Title: Transferable Disturbance Permits for Biodiversity Conservation: Assessment of Implementation Options

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Submitted to: 11th BioEcon Conference, "Economic Instruments to Enhance the Conservation and Sustainable Use of Biodiversity"

May 20, 2009

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Abstract

Tradable disturbance permits have been proposed as a cost-effective method for assigning rights to the environment and managing cumulative impact on biodiversity on publicly owned forest landscapes, however the details of how such a policy might be implemented have not been explored. The boreal forest presents a number of challenges for instrument design including stand dynamics, overlapping tenures, and asymmetric information. Economic theory provides little guidance about how such instruments perform in such settings. Instead experiments can shed light on the potential performance of various design options. In this paper we use lab experiments to evaluate the effect of the market institution, the initial allocation, banking, and an adaptive cap on economic and ecological outcomes in a disturbance permit program. As one would expect, we find that the market institution and initial allocation have a significant impact on both the economic efficiency and environmental outcome. Economic outcomes improve under the double auction suggesting that gains from information about the value of permits outweigh competitiveness issues associated with the open market format. Surprisingly we find that a more relaxed ecological constraint actually reduces the economic surplus under the system because flexibility reduces the discipline of the market and increases mistakes. With full compliance, these mistakes translate into improvements in the ecological outcome however this is reflected in over-compliance relative to the goal and is not necessarily desirable from society's perspective.

1 Introduction

Thirty percent of the world's boreal forest is found in Canada, where it covers 58% of the land base (e.g. Burton et al.). The boreal forest is comprised primarily of coniferous/deciduous mixedwood forests, peatlands, and sparsely treed muskeg. Over the previous 5000+ years, the primary drivers of landscape change have been natural disturbance – primarily fire. On average, 0.65% of the landbase burns every year. In addition large fires (many exceeding 100,000 ha in size) have played a dominant role in structuring landscape patterns both in terms of vegetative types (aspen dominated versus conifer dominated) and age structure. Although vegetative types and age structures appear relatively static over short time periods of 10 years, over time spans of 100+ years the location of these characteristics moves across the landscape within a range of natural variation. It is estimated that over 23,000 species are supported by North America's boreal forests (e.g. Zasada, et al. 1997). In addition, the forest is home to numerous communities and First Nations, many of which depend directly on the forest for jobs, recreation and cultural activities and sustenance.

Both conifer and deciduous tree species provide excellent wood for timber and pulp. In the western provinces of Saskatchewan, Alberta, and British Columbia, large parts of the forest lie above the Western Canadian Sedimentary Basin, one of the world's most important energy resources. While vast tracts of the boreal in Canada remain relatively undisturbed, the increasing development of the forest for fuel, food, and fibre threatens the boreal ecosystem, particularly in 'hot-spots' like Alberta. In recent years, the amount of area disturbed by the energy sector has been equal to or exceeded the annual area harvested by the forest industry.[1] Most of this footprint has been related to development of conventional energy sources. However, the basin contains a number of unconventional energy sources for which current technologies are now becoming economically viable and which will be developed over the next 20 to 50 years. For example, Alberta's recoverable bitumen reserves place are just behind Saudi Arabia in terms of total oil reserves. Where the bitumen deposit is close enough to the surface (< 75 m) it is extracted using open pit surface mining. The total surface mineable area is approximately 370,000 ha. Where the bitumen is deeper than 75 m, it is extracted using steam assisted gravity drainage technology which produces an intense footprint of well pads, pipelines and access roads, central processing facilities, and a mesh of seismic lines that are 60 m apart, implying a seismic density of 33 km/km^2. The intensity of this human footprint can be expected to occur across most of the non-

[1] In addition to drilling wells, exploration includes cutting seismic lines through the forest to locate gas pools, roads to bring in drilling equipment, and if successful, pipelines to link wells to existing pipeline networks.

mineable bitumen areas of the basin. Other emerging non-conventional energy resources in the boreal include coal bed methane and oil in shale, both of which also require an intense footprint.

Organizing development in order to manage cumulative effects is a challenge under current policy. Most of the boreal forest in Canada is Crown Land owned by the provinces and allocated for resource development through leases and other dispositions. The wide variety of resources and leasing options has resulted in complex system of overlapping resource tenures. Unlike traditional forest management which is subject to stringent regulations and policies around ecosystem management and forest planning, the emerging energy sector footprint in the boreal is the result of thousands of individual operators competing to find and develop resources, often in waves corresponding to cyclical prices and markets. These disturbances wreak havoc with forest management plans and contribute to significant fragmentation of habitat, with an impact on species well in excess of the amount of habitat lost (Schneider et al., 2003). In the future new policy instruments will be required to integrate and coordinate the activities of both the forest and energy sectors in order to manage cumulative effects and ensure continued maintenance of ecological integrity and biodiversity in the forest.

Tradable permits have proven to be a cost-effective method for organizing users of public goods to achieve environmental objectives in a number of contexts (Tietenberg and Johnson, 2004). Weber and Adamowicz (2002), and Weber (2004) explore how tradable permits could be used as a cost effective way to manage cumulative effects using habitat thresholds in the boreal mixedwood. Of course the realization of these theoretical cost savings depends on the design of such systems. In particular, stochastic ecological and economic environments, asymmetric information, and market structure issues can lead to inefficiencies and create opportunities for strategic behavior that undermine the potential of market based approaches. Unfortunately economic theory provides little guidance about how market based instruments should be designed in ecologically and economically complex settings such as the boreal forest context described above. In the absence of tractable analytical solutions, lab experiments are useful to testbed policy alternatives in order to shed light on the relative performance of various design options and have been used extensively in the design of regulation in the US (e.g. Smith, 1991). For example, the US Department of Energy used experiments to examine various elements of the emissions trading scheme under the 1990 Clean Air Act Amendments. The experiments highlighted potential design issues related, for example, to the presence of both mandatory and voluntary markets, the revenue neutral auction, and the efficiency of banking (Franciosi et al., 1999; Mestelmann et al., 1999).

In this paper we use experiments to test various options for conserving old growth forest using tradable permits. We define Tradable Disturbance Permits (TDPs) as rights to disturb forest which are exercised in conjunction with other leases and dispositions to access resources. In a TDP system, the total amount of disturbance (in terms of hectares) permitted on the landscape for a given time period is capped and rights to disturb under the cap are allocated to firms either through grandfathering or auction. Permits are treated as equivalent no matter where the disturbance occurs and irrespective of the quality of habitat disturbed. With grandfathering firms are also able to trade permits in a secondary market. Grandfathering arguably increases the feasibility of the system and in theory the outcome of the market should be independent of the initial distribution (Tietenberg, 2003; Montgomery, 1972). Permit banking gives firms greater flexibility in managing the costs environmental constraints inter-temporally (Tietenberg, 2003). However banking rules can also affect market outcomes (e.g. Cronshaw and Brown, 1999). Banking of TDPs would allow firms to transfer disturbance to the future, and would also allow firms to hedge risk against fire. In the experiments we evaluate the performance of banking with and without fire. Technically the permit requirement is associated only with the annual amount of disturbance however because of the effects of long term and semi-permanent features on the growing stock of forest, or due to unexpectedly large fires, it may be necessary to adjust the cap over time to ensure that the target level of old growth is maintained. Therefore we consider both a rigid and an adaptive permit cap.

