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Lottery-rationed public access under alternative tariff arrangements: changes in quality, quantity, and expected utility ☆

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Abstract

A recent phenomenon is the emergence of quotas restricting individual access to public resources. As regulators commonly ration access opportunities by lottery, this paper extends the traditional, open access destination choice framework for non-market demand and welfare analysis. Conceptual results for one- and two-part tariff lotteries indicate that individuals may sustain welfare losses from improvements in quality or increases in the quota if aggregate demand is sufficiently responsive relative to individual utility. Nested random *expected* utility models (REUMs) are estimated with a panel dataset of individual choices of lottery-rationed harvest rights for wild game. Empirical results indicate that the types and timing of tariff payments affect participation, choices over rationed and open access alternatives and the benefits derived from changes in the quality and quantity of the lottery-rationed access opportunities.

Keywords: Access; Lotteries; Quotas; Tariffs; Recreation demand; Nested multinomial logit

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1. Introduction

Portfolios of regulations are managed by state and federal agencies to mitigate pressures upon the natural environment. Common amongst these are quotas restricting aggregate resource use by firms. Beginning with caps imposed upon emission of pollutants, quotas currently span the use of all natural inputs to production (i.e., air, land, and water resources). A more recent phenomenon is the emergence of quotas restricting aggregate resource use by individual consumers. Popular examples include quotas on Grand Canyon river-rafting and Alaskan fishery harvests, yet quotas also restrict individual access to public facilities, lands, and waters for hunting, site-seeing, boating, camping, rock-climbing, and driving off-road vehicles.

Regulators impose quotas when congestion or aggregate consumption is deemed relatively excessive. In the process, they confront the dilemma of allocating access rights in an equitable manner while avoiding recurrent budget shortfalls. While efficiency has guided the choice and design of auctions and competitive bidding mechanisms for rationing to firms, equity concerns have influenced the adoption of lotteries for rationing to consumers.[1] As with choices made over open access alternatives, individuals make qualitative and quantitative choices given their preferences and budget constraints. In contrast, uncertainty accompanies choices over lotteries.

Considering the frequent adoption of lotteries for allocating access rights and the array of lottery formats observed in practice, it is natural to question their roles as management instruments and implications for non-market demand analysis. As such, this study conceptually and empirically evaluates lottery rationing in the context of under-priced public access rights. In the next section, expected utility maximizing individuals confronting one- and two-part tariff lotteries are shown to incur welfare losses (gains) from improvements in the quality of the resource stock and increases in the size of the quota if aggregate demand is relatively responsive (unresponsive). Individual non-market values derived from changes in the characteristics of lottery-rationed goods are shown to be equivalent to changes in the tariff rates.

In Section 3, lottery-choice data generated through a natural policy experiment is exploited. A panel dataset containing more than 50,000 individual choices of public-land hunts for wild game is used to estimate random *expected* utility models (REUMs) under alternative lottery formats and with choice sets comprised of lottery-rationed and open access substitutes. The implications for regulatory design and policy analysis and estimates of willingness-to-pay (WTP) are discussed in Section 4. Results indicate that the types and timing of tariff payments affect individual participation, choices over rationed and open access alternatives, and non-market benefits and the revenues collected by the regulator. Section 5 concludes.

[1]However, examples of rationing by lottery to firms include US Fish and Wildlife Service lotteries for fishery harvest rights in Maine to reduce Atlantic Salmon by-catch; Bureau of Land Management lotteries for natural gas leases; Federal Communications Commission spectrum lotteries; and Federal Aviation Administration gate "Slotteries" at LaGuardia Airport.

2. Rationing public access by lottery

Public facilities and resource stocks suffer from inefficient use under open access [5]. To mitigate public pressures, state and federal agencies—including the US Forest Service, National Park Service, Bureau of Land Management, and US Fish and Wildlife Service—have historically allowed unlimited aggregate access (e.g., visitation) while regulating usage at the individual level. More recently, agencies have begun imposing quotas on aggregate access. While debate is ongoing in land and water management forums on the merits of the various approaches to rationing fixed numbers of access rights, what can not be debated is the frequent adoption of some sort of lottery by managing agencies.

Although their objectives may differ, a survey reveals that several characteristics are shared by lottery systems managed at state and federal levels. First, the lotteries usually award no more than one license to an applicant (or party) per period (e.g., annually), and in some cases the period spans a lifetime. Second, the licenses are typically non-transferable so as to discourage speculators from participating [4]. Third, the lottery systems are often comprised of a number of heterogenous lotteries that spread visitation over periods and/or geographic areas. Fourth, and of interest here, agencies collect revenues from participants through some tariff payment arrangement. One-part tariff lotteries require payment of a non-refundable entry fee to participate. Two-part tariff lotteries require payment of the entry fee and an additional access (or license) fee. The latter may be collected up-front with the entry fee or after the random assignment of the licenses. When collected up-front, the license fee is refunded to unsuccessful participants; otherwise, the fee is collected after the random draws from successful participants.

The non-refundable entry fees tend to be set rather low (e.g., \$5–\$10) regardless of the tariff arrangement. In contrast, the secondary license fees charged in two-part tariff lotteries are often several hundred or thousand dollars. As a result, the timing of their collection by the agency may have a profound affect upon individual participation, choices over alternatives, and consumer surplus in addition to the tariff revenues collected by the agency. Yet turning to the literature for insight on public lotteries (see [4,8,12,15,18]), one finds that the lottery format remains largely unexplored. Given the significance of the tariff payment mechanism in rationing under-priced non-market goods, one- and two-part tariff lotteries are evaluated below.

2.1. Lottery rationing and the tariff arrangement

The regulator is assumed to manage J public resource stocks or facilities. Alternative $j \in J$ is characterized by an attribute vector Q_j comprised of environmental amenities, time and geographic components, and individual and aggregate consumptive-use regulations. The regulations of interest are the exogenously determined quotas, which restrict aggregate consumption to S_j units per period $\forall j \in J$.

The regulator is confronted by a population of N expected utility maximizing individuals who derive utility from accessing the resource stock or facility. Individual $i \in N$ receives income per period of Y_i and discounts the future at rate r. Income is exhausted upon the lottery and a composite good K priced at P_K per unit. Individuals may request access to a single alternative per period. Similar to [5,19], the number of individuals desiring access to the jth alternative (N_j) and the quota (S_j) are assumed to be known by all. Thus, the probability of being drawn is known and equal to $\phi_j = S_j/N_j \; \forall j \in J$. In period one, an individual selects the expected utility maximizing alternative, and in the second period the regulator randomly assigns access rights (e.g., licenses) to alternatives attracting applicants in excess of the quotas.

As the types and timing of tariff payments affect the individual's budget constraint, the expected utility derived from a given alternative will differ between tariff payment formats. In evaluating the tariff format, additional transactions costs incurred in acquiring access are suppressed. These may include search and information costs incurred in the first period and travel costs incurred if granted access in the second period.

