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OPTIMAL INTER-TEMPORAL MANAGEMENT OF A RENEWABLE RESOURCE: A POLICY ANALYSIS

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ABSTRACT

Motivated by the problem of deer overabundance in many areas of the United States, this thesis investigates innovative incentive-compatible policy options to address the problem. Economists view deer populations as a renewable resource, a composite asset that provides both benefits and costs to humans over time. As with any other asset, the economic goal of deer management should be to achieve the deer population that optimizes the value of the asset over time. Specifically, the first essay investigates attitudinal differences among hunters using hunter survey data from north-central Pennsylvania. A latent-class model (LCM) with covariates is used to separate hunters by their attitudes toward deer hunting, deer damage, and their role as managers of the deer population. The results indicate that hunters can be separated into general attitudinal categories which wildlife management agencies should consider when designing harvest allocation schemes. The second essay investigates the feasibility of nonlinear pricing for deer harvest tags which is incentive compatible with hunters who vary by their willingness to pay for tags. The same hunter survey data from Pennsylvania is used in an ordered probit model to estimate hunter demand for three hunter categories. A subsequent nonlinear programming model allows a social-welfare comparison between the current licensing system and improved pricing schemes. The results indicate that welfare improvements of up to 10% are possible. The third essay investigates the specific policy option of paying hunters to harvest antlerless deer as an incentive. A bioeconomic model is developed, calibrated with Pennsylvania data, and solved as a dynamic programming problem. The results indicate that significant social welfare improvements are possible, but that the payments to hunters may exceed what is politically feasible under current conditions.

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INTRODUCTION

Background

For most of the past century, wildlife managers in the United States have sought to protect and enhance the populations of white-tailed deer (Odocoileus virginianus). “With the specter of extirpation still haunting their memory” (Waller and Alverson, p.217), wildlife managers in the 1900s worked hard to devise and enforce bag limits, short hunting seasons, and buck-only hunts in order to protect the recovering deer herds. Farmers, silviculturalists, and hunters assisted in this effort, creating habitats that would best support larger deer populations. The result by the late 1980s was an astounding success story; deer populations in many areas were at all-time highs, exceeding the number of deer that roamed the forests before Europeans arrived on the North-American continent in 1492.

But ironically, the complete restoration of deer populations (which represented the premier example of successful wildlife management) “has now led to what is probably the most challenging problem faced by wildlife managers; deer overabundance” (Warren, p. 213). Steadily increasing populations of white-tailed deer, and their detrimental ecological and environmental impacts in the eastern United States, have been a topic of research for almost twenty years. An entire volume of the Wildlife Society Bulletin (25:2, 1997) was dedicated to the topic. Current white-tailed deer populations in many eastern States are generally considered to exceed the cultural carrying capacity of the habitat (Hardin) - a loosely-defined term that can be thought of as the deer population that the human community is willing to tolerate. Game managers, biologists, forest managers, and other experts have worked tirelessly to quantify the “correct” population of white-tailed deer based on the biological carrying capacity of the habitat. The numerous stakeholders all have conflicting goals and desires pertaining to the deer population, which causes the cost-benefit analysis to determine the optimal deer density to be a complicated exercise.

This is what makes deer overabundance such a great management challenge. It is not simply a biological or ecological problem. The social, political, legal and economic impacts, that are collectively referred to as the human dimensions of the deer overabundance problem, need to be analyzed and considered for the problem to become tractable. The hunting laws and regulations that were so successful in protecting the recovering deer herds throughout the 1900's are now part of the problem. These laws have created expectations among hunters, conservation officers, and non-hunters alike as to what is acceptable practice when managing deer through regulated harvests. A reconsideration and honest critique of the current laws and practices is required.

Economics of Deer and Deer Hunting

Wildlife populations, including deer, are considered by economists as composite assets that provide benefits to humans over time (Schuhmann and Schwabe), and like any other asset, society should attempt to optimize the value of this natural resource. The primary goal of deer management, from an economist's perspective, is to find the population size or population density that maximizes the net benefits to society. The optimal population density can not be calculated independently from the means of achieving that density; deer management must consider the alternative methods of deer harvest to properly determine the optimum density. The economic analysis of deer management must combine research that estimates the value of deer with the research that estimates the costs that deer impose on society, while also considering the market failures that exist in a non-competitive market environment such as wildlife.

The overall economic analysis of deer is complicated by several factors. The consumptive uses of the deer herd (i.e., hunting harvest) are rivalrous, for of course one person's harvest and consumption of deer takes away directly from another person's use. Many of the non-consumptive uses of deer, however (wildlife watching, photography, bequest values), are both non-rivalrous and non-excludable, in that one person's enjoyment does not preclude others from that same enjoyment. So deer can be considered a public good in some aspects, but not in others, complicating the policy analysis considerably.

The complicating factors to consider in the cost-benefit analysis of deer are numerous. First, the individuals in society who accrue the benefits from a given deer population are different from those individuals who accrue the costs. Second, both the benefits and the costs are distributed non-uniformly across both space and time. Third, the benefits of deer (like many natural resources) are largely composed of non-market valuations. Use value and non-use values of deer are also expected to be nonlinear with respect to deer density. Costs of deer are also expected to be nonlinear with respect to deer density, and accrue to a diverse group of stakeholders who all must be considered.

Although wild deer in the United States are not owned by individuals, much (or most) of the habitat they live on *is* owned by individuals and private firms. Although these individuals can not buy and sell the deer as a public good, they can certainly restrict access to the deer through enforcement of property rights and trespass laws. The monopoly owner of the deer, represented by the state game management agency (which in Pennsylvania is the Pennsylvania Game Commission, or PGC) does not buy and sell deer directly. The right to a deer harvest is controlled by the PGC, and the harvest component of the value of a deer varies across individuals using deer for consumptive purposes. And again, even the monopoly owner of the deer can not infringe upon the landowner rights of private citizens, complicating the control of the deer density even further. These issues must be considered in any realistic analysis of deer overabundance, as well as any realistic policy proposals to address the problem.

One result of these economic complexities is disagreement among interested parties over the precise parameters to utilize in the economic analysis. Exact parameter estimates are not my main concern here, however. *My concern in this series of essays is to focus on innovative techniques for optimizing total economic surplus or social welfare from the deer herd in areas of overabundance.* Parameter estimates will be taken from previous research where available, and sensitivity analysis is used to articulate the confidence levels over the ranges of parameter estimates used. The parameters in the model must be accurately measured by the PGC and others if the methodology I propose for addressing the problem of deer overabundance is to be utilized.

To be specific for this dissertation, the deer hunting regulations and license practices of Pennsylvania will be used as an example. The laws of New York, Maryland, New Jersey, and Ohio (other states with deer overabundance problems) are very similar, both in word and in spirit, to those of Pennsylvania. The evolution of these regulations and licensing practices also outline how game managers have tried to deal with the problem of deer overabundance in an ad hoc fashion (creating a patchwork of licenses, seasons, and prices) instead of systematically analyzing the optimal harvest methodology and applying it to a dynamic system.