The government can either use an auction or grandfather permits and allow resale in a secondary market. For our experiments we test three different market mechanisms for allocating permits. The first institution tested was a second price (Vickrey) sealed bid multi-unit uniform priced auction. For simplicity we refer to this auction as a tender auction, as this type of auction is frequently used in government tender. In the tender auction, the bidder submits a price schedule for the auctioned items, and the auctioneer grants the item to the highest bidder at the price submitted by the second highest bidder. Each bid contains the number of units and the price the bidder is willing to pay for each unit. The auctioneer orders the bids and allocates the permits to the highest bidders, until all permits are allocated. The uniform price paid for the permits is equal to the bid price of the highest unsuccessful bid. An alternative to auctioning rights is to grandfather rights to firms and then allow them to trade in a secondary market. Trade in grandfathered licenses is equivalent to how an 'offset' system would operate on public lands, where the only way to offset ones impacts on the landscape is to purchase existing development rights from other firms. Experience in markets suggests that coordination of buyers and sellers increases market efficiency.

We consider two types of coordinated resale markets for grandfathered permits - a double auction and a call market, and compare the results to the tender auction. In the double auction players are allowed to trade permits on a computerized open market where participants send improving buy and sell offers which are immediately displayed and seen by every participant. Once the best buying offers and selling offers match, the sale happens and the market clears. Based on the construction of the market each and every sale may have a different price. The call market allows buyers and sellers to trade *on a sealed market*, with each sealed bid containing the price per unit and the amount the participants want to buy or sell.

The institutions described above differ in terms of who has control over permits and how they are distributed between players, as well as the level of information that is shared between participants. The information that buyers and sellers in the market have about the value of permits is a powerful determinant of the performance of the market. However the role of information is not always clear. In general the more participants know about each other's values, the more likely that a good will be allocated to the bidder with the highest valuation as long as the market is competitive. Allowing participants to learn about the market and revise their strategies may improve the efficiency of the allocation and correct for misallocations made early on by poor strategies (Cumming et al., 2004). However, communication and information sharing can lead to strategic behavior which reduces the benefits of information sharing (Cason et al., 1999). With asymmetric information, the auction's properties will depend on the beliefs of the players. In the case of the Vickrey auction, a player can do no better than to bid the true value for the good since the bid does not affect the price that will be paid. Economists advocate this auction format because it removes strategic uncertainty that arises when bidders are not certain about the behavior of other bidders, which can lead to overly conservative behavior in real life auctions (e.g. Binmore and Swierzbinksi, 2000). In a multiple item setting, the second price sealed bid auction suffers from a major weakness in that these auctions can result in very low revenues for sellers (Ausubel and Milgrom, 2006).

As one would expect, we find that the market institution and initial allocation have a significant impact on both the economic efficiency and environmental outcome. Economic outcomes improve under the double auction format suggesting that improvements in information between players outweigh competitiveness issues associated with the open market format. Surprisingly we find that a more relaxed ecological constraint (rigid permit allocation and permit banking) actually reduces the economic surplus under the system because flexibility reduces the discipline of the market and increases mistakes. With full compliance, these mistakes translate into improvements in the ecological outcome however this is reflected in over-compliance relative to the goal and is not necessarily desirable from society's perspective. The remainder of the paper proceeds as follows. In the next section we outline the model and in section 3 we describe the experiments. Results and discussion are presented in Section 4.

2 Model Description

2.1 Optimal Disturbance

In this section we present a simplified model of a TDP market with two types of agents, forest companies and energy companies, in order to test different institutions for maintaining an old growth constraint[2]. A TDP represents the right to disturb 1 unit of land. The permits could be allocated via government tender auction, grandfathered with resale in a secondary market, or a combination of the two. In this simplified model all agents (whether forestry or energy) are required to hold a TDP for any unit of land they disturb. The following formulation assumes that both types of agents have a long term lease on the land and their operations are limited to their own boundaries and the issue of overlapping tenures is ignored[3]. Hence their profit functions only depend on their own land inventory, net revenue and the price they may pay for a permit. The firms' properties are heterogeneous by size and potential revenue generation possibility.

The socially optimal level of disturbance in each period is one that maximizes the net present value of benefits:

(1) $$\text{Max} \sum_{t=1}^{T} \beta^t \sum_{n=1}^{N} \sum_{a=1}^{A} R_{a,n} X_{a,n}^{t}$$

subject to

(2) $$L_{1,n}^{t} = \sum_{a=1}^{A} (X_{a,n}^{t-1} + \mathrm{F}_{a,n}^{t-1}) \; \forall t:[2..T] \; ;$$

(3) $$L_{a,n}^{t} = L_{a-1,n}^{t-1} - \mathrm{X}_{a-1,n}^{t-1} - \mathrm{F}_{a-1,n}^{t-1} \forall a:[2..A-1] \, ;$$

(4) $$L_{A,n}^{t} = L_{A-1,n}^{t-1} - \mathrm{X}_{A-1,n}^{t-1} - \mathrm{F}_{A-1,n}^{t-1} + L_{A,n}^{t-1} - \mathrm{X}_{A,n}^{t-1} - F_{A,n}^{t-1} \, ;$$

(5) $$F_{a,n}^{t} = \delta L_{a,n}^{t} \text{ where } 0 \le \delta \le 1 \, ;$$

(6) $$OG_t \ge \sum_{n=1}^{N} \sum_{a=O}^{A} \left(L_{a,n}^{t} - X_{a,n}^{t} - F_{a,n}^{t} \right)$$

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[2] Old growth was selected as the ecological objective however the approach would apply equally to any other habitat constraint on forest stands.

[3] The overlapping tenure problem results in conflict in access to specific forest areas. We do not model the problem in this paper since if an institution does not perform well in the simpler setting, we do not expect it to perform any better in a more complex setting. In addition, we assume that overlapping tenure issues will continue to be resolved as per current regulation, where energy companies are allowed to access sub-surface rights subject to timber damages. Therefore we can treat sub-surface development as an additional 'random' disturbance similar to fire from the perspective of a forest company.