2.1.1. One-part tariffs

Under a one-part tariff arrangement, participants pay a non-refundable fee (P_L) in period one for the opportunity to receive a license in the second period. Individual i's budget constraint in period one is $Y_i = P_L + P_K K$ and in period two is $Y_i = P_K K$. The expected utility derived by the individual from the opportunity to access alternative j is written:

$$E(U_{j,i}) = \frac{\phi_j V(Y_i, Q_j) + (1-\phi_j)V(Y_i)}{(1+r)} + V(Y_i - P_L) \quad \forall j \in J; \;\; i \in N. \tag{1}$$

The first term on the right-hand side is the expected utility discounted from period two. The expected gain is equal to the product of the utility derived from access, $V(Y_i, Q_j)$, and the access probability, ϕ_j. The status quo level of utility, $V(Y_i)$, is obtained with probability $(1-\phi_j)$ otherwise. The second term, $V(Y_i - P_L)$, represents the utility experienced in period one with income remaining after payment of the non-refundable entry fee. As the individual is either granted access or incurs the utility of income, note that the second period expected utility of participating is greater than the utility derived from not participating. However, given the payment of P_L in period one, the expected future gain comes at the expense of current utility.

2.1.2. Two-part tariffs with simultaneous payments

With two-part tariff lotteries the agency collects the non-refundable P_L and an access (or license) tariff denoted $P_j \; \forall j \in J$. This additional fee may be collected simultaneously with P_L and then refunded in the second period to those not drawn or it may be collected after the drawings from successful participants. Considering the former, the period one budget constraint is $Y_i = P_L + P_j + P_K K$ and the expected period two budget constraint is $Y_i + (1-\phi_j)P_j = P_K K$.

The expected utility derived from the alternative j access opportunity by individual i is

$$E(U_{j,i}) = \frac{\phi_j V(Y_i, Q_j) + (1-\phi_j)V(Y_i + P_j)}{(1+r)} + V(Y_i - P_L - P_j) \quad \forall j \in J; \;\; i \in N. \tag{2}$$

As with the one-part tariff arrangement, the first term is the expected utility discounted from period two, and the second term is the utility obtained in period one with income remaining after payment of the tariffs.

2.1.3. Two-part tariffs with staggered payments

The regulator may instead defer collection of the access tariff P_j until after conducting the random draws. In this case, the period one budget constraint is identical to that of the one-part tariff arrangement, and the expected second period budget constraint is $Y_i = \phi_j P_j +$

$P_K K$. The expected utility derived from the alternative j access opportunity by individual i is written:

$$E(U_{j,i}) = \frac{\phi_j V(Y_i - P_j, Q_j) + (1 - \phi_j) V(Y_i)}{(1 + r)} + V(Y_i - P_L) \quad \forall j \in J; \;\; i \in N. \tag{3}$$

Here, the access tariff appears as a deduction from the second period income if drawn. All else constant, the utility in period one exceeds that realized with the simultaneous tariff lottery and is equal to that realized with the one-part tariff lottery, while the opposite holds in period two.

Comparison of (2) and (3) reveals that as the lag between applying and the random draws approaches zero or if $r = 0$, then expected utility is equivalent between the two-part tariff lotteries. Further, as P_j approaches zero, expected utility under the two-part tariff lotteries converges upon that of the one-part tariff lottery. And in all cases, as ϕ approaches one the individual's problem converges upon the standard utility maximizing destination choice problem; however, the present value of the access opportunity will be lower with the simultaneous payment format relative to the staggered payment format since P_j is collected in period one.

2.2. Welfare effects of changes in quality and quantity

When aggregate public access is restricted by quotas, improvements in quality may be met by increases in aggregate demand but not necessarily in the quotas. A historic example is access to the Grand Canyon for river-rafting. Bound by quota under the Hatch Amendment since 1980, non-commercial trips were allocated by the National Park Service through a lottery in the quota's first year and a queue (or waiting-list) in all years since. Although variation in river flows may affect the recreational experience over time, the quota has remained constant. The queue currently exceeds 7000 participants and wait-times of about 15 years for new entrants.

Changes in the quality of lottery-rationed resources affect expected utility *directly* through indirect utility, $V(Y - P, Q)$, and *indirectly* through aggregate demand, $N(P, Q)$. Assuming individual utility is increasing in quality, it follows that the total welfare of the S license recipients will necessarily increase with quality improvements. As this holds across all combinations of recipients, the average (or expected) social welfare will increase with an improvement in quality.[2] However, as aggregate demand is also increasing in quality, the likelihood of being awarded a permit will decline as quality improves. Hence, a natural question arises regarding the relationship between resource quality and the expected utility of the access opportunity. The answer is intuitive: If aggregate demand is responsive to changes in quality relative to the utility derived by the individual, then expected utility will decrease. Otherwise, it will increase (or remain constant). This relation may be expressed in terms of elasticities.

Consider first a change in a quality attribute. With one-part tariff lotteries and assuming the attribute vector Q is comprised of a single, continuous measure of quality, the partial derivative of

[2] As with quality improvements, if the quota is treated as an element of the attribute vector, an increase in its size will necessarily lead to an increase in the utility incurred by a given recipient compared to before the change in the quota. Further, the number of recipients increases. As a result, the average (or expected) total social welfare will increase with an increase in the quota. A similar result is obtained if the quota is treated as being independent of Q; however, the increase in social welfare is attributed solely to the greater number of recipients.

expected utility with respect to Q is

$$\frac{\partial E(U)}{\partial Q} = \frac{\phi_Q(V(Y,Q) - V(Y)) + \phi V_Q(Y,Q)}{(1+r)}. \tag{4}$$

The subscripts denote partial derivatives, and the individual and alternative-specific subscripts (i and j, respectively) are suppressed for clarity. As $\phi = S/N$ and $N = N(P,Q)$, (4) is re-written:

$$\frac{\partial E(U)}{\partial Q} = \frac{\phi}{(1+r)}\left(V_Q(Y,Q) - \frac{(V(Y,Q) - V(Y))}{N}\frac{\partial N}{\partial Q}\right). \tag{5}$$

Since ϕ and r are positive, the sign of (5) depends upon the sign of the term in parentheses. Thus,

$$\frac{\partial E(U)}{\partial Q} > 0 \quad \text{iff} \quad V_Q(Y,Q) > \frac{(V(Y,Q) - V(Y))}{N}\frac{\partial N}{\partial Q}. \tag{6}$$

Multiplying the right-hand side of the conditional statement by Q/N and rearranging reveals a relationship between expected utility and quality in terms of the elasticity of aggregate demand:

$$\frac{\partial E(U)}{\partial Q} > 0 \quad \text{iff} \quad \frac{\partial N/N}{\partial Q/Q} < \frac{V_Q(Y,Q)Q}{V(Y,Q) - V(Y)}. \tag{7}$$

Hence, the effect of a change in quality on expected utility may be decomposed into direct and indirect effects; the former appear through the indirect utility function and the latter appear through the aggregate demand function.

Similar to with the indirect effect of aggregate demand on expected utility, the direct effect through the utility function may be expressed in terms of an elasticity. Formally,

$$\frac{\partial E(U)}{\partial Q} > 0 \quad \text{iff} \quad \frac{\partial N/N}{\partial Q/Q} < \frac{\partial V(Y,Q)/V(Y,Q)}{\partial Q/Q}\left(\frac{V(Y,Q) - V(Y)}{V(Y,Q)}\right)^{-1}. \tag{8}$$

The result (8) states that expected utility will increase if the indirect aggregate effect of the quality change (represented by the aggregate demand elasticity) is less than the direct, individual effect. The latter depends both upon how responsive utility is around the initial level of quality (represented by the elasticity of utility) and upon the extent of the divergence between the utility derived from access at the initial level and the status quo utility of income. If indirect utility is increasing and concave in Q, then the compound individual effect diminishes as Q increases. And if indirect utility is linear in Q, the separate individual effects exactly offset one another, and the compound individual effect is therefore equal to one at all levels of quality. Similar results are derived in Appendix A for the simultaneous and staggered tariff lotteries.