Objectives and Brief Outlines of Three Essays

This thesis will investigate the feasibility of innovative approaches to addressing the deer overabundance problem in the northeastern United States. The overarching dissertation objectives are: a) improve the economic efficiency of a valuable but poorly managed renewable resource, and b) identify and evaluate innovative management policies to address overabundant deer. The thesis consists of three independent essays; each essay has different assumptions about hunters and deer overabundance that affect the construction of the economic model in the essay. Each essay is a unique application of environmental economic theory or techniques, and also unique within the literature on deer management and deer hunting. The first essay contributes empirical support for the categorization of deer hunters into typologies useful for deer managers. The second essay uses hunter typologies to create a nonlinear pricing hunter licensing scheme that maximizes the allocative efficiency of deer harvest. This essay assumes there is unmet demand for harvest tags among a select group of high-demand hunters under current licensing systems. The third essay creates a bioeconomic model to calculate the socially optimal deer densities and hunter effort, then models a policy proposal to achieve a second-best optimum. The bioeconomic model assumes that all hunters are currently unconstrained in their harvest effort, and calibrates composite hunter utility from this assumption. In each essay, the focus remains on the methodology and the policy proposals for game managers concerned with deer overabundance.

Essay one uses a latent-class model to categorize hunters based on their attitudes and perceptions toward deer overabundance, reasons for hunting, role of hunters as game managers, and regulations changes. The objective of this essay is to identify hunter typologies that are possibly useful to game managers interested in reducing deer densities. The model then uses covariates to identify behaviors or demographics that are more likely in one category of hunters, including the propensity and willingness to purchase multiple antlerless deer harvest tags, which supports the analysis in essay two. The results of the latent class analysis indicate that game managers should consider tailoring deer management regulations and incentives to these different hunter types for maximum effectiveness. The model also contradicts some common perceptions among game managers about older, rural, and less educated hunters in the state of Pennsylvania.

Essay two builds upon the hunter typology concept in essay one to now separate hunters based on their willingness to pay for harvest tags. First-best and second best nonlinear pricing policies are then modeled that consider hunter types differentiated by both demand and harvest success rates. The estimated improvements in intra-seasonal economic efficiency, and the distributional effects of changing from the current rationing method of harvest allocation to a price-driven allocation, are estimated for the state of Pennsylvania as a whole. The results indicate that large improvements in static efficiency can be achieved through price-rationed harvest tag allocation, but some antlerless deer hunters may protest a reduction in their economic surplus from hunting, and indeed may even stop hunting antlerless deer altogether.

The third essay addresses the dynamic efficiency of the deer herd, and considers a specific policy of paying deer hunters for antlerless harvests as an incentive to reduce an overabundant herd. A dynamic programming model is used with calibrated parameters for the state of Pennsylvania. The dynamically efficient steady state deer density, annual harvest rate, hunter effort, and recommended payment for harvest are all calculated under different parameter assumptions. The results indicate an optimal deer density significantly lower than what currently exists. Sensitivity analysis shows that increasing hunter efficiency in any socially acceptable manner should be the first goal of deer management agencies in areas of deer overabundance. Incentive compatible payments for antlerless deer harvests were significant enough (~$200) to logically affect hunter behavior, but possibly too high to be politically acceptable.

Contribution of the Thesis

The synthesis of diverse areas of scientific research and economic theory was required for this thesis. An overview of the appropriate applied and theoretical literature is conducted within each essay, but in each the application of the economic theory is unique within both the broader environmental economics literature and the more narrow deer management literature. A partial list of the applied and theoretical literature relied upon for this thesis includes bioeconomic modeling, dynamic programming in discrete time, nonlinear pricing and monopolist principle-agent theory, latent-class modeling and environmental economics applications, and deer biology and deer management literature including adaptive resource management.

The analysis within each essay was conducted with the goal of achieving the most realistic model, and using the most recent data available for the area of interest (the State of Pennsylvania). The methodology is an important contribution of this thesis as well; accurate policy analysis requires appropriate modeling, but environmental economists, game managers, and policymakers can all apply the models developed in this thesis to their own data and make their own conclusions. My hope is that the techniques and innovative policies modeled here may contribute in some form to the debate over, and ultimately a solution to, the problem of deer overabundance.

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Essay 1

Categorizing Hunters by Typologies Useful to Game Managers: A Latent-Class Model

1.1 Introduction, Objectives, and Methodology

Steadily increasing populations of white-tailed deer, and their detrimental ecological and environmental impacts in the eastern and mid-western United States, have been a topic of scientific research for almost twenty years. An entire volume of the Wildlife Society Bulletin (25:2, 1997) was dedicated to the topic. Current white-tailed deer populations in many eastern States are generally considered to exceed the "cultural carrying capacity" of the habitat (Hardin) - a loosely-defined term that can be thought of as the deer population that the community is willing to tolerate. Concurrent with the recent increase in deer populations, however, is a decrease in the hunter populations of these eastern and Midwestern states. A study by Lauber and Brown of Cornell's Human Dimensions Research Unit (HDRU) in January 2000, recognized the deer management challenges that are caused by recent hunter trends. In Lauber and Brown's study, the authors suggested several questions that would be worthwhile to explore in future research. These included: 1) Can hunters' willingness to take antlerless deer (does) be increased by regulatory changes or education, and if so, how? 2) Given that some hunters would like to take more deer than they do, can hunters' success at taking deer be increased to more closely match their interests, and if so, how? A partial analysis of these research questions will be conducted in this paper, to determine if categories of hunters exist that would be useful to game managers attempting to decrease deer density in specific geographical areas.

Because hunting is a multi-attribute amenity, hunter motives, attitudes, and satisfactions are of course different from person to person. An analysis of hunter typology is well suited to the method of latent-class modeling, or latent-class analysis. I hypothesize that there are different hunter types, and these hunter types vary in their attitudes towards hunting as a management tool, and towards the importance they place on antlerless deer harvest to control deer populations. Game managers emphasize hunting as the only realistic large-scale management tool currently available to control deer densities (Latham, et al.) Identifying the attitudinal characteristics of hunters who also place importance on deer hunting as a management tool could be valuable to game managers. An analysis of behavioral or demographic characteristics (age, education, hunting methods) that are correlated with hunter attitudes more likely to be concerned

with the impacts that overabundant deer have on the environment may be valuable as well. Estimating the proportion of these hunters in the overall hunter population, and classifying their attitudes and behaviors, may be useful to game managers as well.
The specific objectives of this essay are the following:

1. Apply the technique of Latent-Class Modeling to hunter survey data in Pennsylvania. Identify hunter typologies based on attitudinal variables.
2. Analyze the resulting latent-hunter classes and covariates to determine if hunter categories exist that are useful to game managers challenged by overabundant deer.

An outline of the essay is as follows. Section 2 introduces the logic of latent class analysis for the uninitiated, and uses a small portion of the available hunter data to explain the formal latent-class model. Section 3 defines the estimation procedures, best-fit techniques, and the inclusion of covariates into the model. Section 4 applies the latent-class technique to the available Pennsylvania hunter data set and determines the appropriate number of hunter categories and covariates. Section 5 organizes and explains the results of the model from the perspective of game managers attempting to control deer populations, and finally Section 6 discusses the policy implications of the model's results.