(7) $X^t_{a,n} \le L^t_{a,n}$;

(8) $L^1_{a,n} = \bar{L}_{a,n}$;

where

T =1, … t	number of time periods;
a = 1,… A	age categories ordered youngest to oldest;
OG = O, … A	old growth age categories which are a subset of {a};
n = 1, …N	set of agents (both energy and forestry);
$L^t_{a,n}$	total amount of land in time t in the a^{th} age class owned by the n^{th} agent;
$X^t_{a,n}$	area harvested in time t;
$D^t_{a,n}$	area burned in time t;
$R_{a,n}$	net revenue function for 1 unit of land.

Equation (1) shows the net present value of forest disturbance for the whole region. The first constraint, Equation (2) shows that the amount of land in the youngest age class in any period is just equal to the amount of land disturbed in the previous period by either harvest or fire. Equations (3) and (4) show the transition of the forest into different age class categories as a function of harvest and fire, with the total amount of old growth in any period being determined by the amounts of the second oldest and oldest age classes not disturbed in the previous period. Equation (5) shows the amount of area burned. As fire is a stochastic event δ would follow some distribution, which would make this problem a stochastic programming model which is N infinite, so it is not analytically solvable. However we can fix δ to be equal to the mean fire damage which is equivalent to solving based on the expected value of the fire damage. The old growth constraint is given by Equation (6), where old growth is a subset of the oldest age classes. Finally Equation (7) shows that we never can harvest more than the available land in each given category by each player, and Equation (8) specifies the initial allocation of land to each agent.

In the formulation of the social planner's objective function we do not distinguish between energy and forestry agents, however by giving a different structure of the revenue, we can model the two sector's differences. In particular, the revenues of the forest sector depend on the value of merchantable timber and change as a function of the stand inventory. Without any additional constraints the optimal harvest sequence would result in a Faustmann rotation age for each stand.We assume that the value of the stands is incidental to the energy sector, i.e., that the decision rule on where and how much to drill is independent of the value of timber on the surface. Therefore we simplify the revenue function to be independent of the value of the stand $R_{a,n} = R_n$ for energy agents[4]. In the following periods the land inventories are changing depending on the harvest.

2.2 Tradable Disturbance Permits

Under tradable disturbance permits the old growth constraint is implemented as a cap on the total amount of disturbance from any age class in a given time period. Note that although the ultimate goal is to keep old growth forest, where a>=O, the cap should apply to every age category since otherwise forest companies would harvest all forest before it becomes old growth. This is because the constraint facing the firm is on the total amount of forest disturbed, rather than on the total amount of forest left in old growth which would be more similar to an offset system or the type of old growth retention system described by Chomitz (2002).

The cap on the total amount of disturbance on the landscape in each and every period is given by Equation (9). If the regulator has a perfect knowledge of the $R_{a,n}$ values, then the cap for each period can simply be defined to be equal to the total optimal harvest given the optimal solution to (1):

$$CAP_t^* = \sum_{n=1}^{N} \sum_{a=1}^{A} X_{a,n}^{*t} \tag{9}$$

Equation (9) represents the cap under a *rigid* institution. In the rigid case, the regulator forecasts future land use patterns and decides how many permits will be issued in each and every period *ex-ante* based on the optimization problem. In reality the exact value of the $R_{a,n}$ vector is unknown to the regulator, which may create a potential error in setting the cap level on the long run. Furthermore, the realization of fire events could result in either more or less old growth than desired in a given period. Therefore an adaptive cap which is updated each period would be a more accurate way to manage the

[4] Note that under current public land management, dispositions rights to various revenue streams (e.g. from forestry, minerals, energy) are unbundled. Energy companies have no right to the value of timber harvested therefore the exploration and development behavior of the sector is assumed to be driven solely by sub-surface geology rather than timber values. There is no loss of generality to assume that the timber value of the stands disturbed is not factored into the energy agent's decision function, except as an incidental cost. Our formulation simply assumes that the sector treats this as a 'fixed' cost, independent of the age class structure of the forest.

environmental objective within desired levels in each period. The cap under the *adaptive* institution is given by Equation (9'):

$$(9') \qquad CAP_{t+1} = CAP^*_{t+1} - \sum_{a=o-1}^{A} (\hat{X}^{t}_{a,n} - X^{*t}_{a,n}) - \sum_{a=o-1}^{A} (\hat{\delta}_t - \delta) L^t_{a,n} ,$$

where $\hat{X}^{t}_{a,n}$ and $\hat{\delta}$ are actual realizations of harvesting and fire in each period. Under the adaptive institution the regulator forecasts the cap in t=1, and announces the expected cap in each period but only uses the cap for t=1. In subsequent periods the regulator adjusts the cap based on the outcome from the given period. The advantage of the rigid allocation is that it provides certainty for the firms in that they know exactly how many permits will be allocated in a given time by the government. This creates security for firms and one would expect that the regulator would receive less resistance from firms when implementing the system. However, when government presets the cap, it needs to have very good idea of future land use (including who will actually end up harvesting and how much) as well as the future fire regime (a tall order with climate change) in order to ensure that the environmental objective is maintained. Unexpectedly large fires in a given period coupled with a predetermined harvest level can lead to persistent underachievement of the environmental objective. Although there is always a possibility to buy back permits from the companies in case of such an event, it can be very costly. Similarly, unusually mild fire seasons can result in an overly stringent cap, the costs of which can't be averaged over time due to discounting. To reduce the uncertainty to firms under an adaptive regime the government can provide an expected permit projection *ex-ante* which we did during the experiments.

2.2.1 Banking

In many pollution permit schemes permits can be banked for later use. The possibility for inter-temporal substitution increases flexibility for firms which should in theory reduce costs. For example, if there is an unexpectedly large fire and firms hold excess permits then they can use or sell the permits later instead of using them on premature forest or losing them. If the regulator allows banking and uses adaptive permit issuing, then the cap should be updated as per Equation (9''):

$$(9'') \qquad CAP_{t+1} = CAP^*_{t+1} - \sum_{a=o-1}^{A} (\hat{X}^{t}_{a,n} + B^t_{a,n} - X^{*t}_{a,n}) - \sum_{a=o-1}^{A} (\hat{\delta}_t - \delta) L^t_{a,n} ,$$

Theoretically the only disadvantage of the banking is that the amount of disturbance that actually happens in a given period becomes more unpredictable. It may create large fluctuations in the environmental goal. However, as borrowing is not allowed this should lead to achievement of the overall objective on average.

