V_{HTDPC} = 2886.84 - 2313.93 = \$572.91$.

The losses calculated in the previous paragraph are the combined loss for the corridor and the permit restrictions. Attributing a part of the loss to the corridor and a part of it to the TDP restriction can be difficult because of interaction between the two. However, a maximum loss for the corridor portion can be determined by considering the case in which the corridor requirement is imposed with no TDP system in place or anticipated. A permit holder on a potential corridor parcel cannot reduce her loss by selling the permit. Nor would the harvest

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[29] With the 18-parcel landscape, the least-cost corridor can shift between the rightmost and leftmost columns every two time periods. With the 12-parcel landscape, once one of the two columns is chosen, switching cannot occur without increasing costs. The degrees of freedom are too few.

[30] The next-best corridor locations are the middle two columns. A corridor in either of these locations, or a combination of them, would yield a harvest value of \$1,542.07 and a loss from the corridor of \$418.97.

profit of a parcel owner be reduced by having to buy a permit. The cost of the corridor is simply the lost harvest profit for the three parcels that constitute the corridor. This cost will be smallest if either the rightmost or leftmost column become the corridor. For either of these columns there will be a forgone harvest profit of 25+35+25=$85 every second time period. The loss will be shared among parcel owners in a corridor according to their relative harvest revenue, and will total to $255 over six time periods. If the TDP system is then imposed, the additional loss will be 394.91-255=$139.91 for four permits on the 12-parcel landscape, or 572.91-255=$317.91 for six permits on the 18-parcel landscape.

If the TDP system is already in place, there will be positive prices for permits. When the permits have positive prices because of a TDP system, a permit holder on a potential corridor parcel could gain revenue from selling the permit, making the harvesting option less profitable relative to the corridor option. Similarly, a parcel owner without a permit would have to buy a permit to harvest, making the harvest option less valuable relative to the corridor option. For example, with a permit price of $30, an L-parcel owner would always sell (or not buy) a permit to harvest, experiencing no loss from being part of a corridor. With positive permit prices, the loss from the corridor should be less.

In our experiment, with a TDP system in place, we ask a group of parcel owners in a column to assess their joint cost of giving up their right to harvest for one time period. In general, this cost will depend on the initial allocation of permits, on prices in the permit market, and on transaction costs. Since corridors must be jointly supplied, there is no habitat value to the corridor unless all three parcels in a column are left mature by the landowners. The previous literature has treated this as a co-ordination problem, and allowed multiple decision rounds for individual landowners to align their decisions. Instead we assign the three landowners in each column to a group and allow them to communicate with each other to decide what compensation they require to jointly give up their harvesting rights. The goal is to have a corridor provided in all six rounds of the experiment, although the location may change.

A procurement auction will be used to determine the allocation of the corridor contract and the required compensation to the group that wins the auction. The fact that TDP trading is unlikely to be efficient means that corridor-contract costs are uncertain to the regulator and to individual parcel owners. This makes an auction a useful method of allocating the corridor contract, but it also means that the auction will have aspects of a common value auction, with the related problem of winner’s curse. This is a problem both to the parcel owner, whose share of her group’s bid turns out to be less than the corridor contract will cost her, and to the regulator, who risks not having a wildlife corridor when the parcel owner reneges on the contract.

Participants in an auction can have private or common values for the item on which they are bidding. Private values are known with certainty, but vary across bidders. In our case, the harvest values are known by the parcel owners, but vary across parcels. The common value component is the effective price at which permits can be bought or sold. Because of inefficiencies in the permit market, different parcel owners, and therefore different groups, may have different assessments of the permit price. Each group will make an assessment of permit prices and costs over its three parcels. If one group’s prior assessment of the permit price is high, that group will bid a smaller amount for the corridor than another group whose assessment is low. If the auction winner is the lowest bidder and the realized permit price is lower than the prior assessment, there is the possibility of winner's curse. For example, consider a group with a potential permit seller who makes a relatively high assessment of the effective permit price. At that member's urging, the group then makes a low corridor bid, and wins the corridor. If the realized effective permit price is lower, the permit seller will wish her group had made a higher corridor bid and may renege on the contract. Similarly, a potential buyer, expecting a high permit price, would urge her group to make a low corridor bid. A lower realized permit price would mean a greater than expected harvest profit and the corridor bid turns out to be too low. Again, the corridor would be reneged on.