Expected utility will also vary with the quota size. Here, the effect is dependent upon the relation between the quota and utility. If utility is increasing in the quota and assuming the attribute vector is comprised solely of the quota for notational ease (i.e., $Q = S$), the relationship between expected utility and the quota with the one-part tariff lottery is expressed:

$$\frac{\partial E(U)}{\partial S} > 0 \quad \text{iff} \quad \frac{\partial N/N}{\partial S/S} < 1 + \frac{\partial V(Y,S)/V(Y,S)}{\partial S/S}\left(\frac{V(Y,S) - V(Y)}{V(Y,S)}\right)^{-1}. \tag{9}$$

In this case, the individual effect may be interpreted in a manner similar to (8) for concave and linear indirect utility functions. However, in contrast to (8), changes in the quota affect both the numerator and denominator of the access probability, and as a result, (9) contains an additional term attributed to the appearance of the quota in the former. Given that ϕ is increasing in its numerator, the downward pressure on ϕ resulting from an increase in aggregate demand will be partially offset by the increase in the quota. If indirect utility and the quota are instead assumed to be independent (i.e., $Q \neq Q(S)$), then the direct, individual effect disappears, and expected utility will increase (decrease) if the aggregate demand elasticity is less than (greater than) one.

Individual non-market values attached to changes in quality or the quota are defined by the incremental income required to maintain expected utility at the status quo (i.e., maximum willingness-to-pay, WTP). Because $E(U)$ will decline if aggregate demand is sufficiently responsive to changes in quality or the quota, welfare losses will be incurred by some individuals as a result. Expressed in terms of period one income, WTP for a change in quality or the size of the quota under one-part tariff lotteries (1) is represented as

$$\begin{aligned} &\frac{\phi V(Y,Q) + (1-\phi)V(Y)}{(1+r)} + V(Y - P_L) \\ &\quad = \frac{\phi^* V(Y,Q^*) + (1-\phi^*)V(Y)}{(1+r)} + V(Y - P_L - WTP), \end{aligned} \tag{10}$$

where Q^* and ϕ^*denote the altered vector of lottery attributes and access probability, respectively. Similarly, with simultaneous two-part tariff lotteries (2), WTP is represented:

$$\begin{aligned} &\frac{\phi V(Y,Q) + (1-\phi)V(Y+P_j)}{(1+r)} + V(Y - P_L - P_j) \\ &\quad = \frac{\phi^* V(Y,Q^*) + (1-\phi^*)V(Y+P_j)}{(1+r)} + V(Y - P_L - P_j - WTP). \end{aligned} \tag{11}$$

And with staggered two-part tariff lotteries (3), WTP is represented:

$$\begin{aligned} &\frac{\phi V(Y-P_j,Q) + (1-\phi)V(Y)}{(1+r)} + V(Y - P_L) \\ &\quad = \frac{\phi^* V(Y-P_j,Q^*) + (1-\phi^*)V(Y)}{(1+r)} + V(Y - P_L - WTP). \end{aligned} \tag{12}$$

In all cases, the welfare measure is independent of the outcome of the lottery and equivalent to the change in the non-refundable tariff (P_L) that maintains expected utility at the status quo.

Given that changes in expected utility can not be signed in general from the conceptual model as indicated by the elasticity analysis, their sign (and size) in practice will be uncertain for changes in a given system of lotteries. Considering the frequent use and ongoing adoption of lotteries for rationing recreational access rights and the variety of forms in which the lotteries may be constructed, the remainder of the paper develops and empirically implements a discrete choice approach for lottery demand analysis.

3. Empirical analysis

Similar to open access recreation demand models, lottery demand models have taken either (i) a multi-site travel cost approach relating zonal aggregates (e.g., counties or zip-codes) of lottery applications to travel costs and characteristics of the lotteries [10,17]; or (ii) an individual-level discrete choice approach, whereby the probability of selecting an alternative on a given occasion is modeled as a function of travel costs and characteristics of the lotteries and, perhaps, the individual decision makers [1,3,16]. Regardless of whether the interest rests in evaluating open access or lottery demand, individual-level models are generally preferred as they eschew biases associated with representative-consumer models (see, e.g., [7,9]) and allow substitution patterns across alternatives to be identified.

Individual-level lottery demand models have only recently begun to appear in the non-market valuation literature. Noting that regulators typically allow one application per person for a non-transferable license with well-defined characteristics and that uncertainty accompanies the choice occasion, Boxall [3] developed the first random *expected* utility model (*REUM*) for analysis of lottery demand. However, estimated non-market values produced by the model are biased upward in absolute value as the access probabilities are invariant to changes in the attributes of the lotteries. Akabua et al. [1] evaluated Boxall's [3] model with different specifications of expected utility, but the access probabilities were again held constant. More recently, Scrogin and Berrens [16] jointly modeled the probability of access and lottery choice. However, they continue in the tradition of the earlier studies by estimating a standard (non-nested) multinomial logit model despite its restrictions.

Although the earlier studies established lottery-rationing as a legitimate focus for research efforts, several issues remain to be addressed empirically. The first regards the extent to which the tariff arrangement affects individual choice and non-market benefits and the tariff revenues collected by the regulator. And second, given that aggregate public access has historically been unregulated, the role of open access substitutes in individual choice sets is also of interest.

3.1. The data

The data is the product of a natural policy experiment conducted by a public resource management agency. In the first year of data (1997)—and the 20 years preceding—the New Mexico Department of Game and Fish (NMDGF) managed quota hunts on public lands for deer, elk, antelope, bighorn sheep, wild pig, bison, ibex, and oryx through a system of non-transferable lotteries with two-part tariffs collected simultaneously from applicants (2). In the second year (1998) the tariff collection was staggered: entry fees (P_L's) were collected with the applications, but the license fees (P_j's) were collected after the random draws (3). The agency director announced that the policy change "…is intended to remove a financial barrier for many families; will simplify the [application] process for both hunters and [NMDGF]; and will eliminate some significant costs in processing applications and refunds" [14, p. 5]. About 40,000 additional applications were subsequently submitted for big-game hunting licenses.

The focus here is upon resident choices over the 136 hunts for elk with a rifle. The choice set consists of quota hunts and open access hunts. An individual could submit a single application for a license to harvest one elk in either a quota hunt or an open access hunt. The 1997 data contains

Table 1
Distribution of hunts and participants by access category

	Simultaneous tariff payments (1997)			Staggered tariff payments (1998)		
	Open access	Quota access ($\phi = 1$)	Quota access ($\phi < 1$)	Open access	Quota access ($\phi = 1$)	Quota access ($\phi < 1$)
Elk Hunts						
N	8	20	108	8	23	105
% of total	6	15	79	6	17	77
Participants						
N	645	1257	16,832	1025	3166	28,480
% of total	3	7	90	3	10	87
Per hunt	80.63	62.85	155.85	128.13	137.65	271.24
	(63.71)	(59.20)	(175.69)	(111.73)	(146.51)	(331.84)
Age	40.19	38.35	40.45	40.10	38.28	39.23
	(14.59)	(13.54)	(14.53)	(14.87)	(13.90)	(14.61)
% Male	93	90	91	93	93	90

Notes: The NMDGF defines hunts in terms of time and geographic location. The term ϕ refers to the *ex ante* access probability calculated from quota and applicant data reported in the application books. Numbers in parentheses are standard deviations.