3 Experimental Design

A total of 48 experimental sessions were carried out at the University of Alberta main campus during 2007/2008. Each session had 12 participants who ranged in age from 18 to 72 years with a mean age of 24 years. The participants were mainly undergraduate students with some administrative staff from the University with various majors and backgrounds. Each participant received a show up fee, as well as payment based on the revenue they generated from the experiment. Each round of the experiment consisted of managing the forest over three periods (T=3). Each session was 2-2.5 hours long and started with a PowerPoint instruction followed by a 20 question quiz which tested the subjects' understanding of the experiment rules such as tree growth, selling and buying options, and the payment structure. After the quiz the subjects participated in a practice round during which participants were given an opportunity to learn the rules of the game and practice with the software. Subsequently participants played five rounds of the game. We allowed for repeated participation in sessions. To ensure that repeat subjects did not learn the experimental data or the market prices between sessions, revenue functions for each player were shifted by a random number (the same for each player) in each session. This ensured that relative values in the experiment were not changed, but that participants faced different absolute values and market clearing prices in each session. In addition, subjects were only allowed to participate in multiple sessions if the sessions differed in at least 2 treatment options.

To test the various institutions in the laboratory setting, we followed the model described in Section 2 very closely. The harvest and disturbance decision of the forestry and energy agents was modelled by assigning each participant their own land inventory and revenue. For simplicity we used only 3 age categories: young, mature and old, (a=1,2,3). Only the last category was considered old growth forest (O=3). Participants were informed that their inventories evolved between periods according to the dynamic described in Equations (2)-(5). The initial inventory was reset in each round and the rounds were independent. The sequence of decisions in each period was carried out as follows. First players viewed their inventory and revenues associated with each age category. Then they participated in the permit market and permits were allocated for the period. Participants then executed their harvest decisions. For sessions with fire, stands were burned prior to the harvest decision. In sessions with banking, permits that weren't used during harvesting could be saved in order to be used or sold in future periods. Each unit harvested earned revenue based on its age class according to the sector specific revenue functions in Equation (1). Revenues were independent from the period harvested, i.e., there was no discounting (β=1). Permits could be used for any age class. Compliance was forced in that players could not overharvest relative to the cap. Therefore while they could not violate the old growth target, they could under-harvest.

The sessions were carried out using Ztree software. The participants always had a visual display of their forest inventory (see Figure 1) and the software recorded every bid and offer decision as well as landscape changes in each period for each individual. At the end of each session participants were asked to fill out a short questionnaire with basic demographic questions (age, gender, etc.) as well as questions assessing their attitudes toward risk and discounting[5].

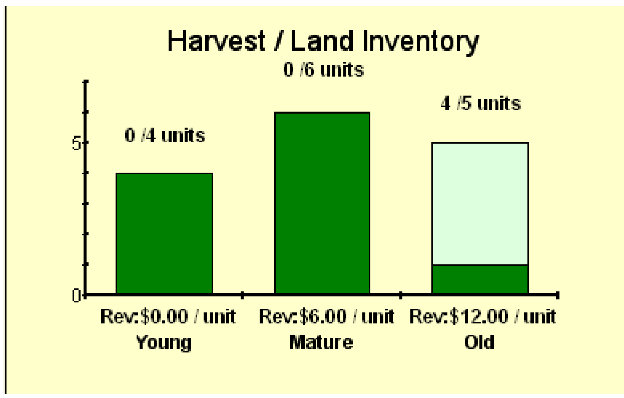

Figure 1 Example of a subject's harvest and land inventory

3.1 Data

The players' data was calculated from real data from Alberta's Forest Management Units. The data contain eight different forest types with each type divided into five year incremental age categories from 0 to 220 yrs, as well as mill locations within each FMU. Each forest type was associated with an individual yield curve. Detailed forest inventory data (AVI, 2001) was aggregated into three age classes: young (below 40 years), mature (45-85 years), and old growth (90+) forest. During the aggregation a proportional weight was used to represent the size of the Forest Management Unit (FMU) inventory, and inventories were scaled down so that 1 forest unit represented 7000 ha of actual forest in any given age category. This process produced a simplified 3 age category inventory for each FMU. Based on the construction and given the 3 period setting, each period was designed to represent

[5] The risk assessment questions were in the form of "Would you flip a coin between $X and $Y or take a fixed $Z payment". The discounting assessment questions were in the form of "Would you take $X today or $Y in Z weeks from now". Based on their responses participants were divided into risk five risk categories, and three discounting categories as well as whether discounting increased, decreased or was stable over time.

40 years[6]. Net revenues were generated for each age class for each FMU by calculating representative timber volumes for each unit of forest in every FMU using weighted averages from the eight yield curves. Assuming softwood $72/m^3, hardwood = pulp 48/m^3 price the total revenue at the nearest mill was calculated. The get net revenue, we incorporated harvesting and average transportation costs for each FMU. Since we only had average transportation cost data for 28 FMUs, these were the final locations from which the experimental data were created. These FMUs include the smallest and largest FMU in the province, and also contain a variety of forest cover types. In addition, there was large variation in locations with some FMUs located in Central Alberta close to major markets with cheap transportation costs, and others located in Northern Alberta in more remote areas. Hence the 28 FMUs are assumed to represent the heterogeneity of forestry firms and inventories across the province. As the location of the FMUs was known, we matched drilling activity levels to each of the FMUs in order to generate relative demands for surface access by the energy sector (see Table 7 in appendix).

To initialize the experiments we selected 9 FMUs from this pool to represent forestry firms in two separate draws. Drawing from the 9 FMUs we then created an additional 3 players to represent energy companies[7]. The exact revenues of the energy companies was not known therefore we arbitrarily chose revenues for the energy sector to be at least 30% above the highest forestry revenue in the given draw. This construction gave us the data for our final draws shown in Table 89 and 11 in the appendix. The environmental target was to maintain at least 30% of the total landscape was in old growth forest. Since the target was higher than initial levels of old growth, the disturbance cap in each period was calculated so that at the end of the 2nd and 3rd time period at least 30% of the land is old growth, and the amount of old growth never falls below 20% in the first period. Using GAMS we solved for the optimal number of permits in each period based on Equations (1)-(9).

In the boreal forest fire destroys an average 0.6% of the forest in each year (Stocks et al., 2003). As our periods represent a much longer time period (40 years) we chose a mean incremental burn rate of 11.5% per period. Actual fire in each period was generated by drawing randomly from a uniform distribution of between 0 and 45% area burned for a given FMU. On average 12.04% fire damage occurred in the fire sessions, which was quite close to the aimed 11.5%. The caps for each draw are found in

Table 9 and Table 11 in the appendix. Fire has a negative impact on the cap in each period, but a much greater impact on the number of TDPs available in the first draw than on the second draw.

[6] In reality a period could be significantly shorter, for example five years. Three periods was deemed sufficient to understand the inter-temporal aspects of the permit market.

[7] We chose three based on the rule of thumb that three players of one type is sufficient to force behavior in the experiment (Kagel and Roth, 1995).

