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Title: Reducing Deer Overabundance by Distinguishing High-productivity Hunters: Revealed-Preference, Incentive-Compatible Licensing Mechanisms

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Abstract: This paper models the current problem of overabundance (and under-harvesting) of white-tailed deer as a Principal-Agent problem, with adverse selection and moral hazard. Using econometric analysis of data available from hunter behaviors studies in Pennsylvania, overall welfare gains are estimated from increased hunter satisfaction and license revenue. Results indicate that significant gains in economic surplus result when licensing schemes are unrestricted by current quota systems.

Key words: deer overabundance, incentive compatible, deer harvest

Distinguishing High-productivity Hunters Through Revealed-Preference, Incentive-Compatible Licensing Mechanisms: a Principal–Agent Model

The overabundance of white-tailed deer in both rural and suburban areas of the United States is causing economic harm to various groups. These groups include farmers whose crops are damaged and destroyed, forest owners whose resources are damaged by browsing deer, people injured in auto accidents involving deer, outdoorsmen who are exposed to lyme disease borne by deer ticks, and homeowners whose domestic plants and shrubs are destroyed by hungry deer in the winter months. The most cost-effective and time-honored method of controlling deer populations is through hunting, but recent decreases in hunter numbers in some northeastern states (see Figure 1) and a decrease in overall hunter effort as the hunting population ages (Riley et al, 2003) have resulted in the inability of the current hunting license practices in some of these states to maintain deer populations at the ecologically/environmentally correct levels.

There exists a dichotomy in current deer-hunting laws and regulations that has not gone unnoticed by hunters. Concurrent with the decrease in hunters has been an anecdotal (but generally accepted) decrease in the *hunting effort* made by the average hunter, i.e. hunting fewer hours, hunting only in good weather, and hunting only in easily accessible areas of the woods. Defining people who exert low levels of effort as "Casual Hunters" (CH), it is currently the case that even when licenses to harvest deer are sold in large numbers, the number of deer harvested is not adequate to properly control the deer population. But in concert with the limited harvest, there exists an intricate system of policing, laws, and game regulations that penalizes anyone who shoots a deer without a valid license. Under current management systems, "Serious Hunters" (SH), i.e. those who enjoy hunting immensely, like to shoot deer, and are proficient enough to harvest multiple deer are prevented from harvesting more than their allotted deer. They can not purchase additional deer tags, and they can not hunt deer without a tag. Thus, as game managers and biologists lament the fact that deer are not being harvested, the very hunters (SH) who would gladly continue hunting, killing deer, and getting utility from the experience are not allowed to do so.

This dichotomy in deer hunter-licensing methods thus creates two types of economic inefficiency if the resulting deer densities are too high. The first, quantitative inefficiency, has been extensively covered in the literature (see Latham et al, Rondeau, Rondeau and Conrad, Conover, Ritz and Ready). In fact, game management agencies tasked with setting annual antlerless deer-harvest targets use this basic methodology to determine deer density goals that equate the benefits of the deer herd to the damage caused (DuBrock, 1999). The second type of economic inefficiency, which has only been mentioned in passing in the literature (Heberlein, 1991), is allocative inefficiency. Numerous articles discuss the need for game managers to be creative in using hunting to reduce deer densities (Riley et al,2003, Lauber & Brown, 2000, Brown et al, 2000) but none of the literature has considered the method of incentive-compatible pricing for deer licensing mechanisms. My purpose in this analysis is to quantify the gains in economic surplus that could occur if an improved allocation of antlerless deer licenses was possible. How does it compare in comparison to the economic losses from overabundant deer, and should allocative inefficiency even be addressed when new licensing practices are being considered? Then, using the theory of nonlinear pricing and principle-agent models, I will suggest a workable licensing mechanism to replace the lottery/quota system that currently exists and again measure the improvements in economic surplus from such a system.

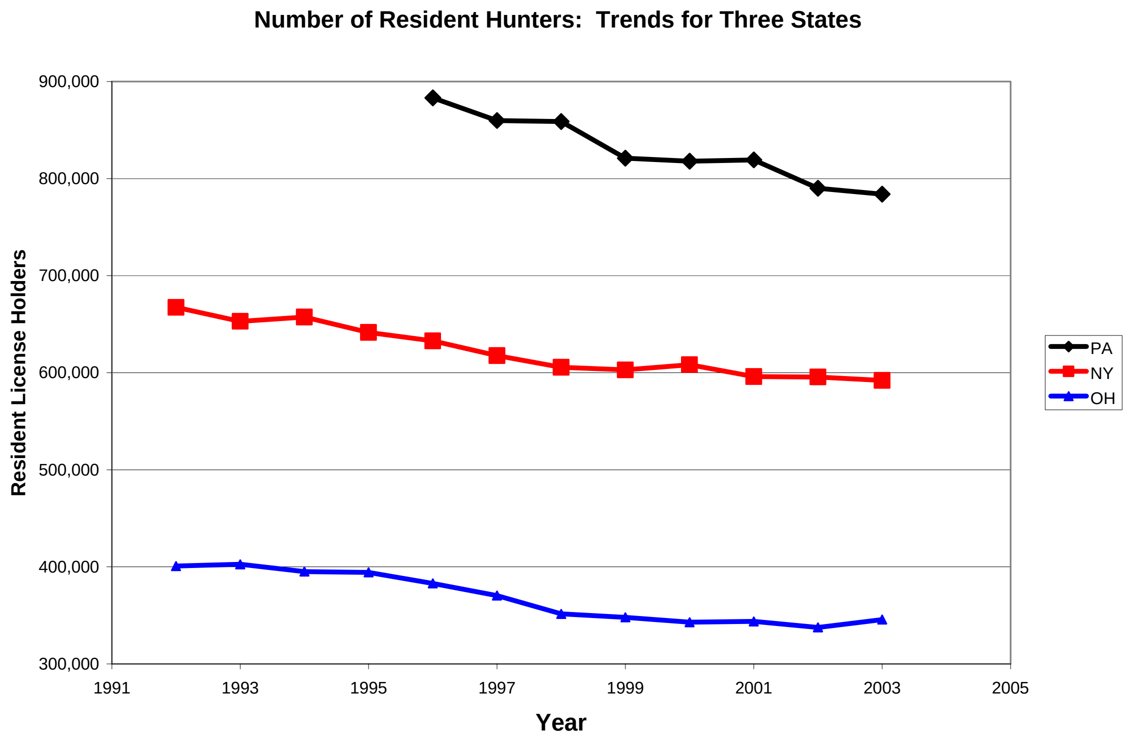

FIGURE 1

Inefficiency of Current Practices for Antlerless Deer Tags

Ohio, New York, New Jersey, Maryland, and Pennsylvania are all northeastern states with localized overabundant deer problems. Maintaining desired deer densities is accomplished by antlerless (doe) deer harvests in the fall, under similar antlerless licensing mechanisms in each state. To avoid a discussion of small differences in state licensing practices, and because the hunter survey data available is from Pennsylvania, Pennsylvania's licensing practices are used here as a baseline for comparison with improved mechanisms.

After purchasing a general hunting license, all hunters who desire to hunt antlerless deer can apply to the Pennsylvania Game Commission (PGC) for an antlerless *deer tag*. The cost is \$6. The tag is hunter-specific and wildlife management unit (WMU) specific, and must be carried at all times when hunting antlerless deer. The tag is then marked and dated (consumed) when an antlerless deer is harvested, preventing it's re-use. In the early years of this system, not all hunters who applied were awarded a tag, so the deer tags were awarded randomly amongst those who applied. Today, in most WMU's, the allotted antlerless tags are not all awarded in the first round of applications (i.e. every hunter who desires an antlerless tag receives one), so there is then a second round of applications for remaining tags. The antlerless tags remaining are offered up again, at the price of \$6, and awarded randomly amongst those (fewer) hunters who apply for a second tag. As described and implemented, this system of awarding antlerless deer tags is a restriction, or quota, on each hunter. Hunters are treated as equivalent in their desire for antlerless tags, and all hunters receive one (or at most two) tags per season.