In the next section, before introducing the corridor, we describe the experimental treatments (the baseline treatments) that were used to assess the efficiency of permit trading in absence of a corridor.

The Experiment: Baseline Treatments

The baseline treatments involved only the initial permit allocation and trading.[31] There was a dual purpose for the baseline treatments. First, they enabled the participants to gain experience with permit trading before the corridor auction was introduced. Second, they gave an assessment of the degree of inefficiency in the pure permit market. Permits could be bought/sold only once per round. They were traded in a double auction at prices set via bilateral transactions. Trades can and do take place at different prices. The baseline treatments were done with 18, 15, or 12 parcels.

Table 1 below shows the results for the baseline treatments. Trading resulted in 0.76 to 0.97 of the maximum harvest value being obtained in the baseline treatments, with an average of 0.88 and a standard deviation of 0.06. Including the land-sale value resulted in 0.89 to 0.99 of the maximum harvest-plus-land-sale value being obtained in the treatments. On average, 0.94 of the maximum value was obtained, with a standard deviation of 0.03. As would be expected, actual harvest profits tend to be a lower fraction of optimal harvest values than the fraction of actual land values to optimal land values. There is also more variation in the harvest values than in the land-sale values.

Another indication of inefficiency in trading is the presence of inadvertently formed corridors. Had trading produced the maximum profits, no wildlife corridors would have been observed, except in the first round, in which all forest was mature. One of the side-effects of inefficient trading is that wildlife corridors are produced inadvertently. Out of 15 baseline treatments, eight produced a corridor over all six rounds of the treatment, and seven did not. Since trading was less than efficient, there is reason to expect that parcel owners were not fully cognizant of their potential gains from trade. This also implies that they will have less than full information about the losses they will incur as part of a corridor.

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[31] All experiments were carried out using the Calgary Behavioural and Experimental Economics Laboratory at the University of Calgary (http://www.cbeel.ucalgary.ca/). The Zurich Toolbox for Readymade Economic Experiments (z-Tree) software was used to carry out the experiments (http://www.iew.uzh.ch/ztree/index.php). Participants were University of Calgary students in engineering, science, and economics and other social sciences.

TABLE 1: PROFITS GENERATED IN BASELINE EXPERIMENTS

No. of Plots	Actual Profit			Optimal Profit			Fraction of Optimal Profit		
	Harvest	Land Sale	Total	Harvest	Land Sale	Total	Harvest	Land Sale	Total
18	870	1,224	2,094	1,140	1,201	2,341	0.76	1.02	0.89
18	975	1,119	2,094	1,140	1,201	2,341	0.86	0.93	0.89
15	910	1,039	1,949	975	1,029	2,004	0.93	1.01	0.97
15	935	1,033	1,968	975	1,029	2,004	0.96	1	0.98
12	750	810	1,560	780	814	1,594	0.96	1	0.98
12	715	816	1,531	780	814	1,594	0.92	1	0.96
18	950	1,227	2,177	1,140	1,201	2,341	0.83	1.02	0.93
12	620	831	1,451	780	814	1,594	0.79	1.02	0.91
18	975	1,221	2,196	1,140	1,201	2,341	0.86	1.02	0.94
12	655	816	1,471	780	814	1,594	0.84	1	0.92
18	980	1,230	2,210	1,140	1,201	2,341	0.86	1.02	0.94
12	690	833	1,523	780	814	1,594	0.88	1.02	0.96
12	735	810	1,545	780	814	1,594	0.94	1	0.97
12	685	811	1,496	780	814	1,594	0.88	1	0.94
12	760	816	1,576	780	814	1,594	0.97	1	0.99
						Mean	0.88	1	0.94
						SD	0.06	0.02	0.03

The Experiment: Contract for the Wildlife Corridor

The next step in the experiments was to introduce the wildlife corridor. The TDPs were supplemented with an auction for a wildlife-corridor contract. The regulator’s objective was to ensure that one column of mature forest was available as a wildlife corridor through the greater forest landscape at all times. Groups representing all possible corridors were allowed to bid for a corridor contract. Two different versions of the corridor contract were used.