1.2: The Logic of Latent-Class Modeling (LCM)

In his 1987 essay on the methodology for analyzing categorical data, Allan McCutcheon uses the example of "religious commitment" as a theoretically interesting concept that can not be directly observed. However, a high level of religious commitment *is* likely to result in several observable behavior patterns such as more frequent church attendance, greater behavioral orthodoxy, more frequent prayer, and the reporting that a person's religious beliefs are relatively important to them. Thus, if we believe that the variation in these observable indicators is actually due to the level of the unobservable, or latent, variable known as "religious commitment," then the latent variable is said to "explain" the relationships between the levels of the observed variables (McCutcheon, 5). Additionally, controlling for this latent variable should also reduce the covariation between the observed variables to random error.

Agresti argues that “the Latent-Class Model is useful and plausible when the observed variables are several indicators of some concept, such as prejudice, religiosity, or opinion about an issue” which is not directly observable, or latent. My purpose in this paper is to develop a latent-class model of hunters that is estimated only with attitudinal data. The latent classes that will be identified can be considered hunter typologies, or hunter categories. I want to determine if categories of hunters exist that are concerned about the environmental damage caused by overabundant deer, and consider their role as hunters is (at least partially) to assist in managing the deer population. Game managers and policy-makers could use the information on these different hunter classes when designing regulations to address the problem of deer overabundance.

Latent Class Modeling has been applied for decades in other social sciences, but only recently in the field of environmental economics. Previous applications in the broad area of environmental economics include: Provencher et al. for recreational fishing utility; Boxall and Adamowicz for wilderness park choice; Shonkwiler and Shaw for reservoir recreation along the Columbia River; and Milon and Scrogin for wetland ecosystem preferences. An application of latent class modeling using only attitudinal data to separate latent classes, which is the method employed in this essay, is that of Morey, Thacher and Breffle. Morey et al. developed a model of angler preferences in Green Bay, Wisconsin, using only attitudinal data to create the angler preference groups. The subsequent groups were then described and analyzed with demographic and behavioral data, which will also be the method followed in this analysis.

1.2.1: An Example of a Formal Latent-Class Model (LCM)

Goodman (1974) was the first to develop an algorithm for analyzing unobservable qualitative variables. Clifford Clogg developed the first latent-class software program, MLLSA, which was limited to analyzing a small number of nominal variables (Vermunt & Magidson, 2004). Additional textbooks and papers on the standard latent-class model are McCutcheon, Clogg, Heinen, and Vermunt. One of the clearest explanations of the basic model is that of Vermunt and Magidson (2004), and I will use their symbology to explain the genesis of the hunter category model developed for this analysis.

The Kinzua Quality Deer Cooperative (KQDC) hunter study was conducted by the Human Dimensions Unit at the Pennsylvania State University in the fall of 2004[3]. The written survey questionnaire used in the KQDC hunter study provided both quantitative and categorical data on Pennsylvania deer hunters. The KQDC survey provided data on such characteristics as age, education level, annual income, hunting methods, number of years hunting, place of residence, and number of deer harvested. The survey also included Likert-scale attitudinal questions, such as the following:

Question 11. How important are each of the following reasons for your participation in hunting: (circle one response per statement)

1 = Not Very Important (NVI)
2 = Somewhat Important (SI)
3 = Important (I)
4 = Very Important (VI)

Reasons for Hunting	NVI	SI	I	VI
a. To get outdoors…………………………	1	2	3	4
b. To get away from my everyday routine…	1	2	3	4
c. To obtain venison………………………..	1	2	3	4

etc.

The attitudinal questions in the KQDC survey provide important information for the creation of different hunter categories. (A complete list of the survey questions is at Appendix A.) An investigation of hunter categories that considers attitudinal data to separate hunters, and then behavioral data to assist in describing the category, will be conducted using latent-class modeling.

If we call the attitudinal variables in the KQDC survey for which we have data the manifest variables, then one of the goals of latent-class analysis is to define a reasonable latent variable, with a discrete number of classes, which explains the responses to the manifest variables by individual hunters. Latent-class models assume the existence of a latent categorical variable that is qualitative. We can call this latent categorical variable **X**, and assume there are subclasses, or categories, $x \in \mathbf{X}$. Let C be the number of latent classes, so a particular latent class is denoted by x, $x = 1,2,\ldots,C$. The model also assumes that each individual belongs to one, and only one, of these latent classes. Different classes should answer attitudinal questions similarly within classes, but differently

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[3] This section, with a short example of the latent-class technique, needs only a short description of the KQDC data set. The survey and data are analyzed in more detail in Section 4.

between classes. Then given the unobserved categorical variable *x,* the LCM assumes that all of the observed response variables are *conditionally independent*. In other words, knowing to which category a hunter belongs explains fully that hunter's attitudes and beliefs about hunting. For my purposes, the KQDC survey data questions that included hunter attitudes and hunter participation importance variables are of interest.

The Likert-style questions of hunter support for current deer management regulations (questions 8a-8d in Appendix A), hunter agreement with certain statements (questions 9a-9u) and hunting importance (questions 11a-11j) are thus categorical. We can index these observed categorical variables as (Y_1, Y_2,…,Y_T), so Y_t indicates a single observed variable. Denote the number of levels in each Y_t by D_t, so a particular value of Y_t is enumerated by y_t, $y_t = 1,2,\ldots, D_t$. For the Likert-style importance questions, for example, $D_t = 4$. The vector notation **Y** and **y** can then be used to refer to a complete response pattern. I hypothesize that there are a discrete number C of hunter types, and knowing this type will predict strongly the response outcomes ($y_1, y_2,\ldots, y_T$) for each class *x* of **X**.

Aggregating variables on the Likert-scales for simplicity, we can use actual data from the KQDC hunter survey to create the following small data set as a way of exposition:

Table 1.1: Frequency Table of Two selected Attitudinal Manifest Variables

Y_1	Y_2	Frequency	$P(\mathbf{X} = 1 \mid \mathbf{Y} = \mathbf{y})$	$P(\mathbf{X} = 2 \mid \mathbf{Y} = \mathbf{y})$
1	1	63	.84	.16
1	2	68	.39	.61
1	3	161	.07	.93
2	1	28	.96	.04
2	2	18	.77	.23
2	3	20	.29	.71
3	1	184	.99	.01
3	2	100	.94	.06
3	3	60	.68	.32

The manifest variable Y_1 is the response to the statement "How supportive are you of the Pennsylvania Game Commission's (PGC's) efforts to increase the antlerless deer harvest?" (1=support, 2=neither support nor oppose, 3=oppose). The manifest variable Y_2 is the response to the question "Indicate your level of agreement with: Deer damage to forests in Pennsylvania is a problem." (1=disagree, 2=neither agree nor disagree, 3=Agree). Latent-class analysis makes it possible to identify subgroups with different combinations of these attitudinal variables, from the 702 hunters in the survey population who answered both of these questions.

Not having explained yet how the model selected Latent Class 1 (X=1) and Latent Class 2 (X=2), these conditional probabilities start to give an idea of how hunter types will differ. Looking at the first row of information in Table 1.1 as an example, the interpretation of this information is as follows. Of the 63 hunters in the survey who both support the PGC's efforts to increase the antlerless deer harvest ($Y_1 = 1$) and disagree that deer damage to forests in Pennsylvania is a problem ($Y_2 = 1$), 84% will fall in Latent Class 1 and only 16% will be categorized as Latent Class 2.