18,734 participants (Table 1), while the 1998 data contains more than 32,000 participants. New and existing participants are identified by matching individuals in both periods using a combination of lastnames, firstnames, middle initials, and dates-of-birth. Across periods and participant groups in the second period, the bulk of individuals chose quota hunts with *ex ante* probabilities of access (ϕ's) less than one. And in all cases the mean characteristics of participants are quite similar: the average participant is male and about 39 years of age.

Hunt locations, times, regulations, quota size, and number of applicants in the prior season were reported in the annual application books [13,14]. The variable *QUOTA* is defined as the quantity of licenses to be awarded (Table 2). Dividing *QUOTA* by *PAST PARTICIPANTS* yields the variable *EX ANTE PROBABILITY*. The variable *HARVEST RATE* indicates the percentage of hunters who harvested an elk in the previous reporting period. Additional hunt characteristics include dummies for regulations (*BULL*) and geographic locations (*NE*, *SE*, and *SW*). The *TRAVEL COST* variables measure the round-trip travel costs and *TARIFF* denotes the license fee, which varies with the bag-limit. Lastly, the discount rate (r) must be selected. A two percent rate is used here for discounting over the 3 month period between submission of the applications and the drawings.[3]

[3]It is recognized that individual discount rates may differ from the 2% rate used here. Rates ranging from 0–10% were examined during preliminary analysis; however, the estimation results were not sensitive to the value. As there was approximately a 3 month period between when applications could be submitted and when the random draws occurred, the two percent rate was chosen for discounting over the period as it translates to about an eight percent annual rate.

Table 2
Hunt characteristics: definitions and summary statistics

Variable	Definition	Simultaneous tariff payments		Staggered tariff payments	
		Mean	Standard deviation	Mean	Standard deviation
TRAVEL COST	\$0.325 × Round-trip miles	151.10	80.42	151.19	81.96
TARIFF	License tariff	63.31	14.68	57.04	11.26
QUOTA	Number of licenses to be awarded	94.49	101.11	91.85	96.43
PAST PARTICIPANTS	Number of participants in previous year	261.41	343.13	168.43	192.96
EX ANTE PROBABILITY	Ratio of *QUOTA* to *PAST PARTICIPANTS*	0.48	0.31	0.53	0.29
HARVEST RATE	Ratio of total harvest to hunters in 1995	0.36	0.29	0.36	0.29
BULL	1 if hunt is for a bull elk; 0 otherwise	0.54	0.50	0.51	0.50
NE	1 if hunt is in northeast NM; 0 otherwise	0.27	0.45	0.27	0.45
SW	1 if hunt is in southwest NM; 0 otherwise	0.23	0.42	0.23	0.42
SE	1 if hunt is in southeast NM; 0 otherwise	0.03	0.17	0.03	0.17

Notes: The variable *TRAVEL COST* is calculated from the 18,734 and 32,671 applicants in 1997 and 1998, respectively. The variables *QUOTA*, *PAST PARTICIPANTS*, and *EX ANTE PROBABILITY* are calculated from the 128 quota hunts. Remaining variables are calculated from all 136 rifle hunts for elk.

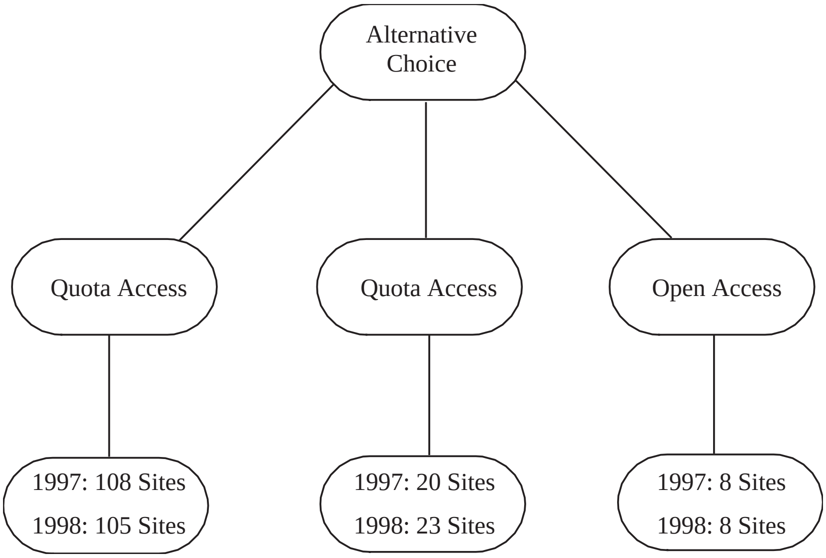

Fig. 1. Three branch decision tree of restricted and open access hunt choice.

3.2. REUMs of recreational lottery choice

Individual choice of big-game hunt is modeled in a multi-stage decision framework with the nested multinomial logit model (see [2,6,11] for technical details) as the hunts may naturally be partitioned by their access type (i.e., open access or lottery access). The decision tree (or nest) examined here contains two levels and three branches (Fig. 1).[4] At the top level, an individual selects either an open access hunt, a quota hunt with ex ante surplus licenses (ϕ's = 1), or a quota hunt with ex ante license shortages (ϕ's < 1). Conditional upon the choice of access category, a hunt is chosen at the bottom level of the nest.

The empirical specifications of expected indirect utility are dependent upon the lottery format, the probability of access, and the individual indirect utility functions. The expected indirect utility functions are expressed in general as

$$E(U_{j,i}) = \phi_j V_{j,i} + \varepsilon_{j,i} \quad \forall j \in J, i \in N, \tag{13}$$

where $\phi_j V_{j,i}$ is the deterministic component of expected indirect utility, and $\varepsilon_{j,i}$ is the random, unobservable component. The nested logit model may be derived from the generalized extreme value (GEV) model, whereby the ε's are correlated within branches but are independent across branches (see [2, pp. 304–309; 11, pp. 183–189]). For both lottery formats, the individual's indirect

[4] Standard multinomial logit and two-branch nested logit models were also estimated. With the former, the assumption of IIA was rejected by the Hausman test; and the latter were found to be statistically inferior to the three-branch model in both years (see Appendix C).

utility function $V_{j,i}$ is defined as linear-in-parameters and linear-in-variables. Substituting the function into (2) and (3) and simplifying yields the deterministic portion of expected indirect utility. With the simultaneous tariff lottery $\phi_j V_{j,i}$ is defined:

$$\begin{aligned}\phi_j V_{j,i} = {} & \alpha_1\phi_j\, OPEN_j{*}\, AGE_i + \alpha_2\phi_j\, OPEN_j{*}MALE_i \\ & + \alpha_3\phi_j\, RESTRICTED_j{*}AGE_i + \alpha_4\phi_j\, RESTRICTED_j{*}MALE_i \\ & + \beta_1(\phi_j\, TRAVEL\ COST_j(1+r)^{-1} + TARIFF_j(1-(1-\phi_j)(1+r)^{-1})) \\ & + \beta_2\phi_j\, HARVEST\ RATE_j + \beta_3\phi_j\, QUOTA_j + \beta_4\phi_j\, BULL_j \\ & + \beta_5\phi_j\, NE_j + \beta_6\phi_j\, SE_j + \beta_7\phi_j\, SW_j. \end{aligned} \tag{14}$$

And with staggered tariff lottery $\phi_j V_{j,i}$ is defined:

$$\begin{aligned}\phi_j V_{j,i} = {} & \alpha_1\phi_j\, OPEN_j{*}AGE_i + \alpha_2\phi_1\, OPEN_j{*}MALE_i \\ & + \alpha_3\phi_j\, RESTRICTED_j{*}AGE_i + \alpha_4\phi_j\, RESTRICTED_j{*}MALE_i \\ & + \beta_1\phi_j(TRAVEL\ COST_j + TARIFF_j)(1+r)^{-1} + \beta_2\phi_j\, HARVEST\ RATE_j \\ & + \beta_3\phi_j QUOTA_j + \beta_4\phi_j\, BULL_j + \beta_5\phi_j\, NE_j + \beta_6\phi_j\, SE_j + \beta_7\phi_j SW_j. \end{aligned} \tag{15}$$

Rows one and two in (14) and (15) denote the expected indirect utility derived from the access category chosen at the top of the nest. The variable *OPEN* equals one with the open access hunts and is zero otherwise. The variable *RESTRICTED* equals one if the hunt has an access quota *and* surplus licenses ex ante and is zero otherwise. Rows three and four contain the expected indirect utility of the hunt. Given the definitions of the access-type dummies, it follows that ϕ appears explicitly solely in the bottom level of the nest. Further, the specifications are equivalent if $r = 0$.