3.2 Treatments and Market Institutions

During the experiments three market mechanisms for allocating permits were tested: tender auctions, double auctions, and call markets. During the tender auction, the total amount of permits was auctioned at the beginning of each time period. Participants were given 1 minute to submit their bids after which the auction closed and the bids were ordered and allocated to the highest bidder at the uniform price equal to the highest unsuccessful bid. In the double auction, permits were grandfathered to forest sector players (energy agents did not receive an initial allocation) and traded on an open market. Each buy/sell offer contained a price per unit, as well the number of units the buyer or seller wanted to trade. Once there was a match between buyers and sellers a sale was executed. Based on the construction of the double auction each sale has a different price. Partial offer trading was also allowed. For example if the best selling offer was for 10 units at $20/unit and a buying offer arrived for only four units at this price, four units were sold and with the selling offer staying at the same price but with six units available. During the double auction three minutes of trading were allowed at the beginning of each period. There was no limitation how many permits could be bought or sold by any participants. In addition, participants could act as middlemen, buying and reselling permits within a given trading period.

The second two sided market institution tested was the call market. During these sessions, the permits were again grandfathered to forestry agents. The permits could then be traded in a sealed bid market. At the beginning of each period participants had 1 minute to send sealed selling and buying offers to the auctioneer. Each offer contained a price per unit and the amount the participant wanted to buy or sell at that price. At the end of the auction, supply and demand curves based on the arrived offers were created, the market clearing price established, and the market cleared. In order to ensure that the payment structure and incentives were the same between market institutions, the tender auctions were carried out in a revenue neutral way. Revenue collected from the tender auction was redistributed back to the firms based on the same proportional share as used in the other two trading formats for grandfathering. This ensures that the agents get exactly the same revenue in each of the market institutions if the prices are the same. The main difference between market institutions is in control over the permits. In case of the tender auction, firms cannot hold back their permits if the market price is above their bid price.

We considered three treatments: fire vs. no fire; banking vs. no banking; rigid vs. adaptive cap. Each of the treatments interacted with each of the 3 institutions. The experimental sessions were organized to have a 2 x 2 x 2 x 3 full factorial design with 2 repetitions of each combination executed with the 2 different sets of agents (see Table 1 below).

Table 1 Experimental Design

Treatments	**a) Rigid permit issuing**	**b) Adaptive permit issuing**
1) No Fire, No Banking	3 institutions , 2 draw each	3 institutions , 2 draw each
2) No Fire, Banking	3 institutions , 2 draw each	3 institutions , 2 draw each
3) Fire, No Banking	3 institutions , 2 draw each	3 institutions , 2 draw each
4) Fire, Banking	3 institutions , 2 draw each	3 institutions , 2 draw each

To test the implications of fire we ran half of the treatments with fire and half without. During the fire sessions a randomly drawn fire would burn down a certain percentage of each individual's inventory after permits were purchased. We created randomly generated fire sequences prior to the experiments to exclude unrealistic fire sequences, for example no fire ever, or fire every period for a participant. Banking was implemented at the end of each period by allowing participants to decide how many permits they wanted to use, and how many they want to carry over to the next period. There was no limitation on how long they could carry forward a permit, nor whether a permit could be used for harvesting or sold. At the beginning of each round players received information about the cap. In case of the tender auction, the participants were informed about the total amount of permits that would be issued. In case of grandfathering each participant was informed about how many permits they would be receiving individually during the different periods. In the adaptive case individuals were told that these predetermined amounts could change based on realizations of harvesting and fire in each period.

4 Results

To assess the effectiveness of the different sessions, we created measures of economic and environmental performance. In order to ensure comparability between sessions all measures are relative and given as the % of the optimal value achieved. Each measurement's value was calculated for each round (and not from the periods within the rounds). The optimum permit allocation and harvest pattern was given by the solution to Equations (1)-(9). The measures used to describe economic and environmental outcomes are described in Table 2 below.

Table 2 TDP Performance Measures

Total Value	Measures total value of energy and forestry production relative to the expected optimum
ForestHarv	Measures forestry industry output relative to the optimum.
EnergyHarv	Measures energy industry output relative to the optimum.
OG	Measures the amount of old growth remaining on the landscape at the end of the 3rd period relative to the goal.
OGGini	Measures the distribution of old growth at the end of the third period using a Gini coefficient. A lower value indicates old growth is evenly distributed between FMUs, a higher value implies larger blocks of old growth clustered on some FMUs
TradeVolume	Measures the number of permits sold relative to the optimum.
WrongHand	Measures number of permits misallocated relative to the total number of permits. E.g. 0.1 means 10% of the permits were misallocated. By definition a permit is misallocated if firm A should have had it but it ended up in firm B's hand.
WastedandImmature	Measures number of permits sub-optimally used on immature forest or thrown away relative to the total number of permits. E.g. 0.04 means 4% of the total permits were suboptimal used on immature forest or thrown away. This measure is a subset of the previous measure. It only contains those cases when firm B, which was not supposed to have the permit, actually wasted the permits or the permits on immature forest.
ResaleVolume	Measures number of permits sold twice relative to the total traded permits e.g. 0.1 means 10% of the traded volume was resale. This variable is a proxy for middleman activity. It contains both resale within the same period and resale between periods.
ResaleSurplus	Measures the surplus captured by middlemen from reselling permits relative to the total gain from the trade. E.g. 0.01 means that 1% of the total trade surplus was earned by middleman activity.

4.1 Descriptive statistics

Descriptive statistics for each of the performance measures are provided in Table 3. The statistics are broken down between sessions with and without fire. Otherwise, the data are aggregated across rounds.

Table 3 Descriptive Statistics

Performance Measures		NO FIRE				FIRE			
		Mean	Std dev	Min	Max	Mean	Std dev	Min	Max
Economic and Ecological Objectives	Total	92.73%	5.37%	73.18%	99.76%	90.91%	6.42%	70.87%	100.32%
	ForestryHarv	93.47%	6.89%	69.22%	102.62%	91.26%	8.09%	66.50%	111.84%
	EnergyHarv	91.10%	12.52%	47.69%	100.00%	90.16%	12.51%	50.38%	100.00%
	POG	103.91%	5.61%	92.75%	123.19%	99.01%	3.55%	90.58%	113.77%
	OGGini	0.1394	0.0877	0.0003	0.3663	0.0919	0.0604	0.0009	0.2411
Market Activity	TradeVolume	105.99%	29.84%	55.26%	282.67%	99.24%	16.29%	51.52%	146.27%
	ResaleVolume	17.59%	15.00%	0.00%	75.00%	10.74%	11.24%	0.00%	48.44%
	ResaleSurplus	0.10%	4.92%	-34.0%	21.94%	0.32%	3.41%	-26.00%	16.19%
Market Efficiency	Wrong Hand	21.49%	10.69%	5.23%	48.00%	17.38%	9.11%	1.94%	45.88%
	ImmandWasted	4.93%	6.44%	0.00%	28.67%	4.68%	6.45%	0.00%	37.61%