- A fixed-price contract of $100, with a negotiated split among group members. A default split, according to relative harvest values, was provided.
- A declining-price reverse (procurement) auction with the winning bid split among group members according to the relative mature harvest values of the land.

The Fixed-Price Contract with a Negotiated Split

The first version of the payment for the corridor was a fixed $100 payment per corridor, with group members negotiating how this payment would be split among the three of them. A group that agreed upon a split became eligible to be considered for the $100 payment. If more than one group became eligible for the contract, the winner was randomly chosen from among the eligible groups. The purpose of this treatment was to see how well groups could negotiate the split without having to worry about the bid level they were willing to accept. Recall from the above discussion, that an L-parcel owner facing a $30 permit price would experience no loss from the corridor, but facing a zero permit price, would experience a $25 loss. The relative losses that corridor owners face, as well as their overall loss, depends on the permit price. The fixed payment of $100 was intended to be large enough to cover the cost of any corridor including transaction costs, so any group obtaining the contract was getting a good deal. A default split was also provided. It was based on relative land values, and was 29/42/29 for the L/H/L columns, and 32/36/32 for the A/H/A columns.

Over five treatments, there was only one in which the regulator's requirement of a corridor over all six rounds was met. Table 2 shows the results of the treatments in which the fixed payment with a negotiated split was used. The first row shows a treatment with no penalty for reneging on the contract except losing the $100 payment. No contract was awarded in any round because the sharing of the payment could not be agreed upon. Subsequent treatments included a $40 penalty for reneging. However, in only one of them was a corridor formed in every round. The bargaining over the split of the $100 seems to have been what precluded groups from bidding on the contract, or caused reneging when there was a bid. A successful strategy, evident in the bottom row, was to avoid negotiation and simply use the default split provided (32/36/32). The group chose a very uneven split in the first round, reneged on the contract, and then went with a predetermined split based on relative harvest values.

TABLE 2: CONTRACTS AWARDED, SHARES AND PENALTIES IN NEGOTIATION EXPERIMENTS

Parcels	Contracts Made	Negotiated Shares						Penalties or Default
18	0	No Contracts Awarded						No Provision for Penalties
18	5	**32/36/32***	33/33/34	29/42/29	29/42/29	29/42/29	34/33/33	1
12	5	29/42/29	32/32/36	33/34/33	32/36/32	32/36/32	34/33/33	0
12	5	33/34/33	**40/30/30***	29/42/29	32/36/32	32/36/32	29/42/29	1
18	5	**10/80/10***	32/36/32	32/36/32	32/36/32	32/36/32	35/35/30	1

** Default on contract.*

Because of the difficulty in negotiating shares for the relatively lucrative fixed-price payment, the split of the payment was predefined for all subsequent auction treatments. Since most of the awarded contracts that were not reneged upon were close to the default splits, the default splits of 32/36/32 or 29/42/29 were the pre-specified allocations of the bid in all subsequent treatments. Since it need not be the case that the actual costs to members of a group will accrue in the defined split proportions, the bid that will ensure each member's cost is covered will be higher than it would have been had costless negotiation of the split been possible. In an efficient permit-trading scenario, landowners with $25 parcels in a corridor would not have harvested in any round and would incur no loss. Only the $35-parcel owner would incur a loss. Ensuring that the $35-parcel owner is fully compensated for her loss will overcompensate the $25 owners. This overcompensation is effectively the transaction cost of negotiating the split.