One of the requirements of state game management agencies is to award all hunters a fair chance at a deer harvest, which is understandable. If all hunters were identical in their utility received from hunting, and their willingness to pay for an antlerless deer harvest, there would not be allocative inefficiency in the current system. However, deer hunters vary widely in their motivation, hunting skill level, and opportunity cost of time (Decker et al, 1980, Decker & Connelly, 1989). For this reason, I hypothesize that the price hunters would be willing to pay for an antlerless deer tag also varies widely. An allocatively efficient system would get the deer tags, and subsequent deer harvests, to those hunters who valued them the most. Identifying individual hunters by type (their willingness to pay for antlerless tags) is unrealistic, but estimating the distribution of hunter types within a state is not. If the PGC, or game managers in other states, could identify a distribution of hunter types, the managers could devise a pricing mechanism that is incentive compatible to hunters that would discriminate amongst hunters when allocating antlerless deer tags. This practice could theoretically increase the economic surplus from hunting and harvesting deer.

Additionally, if the willingness to pay for an antlerless deer tag is correlated with hunter skill and hunter harvest success rates, then allocating the deer harvest tags to these higher-valuation hunters would also reduce the uncertainty in fall deer harvests. Game managers could improve their ability to maintain deer densities at the desired levels if high-skilled hunters with higher success rates are awarded deer tags instead of low-skilled hunters with lower and more variable success rates.

Separating Hunters by Type; The Feasibility of Nonlinear Pricing

Wilson (1993), as well as others, outlined the four preconditions for nonlinear pricing to be feasible. All of these preconditions are satisfied for antlerless deer tags. They are:

(1) The seller has monopoly power. The PGC (or other game management agency for states other than Pennsylvania) is the lone legal authority for authorizing harvest of deer, even on private land.

(2) Resale markets are limited or absent. Deer tags and licenses are sold specifically to individual hunters, for use in specific WMU's. (New York State has recently experimented with allowing the transfer of the antlerless tags from the purchaser to other individuals).

(3) The seller can monitor customer purchases. Hunting licenses and deer tag sales are currently tracked by name and address to individual hunters.

(4) There is heterogeneity among customers, where different customers value successive increments of the product differently. This hypothesis is tested in the analysis that follows.

The issue becomes discriminating amongst customers, in this case hunters. Unlike electric utility companies being able to distinguish between residential and business customers, or book sellers who can distinguish among customers with a slightly differentiated product (hardcover vs paperback), game management agencies must accept incomplete information about hunters. The hunters know their own type, but at a set price for deer tags they do not have an incentive to self-identify and possibly pay higher prices for a deer tag. Any mechanism that attempts to get deer tags into the hands of high-valuation hunters must be self-revealing, and thus incentive compatible. The mathematical notation for the analysis that follows is found at Appendix 1.

Initially, I envisioned the hunter-type modeling problem as one of Adverse Selection (hidden information) rather than Moral Hazard (hidden action), due to the asymmetric information whereby the hunter knows his “hunter type” (serious vs. recreational, sport vs. meat, skilled vs. unskilled) but the Game Commission does not. However, once the license is sold, there is also unobservable effort on the part of the licensed hunter. This could result in lower-than-desired deer harvest if each hunter’s effort level, e, was lower than expected during the hunting season, i.e. his $e_{\text{actual}} < e_L < e_H$ for each type.

We need a contract so that in every realized state, θ, the hunter is willing to be both truthful in stage 1 (buying the license) and obedient in stage 2 (effort during the actual hunting season). i.e., he finds it optimal to choose effort level e(θ) in state θ. Paragraph 1 on page 502 of Mas-Colell, Whinston and Green explains, because of the observability of the payoff π, (which in this case is the hunter’s deer harvest), that this allows the PGC “contract” or license scheme to specify effort, e. See APPENDIX 2 for a summary of this discussion in MWG (1995).

The theoretical basis for an improved deer tag allocation scheme comes directly from the paper titled, “Monopoly with Incomplete Information” by Maskin and Riley (1984). The PGC monopolist produces a single “product” (the right to a deer harvest) at constant marginal cost, c. A hunter of type i has preferences represented by the following utility function (and thus we are ignoring income effects, which is reasonable if the proportion of any single hunter’s income spent on deer tags is small compared to his total income):

$$U_i(q,-T) = \int_0^q p(x;\theta_i)dx - T, \tag{1}$$

where q is the number of deer tags purchased form the monopolist, and T is total spending on these units. That is, we take the standard consumer surplus approach and assume that differences in tastes are captured by the single parameter θ. The PGC does not observe θ, but knows $F(\theta)$, the distribution of hunters’ preferences. (This hypothesis is analyzed in the Empirical Analysis section, from the hunter surveys available). Throughout I shall assume that higher levels of θ are associated with a higher demand. I also assume that the demand price $p(q;\theta)$ is decreasing in q and that there is some maximum quantity $q^e(\theta)$ for which demand price exceeds marginal cost. For each θ, $q^e(\theta)$ is thus the efficient consumption level for each hunter type.

To be precise, we must impose the following restrictions.

(i) For all feasible θ the demand price function $p(q;\theta)$ is nonincreasing in q and nonnegative, and there exists $q^e(\theta) \geq 0$ such that $p(q;\theta)$ is decreasing in q for $q \leq q^e(v)$, and $p(q;\theta) \geq c$ if and only if $q \leq q^e(\theta)$.

(ii) $q^e(\theta)$ is twice continuously differentiable for $q \leq q^e(\theta)$.

(iii) $p(q;\theta)$ is strictly increasing in θ whenever $p(q;\theta)$ is positive.

A selling procedure is then a schedule of pairs $< q_s, T_s >_{s\in S}$, which the PGC offers to the hunters. If a hunter chooses s, he receives q_s and pays a total of T_s. The profit or return to the PGC is then

$$R_s = T_s - cq_s. \tag{2}$$

Of course any selling procedure includes the pair < 0, 0 >, that is, the hunter always has the option of buying (and paying) nothing.

Combining (1) and (2), we can rewrite the utility of a hunter of type *i* as

$$U(q, R; \theta_i) = \int_0^q p(x;\theta_i)dx - cq - R \equiv N(q;\theta_i) - R \qquad (3)$$

where $N(q;\theta_i)$ is the social surplus generated by the sale. Thus, we can think of the trades between the PGC (the principle) and hunters (agents) as giving each hunter the entire social surplus less a fee R. The selling/licensing procedure is then a schedule of pairs $\langle q_s, R_s\rangle_{s\in S}$, offered to each of the hunters

We can graphically illustrate the PGC's optimal price schedule. A hunter's utility from any pair $\langle q, R\rangle$ is, from (3), just the social surplus $N(q; \theta_i)$ less the PGC's profit, R. Given our definition of $q^e(\theta)$ as the efficient level of consumption by a hunter with parameter θ_i, it follows that, for any R, $U(q, R; \theta_i)$ increases with q until it reaches a maximum at $q = q^e(\theta)$.