On average TDP markets achieved a significant amount of the total available surplus, suggesting that the market was on average effective at allocating harvesting and disturbance rights. With fire, the optimal surplus is calculated based on the expected fire loss as opposed to actual fire loss. Therefore the cost associated with fire is the cost of the surprise, not the cost of fire per se. As one would expect, fire decreased the value of the total expected surplus achieved on average, and at the same time increased the volatility of the surplus (we see a higher standard deviation). It is important to note that with fire uncertainty, the total surplus actually could exceed the 100% of the optimum if the random fire was lower than the expected. Energy industry production has a similar mean / min and max and standard deviation value regardless of the fire. So the total surplus changes seem to be driven by the forest industry, whose production performance was lower and more volatile with fire. The remaining old growth forest also was affected by the random fire, although even with fire OG was on average close to the target (the mean is 99.1%). Without fire we can see that on average there is over-compliance with the target (103.9% mean). Furthermore, fire actually increased the stability of the environmental goal as the standard deviation of OG is 3.55% with fire and 5.61% without. One possible explanation for being tighter to the target with fire is that fewer permits are issued. Hence they are more valuable and there are fewer misallocated permits. Also the distribution of the remaining old growth seems to be more evenly distributed with fire, as mean of the OGGini variable is much lower. This suggests that the effect of fire is to reduce heterogeneity on the landscape.

Although the mean trade volume is very close to the optimal both with and without fire, less trade occurs in the fire sessions 99.24% as opposed to 105.99%. On the other hand there is greater stability in trade volume with fire as the standard deviation is 16.29% versus 29.84% without fire. In both cases with the double auction there is significant resale activity (10.74% and 17.59% of the total permits were sold twice on average with and without fire respectively). This suggests that the tighter the cap, the less room for middleman. In addition, despite the fact that a significant proportion of the trade was resale, the actual surplus taken by the middleman took out was negligible - less than half % of the total surplus on average. This is, at least partially, due to the fact that middleman activity is quite a risky business, which shows up in the large negative minimum values. When banking was allowed 17% of the permits were banked on average, however there was large variation (0-67% banked) between sessions.

In spite of reaching around 90% of the available surplus, almost 20% of all the permits were used by the wrong subjects. There was not a single observation where there was not misallocation. The fire and tighter cap also seems to have effect here. Both the mean and the standard deviation of misallocated permits is lower with fire sessions, which means that as there are fewer, more valuable, permits, the allocation is closer to optimal with less volatility. Around 25% of the misallocated permits were wasted or used on immature land (5% of the total permits on average). The majority of the permits that were misallocated actually were used on old growth forest but not the most valuable old growth.

4.2 Regression Results

The experimental data were analyzed as panel data with group fixed effects in order to test the effect of the institutions and treatment variables on performance. Each session was treated as a group, with each round within a session treated as an individual time period. Each session had 5 repetitions. One round in one session was thrown out as it was an outlier based on the trade volumes of an individual trader. The regressions used the following format:

$$M_{s,r} = \alpha + \beta V_{s,r} + u_s + e_{s,r}$$

s = 1, … 48	Session (group) identifier
r = 1, … 5	Round (time) identifier
$M_{s,r}$	Performance measures (actual results from each round/session)
$V_{s,r}$	Treatment variables (dummies for the full factorial design)
u_s	Group fixed effects

$e_{s,r}$ Random effects error term

Each measure was regressed against the basic treatment and institutional dummy variables (see Table 4), and the round which represented the repetition within the session. For further analysis only significant variables were kept and using interactive variable with the institutions, to get a deeper understanding how the different treatment may have different effects based on the trading method. The interactive terms are self explanatory, for example Roundda comes from interacting the round variable with the DDA variable.

Table 4 Treatment and Institutional Variables

Round	*The repetition number within the session*
DDraw	*Dummy, 1 if it the session used 2nd draw, 0 otherwise*
DBanking	*Dummy, 1 if banking is allowed, 0 otherwise.*
DRigid	*Dummy, 1 if permits issuing was rigid, 0 otherwise.*
DFire	*Dummy. 1 if there was fire damage, 0 otherwise.*
DFireDraw	*Dummy,1 if there was fire damage and used 2nd draw*
DDA	*Institution Dummy. 1 if it is double auction, 0 otherwise.*
DCallm	*Institution Dummy. 1 if it is call market, 0 otherwise.*
DTender	*Institution Dummy. 1 if it is tender auction, 0 otherwise.*
Cons	*Constant*

4.2.1 Economic and Ecological Objectives

Table 5 shows the basic regression results for the economic and environmental outcomes. The basic regression on the total surplus (dependent variable "Total") shows that the achieved surplus is very close to the optimal under any of the treatments and institutions as the constant term is significant and close to 90% of the maximum achievable surplus. The double auction performs the best by adding an additional 4% to the surplus, while fire decreases the surplus by about 3%. There is also a positive learning effect between the repetitions (rounds) in the same session - on average there is an increase of surplus by about 1% for each extra round. The extended analysis (Table 6) which includes interaction terms illustrates more clearly how the institutions differ. The call market leads to the lowest surplus on average 86.94%, but it has the highest learning effect (1.52%) in each additional round and fire seems to have a significant effect on the surplus. The tender auction reaches 91.48% surplus without fire, but the fire the surplus decreases to 85.54%. Similar to the call market the learning is 1.14% per round. The double auction performs the best both with and without fire, however double auction has the lowest learning (1.03% per round). The double auction provides participants with more information and opportunities to learn and correct mistakes within rounds. The results suggest that the efficiency of this format outweighs concerns about potential strategic behavior, at least within the market structure tested. Fire reduces the number of permits available and increases the costs of mistakes, therefore both of the sealed bid institutions perform significantly worse with fire, but the learning effect is more pronounced.

Table 5 Basic Results for Economic and Ecological Outcomes

Variable	Total	ForestryHarv	EnergyHarv	OG	OGGini	WrongHand	Wasted and Immature
Cons	**0.8808*** **	**0.8961*** **	**0.8545*** **	**1.0608*** **	**0.0689*** **	**0.2979*** **	**0.0578*** **
DDA	**0.0430*** **	**0.0348***	0.0520*	**-0.0343*** **	0.0217	-0.0405	**-0.0516*** **
DCallm	0.0169	0.0195	0.0098	**-0.0189** **	0.0208	0.0028	**-0.0363** **
Round	**0.0123*** **	0.0019	**0.0309*** **	0.0001	0.0012	**-0.0145*** **	0.0012
DDraw	-0.0014	0.0127	-0.0336	-.0174*	0.0394	-0.0301	0.0047
DBanking	-0.0110	0.0167	**-0.0652** **	-0.0076	0.0227	-0.0025	0.0048
DRigid	-0.0083	-0.0006	-0.0124	**0.0163** **	**0.0436** **	0.0001	**0.0249** **
DFire	-0.0306	**-0.0416** **	-0.0156	**-0.0525*** **	-0.0345	**-0.0666** **	0.0008
DFiredraw	0.0246	0.0399	0.0098	0.0071	-0.0264	0.0487	-0.0063
N	239	239	239	239	239	239	239
Chi2	64.9897	14.7643	77.2315	69.1969	20.6685	36.2954	19.1553
Rho	0.5488	0.3503	0.4784	0.1587	0.5724	0.6205	0.2829
R2_o	0.2325	0.1363	0.2369	0.3348	0.2409	0.1559	0.1550
R2_w	0.2162	0.0022	0.2578	0.0000	0.0016	0.1294	0.0012
R2_b	0.2380	0.2460	0.2195	0.6379	0.3419	0.1642	0.3249