Reverse Auction Treatments

In the rest of the corridor treatments, the reverse auction was used because what is being auctioned is a procurement contact. The regulator wishes to contract with a group of forest-parcel owners for the provision of the corridor (a column of three mature parcels left unharvested). However, because of uncertainty about the TDP market, parcel owners are uncertain about the relative value of harvesting versus not harvesting. This gives the auction aspects of a common value auction. A feature of common value auctions is the winner's curse. In procurement auctions with uncertainty about the seller's cost, a naive and imperfectly informed bidder is overly optimistic about the permit price. A high permit price means a low cost of supplying the product, and she underbids to win the contract.[32] This is likely to lead to the winner defaulting on the contract.[33] The usual strategy to avoid the winner's curse takes the form of a second price auction.[34] For example, using a reverse English auction, in which the price descends until the second-last bidder withdraws, the remaining bidder wins and receives the price at which the second-last bidder withdrew.

The auction results presented here are for a reverse English auction.[35] The descending price auction started at $110 and decreased in increments of $5.[36] Each group exited the auction at the price below which they no longer wanted the contract. In theory, we could have corrected for winner's curse in the English descending auction by allowing the winning price to be the price at which the second-last bidder exited. In practice, some of the rounds in our treatments had only one bidder. While the fact that there was only one bidder was not known to that bidder, and abnormally high bid prices were generally not observed, there was no second bidder. However, because of the dynamic nature of the experiment, we were able to observe cases of reneging on the corridor contract. As would be expected, the renegers were usually H-parcel owners facing low realized permit prices. Because we could observe reneging, our approach to avoiding the winner's curse was to lower the minimum bids across otherwise identical treatments until reneging on the contract occurred. The alternative minimum bids were $40, $35 and $30. The winning bid was the price at which the last bidder exited the auction. In addition, a $40 penalty for reneging was included to help reduce winner's curse.

Table 3 shows the winning bids for nine reverse auctions. No reneging occurred until the $30 minimum bid was used. In the second-last auction, reneging took place in the last two rounds. Both were at prices ($35 and $40) above the minimum ($30). Both were potential sellers who did not sell their permits, probably because of a lower than expected permit price. It is possible that the lack of competition in some of the auctions was recognized by bidders, and that this caused some of the higher bids ($70, $60, $55).[37]

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[32] H. Hong and M. Shum, "Increasing Competition and Winner's Curse: Evidence from Procurement," *Review of Economic Studies* 69(4) (2002): 871-898.

[33] With sophisticated bidders, sometimes the winner's curse is referred to as the adjustment winners make to the bids to avoid the winner's curse. In procurement auctions, this may mean they overbid, rather than underbid. The problem means that the buyer pays too much, rather than running the risk of having the seller unable to provide the good at the bid price. See Hong and Shum (2002).

[34] W. Vickery, "Counterspeculation, Auctions and Competitive Sealed Tenders," *Journal of Finance* 16(1) (1961): 165-91.

[35] In earlier work, a sealed bid auction and an ascending price auction were tried. However, these auction formats presented no information on the range of bids. In addition, at bids higher than $40, there were rounds in which corridors did not form, or were reneged upon. Experiments without a penalty for reneging were also tried, but led to few corridors being formed.

[36] The instructions for the baseline and descending auctions treatments are available upon request to the author.

[37] One of the features of the experiments was a pre-bid chat room for each of the groups. In one case (the $70 bid), there was an indication in the chat that the group thought it could win with a higher bid in that round.

TABLE 3: WINNING BIDS AND PENALTIES IN ENGLISH REVERSE AUCTION EXPERIMENTS

Parcels	Corridor Contracts	Winning Bids						Penalties or Default
$40 minimum bid								
12	6	45	55	55	50	50	50	0
$35 minimum bid								
18	6	50	45	35	40	45	45	0
18	6	60	60	50	45	40	35	0
$30 minimum bid								
12	6	35	30	35	35	35	35	0
12	6	35	35	35	30	40	60	0
12	6	35	70	55	55	50	55	0
12	6	35	45	50	35	40	40	0
12	6	35	35	45	35	35*	40*	2
12	6	35	30	35	35	35	35	0