Again, the underlying premise of the latent-class technique is that the probability of obtaining a specific response pattern **y**, which is denoted as $P(\mathbf{Y} = \mathbf{y})$, is a weighted average of the C latent-class specific probabilities $P(\mathbf{Y} = \mathbf{y} \mid \mathbf{X} = x)$:

$$P(\mathbf{Y} = \mathbf{y}) = \sum_{x=1}^{C} P(\mathbf{X} = x) \cdot P(\mathbf{Y} = \mathbf{y} \mid \mathbf{X} = x) \qquad (1)$$

Combining this with the conditional independence assumption explained earlier, the manifest variables (T=2 for our simple table) are assumed to be mutually independent within latent classes. This leads us to the following formulation:

$$P(\mathbf{Y} = \mathbf{y} \mid \mathbf{X} = x) = \prod_{t=1}^{T} P(Y_t = y_t \mid \mathbf{X} = x) \qquad (2)$$

Methods for obtaining/estimating these conditional response probabilities $P(Y_t = y_t \mid \mathbf{X} = x)$ are described later. Once the estimates are obtained, comparing the conditional response probabilities between latent classes indicates how the classes differ. The latent classes can be "named", or described, in a way that outlines the relevant characteristics of each class. Combining the basic equations (1) and (2) above yields the following model:

$$P(\mathbf{Y} = \mathbf{y}) = \sum_{x=1}^{C} P(\mathbf{X} = x) \prod_{t=1}^{T} P(Y_t = y_t \mid \mathbf{X} = x) \qquad (3)$$

A 2-class model can be estimated with our small data set. Estimates were obtained from the Latent Gold® software package (Statistical Innovations, Belmont, MA).

Table 1.2: Two Hunter Latent Classes, Results Profile

	(no harm, more Deer) **X** = 1	(less deer, better forests) **X** = 2
$P(\mathbf{X} = x)$	.65	.35
$P(Y_1 = 1 \vert \mathbf{X} = x)$	.20	.81
$P(Y_1 = 2 \vert \mathbf{X} = x)$	.10	.08
$P(Y_1 = 3 \vert \mathbf{X} = x)$	.70	.11
$P(Y_2 = 1 \vert \mathbf{X} = x)$	.58	.05
$P(Y_2 = 2 \vert \mathbf{X} = x)$	.30	.21
$P(Y_2 = 3 \vert \mathbf{X} = x)$	.12	.74

The first latent-class, which I have labeled the "no harm, more deer" group, contains 65% of the hunters surveyed. This group mostly disagrees or is neutral about the harm deer are doing to Pennsylvania forests ($Y_2 = 1,2$) and subsequently a full 70% of this group oppose the PGC's efforts to increase the antlerless deer harvest ($Y_1 = 3$). The second latent-class, labeled "less deer, better forests" only contains 35% of the total hunter population surveyed. This group overwhelmingly agrees that the deer population is damaging forests in Pennsylvania ($Y_2 = 3$), and subsequently over 80% of this group of hunters support the PGC's efforts to increase antlerless deer harvests ($Y_1 = 1$).

Another important result from the latent-class model is the ability to assign individual respondents to one of the latent classes. Called a posterior membership probability, it can be calculated from Bayes rule as:

$$P(\mathbf{X} = x \mid \mathbf{Y} = \mathbf{y}) = \frac{P(\mathbf{X} = x)P(\mathbf{Y} = \mathbf{y} \mid \mathbf{X} = x)}{P(\mathbf{Y} = \mathbf{y})} \tag{4}$$

Using each individual hunter's response pattern, $\mathbf{y} = (y_1, y_2, \ldots, y_T)$, the individuals are assigned to the latent-class x with the highest posterior membership probability, $P(\mathbf{X} = x \mid \mathbf{Y} = \mathbf{y})$. This is referred to as the "modal classification rule" (Vermunt and Magidson, 2004). The class-membership probabilities shown in Table 1.1 represent this modal assignment for our small data set. Disagreement with the statement that deer damage to forests in Pennsylvania is a problem ($Y_2 = 1$) was the primary indicator of membership in the first latent group. A "neutral" response to either question Y_1 or Y_2 also placed a hunter in the first latent class (or category) with much higher probability.

1.3: Estimation Procedures

The procedure utilized to determine the parameters of the latent-class model is maximum likelihood estimation. This classical technique for latent cluster models was developed by Goodman (1974a, 1974b, 1979). Again using the symbology and methodology from Vermunt and Magidson (2004), let ***I*** denote the total number of possible answer patterns for the T manifest variables you have selected to model, so ***I*** = $\prod_{t=1}^{T} D_t$. Thus, there are ***I*** cell entries in our frequency table of answer patterns. For our small example data set, ***I*** = 9, but my subsequent models with 10-15 manifest variables often had ***I*** > 5.6 million. Let i denote a particular cell entry, n_i the observed frequency in that cell, and $P(\mathbf{Y} = \mathbf{y}_i)$ the probability of having the response pattern represented by cell i.

The kernel of the multinomial log-likelihood function to be maximized is thus:

$$\ln \mathcal{L} = \sum_{i=1}^{I} n_i \ln P(\mathbf{Y} = \mathbf{y}_i) \tag{5}$$

with the $P(\mathbf{Y} = \mathbf{y}_i)$ coming from equation (3). The estimation goal is to find the parameter values that best explain the observed response patterns, subject to the following constraints.

Notice that the sum of the latent class probabilities over all C latent classes must be one:

$$\sum_{1}^{C} P(\mathbf{X} = x) = 1.0 \tag{6}$$

Additionally, we can define the following “response probability”, $\pi_{ti|x}$, which represents the probability that an individual in latent class x answers level i to question t. For each question and each latent class, these response probabilities must also sum to unity:

$$\sum_{i=1}^{I} \pi_{ti|x} = 1.0 \qquad \forall\, t, x \tag{7}$$

The (6) constraint simply indicates that the latent-class probabilities must sum to unity, as the model directs. The (7) constraint imparts the logic of how each manifest variable is represented. For any latent class x, there is a multinomial probability distribution over the possible answers for each manifest variable. The probabilities for these possible responses to each manifest variable Y_t must sum to one, and again this identity must hold for each latent class x.

There are two recognized procedures in the literature for maximizing (5) with respect to (6) and (7). Each procedure has its own advantages and disadvantages. The Newton-Raphson method (Haberman) is a relatively faster algorithm, and can also provide standard errors for the model parameter estimates (Agresti). The more common estimation procedure is the EM (expectation-maximization) algorithm for incomplete information (Dempster et al.). The convergence of the EM algorithm is slower than that of the Newton-Raphson method, but the EM algorithm is computationally simple and relatively stable (Agresti). The idea behind the algorithm is to replace unobserved information with its expected value. Treating these expectations as if they were "correct" allows the maximum likelihood estimation to be conducted. These ML estimates are then used to update the original expectations for the unobserved information, and the process is repeated until the improvement in the log-likelihood function becomes very small.