Thus, indifference curves must be as depicted in Figure 2. Note that at $\langle q, R\rangle$ the slope of the corresponding indifference curve is

$$\left.\frac{dR}{dq}\right|_{dU=0} = -\frac{\partial U}{\partial q}\Big/\frac{\partial U}{\partial R} = p(q;\theta) - c$$

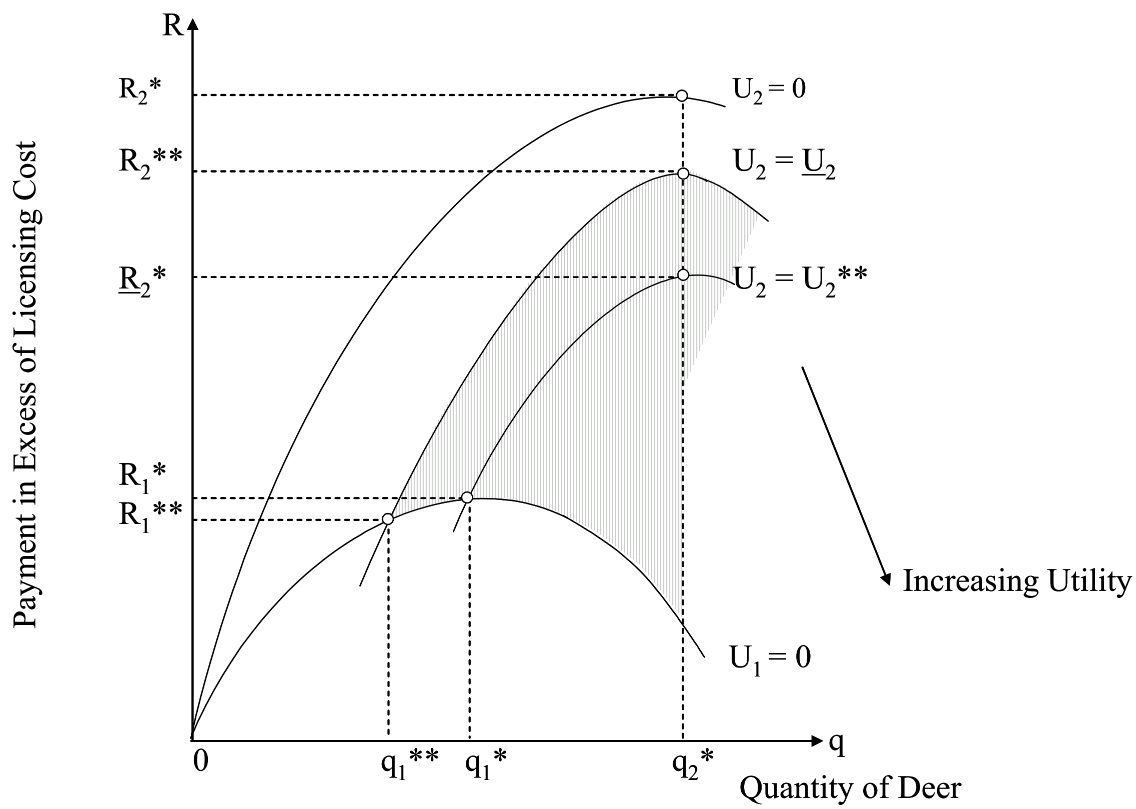

FIGURE 2 -adapted from Maskin and Riley (1984)

Therefore, at any point ⟨q, R⟩ the indifference curve for a hunter with a higher parameter value has a greater slope. *Sorting is feasible precisely because different hunters have different marginal rates of substitution between deer tags and income*. My assumption that one hunter's marginal rate of substitution is everywhere higher than another's is an important but reasonable simplification. Other methods of optimizing economic surplus would be required if this assumption fails to hold for a large number of hunters in the population.

For the simplest case of two hunter types, we can illustrate the profit-maximizing selling strategy with the help of Figure 2. If the PGC had complete information about hunter types, they could extract all consumer surplus by introducing the schedule $I^* = \{\langle q_1^*, R_1^*\rangle, \langle q_2^*, R_2^*\rangle\}$. But since we assume that the PGC has no direct means of distinguishing hunter types, this selling procedure will not extract all surplus. Indeed, high demanders of type θ_2, who I will refer to as Serious Hunters (SH), can be distinguished from Casual Hunters (CH) of type θ_1, where ($\theta = \theta_2 > \theta_1$) are strictly better off buying q_1^* units at a total cost of $R_1^* + cq_1^*$.

From the figure it is easy to see, that the PGC can do strictly better than I*. Consider the indifference curve for a SH (type θ_2, high demander) through $\langle q_1^*, R_1^*\rangle$. Any such hunter cannot be dissuaded from choosing $\langle q_1^*, R_1^*\rangle$ if available, unless also offered an alternative on or below this curve. Thus, assuming the PGC also offers $\langle q_1^*, R_1^*\rangle$, we find that the PGC maximizes their return by offering the alternative pair $\langle q_2^*, R_2^*\rangle$. Note that at the points chosen by each type, the associated indifference curves had zero slope. That is, the pairs $\langle q_1^*, R_1^*\rangle$ and $\langle q_2^*, R_2^*\rangle$ are efficient.

We next establish, however, that the PGC can do better than $\underline{I} = \{\langle q_1^*, R_1^*\rangle; \langle q_2^*, R_2^*\rangle\}$ by introducing inefficiency. Consider the alternative $\langle q_1^{**}, R_1^{**}\rangle$, depicted in Figure 1, which also extracts all the surplus from type θ_1, CH (low demanders). Much as before, the PGC maximizes their return from the SH, given that they offer $\langle q_1^{**}, R_1^{**}\rangle$, by also offering $\langle q_2^{**}, R_2^{**}\rangle$. By presenting hunters with $I^0 = \{\langle q_1^{**}, R_1^{**}\rangle, \langle q_2^*, R_2^{**}\rangle\}$ rather than $\underline{I}$, the monopolist gains relatively from the SH's $\langle R_2^{**} > \underline{R}_2\rangle$ and loses from the CH's $\langle R_1^{**} < R_1^*\rangle$. But observe that at least for small moves to the left of q_1^*, the slope of the indifference curve for type 1 hunters (CH) is approximately zero. To be precise, there is a first-order rise in the return from high demanders (SH) and only a second-order decline from low demanders (CH).

As the ratio of SH to CH increases, the offer $\langle q_1^{**}, R_1^{**}\rangle$ moves further to the left until eventually $\langle q_1^{**}, R_1^{**}\rangle = \langle 0, 0\rangle$. Then, if the ratio of SH to CH is sufficiently great, I^0 in effect becomes simply $\{\langle q_2^*, R_2^*\rangle\}$. Regardless of whether I^0 or $\{\langle q_2^*, R_2^*\rangle\}$ is optimal, however, only SH's purchase the efficient quantity $q_2^* = q^e(\theta_2)$, and the low demanders' demand price for the last unit purchased exceeds marginal cost.

A straightforward generalization of this argument establishes that, with more than two types of hunters, demand price will exceed marginal cost for all except the highest demanders.

Empirical Analysis of Hunter Types: A Hunter Survey from the KQDC

The Kinzua Quality Deer Cooperative (KQDC) is a state-forest in north-central Pennsylvania. A survey of KQDC hunters was conducted by the Human Dimensions Unit at The Pennsylvania State University, and the results made available to this author, in the fall of 2004. The survey provided data on 706 individual hunters for the 2003 hunting season, and included questions concerning hunter demographics, behaviors, and attitudes concerning deer management. There is currently an overabundance of deer in the KQDC area, and the PGC (who partially sponsored the survey) is interested in capturing demographic data from the hunters in this area. In the two hunting seasons previous to the survey, the antlerless tags made available to hunters who hunted the KQDC were much larger than the general hunting population in the rest of Pennsylvania. Summary statistics from the hunter survey are provided in Appendix 3.