To proceed to estimation, the access probabilities must first be specified. One option is to define them by the variable *EX ANTE PROBABILITY* used to partition the quota hunts in the nest. But this is problematic if the choice model is to be used for policy simulations or calculating *WTP* since ϕ will vary with changes in quality or the quota. As such, the preferred option is to model ϕ directly. The approach taken here fits a probability model to the binary outcomes of the lottery (drawn or not drawn) over the 196 quota hunts for elk (rifle, bow, and muzzle-loader). The estimated model is used to generate fitted values of the ϕ_j's, which are then substituted into (14) and (15) to obtain the expected indirect utility functions. Denoting $A_{j,i} = 1$ as the outcome 'individual i drawn in lottery j' and $A_{j,i} = 0$ as the outcome 'individual i not drawn in lottery j', the probabilities of being drawn and of not being drawn are written:

$$\begin{aligned}\phi_{j,i} &= \mathrm{Prob}(A_{j,i} = 1|z_j) = F(z_j, \lambda), \\ 1-\phi_{j,i} &= \mathrm{Prob}(A_{j,i} = 0|z_j) = 1 - F(z_j, \lambda). \end{aligned} \tag{16}$$

The term $F(\cdot)$ represents a continuous cumulative distribution function (e.g., standard normal or logistic), z_j is a vector of regressors, and λ is a parameter vector to be estimated.

Conditional upon (16), the nested logit model may be estimated. Dropping the individual specific subscript i for clarity, the probability of choosing alternative j within access category

$k \in K$ is expressed as the product of conditional and unconditional probabilities:

$$\text{Prob}(j,k) = \text{Prob}(j|k) \cdot \text{Prob}(k). \tag{17}$$

The probability of choosing alternative j conditional upon choosing access category k is written:

$$\text{Prob}(j|k) = \frac{e^{X'_{j,k}\beta}}{\Sigma_{j=1}^{J_K} e^{X'_{j,k}\beta}}, \tag{18}$$

where β is a parameter vector and $X_{j,k}$ is a vector of regressors; the term $X'_{j,k}\beta$ represents the third and fourth rows of (14) and (15). The probability of selecting access category k is written:

$$\text{Prob}(k) = \frac{e^{Y'_k\alpha + I'_k\gamma_k}}{\Sigma_{k=1}^{K} e^{Y'_k\alpha + I'_k\gamma_k}}, \tag{19}$$

where α is a parameter vector and $Y_{j,k}$ is a vector of regressors; the term $Y'_{j,k}\alpha$ represents the first and second rows of (14) and (15). The term γ_k is a parameter attached to the scalar 'inclusive value' I_k that links (18) and (19) and which is written:

$$I_k = \ln\left(\sum_{j=1}^{J_k} \mathrm{e}^{X'_{j,k}\beta}\right). \tag{20}$$

Conditional upon the estimated models of the probability-of-access, the nested multinomial logit models of lottery choice are estimated by full information maximum likelihood (FIML).[5]

3.3. Estimation results

Four binary models of the access probability were evaluated: standard probit and logit and heteroscedastic probit and skewed logit. Heteroscedastic probit was identified as the superior model from comparison of goodness-of-fit statistics (see Appendix B). The parameters of the model are significant within the periods, and the null of their equality across periods is rejected in all cases (Table 3). Results indicate the probability of access is positively related to *EX ANTE PROBABILITY* and negatively related to *HARVEST RATE*.

Conditional upon the estimated access probability models, nested logit models are estimated separately for the two periods and two participant groups represented in 1998. Three sets of estimates are obtained: α associated with the choice of access category, β associated with the choice of hunt, and the inclusive value parameters, γ. For convenience in reporting, the probability-weighted price proxy variables are denoted by *ACCESS COST*PROBABILITY*.

Considering the top level of the nest, results indicate that the probability of access-category choice differs between tariff arrangements in participant age and gender (Table 4). And in the 1998 data the effects differ significantly between participant groups in many cases. With the bottom-level hunt choice, the parameters are significant in all but one case, and the estimated parameters on the price proxies have the anticipated negative sign. Controlling for the probability of access, the probability of hunt choice is increasing in *HARVEST RATE* and *QUOTA* in all

[5]Estimation was performed with Stata version 8.1.

Table 3
Heteroscedastic probit estimates of the probability of access

Variable	Simultaneous tariff payments	Staggered tariff payments
Mean function: μ		
EX ANTE PROBABILITY	0.89*	1.44*
	(0.03)	(0.04)
HARVEST RATE	−0.66*	−0.52*
	(0.03)	(0.03)
CONSTANT	−0.10*	−0.93*
	(0.02)	(0.03)
Variance function: $\text{Ln}(\sigma^2)$		
QUOTA	−0.003*	−0.002*
	(0.0001)	(0.0002)
PAST PARTICIPANTS	0.0004*	0.0004*
	(0.0001)	(0.0001)
N	28,601	45,387
Log-Likelihood	−17,318.51	−27,131.09
Pseudo R^2	0.09	0.09

*Denotes significance at the 0.01 level. Standard errors are reported in parentheses.

cases. Comparing the periods, t-tests reject the null of parameter equality in all cases. Similarly, parameter equality is rejected between participant groups in the 1998 data. And lastly, the inclusive value parameters jointly differ from one, which leads to rejection of the standard (non-nested) multinomial logit.

The prediction success of the models may also be examined. As the reported pseudo-R^2 statistics are equal (at two decimals places), comparing the percentage of correct predictions provides an additional means to gauge the performance of the models. Reported in the bottom of Table 4, the percentage of correct predictions is greater in all cases in the first year relative to the second year. And across the three access categories, the greatest frequency of prediction success occurs with the quota hunts with ϕ's<1, followed next by the open access hunts.