The software used to test the hunter models in this analysis was Latent Gold®. The program uses both the EM and Newton-Raphson algorithms. The estimation process starts with a number of EM iterations to exploit the stability of the algorithm even when it is far from the optimum. When closer to the final solution, the software switches to the Newton-Raphson method to gain the advantage of a faster convergence. A well know problem in latent-class analysis is the occurrence of local maxima (Vermunt and Magidson, 2005). The log-likelihood function (5) can be non-concave, and thus the iterative procedure may bring us to a local, rather than a global, maximum. The analysis of a latent-class model *must* try more than a single set of initial values for the expected conditional probabilities and proportions. For this analysis, we specified 50 random sets of start values to try to ensure convergence to the global maximum.

Another point that should be considered when estimating conditional and latent class probabilities is that the number of parameters is limited by the available degrees of freedom in the frequency table of observed categorical variables, Y_t (McCutcheon). For this reason, usually the number of latent classes, C, is limited to a reasonable number (<10). Notice that the model could define each hunter as belonging to his own latent class, and the model would "perfectly" cluster hunters into latent classes! But this information is obviously not useful to the researcher, nor to the policy-maker. The insight provided by latent-class analysis stems from the resultant grouping of respondents into a reasonable number of "like categories" for ease of explanation to policy-makers and managers.

1.3.1: Comparing Different Models

A legitimate critique of LCM is that no single statistical test exists to compare models. Intuitively, for two models with equal log-likelihoods, the model with the fewest number of latent classes would be preferred. Information statistics that consider the log-likelihood of the model, adjusted for the number of unknown parameters and the sample size, are appropriately called "parsimony indexes." The best-fitting model will minimize the parsimony index selected. The authors in previous articles that utilize LCM have used a number of different indicators to compare and select the optimum model from among those tested (Morey et al.).

One possible test of model fit that has been used in previous studies is the Akaike Information Criterion (AIC). Another often used test is the Schwarz Bayesian Criterion, often referred to as the Bayesian Information Criterion (BIC). With p equal to the number of estimated model parameters, and N the number of observations/respondents/cases, these indices are calculated as:

$$AIC = (-2)\cdot \ln(\mathcal{L}) + 2p \tag{8}$$

and

$$BIC = (-2)\cdot \ln(\mathcal{L}) + p*\ln(N) \tag{9}$$

As can be seen from the definitions above, the lower the values of the AIC and BIC statistics, the better the model.

Model fit can also be tested with the likelihood ratio chi-squared statistic (L^2), the most common test for multiple parameter models solved with maximum likelihood (Eliason). This test statistic, in the context of latent-class analysis, is interpreted as indicating how much of the observed relationship between the variables remains unexplained by the model. Thus, the larger the value of the L^2, the worse the model fits the data. Again using *i* to denote a specific cell in the frequency table, this statistic is calculated as:

$$L^2 = 2\sum_{i=1}^{I} n_i \ln(n_i / N*P(\mathbf{Y} = y_i)) \tag{10}$$

Similar to these parsimony indexes as a measure of how well our model explains the data, if our model fits the data well then the individuals in the data set should be assigned to one of the latent classes with a high probability. Using the modal classification rule from equation (4), the estimated proportion of classification errors, E, under this rule is:

$$E = \sum_{i=1}^{I} (n_i/N)\ \{1 - \max[P(\mathbf{X} = x \mid \mathbf{Y} = \mathbf{y}_i)]\} \qquad (11)$$

The lower the proportion of classification errors, the better the model.

There is also a pseudo R-square statistic that indicates how well the model predicts latent class membership based on the observed manifest variables. The closer this value is to 1, the better the model, similar to an R-square statistic in OLS modeling. This reduction of errors statistic is referred to as lambda, λ, by Vermunt and Magidson, and is measured from:

$$\lambda = 1 - \{E/\max[P(\mathbf{X} = x)]\} \qquad (12)$$

For the analysis of hunter types, the BIC, AIC, E, and λ statistics are reported and used to compare models. It is expected that the best model will have a λ close to 1, a low E, and low BIC and AIC scores relative to other models.

1.3.2: Including Observable Characteristics (Covariates)

The latent-class model can be extended to allow the inclusion of demographic and behavioral variables of interest (age, education, hunting techniques, etc.) that are observable. Attitudinal variables are unobservable; latent classes are determined from these unobservable attitudes and opinions about deer, deer hunting, and deer management. I selected to exclude observable characteristics from the manifest variables that determine a hunter's latent class, but I did want to examine how some observable variables were correlated with hunter categories once they were determined. This method of covariates was first outlined by Dayton and Macready (1988), and their method has been incorporated into the Latent Gold software program. Let $\mathbf{Z} = (Z_1, Z_2, \ldots Z_K)$ represent the non-attitudinal variables (covariates) of interest, and Z_k indicate any specific covariate. If the values of each covariate are finite, we can let z_k denote the value of covariate k, and $\mathbf{z}$ represent the vector of observed z_k. The inclusion of covariates (also known as grouping variables) allows these variables to describe and predict (rather than define or measure) the latent classes (Vermunt and Magidson, 2005). Dayton and Macready specified a multinomial logit model for the probability of belonging to latent class x as:

$$\mathrm{P}(\mathbf{X} = x \mid \mathbf{Z} = \mathbf{z}) = \frac{\exp(\gamma_x^X + \sum_{k=1}^{K} \gamma_x^{X,Z_k} \cdot z_k)}{\sum_{r=1}^{C} \exp(\gamma_{\mathrm{r}}^{\mathrm{X}} + \sum_{k=1}^{K} \gamma_r^{X,Z_k} \cdot z_k)} \qquad (13)$$

Again, these covariates Z_k are *not* used in the EM algorithm to identify the latent classes. The latent classes describe the associations among the categorical variables, Y_t, of interest; associations among the Z_k are not explained. However, once the latent categories and conditional probabilities are determined that minimize the log-likelihood equation (5), the covariates help to describe and predict the latent classes x. I tested numerous covariates that I suspected may be descriptive of hunter categories, and which were available in the KQDC data. Surprisingly, only a few demographic and behavioral variables showed a marked difference across hunter categories, so the covariates were less useful in describing the latent classes than I anticipated.

1.4: An Application to Pennsylvania Deer Hunters

The latent-class model is useful for both exploratory and confirmatory analysis of a group of respondents (McCutcheon). Hunter typologies have been discussed in the literature previously. For example, in 1989, Decker and Connelly did an analysis of motivations for deer hunting. They cited declining hunter success, compounded by declining hunter numbers, as a challenge for properly managing deer populations. In a previous paper, Decker et al.. (1987) identified three primary motivational orientations for deer hunters, which supports the underlying premise of this essay that hunters can be categorized by type. Gigliotti (2001) refers to an article by Kellert (1978) that outlines the “accepted human dimensions principle that different types of hunters exist”(p 34). These typologies reflect the motivations and satisfactions of hunters, but I do not know of published research that has utilized the technique of LCM to develop and analyze hunter categories.