Two of the survey's 41 questions concerned desire for antlerless deer harvest tags at the current price of $6 per tag, and at an increased price of $12 per tag. There were 74 hunters (10.5%) who indicated that they do not hunt antlerless deer, answered illogically which indicated they had misunderstood the questions, or did not answer one or both of the questions. From a histogram of the remaining 632 hunter responses at the $6 price (see Figure 3), three logical hunter types were created. These types were labeled Low, Medium, and High-demand hunters based on their *stated demand* for tags. Dummy variables were created to indicate High-demand hunters (D_{high} = 1) and Medium-demand hunters (D_{med} = 1).

An OLS regression was then conducted on a simple demand specification for all *i* hunters, allowing the demand intercept to vary by hunter type:

$$Q_i = \gamma_0 + \gamma_1 \cdot D_{high} + \gamma_2 \cdot D_{med} + \gamma_3 \cdot \ln(P) + \varepsilon_i \qquad (4)$$

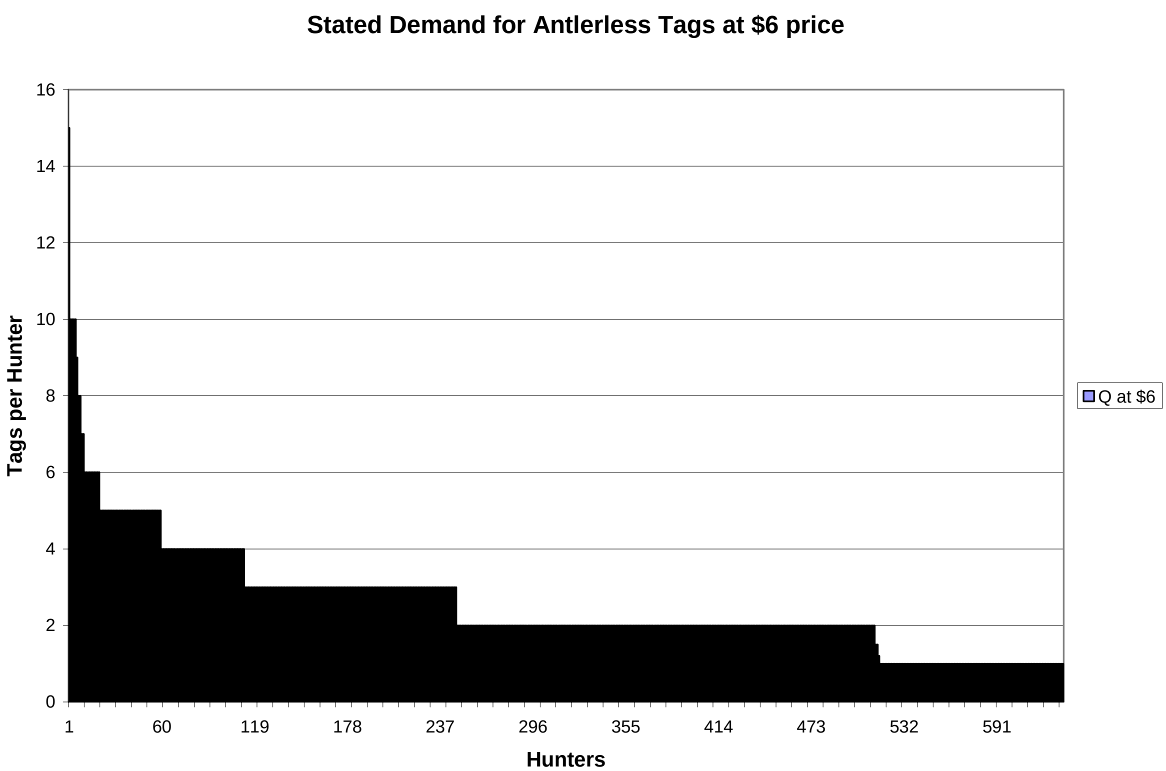

FIGURE 3

The regression results (see Appendix 4) showed a reasonably high goodness of fit (adjusted R-square of .5819) and statistical significance for all variables at any significance level. The demand specifications for these three hunter types, indexed by *j*, was now:

$$Q_j = \gamma_j - \gamma_1 \cdot \ln(P) \qquad j \in (high, medium, low) \qquad (5)$$

which leads to the inverse demand specification:

$$P = \beta_j \cdot \exp(-\beta_1 \cdot Q_j) \quad \text{with } (\beta_1 > 0) \quad \text{where } \beta_1 = 1/\gamma_1 \quad \text{and} \quad \beta_j = \exp(\gamma_j * \beta_1)$$

Total Marshallian Consumer Surplus (CS) can be calculated as

$$CS_j = \int_0^Q \beta_j \cdot \exp(-\beta_1 \cdot Q_j)\, dQ_j = \beta_j/\beta_1(1 - \exp(-\beta_1 \cdot Q)) \qquad (6)$$

Using these coefficient estimates from the OLS regression allowed me to calculate and graph inverse demand curves for hunters of each type (see Figure 4). This simple model of only three hunter types is illustrative for the purposes of estimating increased economic efficiency. It of course does not capture all the variability and omitted variables in a more complex model of hunter demand for antlerless tags. Utility theory would predict that many other factors should be in the functional form for demand for harvest tags, and a future analysis of this type is planned by the Human Dimensions Unit. This basic model does allow a reasonable estimate of the variation in demand for antlerless deer tags to be made, when a small number of discrete hunter types is hypothesized to exist. The technique for separating hunter types and estimating economic surplus will apply to more complicated demand models as well.

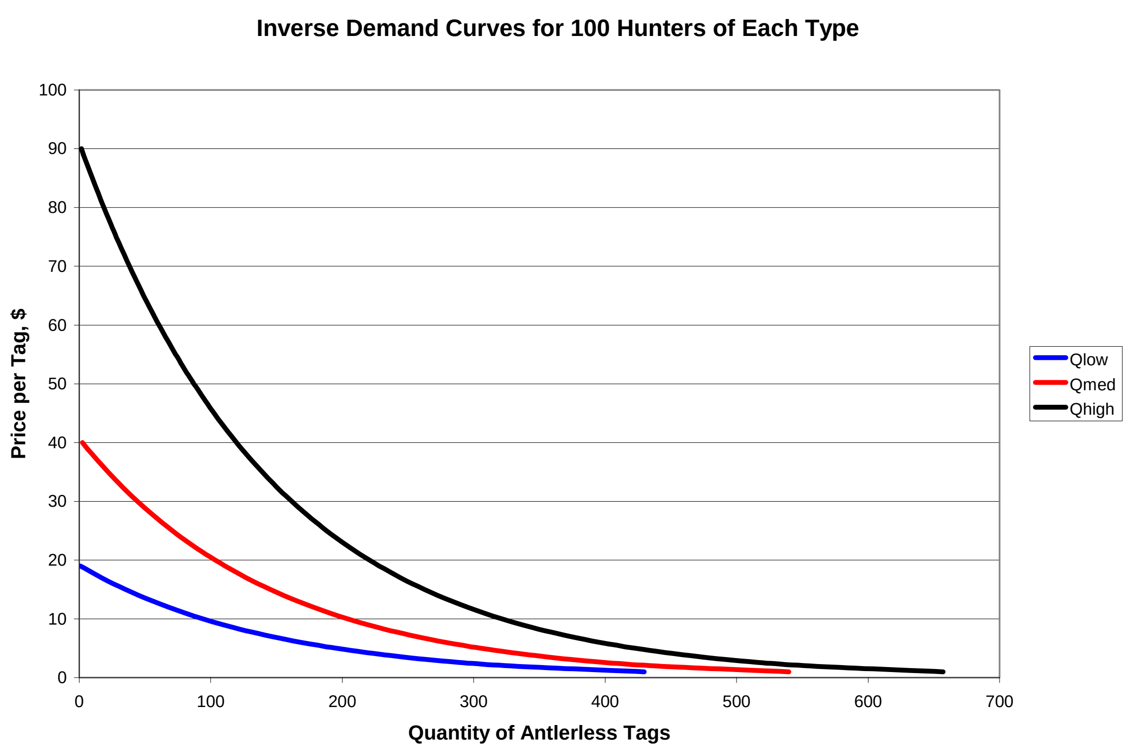

FIGURE 4

Figure 4 indicates that the willingness to pay for a marginal deer tag varies substantially by hunter type, as expected. But note that the graph illustrates the inverse demand curve *for equal numbers* of hunters of each type (I chose 100 hunters of each type for illustrative purposes). Examining the relative numbers of hunter types in the sample revealed the following breakdown of the hunters who hunt antlerless deer:

High Demand Hunters (*A%*):	9.34%
Medium Demand Hunters (*B%*):	29.75%
Low Demand Hunters (*C%*):	60.92%

The Pennsylvania Game Commission provides data on their website and in the annual Pennsylvania Hunting and Trapping Digest on total antlerless deer tags sold and antlerless deer harvested. Extrapolating to the entire 2003 adult resident hunter population in Pennsylvania of 783,955, with approximately 10% of the hunters not interested in hunting antlerless deer at all, leaves the following approximations for my created hunter categories in 2003 for the state of Pennsylvania:

High Demand Hunters (*A%*):	65,900 hunters
Medium Demand Hunters (*B%*):	209,900 hunters
Low Demand Hunters (*C%*):	429,800 hunters

The inverse demand curves for the entire Pennsylvania hunter population in 2003 is graphed in Figure 5.

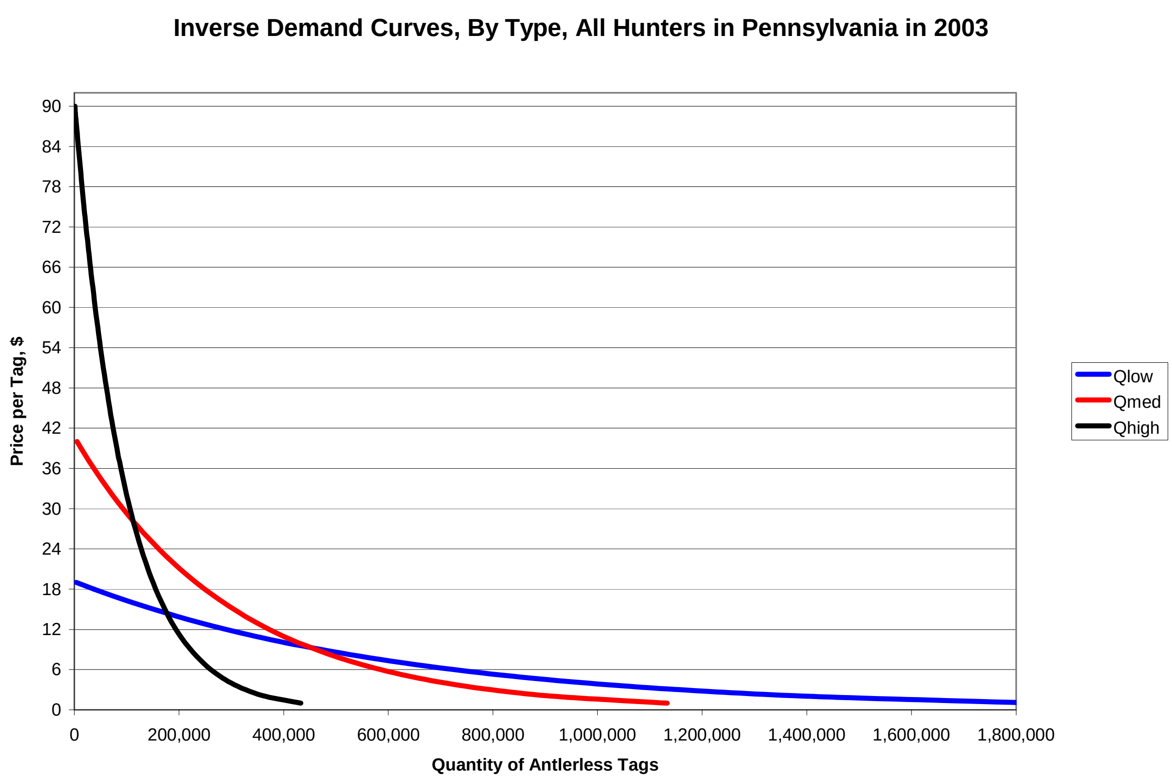

FIGURE 5

An analysis of hunter success rates for these different hunter types was needed as well. 94% of the self-indicated high-demand hunters were successful in harvesting at least one doe in the KQDC survey. Success rates dropped to 56% for the medium-demand hunters, and only 29.5% for the low-demand hunters. Thus, if all of the hunters in the KQDC survey had purchased only a single antlerless tag (which *was not* the case, but is used to illustrate and compare overall success rates), the overall success rate would have been 34.6% for the hunters in our sample. This equated nicely to historical overall success rates for antlerless deer tags in Pennsylvania. From the Pennsylvania Hunting and Trapping Guide, 2003 was a typical year for success rates with antlerless tags, and the overall reported success rate was 34.1% for all antlerless tags.

Game managers consider historical harvest success rates when the annual allocation of harvest tags is determined. Harvest success rates are variable mainly because of weather conditions and the stochastic nature of the sport of hunting itself. If hunters are separated by type, harvest success rates will have to be estimated for each type, instead of an overall harvest success rate estimate. In the calculations that follow, I make the further assumption that success rates vary by hunter type, but remain constant within the type category for subsequent tags. A better model would allow success rates to vary (decrease) as each hunter type purchases subsequent tags.

Economic Surplus Improvements From a Better Allocation of Antlerless Tags

Consider the revenue from deer licenses and deer harvest tags that is collected by the PGC and other state management agencies when hunters purchase these items. This revenue is not profit or producer surplus as in a competitive market for a private good, because the PGC is not a profit maximizing firm. The revenue is used primarily for habitat improvements, wildlife protection and law enforcement, which can be considered public goods. The area underneath the demand curves is thus an accurate measure of total economic surplus from hunting, and the PGC can maximize total economic surplus by selecting prices for tags that will induce the optimal quantities of tags to be purchased by the respective hunter types. An often-heard critique of wildlife management agencies is that they optimize the revenue they receive from hunting licenses instead of optimizing consumer surplus or total economic surplus from hunting. For my calculations that follow, I will consider the PGC as a social welfare maximizing agent.