The differences between sectors in terms of economic performance are also striking. The forestry industry reaches a higher percentage of its potential (~ 90%), while the energy sector performs at 85%. Furthermore, the learning effect is significant for the energy sector but not the forest sector. This is due to the endowment effect. Recall that the energy sector does not receive any permits in the initial allocation and has a higher revenue stream than the forest industry. Therefore the marginal cost of a mistake is higher for this sector, leading to the reduced surplus as well as the significant learning effect. As expected, the energy industry is indifferent to fire; the forestry industry absorbs all fire related revenue losses and its performance drops close to energy industry levels. The double auction has a positive effect for both industry outcomes while banking reduces performance of the energy sector. The regression results in Table 6 provide additional insight. With call markets the forestry industry performs at the 89.44% level regardless of the fire. The other two institutions take the forestry to the 94.12% level without fire; with fire performance reaches 88.6% (tender) and 88.82% (double auction). The energy industry had an 86.04% performance level regardless of fire or the institution. However, banking significantly reduced the performance of this industry with surplus reduced by 7.44% and 11.64% in case of the tender auction and call markets respectively. So the banking generally caused a revenue shift between the two industries when using a sealed bid institution. One possible explanation of this is that the forest companies that initially get the permits hold on to them much more aggressively if they think they may have future use. This may benefit the forestry industry to some extent since now it can hedge its losses against fire, but reduces the energy sector surplus by a much greater extent because energy agents start out with no permits which together with the higher revenue functions results in much higher marginal damages that outweigh forestry benefits of banking. With institutions that don't allow resale opportunity forestry agents cannot correct their mistake of holding back permits which leads to a lower overall surplus level in the economy. Only the double auction institution seems to be immune to this allocation mistake with banking.

Table 6 Regression Results with significant variables and interaction effects

Variable	Total	ForestryHarv	EnergyHarv	OG	OGGini	WrongHand	Wasted and Immature
RoundDA	0.0103***		0.0221***			-.0184***	
RoundCall	.0152***		.0334***			-.0113**	
RoundTender	0.0114***		.0389***			-.0138***	
DDrawDA				-0.0423***			
DDrawCall					.0698***		
DDrawTender			-0.0854**				
DBankingDA				-0.0241**			
DBankingCall		.0609**	-0.1165***	-0.0192**		-0.0659*	
DBankingTend	-0.0422**		-0.0744**				
DRigidDA					0.0638***		
DFire				-0.0548***	-0.0477***		
DFireDA	-0.0420*	-0.0530*					
DFireTender	-0.0594***	-0.0606***					
DFireDrawDA	0.0577**	0.0796**		0.0359**			
DRigidTender				0.0230**	0.0579**		
DDA	0.0475**						-0.0517***
DCallm		-0.0468**					
DTender	0.0454**						
Cons	0.8694***	0.9412***	0.8605***	1.0493***	0.1077***	0.2353***	0.0773***
N	239	239	239	239	239	239	239
Chi2	84.2865	20.0883	86.78	98.9282	24.9840	40.7728	20.1882

Rho	0.4564	0.3353	0.4471	0.0924	0.5345	0.5680	0.2535
R2_o	0.3465	0.1751	0.2656	0.3714	0.2585	0.1939	0.1492
R2_w	0.2230		0.2760		0	0.1291	
R2_b	0.4204	0.3220	0.2569	0.7060	0.3676	0.2184	0.3146

In the basic regression we find that on average in the absence of fire there is over-compliance with the old growth target forest. However with fire old growth is closer to the target level (99.45%). Learning does not seem to have an impact on the target, even in the interactive regressions, which is a good sign as this shows that cap and trade system ensures the environmental goal regardless of the inexperience of the subjects. In the basic model, the two sided market institutions had a significant and negative effect on the amount of old growth, bringing the results more in line with the target. The detailed regressions in Table 6 show that the institutions are only relevant in certain situations. On the other hand, banking had a negative effect on the environmental goal if there was two sided market. Banking reduced the goal by 1.92% in case of call market and with 2.41% in case of double auction. Again, the two draws showed differences in case of fire, but only in case of double auction, where a 3.59% increase was present. Fire led to a more even distribution of old growth (a lower gini coefficient). On the other hand, the double auction led to greater clustering of old growth in the FMUs, illustrating that clustering is tied to gains from trade and economic performance.

Interestingly, the rigid cap increased old growth by 2.3% if tender auction was used, but had no effect with the two sided market. The intuition of this result again relates to the availability of permits under the adaptive versus the rigid cap. Under the adaptive cap, the regulator responds to fire and past mistakes by reducing the availability of permits. This increases the costs of mistakes leading to the anomalous result that the adaptive institution actually outperforms the rigid institution in terms of both economic surplus but the rigid institution outperforms in terms of old growth available, since the shadow value of the old growth constraint is reduced. The old growth constraint is costly to the forest sector but not the energy sector (its revenue is independent of what is being disturbed on the surface). Thus the effects of the rigid institution matter when the forest sector does not receive permits gratis, i.e. in the case of the tender auction.

These effects can be seen more clearly when we consider the misallocation of permits. In the basic regression we find that approximately 30% of the permits were misallocated between agents. On the other hand, only 6% of the misallocated permits were wasted or used on immature forest. This suggests that the majority of the misallocation was due to the fact that forestry agents harvested slightly lower value old growth than what could have been harvested by another forestry agent. Generally the coefficients just confirm what we already could notice from the total surplus regression. The double auction reduced the number of misplaced permits, hence increased the total surplus. The call market led to the highest misallocated permits. Finally, the learning effect was confirmed as the round coefficient is negative showing that as the subjects got more experienced they tended to misallocate fewer permits.