Hypothesizing that hunter categories exist that are relevant to innovative deer management strategies, the available data set for exploratory LCM was the KQDC hunter survey described in the opening paragraph. The Kinzua Quality Deer Cooperative (KQDC) is a consortium of private and public forest in north-central Pennsylvania, that was designed to manage deer, improve habitat conditions, and to increase forest management options. At one time there was an overabundance of deer in the KQDC area, but the management effort has reduced the deer densities recently. The Pennsylvania Game Commission (PGC) put no money into the KQDC survey, but through their relationship with the Human Dimensions Unit at The Pennsylvania State University, the PGC indicated their interest in better understanding the hunters in this area. In the two hunting seasons previous to the survey, the antlerless harvest tags made available to individual hunters who hunted the KQDC were more numerous than the limited tags made available to the general hunting population in the rest of Pennsylvania.

Hunters for the KQDC survey were identified in two ways. The majority of the hunters in this survey were selected randomly from a PGC database identifying those hunters who had applied for an antlerless harvest tag in the KQDC management area. Eight-hundred written surveys and return envelopes were mailed to the hunters in the PGC database, of which 25 were returned as undeliverable. From the 775 deliverable surveys, 594 were returned with usable data (76.6% response rate). An additional 148 written surveys and return envelopes were mailed randomly to addresses provided from the KQDC's annual hunter banquet mailing list, and five of these surveys were undeliverable. From the 143 deliverable surveys, 122 were returned (85.3% response rate). Of the 716 total surveys returned, 3 were duplicates (received and returned by the same hunter), and 7 were not used at the request of the hunter. An additional 4 hunters who had not answered any/the majority of the attitudinal questions of interest (questions 9 and 11) for the latent-class modeling were also dropped, resulting in a final sample size of 702 hunters.

The KQDC survey data has not been used in any other published articles to date. A comparison of the results of the KQDC survey was made with a statewide (telephonic) Pennsylvania hunter survey that was conducted in 2001-2002. The KQDC hunters were not significantly different from Pennsylvania hunters overall in age, education, income, children living at home, or support for statewide antler restrictions (common parameters of the two surveys). The KQDC hunters were significantly different from the

Pennsylvania hunters in proportion of archery hunters (44% in KQDC > 32% in PA), proportion of muzzleloader hunters (50% KQDC > 24% in PA) and most importantly the proportion of antlerless tag holders (90% KQDC > 45% in PA) because of the survey methodology and how respondents were selected to participate. These few dissimilarities between the two groups indicate that the KQDC hunters are probably a representative subset of antlerless deer hunters in Pennsylvania, but perhaps a slightly more avid group of antlerless hunters than the average hunter in Pennsylvania, being licensed for and pursuing antlerless deer in early and late seasons at higher rates.

1.4.1: Exploratory Methodology

Prior to the analysis of the categorical attitudinal variables with LCM, summary statistics from the KQDC survey were analyzed. Summary statistics from the hunter survey are provided in Appendix B. The hunters were asked in one question to rate the importance of hunting (overall) to them on a 4-point Likert-scale. From previous research on hunter-stated reasons for hunting, the next question asked the KQDC hunters to rate the importance of 10 postulated reasons why hunters participate in their sport, again on a 4-point scale. The average importance scores for all 702 hunters, sorted by importance, are found in Table 1.3.

Table 1.3: Average Importance Scores

	Average Score
Hunting overall	3.63
Reason for Hunting	
To get outdoors	3.56
To get away from everyday routine	3.46
The challenge of hunting deer	3.32
To be with my family	3.15
To be with my friends	3.11
To test my outdoor skills	3.06
To return to traditional hunting spots	2.99
To obtain venison	2.71
To help manage the deer population	2.59
To get a large antlered deer	2.12

The results in Table 1.3 illustrate the recent challenges faced by game managers trying to reduce overabundant deer populations, and support the previous studies of hunter motivations as well. Most noticeably, the three reasons for hunting that actually require deer to be removed from the population (obtain venison, manage the deer population, get a large antlered deer) are much less important to hunters (on average) than all other reasons for hunting. Because deer populations are controlled through antlerless deer harvest, hunters who rate *obtaining venison* and *to help manage the deer population* as important or very important would be potentially more useful for game management than those hunters who do not, provided they are willing and able to increase their harvests.

One simplification of an observed Likert-scale variable that was necessary to improve the interpretation of the LCM was the question that dealt with recent deer hunting regulation changes. With the overall goal of improving the quality of Pennsylvania's deer herd, the PGC implemented several new regulations starting with the 2000 and 2001 hunting seasons. The KQDC hunters were asked to rate their support or opposition to these new regulations on a 7-point Likert-scale, recognizing that the regulations had been in effect for 2-3 years and the hunters should have developed an opinion of the new regulations. For ease of interpretation of the latent-class results, these questions were re-scaled to a 3-point Likert-scale. I chose to *combine* strongly support, support, and slightly support on the original 7-point scale, and re-scaled this combination as a "1"; neither support or oppose was re-scaled a "2"; and slightly oppose, oppose, and strongly oppose were combined and re-scaled as a "3". Manifest variable Y_1 in Table 1.1 of our simple illustrative example on page 3 is survey question #8d after it was re-scaled. The summary statistics of these re-scaled variables showed the following results for the KQDC hunter population:

Table 1.4: Re-Scaled Manifest Variables

New Regulation	% Support	% Neutral	% Oppose
8a) Statewide Antler Restriction	68.1 %	4.7 %	27.2 %
8d) Efforts to increase antlerless deer harvest	41.6 %	9.5 %	48.9 %

Again, the hunters who support the efforts to increase antlerless deer harvests (and thus lower the deer population for future years) could be especially valuable to game managers. Discovering what other attitudinal traits and demographic characteristics these hunters have, through latent-class analysis, should be useful information for the PGC.

Finally, prior to the LCM modeling, some of the anticipated covariates were also re-scaled from the original KQDC questions. The Latent Gold® program will re-scale continuous variables into categorical variables, and attempt to select cut-off values and thresholds that create roughly similar count frequencies in each category. Categorical variables based on age, the number of years hunting, income levels, hunt distance from paved and dirt roads, place of residence, and several measures of success based on the number and sex of the deer harvested in the 2003 hunting season were created. These covariate variables are summarized in Appendix C.

I started the exploratory LCM with an analysis of the "hunting reasons" importance questions only. Then, in a separate LCM model, I analyzed only the "level of agreement" questions. In both of these initial models, I was using the latent-class analysis to assess which questions seemed to separate hunters into 2 or more types. Many of the questions showed no discernable groupings among hunters, even when the number of latent classes in the model was raised to 4-5. Subsequent models combined importance, agreement, and covariate variables in various combinations. I then started to refine the models by removing manifest variables that were consistently *not useful* in separating and grouping hunters. Vermunt and Magidson recommend this technique as an alternative to increasing the number of latent variables (Vermunt and Magidson, 2003). Bandeen-Roche et al. (1997) recommended finding the appropriate number of latent classes/hunter categories before including covariates in the model (Morey et al.), so I utilized this technique as well.

The answers to 15 survey questions were used in the final model; 10 attitudinal questions as manifest variables and 5 behavioral questions as covariates. These questions, and the summary statistics from the KQDC hunter responses, are at Appendix D. What I discovered was that there are several areas of attitudinal disagreement among hunters that are important for game management agencies to consider. The perceptions of hunters toward deer overabundance, their experience with posted land that limits their hunting access, and the relative importance of the hunter's role as a game manager are the attitudes that most strongly separate hunters.