From equation (6) derived earlier, the PGC should

$$\text{max:} \quad \sum_{j=1}^{3} \beta_j/\beta_1[1 - \exp(\beta_1 Q_j)]$$

$$\text{s.t.:} \quad xQ_{\text{high}} + yQ_{\text{med}} + zQ_{\text{low}} = \text{Harvest Target} \qquad (x,y,z \text{ are harvest success rates})$$

$$\left.\begin{array}{l} A[\gamma_{0h} - \gamma_{1h}\cdot\ln(P)] \geq Q_{\text{high}} \\ B[\gamma_{0m} - \gamma_{1m}\cdot\ln(P)] \geq Q_{\text{med}} \\ C[\gamma_{0L} - \gamma_{1L}\cdot\ln(P)] \geq Q_{\text{low}} \end{array}\right\} \quad \text{Demand Constraints}$$

$$\left.\begin{array}{l} \text{Qhigh, Qmed, Qlow} \geq 0 \\ P \geq 0 \end{array}\right\} \quad \text{non-negativity constraints}$$

It is obvious that the hunters who receive the most benefit/welfare from antlerless deer tags should receive more tags to increase the economic surplus from hunting. But this is not politically acceptable at low deer populations and high hunter numbers, as the optimal antlerless tag prices would force the low demand hunters out of the market and reserve the tags for only the high demand hunters. At high deer populations and high desired harvests, however, it is possible to design pricing schemes where low-demand hunters get an antlerless tag at a low price, then are "priced out" of the market for subsequent tags. I built a numerical simulation program in EXCEL, and used the What's Best add-on from LINDO/LINGO systems, to determine the optimal tag allocations under different scenarios. The exogenous variables were set at the approximations for Pennsylvania hunters already determined:

Total hunters who hunt antlerless deer: 800,000
Required annual antlerless deer harvest: 350,000 to 600,000
predicted success rates:
- x = 90% for high-demand hunters
- y = 55% for medium demand hunters
- z = 30% for low demand hunters

percentages of hunter types in the total hunter population:
- A = 10% of total antlerless hunters
- B = 30% of total antlerless hunters
- C = 60% of total antlerless hunters

The model was analyzed for small variations of these percentages as well. Obviously, more tags must be allotted and sold when estimated success rates and/or hunter population decline. The relative effect on economic surplus was the same however, when going from the current system of license sales to suggested improvements.

The Current System (constrained optimum)

As described previously, all antlerless deer hunters currently apply for deer tags at a price of $6, and they are awarded (one per hunter) until the allotted tags are gone. This system can be considered a political or social norm constraint, whereby all hunters have an equal chance at the allotted tags. With the estimated demand curves from the KQDC survey, all hunter types want multiple tags per hunter at this low price. The PGC is assumed to select an allotment of tags based on the estimated *overall* success rates for Pennsylvania hunters. Assuming the tags are awarded randomly until they are gone, the estimated economic surplus from antlerless tags is then calculated from the expectation of each hunter type having an equal probability of receiving a tag. The economic surplus increases with desired annual harvest as:

Table 1: Current System with $6 tags

Desired Harvest	PGC Revenue	Economic Surplus
350,000	$4,827,586	$18,995,949
400,000	$5,517,241	$19,858,173
450,000	$6,206,897	**$20,989,453**
500,000	$6,896,552	$22,323,905
550,000	$7,586,207	$23,803,898
600,000	$8,275,862	$25,379,088

The Single-Price Optimum

How does removing the restriction of one low price for antlerless tags affect the results? Consider if the PGC could charge any price for antlerless deer tags that would still achieve the targeted total harvest. What price would result, and how much total economic surplus could be improved, was tested in my simulation and compared to the current system described above. The output from the Solver solution at the 450,000 annual antlerless harvest level is attached at Appendix 5, and provides an example of the results below.

Table 2: Optimal Price

Desired Harvest	Optimal Price per Tag	PGC Revenue	Economic Surplus	Δ Surplus	Δ Surplus (%)
350,000	$17.62	$9,523,518	$25,457,422	$6,461,473	34%
400,000	$15.97	$10,464,256	$29,129,622	$9,271,449	47%
450,000	**$14.47**	**$11,144,197**	**$32,830,799**	**$11,841,346**	**56%**
500,000	$13.11	$11,604,038	$36,616,414	$14,292,509	64%
550,000	$11.88	$11,879,132	$40,527,033	$16,723,135	70%
600,000	$10.76	$12,000,133	$44,591,033	$19,211,945	76%

The efficiency gains from allowing the PGC to charge an optimal price for antlerless tags are significant. At the harvest goal of 450,000 antlerless deer (a number recommended by foresters to reduce damage from deer browsing, see Latham et al, 2005), the economic surplus could be increased by over 50% simply by removing the "one low price" restriction on antlerless tags. Comparison of Table 1 and Table 2 indicates that the revenue to the PGC increases as well, possibly providing an incentive to wildlife management agencies to consider this market-clearing price for antlerless tags. *But notice the disadvantage of this procedure*. The output at Appendix 5 indicates that when the PGC is allowed to charge an optimal price that rations deer tags to those hunters who value them most, over 285,000 low demand hunters do not choose to purchase a tag! In other words, the ranks of antlerless deer hunters shrinks dramatically from the current estimate of 480,000 hunters at a price of $6 per tag. This is one of the justifications that the PGC uses, and rightly so, when charging one low price for deer tags. Hunter numbers have fallen already from their historic levels. To keep and recruit hunters for the future, hunting needs to be encouraged with low cost tags. The sociological literature on hunting indicates that hunters go through stages, and hunt for different reasons at different periods of their lives (Decker et al 1980, Alsheimer 2005). As these currently low-demand hunters gain knowledge and experience, they may move into the ranks of medium and high demand hunters, so they should not be priced out of the market. This is a sociological reason for maintaining low prices on deer tags.

Multi-Part Pricing or Bundling: First Tag "one low price", Subsequent Tags at Optimum

Accepting the fact that there are valid political and sociological reasons for keeping tags available to everyone, I next modeled this scenario. Pricing the first tag at the current price of $6, and ensuring that each hunter who wants one at that price receives one, what should be the subsequent price for second and even third antlerless tags? From Maskin and Riley's theoretical results, a high enough price will keep low-valuation hunters from purchasing tags. The PGC can optimize from the residual demand curves for antlerless tags, after each hunter receives one tag. The residual demand curves, for each hunter type, represent the willingness to pay for subsequent tags after the first tag is purchased for $6. My simulation model output for this scenario is at Appendix 6, and the results summarized below compared to the current system of selling antlerless tags.

Table 3: First Tag low price, Subsequent Tags Optimized

Desired Harvest	Optimal Price for Subsequent Tags	Economic Surplus	Δ Surplus	Δ Surplus (%)
350,000	$44.94	$19,067,984	$72,035	0.4%
400,000	$27.90	$20,922,865	$1,064,692	5.4%
450,000	**$19.30**	**$22,752,627**	**$1,763,174**	**8.4%**
500,000	$16.31	$24,496,963	$2,173,058	9.7%
550,000	$13.78	$26,204,785	$2,400,887	10.1%
600,000	$11.65	$28,001,110	$2,622,022	10.3%

Antlerless tags can now be bundled to achieve these optimal outcomes. Antlerless tags can be sold in groups, with subsequently higher prices for more tags. At a desired annual harvest rate of 450,000 antlerless deer, the tags could be offered at $6 for one, $25.30 for two, and $54.60 for three. Hunters will self select at these prices, with some high-demand hunters purchasing a group of three tags, some medium-demand hunters purchasing a group of two tags (but not three), and low-demand hunters only purchasing a single tag. But the improvement in economic surplus from this scheme was not near as great as what would be possible under the single-price optimum. Even at high desired annual harvests, the resulting improvements in economic surplus were small (~10%) relative to the current system. The large number of antlerless tags going to low-demand hunters at a low price for the initial tag severely limits the potential improvement in overall economic surplus from a principal-agent type selling procedure.

Bundling of antlerless tags, as described above, may be acceptable to most hunters. Because deer are a rivalrous good for consumptive uses, some casual hunters are justifiably concerned about serious hunters removing multiple deer from the herd and reducing the probability of harvest for others. With sharply higher prices for subsequent tags, however, allowing hunters to self-select which bundle to purchase based on their own willingness to pay for antlerless deer harvests may be considered more reasonable. The tags will be available to all hunters, so it will be difficult for low-demand hunters to object to high-demand hunters freely spending their own money on bundles of three, or even more, antlerless tags. The PGC and other game management agencies would have another tool to combat isolated pockets of deer overabundance as well. Allowing high-demand hunters the option of buying multiple tags for areas of deer overabundance would capture that (currently unused) excess demand for antlerless harvests in certain hunter types.