** Reneging on contract.*

Table 4 shows the profits in the descending auction treatments. Columns (2) through (4) show the profits from the auction treatments, exclusive of payment for the corridor contract, for different landscapes. Column (5) shows the aggregate contract payment for each treatment, and column (6) gives total profits including contract payments. Column (7) shows the optimal profits, with a corridor, for the two landscapes. The losses incurred due to the corridor are the difference between unrestricted profits (rounded to $1,961 and $2,886 for the two landscapes) and profits exclusive of corridor-contract payments (column (4)). These losses are given in column (8). Since the regulator pays the parcel owners for the corridor, the parcel owner's loss is reduced by the amount of the contract payment. The rest of the loss (the contract payment) is borne by the regulator. Column (9) shows the losses, net of the contract payment, to parcel owner. For comparison purposes we also show the optimal loss from corridor formation. This is the unrestricted profit minus the optimal profit with the corridor, ($1,991 or $2,886, minus column (7)). Finally, in column (11) we show the ratio of the loss in each treatment to the optimal loss. On average, the treatment losses are 1.5 times as large as the optimal losses. The difference can be accounted for by transaction costs, which prevent efficient trading from occurring and make bid assessments difficult.

TABLE 4: PROFITS AND LOSSES IN THE ENGLISH REVERSE AUCTION EXPERIMENTS

Number Parcels (1)	Actual Profit					Optimal Profit	Loss from TDPs and Corridor Restriction			
	Harvest Profit (2)	Land Sale (3)	Harvest Profit plus Land Sale (HPLSa) (4)	Contract Payment Net of Penalties (CP) (5)	Total Profit (HPLSa+CP) (6)	HPLSo (7)	Lost HPLSa* (8)	Lost HPLSa Minus CP (9)	Lost HPLSo* (10)	Ratio of Lost HPLSa to Lost HPLSo (11)
$40 Minimum										
12	395	849	1,244	305	1,549	1,566	717	412	395	1.82
$35 Minimum										
18	745	1,221	1,966	260	2,226	2,314	921	661	573	1.61
18	900	1,199	2,099	290	2,389	2,314	788	498	573	1.38
$30 Minimum										
12	475	828	1,303	**205**	1,508	1,566	658	453	395	1.67
12	565	805	1,370	**235**	1,605	1,566	591	356	395	1.5
12	620	811	1,431	320	1,751	1,566	530	210	395	1.34
12	600	831	1,431	**245**	1,676	1,566	530	285	395	1.34
12#	560	816	1,376	145	1,521	1,566	585	440	395	1.48
12	575	833	1,408	205	1,613	1,566	553	348	395	1.4
									Mean	1.5
									SD	0.17

 # Reneging on Corridor in at least one of six rounds.

** Unrestricted profit minus HPLSa or HPLSo: $1,961 or $ 2,886 (12 or 18 parcels) minus HPLSa or HPLSo.*

While the losses from combined auction-TDP system are fairly large, it remains to be seen whether they are larger than the losses from a stricter limitation on the number of permits. A stricter limitation is one which would, by itself, result in a corridor. In the 12-parcel landscape, the limitation becomes three permits; in the 18-parcel landscape, it becomes five permits. Table 5 compares the losses from the corridor auctions with the losses from the stricter permit caps. We first compare the optimal losses (losses under efficient trading). The optimal losses for the corridor auction (column (10) in Table 4) are less than the optimal losses from further restriction of the number of permits ($534 or $688). As a comparison of columns (2) and (4) in Table 5 shows, without transaction costs, the corridor auction is less costly.

What happens when transaction costs are included? From Table 1, profits under the various TDP systems are, on average, 0.94 of optimal profits. Using this fraction, we calculate that transaction costs will reduce actual profits under the three- and five-permit system to 0.94 of optimal profits. Using the calculated actual profits, the losses with transaction costs are now $620 or $820 depending on the number of parcels (column (5) of Table 5). Comparing these with the losses from the auction experiments (column (3)), shows the auction treatments to have lower losses in six of the nine experiments. Our results do not support the conclusion that using a strict cap is the less costly alternative.