An important use of latent-class modeling is to analyze how the hunter categories evolve as the number of latent-classes in the model increases. Appendix E indicates that the separation of hunters follows a logical progression as the number of latent categories is increased from 2 categories to 3, and then from 3 categories to 4. The boxes in the figure report the unconditional probabilities of a hunter belonging to each category, and then describe the attributes of each hunter category based on the attitudinal responses that are significantly different between the categories. When the data is used to separate hunters into only two categories, for example, 65% of the hunters fall into a category that should be considered by game managers attempting to reduce deer populations. Hunters in this category disagree that deer cause damage to forests and other land uses, and these hunters mostly oppose the recent regulations changes instituted by the PGC to reduce the deer population through increased antlerless deer harvests.

The attitudinal differences among hunters concerning the effects of posted land start to emerge when the 3-category latent class is specified. The category of hunters who support the PGC and its efforts to increase the antlerless harvest stays mostly intact (decreases by 7% of the total hunter population), but the category of hunters who believe the deer population should remain as it is splits into two sub-categories based on the manifest variables referring to attitudes toward posted land. When a 4-category latent-class model is specified, the figure in Appendix E outlines how the original 2 categories have separated based on how posted land has affected the hunter's ability to find good places to hunt or restricted their hunting activity. We are left with 4 hunter categories, separated by the attitudes outlined in the boxes, which again indicate that only 35% of the hunters fit into broad categories of hunters who support reducing deer densities from their current levels.

1.4.2: Determining the Number of Latent Classes (Hunter Categories)

The goodness of fit measures for the final model are summarized in Table 1.5 below. Using the single-class model as a baseline, which would assume that there are no attitudinal differences among hunters, we can compare the log-likelihood scores when hunters are considered to belong to latent classes. The large differences (improvements) in the log-likelihood scores when multi-hunter categories are modeled indicate that we can reject the single-class model of homogeneous attitudes among hunters. The BIC and AIC criteria show smaller and smaller improvements as the number of latent classes increases, and do not improve at all when 6 hunter categories are modeled. Looking at the classification errors (E) and lambda statistics, the modal assignment probabilities improve for the 4-class model. Because this 4-class model correctly assigns the KQDC hunters with higher probabilities than the 3-class or 5-class models, and because of the BIC and AIC criteria improvements shown, I believe it is the most accurate latent-class model for the KQDC hunters. The resulting hunter categories provided intuitive and explainable results, so the 4-class model will be discussed in more detail.

Table 1.5: Best-Fit Criteria Comparison

# of Hunter Categories	ln *L*	BIC	AIC	E	λ
Single class	-9,403	19,036	18,876	0.000	1.000
2 – class	-9,056	18,413	18,203	.0590	.8312
3 – class	-8,928	18,229	17,970	.1294	.7846
4 – class	**-8,801**	**18,048**	**17,738**	**.1175**	**.8252**
5 – class	-8,736	17,991	17,631	.1446	.7861
6 – class	-8,679	17,988	17,638	.1389	.7903

1.5: Results for the Selected Latent-Class Model

Based on the results of the LCM, the 4 hunter categories show a stark difference in hunter attitudes towards deer damage, posting of land that limits access for hunting, increasing antlerless deer harvest to reduce deer densities, and the importance an individual hunter places on his role as a game manager. From these results, the hunter categories were named and described accordingly. Figure 1.1 highlights selected questions that indicate how the hunter categories differed across the attitudinal questions used in the latent-class analysis. The complete profile of manifest variable results from the final model is in Table 1.6. A discussion of what these results imply for game managers is covered in Section 1.6.

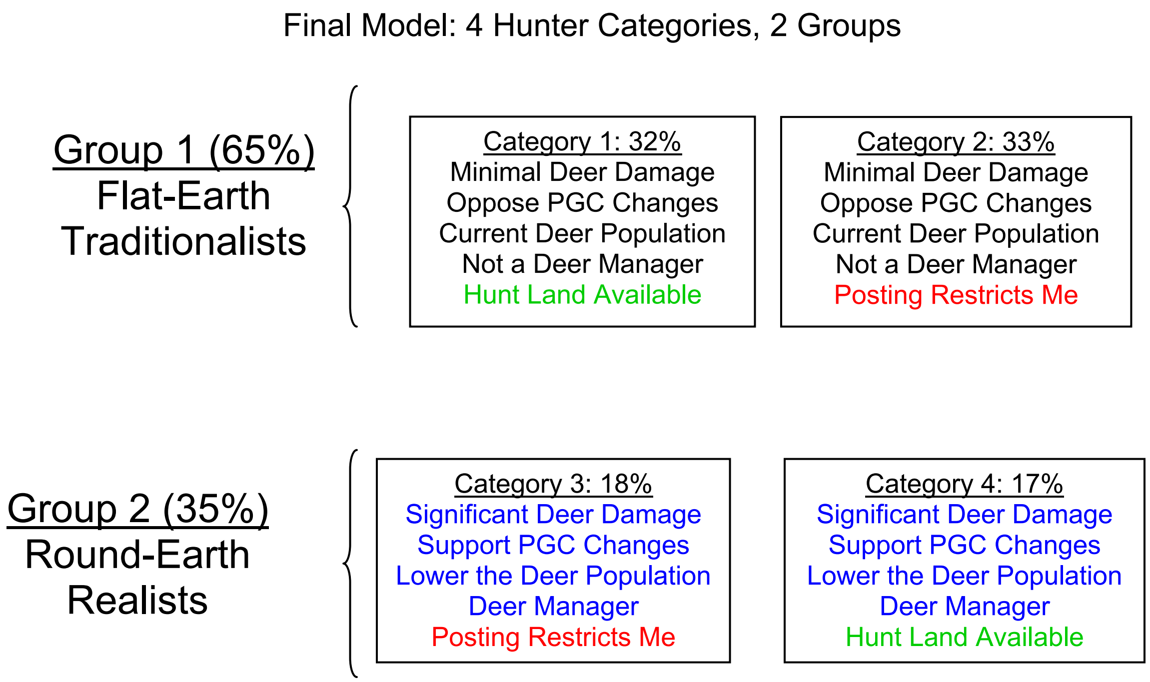

FIGURE 1.1: Hunter Category Descriptions

Table 1.6: Manifest Variables, Final Model Profile

	Cat 1	Cat 2	Cat 3	Cat 4
Proportion of hunter population:	0.3242	0.3289	0.1760	0.1709

Manifest Variables (proportions listed are within a category)

	Cat 1	Cat 2	Cat 3	Cat 4
Q8A: Antler Restrictions				
support	0.6108	0.5338	0.8278	0.9371
neutral	0.0543	0.0561	0.0397	0.0232
oppose	0.3350	0.4101	0.1325	0.0397
Q8D: Increased Antlerless Harvest				
support	0.2280	0.2213	0.7533	0.9367
neutral	0.0999	0.0990	0.0882	0.0233
oppose	0.6721	0.6797	0.1585	0.0401
Q9H: Posting has made it more difficult				
strongly disagree	0.1030	0.0000	0.0000	0.1791
disagree	0.4125	0.0033	0.0022	0.4817
neither agree nor disagree	0.3314	0.0556	0.0438	0.2597
agree	0.1471	0.5096	0.4761	0.0774
strongly agree	0.0060	0.4314	0.4779	0.0021