The control mechanism for changes in the annual harvest level would be the prices of the bundled tags. The initial years of this method may require detailed hunter surveys in certain areas of the state to more accurately assess demand for antlerless tags, but the methodology outlined in this paper could easily be applied. In this era of deer overabundance, having too many tags sold in any one year is not disastrous, as the populations will quickly recover. After a few years of actual purchase data, with slight changes in initial tag and bundled tag prices, the PGC could accurately assess the demand curves and harvest success rates for different hunter types. This would result in more accurate price adjustments in subsequent hunting seasons to achieve the deer densities that wildlife managers desire, as well as resulting in the increases in economic surplus from hunting antlerless deer that have been estimated here.

Higher Proportion of High Demand Hunters in the Total Hunting Population

Finally, as Maskin and Riley indicated, as the percentage of serious hunters increases compared to the casual hunters, the solution changes whereby more and more casual hunters are forced out of the market at the optimum. The high-demand hunters in my three-hunter-types specification are only estimated at 10% of the total hunting population in Pennsylvania. The economic surplus gains are large when deer tags are transferred from low-demand hunters to high-demand hunters. Higher percentages of high-demand hunters will create more of these transfers when the current system is changed to allow prices to regulate which hunters receive the antlerless tags. In states other than Pennsylvania there are possibly higher percentages of high-demand hunters. If the required deer harvest is large enough to accommodate these hunters' higher demand, the economic surplus gains from single pricing or group pricing that separates hunters by type are even larger. Simulations with High-demand hunter types making up larger proportions of the total hunter population verified this result. At similar total harvests, an increase in high-demand hunters to 20% of the hunting population resulted in a 72% increase in economic surplus for the single-price model, and a 10.2% increase in economic surplus from using the multiple-part pricing model with the first tag being sold to everyone for $6.

Discussion

This analysis indicates that the separation of hunters by type, based solely on their willingness to pay for antlerless tags, is supported by the data from the KQDC survey. The demand curves estimated from the survey data provided reasonable characterizations of hunter demand for antlerless tags, with logically supportable prices and quantities. The percentage of hunters in each of the created categories was also consistent with previous literature on hunter types, as well as the impressions of hunters and game managers that the majority of hunters have low success rates and low demand for antlerless tags, but there is a small minority of hunters who would hunt and be successful at harvesting multiple antlerless deer if the system allowed them to do so. More accurate success rates for antlerless harvest will require more detailed survey data to verify, as well as to analyze a more accurate model of how success rates decrease for subsequent tags. But again, the success rates used here are not an unreasonable approximation based on overall historical success rates in the state of Pennsylvania.

The improvement in economic surplus from antlerless deer hunting was significant when the PGC was allowed to set a "market price" for antlerless tags instead of the current price of $6 per tag, which then requires rationing of the tags due to the surplus demand. At a recommended harvest of 450,000 does, the increase in economic surplus would be $10.7 million each year. The PGC's revenue would increase significantly. There would be an additional reduction in management costs that would accrue to the PGC from not having to ration the tags, but I have no way of estimating this improvement in dollar terms without additional information from the PGC. The disadvantage of allowing the PGC to set a market price for tags that clears the market at the desired harvest rate is the possible effect on hunter numbers. The optimal price for a desired harvest of 450,000 antlerless deer was $14.47, seemingly not a price increase that would place the tags out of reach for even the lowest income hunters. But if the demand curves are to be believed, over 285,000 low-demand hunters would not purchase a tag. This does not mean these hunters stop hunting altogether, as they will quite possibly still hunt for antlered deer. But the reduction in antlerless deer hunting could be expected to affect the future recruitment of hunters into the sport, as well as change the dynamics of hunters evolving from low-demand to medium and high-demand hunters throughout their lives.

My attempt to develop a principle-agent licensing scheme, whereby the first tag was sold for one low price and subsequent tags were bundled at higher prices, was successful. The resulting improvements in economic surplus from this pricing system were small relative to the current system, but not trivial at larger desired harvest rates. Higher percentages of high-demand hunters in a hunter population makes this method of selling tags slightly more attractive because it improves the economic surplus from antlerless deer hunting by larger percentages over the current system. Again, there would also be un-measurable reductions in licensing costs for the PGC if the system of allocating licenses was simplified to a self-selecting purchase decision instead of the current system of receiving requests for tags and then allotting them randomly after every hunter receives their first tag. The decision for game management agencies like the PGC is whether these small changes in economic surplus would justify changing the current selling practices. Hunters resist any change to the system of licensing and allocating tags, as Pennsylvania recently witnessed when antler restrictions for buck deer was implemented. The increase in economic surplus from changing the current system includes large increases in revenue to the PGC, so the PGC may be willing to consider switching to a market-clearing price as a way of allocating antlerless tags.

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APPENDIX 1

Glossary of Mathematical Notation and Terms

deer tag – an official document that authorizes the bearer to harvest one deer. The tag is dated and signed upon harvest of a deer, and attached to the deer carcass to prevent the tag's re-use at a later date.

deer license – an official document certifying the hunter has been authorized by the PGC to go afield and hunt deer. *Can include any number of deer tags for harvesting deer.*

PGC – Pennsylvania Game Commission. The monopolist seller of deer tags and deer licenses.

θ - hunter type or tastes. The State Variable. Higher levels of θ are associated with higher demand for deer licenses and deer harvest/kill.

Θ - the state space of hunter types.

θ_L – In the "two-hunter types" model, a hunter of low skill/ability/desire

θ_H – In the "two-hunter types" model, a hunter of high skill/ability/desire

θ_i – For the "many hunter types" model, $i = 1,2,\ldots n$; $n \leq \infty$; with skill/ability/desire increasing in n.

e – effort level of the hunter, correlated directly with type θ

w – payment by the PGC in deer tags. A payment scheme whereby more deer harvests are authorized for higher license fees/prices

π - payoff function in terms of deer harvested. Observable in most cases because of the requirement to report the harvest to the PGC.

q – number of deer tags purchased from the monopolist.

$p(q;\theta_i)$ – the inverse demand curve for deer tags based on hunter type, θ

$N(q;\theta_i)$ - the social surplus generated by the sale of a license to hunter type θ

R – set fee(in $'s) for each deer license

APPENDIX 2: MWG

Let the level of hunting effort *e* now be unobservable, and let deer harvest (payoff to the hunter) be a stochastic function of effort, described by conditional density function f(π | *e*). In essence, what we now have is a hidden action model, but one in which the PGC also does not know something about the disutility of the hunters from hunting effort (which is captured in the state variable, θ).

Analysis of this model begins with the recognition that the revelation principle extends to the analysis of this type of hybrid model. In particular, as Myerson (1982) shows, the PGC can now restrict attention to contracts of the following form:

(i) After the state θ is realized, the hunter "announces" which state has occurred.

(ii) The contract specifies, for each possible announcement $\theta \in \Theta$, the effort level *e*(θ) that the hunter should take and a compensation scheme w(π | θ) (i.e. the number of deer that a hunter can legally harvest).

(iii) In every state θ, the hunter is willing to be both truthful in stage (i) and obedient following stage (ii) [i.e., he finds it optimal to choose effort level *e*(θ) in state θ].

This contract can be thought of as a revelation game, but one in which the outcome of the hunter's announcement about the state is a hidden action-style contract, that is, a compensation scheme and a "recommended action" or level of hunting effort The requirement of "obedience" amounts to an incentive constraint that is like that in the hidden action model considered in Section 14.B on Hidden Actions/Moral Hazard (pages 478-488); the "truthfulness" constraints are generalizations of those considered in our hidden information model.