4. Policy simulations and welfare analysis

As shown in section two, changes in the characteristics of lottery-rationed goods affect expected utility *directly* through the indirect utility function and *indirectly* through the access probability. In contrast to the case of open access to uncongested public resources, welfare losses may be sustained by individual lottery participants as quality improves if the probability of being drawn decreases sufficiently. Using the *REUM*s estimated in the preceding section, individual and aggregate non-market values derived from improvements in resource quality and increases in the

Table 4
Nested multinomial logit estimates of hunt choice

Choice levels and variables	Simultaneous tariff payments		Staggered tariff payments	
	All entrants	All entrants	Previous entrants	New entrants
Choice of access type (α)				
Open Access				
AGE	−0.01*	−0.001	−0.01	0.001
	(0.002)	(0.002)	(0.003)	(0.002)
MALE	−0.16	0.17	0.20	0.17
	(0.11)	(0.09)	(0.18)	(0.11)
Quota access ($\phi = 1$)				
AGE	−0.003	−0.003*	−0.01**	−0.003
	(0.002)	(0.001)	(0.002)	(0.002)
MALE	0.27*	0.46*	0.63*	0.41*
	(0.10)	(0.07)	(0.13)	(0.08)
Choice of alternative (β)				
*ACCESS COST*PROBABILITY*	−0.02*	−0.04*	−0.03*	−0.04*
	(0.0002)	(0.0003)	(0.0005)	(0.0004)
*HARVEST RATE*PROBABILITY*	0.24**	1.77*	1.70*	1.82*
	(0.10)	(0.10)	(0.16)	(0.12)
*QUOTA*PROBABILITY*	0.01*	0.02*	0.02*	0.02*
	(0.0001)	(0.0001)	(0.0002)	(0.0002)
*BULL*PROBABILITY*	0.03	0.61*	0.51*	0.66*
	(0.03)	(0.04)	(0.06)	(0.04)
*NE*PROBABILITY*	−0.14*	0.66*	0.16**	0.93*
	(0.04)	(0.04)	(0.07)	(0.05)
*SE*PROBABILITY*	2.14*	4.02*	3.02*	4.51*
	(0.07)	(0.09)	(0.16)	(0.11)
*SW*PROBABILITY*	1.06*	2.40*	2.00*	2.63*
	(0.04)	(0.04)	(0.07)	(0.05)
Inclusive values (γ)				
OPEN ACCESS	0.71*	0.56*	0.64*	0.52*
	(0.03)	(0.02)	(0.04)	(0.02)
QUOTA ACCESS and $\phi = 1$	0.76*	0.59*	0.62*	0.58*
	(0.04)	(0.02)	(0.04)	(0.03)
QUOTA ACCESS and $\phi < 1$	0.95*	0.91*	0.95*	0.90*
	(0.03)	(0.02)	(0.04)	(0.03)
Observations (N)	2,547,824	4,443,256	1,604,664	2,838,592
Log-likelihood	−79,665.48	−141,074.43	−51,448.10	−89,497.42
Likelihood ratio test of multinomial logit (H_0: $\gamma = 1$)	138.47*	806.16*	170.62*	663.79*
Pseudo R^2	0.04	0.04	0.04	0.04
% of correct predictions				
OPEN ACCESS	5.1	1.9	0.6	2.4
QUOTA ACCESS and $\phi = 1$	0.0	1.2	0.3	1.6
QUOTA ACCESS and $\phi < 1$	10.4	6.2	5.4	6.6
Total % correct	9.5	5.6	4.7	6.0

Notes: The variable *PROBABILITY* refers to the fitted access probability (Table 3), and ϕ refers to the variable *EX ANTE PROBABILITY* (Table 2). The number of observations, N, is the product of the number of hunts (136) and the number of participants. * and ** denote significance at the 0.01 and 0.05 levels, respectively. Standard errors are reported in parentheses.

quota size may be calculated. And in the process, the relative sizes of the direct and indirect effects of the changes on expected utility may be deduced.[6]

The general expression of the empirical measure of *WTP* for changes in the attributes of lottery-rationed goods is written:

$$WTP = \frac{E[E(U)^0] - E[E(U)^1]}{MU_Y}. \tag{21}$$

The term $E[E(U)^S]$ is the *expectation* of the maximum expected utility in state S (i.e., the status quo (0) or altered (1) level).[7] For the nested multinomial logit model the expectation is written:

$$E[E(U)] = \ln\left[\Sigma_{k=1}^{K}\left(e^{\alpha_k' Y_k}\right) + \gamma_k \ln(I_k)\right] + 0.577. \tag{22}$$

The numerator of (21) is converted to a monetary value by dividing by the marginal utility of income (MU_Y). The difference between (21) and *WTP* measured in studies of open access recreation demand rests in the objective function from which the expected maxima are derived (i.e., indirect or expected indirect utility functions). With choices made over open access destinations and linear-in-income indirect utility functions, MU_Y is given by the absolute value of the coefficient on the implicit price variable. Because price appears in the expected indirect utility functions through an interaction variable, MU_Y is calculated as the product of the absolute value of the *ACCESS COST*PROBABILITY* coefficient and the mean probability of access.

In demonstrating the use of the estimated *REUM*s for calculating non-market values, two scenarios are considered: a ten percent increase in the rate of harvest (*HARVEST RATE*) and a ten percent increase in the quota size (*QUOTA*). The former corresponds to about a four-percentage point change in the proportion of hunters who harvest an elk on average; the latter corresponds to about ten additional licenses being awarded annually per-hunt on average or about 1400 additional licenses across the 136 hunts. The access probabilities established after the changes are calculated by substituting the adjusted *HARVEST RATE* and *QUOTA* variables separately into the estimated probit model of the access probability (see Table 3).

[6]The direct and indirect effects in terms of elasticities are not explicitly calculated here. Although the aggregate demand elasticity (reflecting the indirect effect) is straight forward to calculate from the access probability model (Table 3), the direct effect on expected utility is problematic to calculate due to the utility difference appearing in the numerator of the scaling factor (see expressions (8) and (9) and Appendix A). Although utility differences may be calculated with the well-known log-sum formulation, the modeling involved estimation of *expected* utility functions. Therefore, calculation of the utility difference requires amending the formulation appropriately. One possibility is to factor out the access probability from the log-sum formula, but this proves futile. Another possibility is to calculate expected utility differences—rather than utility differences—using (22) and then adjusting the numerator of the scaling factor to account for the access probabilities. But as it is not possible to factor out the access probabilities from the log-sum expressions, it follows that simply multiplying the numerator of the scaling factor by a function of the probability of access will yield lead only an approximation of the direct effect.

[7]Interested readers are referred to [2, pp. 300–305; 11, pp. 183–189; 6, pp. 198–199, 318–322] for technical details.

Table 5
Estimated willingness-to-pay (*WTP*) for changes in quality and quantity

Scenario	Simultaneous tariff payments		Staggered tariff payments	
	All entrants	All entrants	Previous entrants	New entrants
10% increase in HARVEST RATE				
Mean *WTP* (standard deviation)	\$1.08 (0.70)	\$1.44 (0.57)	\$1.54 (0.55)	\$1.40 (0.59)
Minimum	−0.06	0.46	0.70	0.35
Maximum	4.16	4.69	4.84	4.66
Hypothesis tests: $H_0 : \mu_1 = \mu_2$	$\|t\| = 58.74$*			$t = 20.36$*
Total *WTP*	\$20,324	\$47,007	\$18,149	\$29,320
10% increase in QUOTA				
Mean *WTP* (Standard deviation)	\$9.11 (2.16)	\$8.70 (3.18)	\$10.65 (3.37)	\$7.93 (3.11)
Minimum	2.69	−2.64	−2.22	−2.80
Maximum	14.82	16.03	18.45	15.25
Hypothesis tests: $H_0 : \mu_1 = \mu_2$	$t = 17.36$*			$t = 72.07$*
Total *WTP*	\$170,683	\$284,272	\$125,672	\$165,464
Participants (N)	18,734	32,671	11,799	20,872

Notes: μ_1 and μ_2 denote population mean *WTP*'s for periods and groups 1 and 2, respectively; * denotes significance at the 0.01 level. Total *WTP* is obtained by multiplying mean *WTP* (at six decimal places) by N. Standard deviations are reported in parentheses.