5 Conclusion

In this paper we examine the performance of various options for implementing a cap and trade program for land disturbance permits in the boreal forest. Using forestry and energy sector data from Alberta, we constructed hypothetical forest management units which were used in lab experiments to test the effects of fire, adaptive management, the initial allocation and market trading rules on economic and ecological outcomes. The experiments produced a number of insights with respect to the design of such markets. In particular, in the absence of cheating, we found that the tighter the ecological constraint, the greater the discipline of the market. As a result options such as banking which reduce the costs of such constraints actually led to poorer economic performance. In addition, with full compliance there was a tradeoff between economic performance and ecological outcomes since misallocation of permits led to over-compliance. Tighter ecological constraints reduced the number of mistakes, actually leading to reduced old growth. Thus rigid institutions actually improved ecological outcomes but reduced the surplus. It is not clear the extent to which these results might change if cheating were allowed.

In general the open market format of the double auction outperformed the two other institutions examined, and resulted in greater clustering of old growth on the landscape (which may or may not be a desirable property). The second price sealed bid auction was also relatively efficient. Note that while this auction format is efficient at allocating permits, it does not necessarily generate the highest revenues. However in the case of auctioning disturbance permits we assume that the goal of the government is only to efficiently allocate permits, since existing mechanisms for allocating actual dispositions are designed to capture resource rents. In addition, the auction can be designed to be revenue neutral so that the performance of the institutions can be compared based on the aggregate surplus rather than distribution of benefits.

The double auction format could be viewed as analogous to an ‘offsets’ system on public lands, where firms might temporarily sterilize non-permanent development rights held by other firms in order to mitigate the footprint. Interestingly, the call market, which could be viewed as an alternative ‘offset’ approach (since it is based on trading grandfathered permits) performs the least well. This highlights the importance of information and market institutions in efficient allocation of resources and tradable permit outcomes. The sealed bid approach used in the call market might reflect the information context of bilateral trading, where there are high search costs and information asymmetries between agents, leading to inefficient transactions. The difference between the double auction and sealed bid approach illustrates the gains from information and coordinated trading. In addition, without the double auction, the initial distribution of permits was more important, since grandfathering to the forest sector resulted in high costs to energy sector agents. Note that this grandfathering rule assumes that disturbance rights would be tied to current rights to timber rather than to energy dispositions. This rule reflects existing rules for the energy sector in terms of access agreements since they must negotiate with and compensate forest tenure. The purchase of a disturbance permit from the forest sector would be a substitute compensation mechanism for surface access to subsurface rights, and also reflects concerns in the forest sector about not being able to compete with energy sector players for permits on an open market.

In conclusion, tradable disturbance permits are a market based approach to manage cumulative effects on public forest lands. In designing such systems, governments need to consider tradeoffs between economic efficiency, ecological outcomes, and underlying property rights. The study highlights the impact of design options on these various outcomes and the importance of testing policy prior to implementation.

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7 Appendix – Input Data

Table 7 Aggregated FMU Data

Name	ID	Inventory			Revenue			Energy
		Young	Mature	Old	Young	Mature	Old	
a14	1	1	16	17	0	5.16	11.61	**0.03**
a9	2	0	5	4	0	4.58	11.9	**0.06**
f11	3	0	22	6	0	5.12	11.66	**0.02**
f14	4	0	11	10	0	6.32	10.88	**0.02**
f23	5	3	30	16	0	5.4	14.4	**0.18**
f26	6	7	121	90	0	5.18	12.32	**0.04**
g13467	7	2	30	27	0	5.04	11.62	**0.00**
g14	8	0	2	1	0	3.82	11.33	**0.02**
p10	9	0	13	6	0	4.99	10.94	**0.05**
p178	10	1	27	21	0	8.78	24.27	**0.04**
p6	11	1	7	14	0	5.94	12.98	**0.03**
p9	12	1	12	2	0	3.44	10.13	**0.03**
pg15	13	1	22	21	0	4.54	12.66	**0.03**
pp13	14	1	12	15	0	5.06	13.96	**0.06**
s10	15	1	17	8	0	3.62	12.26	**0.02**
s11	16	0	12	4	0	4.29	12.93	**0.04**
s14	17	0	12	5	0	4.14	11.65	**0.03**
s17	18	3	10	28	0	5.35	12.23	**0.03**
s18	19	0	11	13	0	3.9	13.36	**0.02**
s19	20	0	17	6	0	3.87	13.66	**0.04**
s20	21	3	13	23	0	5.35	12.11	**0.03**
s21	22	1	11	5	0	4.97	15.08	**0.04**
s22	23	0	25	8	0	3.7	12.45	**0.05**
s7	24	0	7	4	0	10.08	24.5	**0.02**
w11	25	3	2	4	0	9.49	28.22	**0.04**
w13	26	0	0	1	0.03	6.27	11.46	**0.03**
w2	27	2	2	1	0	2.91	11.94	**0.02**
w34	**28**	**0**	**1**	**8**	**0**	**20.03**	**55.11**	**0.03**

Table 8: Draw 1 Players

	Inventory			**Revenue**			**Permit Share**
	young	**mature**	**old**	**young**	**mature**	**old**	
f-1	1	27	21		8.78	24.27	21.50%
f-2		11	13		3.90	13.36	10.58%
f-3		1		82.67	82.67	82.67	
f-4	3	13	23		5.35	12.11	16.04%
f-5	1	12	2		3.44	10.13	6.29%
f-6		1	1	71.64	71.64	71.64	
f-7		11	10		6.32	10.88	9.12%
f-8	1	16	17		5.16	11.61	14.78%
f-9		1	1	66.13	66.13	66.13	
f-10		13	6		4.99	10.94	8.43%
f-11		1	8		20.03	55.11	4.13%
f-12		11	10		6.32	10.88	9.12%
Total	**6**	**118**	**115**				**100%**

Table 9: Draw 1 limits

	1st Period	2nd Period	3rd Period	Total
Old Growth Goal	80	150 (144with Fire)	139	139
Permit with No fire	32	53	30	115
Permits with Fire	22	26	17	65

Table 10: Draw 2 Players

	Inventory			Revenue			Permit Share
	young	mature	old	young	mature	old	
f-1	3	30	16		5.40	14.40	18.33%
f-2		25	8		3.70	12.45	12.89%
f-3		2	1	36.75	36.75	36.75	
f-4	1	17	8		3.62	12.26	10.22%
f-5		13	6		4.99	10.94	7.54%
f-6		3	1	31.85	31.85	31.85	
f-7		2	1		3.82	11.33	1.16%
f-8	2	30	27		5.04	11.62	22.97%
f-9		2	1	29.40	29.40	29.40	
f-10	1	27	21		8.78	24.27	19.22%
f-11		7	4		10.08	24.5	4.27%
f-12		5	4		4.58	11.9	3.40%
Total	**7**	**136**	**95**				**100%**

Table 11: Draw 2 limits

	1st Period	2nd Period	3rd Period	Total
Old Growth Goal	69	166 (144with Fire)	138	138
Permit with No fire	36	69	45	150
Permits with Fire	25	48	29	102