One special case of this hybrid model deserves particular mention because its analysis reduces to that of the pure hidden information model considered in Section 14.C (pages 488-501). In particular, suppose that hunting effort is unobservable but that the relationship between effort and deer harvest is *deterministic*, given by the function π(*e*). In that case, for any particular announcement θ, it is possible to induce any deer harvest–effort pair that is desired, say (*w,e*), by use of a simple "forcing" compensation scheme: Just reward the hunter with a payment (additional deer tags) of *w* if deer harvests are π(*e*), and give him a payment of - ∞ otherwise. Thus, the combination of the observability of π (hunters must report their deer harvests) and the one-to-one relationship between π and *e* effectively allows the contract to specify effort, *e*. The analysis of this model is therefore identical to that of the hidden information model considered in Section 14.C of MWG (pages 488-501), where payoff-effort pairs could be specified directly as functions of the hunter's announcement of his type.

APPENDIX 3 - KQDC Hunter Survey: Selected Summary Statistics

With 706 hunters

Question/Topic	Results	% of total
Demographic		
Average Age	50.4 years	
Average years hunting	32.2 years	
Mean travel distance to hunting area	76.6 miles	
High School graduates	645	91.4%
College graduates	227	32.2%
Children under 18 years of age at home	280	39.7%
Live in a large or medium sized city	63	8.9%
Live in a small city or suburban area	221	31.3%
Live in a rural town, village, or in the country	422	59.8%
Own, belong to, or use a hunting camp	286	40.5%
Income Data		
Refused to answer	68	9.6%
<$15,000 annually	37	5.2%
Between $15k-$45k annually	224	31.7%
>$45,000 annually	377	53.4%
Hunter Behavior		
Archery licensed	313	44.3%
Muzzleloader licensed	356	50.4%
Both archery and muzzleloader licensed	195	27.6%
Antlerless licensed	635	89.9%
Harvested a buck in 2003	206	29.2%
Average # of days hunted during 12-day rifle season	4.90	
Attitudinal Questions		
Support for statewide antler restrictions	481	68.1%
Agree that deer hunting pressure has decreased	357	50.6%
Agree that deer damage to PA forests is a problem	243	34.4%
Agree that a satisfying **day** of hunting can occur without a deer harvest	619	87.7%
Agree that a successful **season** of hunting does not require a deer harvest	396	56.1%
Reasons for Participation in Hunting (answering "Very Important", 4 on a 4-point scale)		
To get Outdoors	455	64.4%
To be with Family	344	48.7%
To obtain Venison	188	26.6%
To help manage the deer population	117	16.6%

Gender question was not asked in this survey. Previous Pennsylvania surveys and license data show that women are 2-3% of the total hunting population.

APPENDIX 4

SUMMARY OUTPUT: Q regressed on ln(P) and Dummy's for Type

Regression Statistics	
Multiple R	0.763489
R Square	0.582916
Adjusted R Square	0.581923
Standard Error	0.945241
Observations	1264

	df	SS	MS	F	Significance F
Regression	3	1573.394728	524.464909	586.990720	1.1925E-238
Residual	1260	1125.785746	0.893481		
Total	1263	2699.180475			

	Coefficients	St Error	t Stat	P-value
Intercept	4.296814	0.167539	25.646619	4.5499E-117
ln(P)	-1.456407	0.082369	-17.681394	1.14685E-62
Dhigh	2.273128	0.064897	35.026783	2.9932E-188
Dmed	1.100445	0.050324	21.867358	4.02305E-90

APPENDIX 5: Optimization Output Selecting Best Single Price Tags

No Fairness or Political Restrictions (any price)	**Total Hunters**		**Desired Harvest**	Optimal Price per Tag ($)	Total Consumer Surplus	Revenue to PGC
	800,000		**450,000**	$14.47	$21,686,602	$11,144,197
	%(C)	60%				
	Qlow	480,000	Qlow Desired	Qlow Optimal	CS-low	
	alpha0	4.2968141	194,588	0.41	0.90	
	alpha1	1.4564073				
	beta0	19.111369		Qlow Harvest		
	beta1	0.6866211		58,376		
	success rate	30%				
	%(B)	30%				
	Qmedium	240,000	Qmed Desired	Qmed Optimal	CS-med	
	alpha0	5.397259	361,401	1.51	16.40	
	alpha1	1.4564073				
	beta0	40.685512		Qmed Harvest		
	beta1	0.6866211		198,770		
	success rate	55%				
	%(A)	10%				
	Qhigh	80,000	Qhigh Desired	Qhigh Optimal	CS-high	
	alpha0	6.569942	214,282	2.68	72.74	
	alpha1	1.4564073				
	beta0	91.018338		Qhigh Harvest		
	beta1	0.6866211		192,853		
	success rate	90%				**Total Social Surplus from Antlerless Tags**
				Total Harvest		**$32,830,799**
				450,000		

APPENDIX 6: Optimize after 1st Tag sold at $6

Everyone Gets 1st Tag for $6.00	**Total Hunters 800,000**		**Desired Harvest 450,000**	**1st Tag Price ($) 6.00**	1st Tag Consumer Surplus 14,168,086	**Residual Demand**	Total Hunters 800,000		Remaining Harvest 102,000	Optimal Price per Tag 19.30	Residual Consumer Surplus 1,442,045
	%(C)	60%					%(C)	60%			
	Qlow	480,000	Qlow Desired	Qlow Optimal	CS-low		**Qlow**	480,000	Qlow Desired	Qlow Optimal	CS-low
	alpha0	4.296814	809,896	1.00	7.83		alpha0	4.296814139	0	0.00	0.00
	alpha1	1.456407					alpha1	1.456407268	minus 1 already		
	beta0	19.11137		Qlow Harvest		at Q = 1	beta0	19.11136851	0	Qlow Harvest	
	beta1	0.686621		144,000			beta1	0.686621127		0	
	success rate	30%					success rate	30%			
	%(B)	30%					%(B)	30%			
	Qmedium	240,000	Qmed Desired	Qmed Optimal	CS-med		**Qmedium**	240,000	Qmed Desired	Qmed Optimal	CS-med
	alpha0	5.397259	669,055	1.00	23.43		alpha0	5.397259014	260,667	0.09	0.05
	alpha1	1.456407					alpha1	1.456407268	minus 1 already		
	beta0	40.68551		Qmed Harvest		at Q = 1	beta0	40.68551239	20,667	Qmed Harvest	
	beta1	0.686621		132,000			beta1	0.686621127		11,367	
	success rate	55%					success rate	55%			
	%(A)	10%					%(A)	10%			
	Qhigh	80,000	Qhigh Desired	Qhigh Optimal	CS-high		**Qhigh**	80,000	Qhigh Desired	Qhigh Optimal	CS-high
	alpha0	6.569942	316,833	1.00	59.85		alpha0	6.569942028	180,704	1.26	14.31
	alpha1	1.456407					alpha1	1.456407268	minus 1 already		
	beta0	91.01834		Qhigh Harvest		at Q = 1	beta0	91.0183379	100,704	Qhigh Harvest	
	beta1	0.686621		72,000			beta1	0.686621127		90,633	
	success rate	90%					success rate	90%			
				Total Harvest 348,000	Revenue to PGC from 1st Tag $4,800,000					Total Harvest 102,000	Revenue from Subsequent Tags $2,342,495

Total Consumer Surplus $15,610,132

Total Revenue to PGC $7,142,495

Total Social Surplus from Antlerless Tags $22,752,627