Results indicate that the change in the quota is highly valued relative to the change in the harvest rate (Table 5). Evaluated at the sample means and interpreted in terms of the non-refundable tariff (P_L), *WTP* for the harvest rate change is about \$1.00 under the simultaneous payment arrangement and about \$1.50 under the staggered payment arrangement. In contrast, mean *WTP* for the quota change is about 40 cents less with the staggered payment arrangement. Comparing the results across participant groups in 1998, mean *WTP* in both cases is lower for new entrants, and the difference is most notable for the change in the quota.

Although welfare is found to increase on average in all cases, examination of the reported minimum *WTP* values indicates that for some participants the direct effects on expected utility are outweighed by the indirect, aggregate demand effects. Welfare losses are estimated to be incurred by some individuals for the increase in the harvest rate under the simultaneous tariff payment format and for the increase in the quota size for some individuals in both participants groups under the staggered payment format. Lastly, the total *WTP* is calculated as the product of the mean *WTP* values and the respective number of participants. In all cases total *WTP* is notably greater under the staggered payment arrangement. With the harvest rate change, the increased total *WTP* is attributed to increases in participation and in mean *WTP*; with the quota, the change is attributed to the increase in participation.

As a final caveat, because some participants who are granted access in lotteries with staggered tariff payments may choose not to purchase the awarded licenses, the resulting *WTP* estimates may be inflated. In the data evaluated here, ninety percent of the new entrants in 1998 who were

Table 6
Estimated willingness-to-pay (*WTP*) weighted by the predicted probability of a purchase

Scenario	Staggered tariff payments		
	All entrants	Previous entrants	New entrants
10% increase in HARVEST RATE			
Mean *WTP* (Standard Deviation)	\$1.34 (0.53)	\$1.49 (0.54)	\$1.27 (0.54)
Minimum	0.41	0.69	0.30
Maximum	4.63	4.78	4.43
Total *WTP*	\$43,643	\$17,553	\$26,599
10% increase in QUOTA			
Mean *WTP* (Standard deviation)	\$8.09 (2.97)	\$10.30 (3.26)	\$7.19 (2.83)
Minimum	−2.60	−2.20	−2.58
Maximum	15.59	17.98	13.95
Total *WTP*	\$264,146	\$121,544	\$150,077
Mean predicted probability of purchasing an awarded license	0.93 (0.03)	0.97 (0.01)	0.91 (0.01)
Participants (*N*)	32,671	11,799	20,872

Notes: Probability-weighted *WTP* is obtained by multiplying *WTP* by the predicted probability of purchasing an awarded licenses (see Appendix D). Total *WTP* values are obtained by multiplying the mean probability-weighted *WTP* (at six decimal places) by the number of participants. Standard deviations are reported in parentheses.

drawn chose to purchase the licenses, while 97% of existing participants purchased awarded licenses. Thus, and for additional comparison, the *WTP* values under the staggered tariff payment arrangement are re-calculated after weighting the initial estimates by fitted probabilities of purchasing awarded licenses (Table 6).

The purchase probabilities are obtained from a probit model relating the observed, binary outcomes (to purchase or to not purchase) to participant characteristics (see Appendix D). Estimation results indicate that the purchase probability is significantly increasing in participant age and is significantly greater for men than women and for existing participants than new entrants. Comparing the probability-weighted *WTP* estimates, results indicate that the mean values of the changes in the attribute levels are reduced by larger amounts in absolute and relative terms for the group of new entrants. Yet at the population level, the conclusions drawn from Table 5 are retained.

5. Conclusion

As lotteries are frequently used to ration public resources and access opportunities, it is natural to question their roles as management tools and implications for non-market demand and welfare analysis. In this study, conceptual results indicate that individual welfare losses may accompany improvements in resource quality or increases in quota size if the accompanying shift in aggregate demand reduces the probability of access by a sufficient amount. Empirical results indicate that the types and timing of tariff payments affect participation, choices over restricted and open access substitutes, and the non-market values attached to the access opportunities. Further, significant differences in *WTP* for changes in quality and quantity and in the probability of purchasing awarded licenses are found to exist between participant groups.

As a final note, although greater individual and aggregate benefits may be associated with the staggered tariff format of the lottery, so may be the costs incurred by the managing agency. Citing increased administrative costs and un-purchased licenses resulting under the staggered tariff format, the regulator of the public resource examined here returned to the simultaneous tariff format of the lottery in the year subsequent to its policy experiment.

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Appendix A

Effects of changes in quality and the quota with two-part tariff lotteries.

With simultaneous two-part tariff lotteries (2), the relationship between expected utility and an element of Q other than the quota is written:

$$\frac{\partial E(U)}{\partial Q} > 0 \quad \text{iff} \quad \frac{\partial N/N}{\partial Q/Q} < \frac{\partial V(Y,Q)/V(Y,Q)}{\partial Q/Q}\left(\frac{V(Y,Q) - V(Y+P_j)}{V(Y,Q)}\right)^{-1}.$$

And with the staggered tariff lotteries (3), the relationship is summarized:

$$\frac{\partial E(U)}{\partial Q} > 0 \quad \text{iff} \quad \frac{\partial N/N}{\partial Q/Q} < \frac{\partial V(Y-P_j,Q)/V(Y-P_j,Q)}{\partial Q/Q}\left(\frac{V(Y-P_j,Q) - V(Y)}{V(Y-P_j,Q)}\right)^{-1}.$$

With simultaneous two-part tariff lotteries, the relationship between expected utility and the quota is summarized:

$$\frac{\partial E(U)}{\partial S} > 0 \quad \text{iff} \quad \frac{\partial N/N}{\partial S/S} < 1 + \frac{\partial V(Y,S)/V(Y,S)}{\partial S/S}\left(\frac{V(Y,S) - V(Y+P_j)}{V(Y,S)}\right)^{-1}.$$

And with the staggered two-part tariff lotteries, the relationship is written:

$$\frac{\partial E(U)}{\partial S} > 0 \quad \text{iff} \quad \frac{\partial N/N}{\partial S/S} < 1 + \frac{\partial V(Y-P_j,S)/V(Y-P_j,S)}{\partial S/S}\left(\frac{V(Y-P_j,S) - V(Y)}{V(Y-P_j,S)}\right)^{-1}.$$

Appendix B

Estimated access probability models

Variable	Simultaneous tariff payments (1997)				Staggered tariff payments (1998)			
	Probit	Hetero-scedastic probit	Logit	Skewed logit	Probit	Hetero-scedastic probit	Logit	Skewed logit
Mean function								
EX ANTE PROBABILITY	1.43*	0.89*	2.36*	1.78*	1.63*	1.44*	2.63*	2.00*
	(0.03)	(0.03)	(0.05)	(0.14)	(0.03)	(0.04)	(0.04)	(0.03)
HARVEST RATE	−0.88*	−0.66*	−1.43*	−1.23*	−0.54*	−0.52*	−0.95*	−0.84*
	(0.04)	(0.03)	(0.06)	(0.07)	(0.03)	(0.03)	(0.06)	(0.05)
CONSTANT	−0.19*	−0.10*	−0.33*	−1.39*	−1.06*	−0.93*	−1.70*	−16.70*
	(0.02)	(0.02)	(0.04)	(0.43)	(0.02)	(0.03)	(0.04)	(n/a)
Variance function								
QUOTA	—	−0.00*	—	—	—	−0.00*	—	—
		(0.00)				(0.00)		
PAST PARTICIPANTS	—	0.00*	—	—	—	0.00*	—	—
		(0.00)				(0.00)		
Skewness function	—	—	—	0.95	—	—	—	n/a
				(0.40)				
N	28,601	28,601	28,601	28,601	45,387	45,387	45,387	45,387
Log-likelihood	−17,609	−17,319	−17,604	−17,598	-27,166	−27,131	−27,162	−27,125
Pseudo R^2	0.09	0.11	0.09	0.09	0.10	0.12	0.10	n/a

*Denotes significance at the 0.01 level. Standard errors are reported in parentheses.