TABLE 5: LOSSES FROM AUCTION VERSUS FEWER PERMITS

Number Parcels (1)	Auctions		Fewer Permits	
	Lost HPLSo* (2)	Lost HPLSa* (3)	Lost HPLSo* (4)	Lost HPLSa* (5)
$40 Minimum				
12	395	717	534	620
$35 Minimum				
18	573	921	688	820
18	573	788	688	820
$30 Minimum				
12	395	658	534	620
12	395	591	534	620
12	395	530	534	620
12	395	530	534	620
12#	395	585	534	620
12	395	553	534	620

 # Reneging on the Corridor in at least one of six rounds.

** Unrestricted profit minus HPLSa or HPLSo: $1,961 or $2,886 (12 or 18 parcels) minus HPLSa or HPLSo.*

CONCLUSIONS

Our experiments have shown that a combined auction-TDP mechanism can be used to consistently produce connectivity in the form of a wildlife corridor. In addition, we have shown that, even with substantial transaction costs, the losses from using the combined mechanism are not substantially different from the losses associated with a stricter cap. Since much of the cost associated with the auction-TDP alternative is caused by transaction costs, it is worthwhile to consider how they might be lowered. The factors that make the losses high for the corridor-auction experiments are: the need for group decisions among corridor members, imperfect information with which to carry out efficient trading, and a lack of competition in the auction. The need for parcels owners in a corridor to co-ordinate their actions creates substantial transaction costs, and higher bids for corridor contracts. Some of the higher bids may also have been due to lack of competition. Imperfect information about permit prices makes bid calculating difficult, unnecessarily restricts trading, and results in unnecessary losses.

Our transaction costs are from an experimental setting, not the real world. However, they do provide some lessons. Transaction costs are real in both experimental and real-world settings. Experience helps participants learn how to assess the cost of a corridor. In the pre-bid chat among members of a group, discussion about the sale of a member’s permit (or the savings from not having to buy one) became more sophisticated in later rounds of a treatment. Participants who took part in more than one experimental treatment also become more sophisticated. Joint bidding for the corridor contract caused the most difficulty. Practice should help that too, although a lack of competition may drive up bids if the number of groups is too small. Experiments using a greater number of participants will allow for more groups. Longer experiments, with more time for participants to gain experience in negotiating and trading, will help to show whether transactions costs can be substantially reduced while maintaining competition.

A related approach, which has not been tested in our experiments, but might reduce the transaction costs associated with having groups bid for the contract, is to have well-informed intermediaries who, for a price, would act like aggregators in a carbon-offsets market.[38] An intermediary would identify sets of parcels that could provide the necessary connectivity and negotiate with prospective sellers, purchasing the components for a connectivity portfolio to be sold to the regulator. Different parcels could go in and out of the portfolio as long as the habitat objectives were always met. The key to reducing transaction costs is ensuring that the intermediary is well informed with respect to both connectivity and the market. However, introducing intermediaries also raises questions related to market structure and competition in the aggregation market.

What do our results mean for the LARP? The LARP has chosen to negotiate the buyout of some parcels of land to promote connectivity and to institute a TDP system later. Compared to the alternative of achieving connectivity with a stricter TDP system, the chosen alternative may require taxpayers to cover buyout costs, but it is not necessarily more costly overall. When a TDP is instituted, it may still make sense to supplement it with purchases of connectivity.

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[38] Individual farmers do not produce carbon offsets in a sufficient quantity to sell on the Chicago Climate Exchange (CCX) or to large final-emitters. Intermediaries, called aggregators, buy carbon offsets from farmers, aggregate them and sell to large final-emitters or the CCX. See M. Fulton and J. Vercammen, "Optimal Two-Part Pricing in a Carbon Offset Market: A Comparison of Organizational Types," *Southern Economic Journal* 76(2) (2009): 513-532.

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