Appendix C

Nested logit estimates by nesting structure

Variables	Simultaneous tariff payments		Staggered tariff payments	
	2-Branch nest	3-Branch nest	2-Branch nest	3-Branch nest
Access-type choice				
Open access				
AGE	−0.004 (0.003)	−0.01* (0.002)	−0.004** (0.002)	−0.004 (0.002)
MALE	0.42* (0.15)	−0.16* (0.11)	0.58* (0.13)	0.17 (0.09)
Quota access ($\phi = 1$)				
AGE	—	−0.003* (0.002)	—	−0.003* (0.001)
MALE	—	0.27* (0.10)	—	0.46* (0.07)
Alternative choice				
*ACCESS COST*PROBABILITY*	−0.02* (0.0002)	−0.02* (0.0002)	−0.03* (0.0003)	−0.04* (0.0003)
*HARVEST RATE*PROBABILITY*	0.36* (0.09)	0.24* (0.10)	1.36* (0.09)	1.77* (0.10)
*QUOTA*PROBABILITY*	0.01* (0.0001)	0.01* (0.0001)	0.02* (0.0001)	0.02* (0.0001)
*BULL*PROBABILITY*	0.004 (0.03)	0.03 (0.03)	0.41* (0.03)	0.61* (0.04)
*NE*PROBABILITY*	−0.12* (0.04)	−0.14* (0.04)	0.58* (0.04)	0.66* (0.04)
*SE*PROBABILITY*	2.15* (0.07)	2.14* (0.07)	4.04* (0.09)	4.02* (0.09)
*SW*PROBABILITY*	1.07* (0.04)	1.06* (0.04)	2.43* (0.04)	2.40* (0.04)
Inclusive values				
OPEN ACCESS	0.79* (0.03)	0.71* (0.03)	0.59* (0.02)	0.56* (0.02)

Appendix C (*continued*)

Variables	Simultaneous tariff payments		Staggered tariff payments	
	2-Branch nest	3-Branch nest	2-Branch nest	3-Branch nest
QUOTA ACCESS				
(Model 1: $\phi \leqslant 1$)	1.26*	0.76*	1.08*	0.59*
(Model 2: $\phi = 1$)	(0.05)	(0.04)	(0.04)	(0.02)
QUOTA ACCESS	—	0.95*	—	0.91*
(Model 2: $\phi < 1$)		(0.03)		(0.02)
N	2,547,824	2,547,824	4,443,256	4,443,256
Log-likelihood	−79,671.37	−79,665.48	−141,353.72	−141,074.43
Likelihood ratio test of multinomial logit (H_0: $\gamma = 1$)	132.98*	138.47*	490.87*	806.16*
Pseudo R^2	0.02	0.04	0.02	0.04

Notes: The variable *PROBABILITY* refers to the fitted access probability (Table 3), and ϕ refers to the variable *EX ANTE PROBABILITY* (Table 2). The number of observations, *N*, is the product of the number of hunts (136) and the number of participants. * and ** denote significance at the 0.01 and 0.05 levels, respectively. Standard errors are reported in parentheses.

Appendix D

Probit estimates of the probability-of-purchase model.

Variable	Coefficient	Standard error
AGE	0.01*	0.001
MALE	0.13**	0.07
PREVIOUS PARTICIPANT	0.73*	0.21
*AGE*PREVIOUS PARTICIPANT*	0.003	0.00
*MALE*PREVIOUS PARTICIPANT*	−0.37**	0.18
CONSTANT	1.01*	0.08
Number of participants drawn	11,106	
Log-likelihood	−2741.35	
Pseudo R^2	0.03	

Notes: The variable *PREVIOUS PARTICIPANT* takes a value of one if the individual appeared in both years of data and a value of zero if the individual appeared only in the 1998 data. * and ** denote significance at the 0.01 and 0.05 levels, respectively.

References

[1] K.M. Akabua, W.L. Adamowicz, W.E. Phillips, Implications of realization uncertainty on random utility models: The case of lottery rationed hunting, Can. J. Agr. Econ. 47 (1999) 165–179.
[2] M. Ben-Akiva, S.R. Lerman, Discrete Choice Analysis: Theory and Application to Travel Demand, The MIT Press, Cambridge, MA, 1985.
[3] P.C. Boxall, The economic value of lottery-rationed recreational hunting, Can. J. Agr. Econ. 43 (1995) 119–131.
[4] J.R. Boyce, Allocation of goods by lottery, Econ. Inquiry 32 (1994) 457–476.
[5] R. Dorfman, On optimal congestion, J. Environ. Econ. Manage. 11 (1984) 91–106.
[6] T.C. Haab, K.E. McConnell, Valuing Environmental and Natural Resources: The Econometrics of Non-market Valuation, Edward Elgar, Cheltenham, UK, 2002.
[7] D. Hellerstein, Welfare estimation using aggregate and individual-observation models: A comparison using Monte Carlo techniques, Amer. J. Agr. Econ. 77 (1995) 620–630.
[8] G.N. Kerr, Managing congestion: Economics of price and lottery rationing, J. Environ. Manage. 45 (1995) 347–364.
[9] C.L. Kling, Comparing welfare estimates of environmental quality changes from recreation demand models, J. Environ. Econom. Manage. 15 (1988) 331–340.
[10] J. Loomis, Use of travel cost models for evaluating lottery rationed recreation: Application to big game hunting, J. Leisure Res. 14 (1982) 117–124.
[11] J.J. Louviere, D.A. Hensher, J.D. Swait, Stated Choice Methods: Analysis and Application, Cambridge University Press, Cambridge, UK, 2000.
[12] G.E. Mumy, S.H. Hanke, Public investment criteria for underpriced public products, Amer. Econ. Rev. 65 (1975) 712–720.
[13] New Mexico Department of Game and Fish, Hunting big-game in New Mexico: Proclamation of seasons, New Mexico Department of Game and Fish, Santa Fe, NM, 1996.
[14] New Mexico Department of Game and Fish, 1997–98 Proclamation of big-game and furbearer seasons, New Mexico Department of Game and Fish, Santa Fe, NM, 1997.
[15] R.C. Porter, On the optimal size of underpriced facilities, Amer. Econ. Rev. 67 (1977) 753–760.
[16] D. Scrogin, R. Berrens, Rationed access and welfare: Case of public resource lotteries, Land Econ. 79 (2003) 137–148.
[17] D. Scrogin, R. Berrens, A. Bohara, Policy changes and the demand for lottery-rationed hunting privileges, J. Agr. Resource Econ. 25 (2000) 501–519.
[18] J.J. Seneca, The welfare effects of zero pricing of public goods, Public Choice 8 (1970) 101–110.
[19] G.A. Taylor, K.K. Tsui, L. Zhu, Lottery or waiting-line auction?, J. Public Econ. 87 (2003) 1313–1334.