	Cat 1	Cat 2	Cat 3	Cat 4
Q9J: Increasingly difficult to find good place				
strongly disagree	0.0904	0.0101	0.0320	0.2091
disagree	0.4136	0.1201	0.2437	0.5322
neither agree nor disagree	0.2235	0.1682	0.2193	0.1599
agree	0.2179	0.4251	0.3562	0.0867
strongly agree	0.0547	0.2766	0.1489	0.0121
Q9K: Deer damage to forests is a problem				
strongly disagree	0.2079	0.1922	0.0015	0.0009
disagree	0.3906	0.3833	0.0268	0.0191
neither agree nor disagree	0.3049	0.3175	0.1930	0.1623
agree	0.0921	0.1017	0.5376	0.5344
strongly agree	0.0045	0.0052	0.2410	0.2833
Q9N: Private lands restricted to me				
strongly disagree	0.0640	0.0001	0.0000	0.0862
disagree	0.2659	0.0056	0.0026	0.3058
neither agree nor disagree	0.3349	0.0648	0.0415	0.3292
agree	0.3118	0.5512	0.4898	0.2619
strongly agree	0.0234	0.3782	0.4660	0.0168
Q9O: Deer cause serious conflicts				
strongly disagree	0.1401	0.1378	0.0032	0.0075
disagree	0.3103	0.3083	0.0334	0.0591
neither agree nor disagree	0.3065	0.3075	0.1570	0.2072
agree	0.2198	0.2226	0.5362	0.5278
strongly agree	0.0233	0.0238	0.2702	0.1985
Q9T: Successful season without harvest				
strongly disagree	0.0822	0.1656	0.0846	0.0556
disagree	0.1892	0.2788	0.1926	0.1486
neither agree nor disagree	0.1169	0.1260	0.1176	0.1066
agree	0.3640	0.2868	0.3618	0.3850
strongly agree	0.2478	0.1428	0.2434	0.3041
Q9U: Number of deer has no effect on forest regeneration				
strongly disagree	0.0855	0.0882	0.5623	0.5976
disagree	0.3803	0.3853	0.3841	0.3588
neither agree nor disagree	0.3213	0.3197	0.0498	0.0409
agree	0.1485	0.1450	0.0035	0.0025
strongly agree	0.0645	0.0618	0.0002	0.0001
Q11J: To help manage the deer population				
not very important	0.2318	0.1763	0.0402	0.0546
somewhat important	0.3414	0.3175	0.1668	0.1948
important	0.3450	0.3924	0.4753	0.4768
very important	0.0818	0.1138	0.3178	0.2739

	Wald	p-value	R^2
Antler Restrictions	40.5330	8.2e-9	0.1112
Increase Antlerless Harvest	102.3315	4.9e-22	0.2981
Q9H	44.6756	1.1e-9	0.6337
Q9J	81.7499	1.3e-17	0.2689
Q9K	83.1570	6.5e-18	0.4755
Q9N	75.3369	3.1e-16	0.4431
Q9O	102.8219	3.8e-22	0.2829
Q9T	22.7447	4.6e-5	0.0493
Q9U	96.9750	6.9e-21	0.3023
Q11J	55.6892	4.9e-12	0.1193

An analysis of the covariates (non-attitudinal, observable variables) in the final model shows that some behavioral and demographic factors did vary significantly dependent upon the latent hunter categories. Table 1.7 below highlights selected questions, and the KQDC hunter responses, that indicate differences among the hunter categories by these covariates in the latent-class model. The complete results for the covariate analysis in at Appendix F. Remember that these covariates were not used to separate the hunters by latent-class; the covariates are only used to describe and differentiate among the hunter classes after the model's attitudinal variables determined the appropriate class for each individual hunter.

Table 1.7: Covariates in Final Model
(highest percentage in **bold**)

	Hunter Category			
Within each category, % of:	Cat 1	Cat 2	Cat 3	Cat 4
hunters who own or use a camp*:	33.4%	31.5%	43.7%	**47.8%**
hunters who reside in rural town/village*:	65.0%	53.2%	54.1%	**65.6%**
hunters who reside in a medium/large city*:	7.5%	8.2%	**16.0%**	7.1%
hunters reporting earning >$45k annually*:	49.7%	46.3%	**60.1%**	**60.1%**
hunters who hunt early and/or late seasons*:	49.5%	56.5%	**67.8%**	60.6%
hunters who purchase 3 or more tags at $6*	28.7%	29.2%	45.6%	**48.2%**

(* indicates all were statistically significant at the .05 level, based on the Wald-statistic)

1.6: Discussion and Implications for Game Managers

To start the discussion, notice from Figure 1.1 that the hunter categories that generally support recent PGC initiatives to lower the deer population and impose antler restrictions (whom I have labeled "Round-Earth Realists") are the smallest proportion of the overall hunting population. In general, categories 3 and 4 are the hunters who are more likely to believe that deer damage forests and other land uses, support the PGC's recent initiatives to lower the percentage of antlerless deer and increase the buck-doe ratio in the herd, and think it is important or very important to hunt to manage the deer population. These category 3 and 4 hunters represent roughly 35% of the hunting population in the KQDC. Possibly, the recognition among this group of hunters that overabundant deer are causing damage to forests and other land uses is part of the reason they support the PGC's efforts to increase the antlerless deer harvest, as well as the recognition of their important role as game managers. The contrast with Group 2 hunters, whom I have labeled "Flat-Earth Traditionalists", is this recognition that deer are causing harm to forests and other land uses. The Flat-Earth traditionalists do not place importance on their role as game managers. Indeed, they do not generally believe that deer are causing harm, or that current deer populations are a problem, and thus do not support the PGC's efforts to lower and balance the deer population. If hunters can be convinced in large numbers that overabundant deer cause unacceptable damage to the ecosystem, then possibly the proportion of hunters who support an increased antlerless deer harvest will increase.

Categories 2 and 3, representing roughly 50% of the hunters surveyed, contain hunters who agree or agree strongly that posting of hunting land has made it more difficult to hunt deer, or has restricted their access to places where they would hunt. Likewise, Categories 1 and 4 represent the hunters who do not seem to have been personally affected by posted hunting land. These hunters share attitudes towards posted land, but little else, so they fall into distinct hunter categories in the 4-class model. This is an interesting observation, as intuition may lead us to believe that hunters who have lost favorite hunting land to development and/or posting may have similar attitudes and beliefs toward other aspects of deer management. But this is refuted by the latent-class model. Hunters who have been affected by posting can be starkly different in their attitudes toward deer damage, antlerless harvest, and other variables. Addressing the issue of hunter access to posted lands has been a concern of game managers for many years. This analysis confirms that half of the KQDC hunter population falls in broad categories whose attitudes toward posted land are that is restricting them personally.

From the PGC's perspective, or for other game management agencies in areas of overabundant white-tailed deer, the category 4 hunters are probably the most interesting. This small group of hunters (17% of the total surveyed) recognize the damage that overabundant deer are causing, especially to forest regeneration. These hunters overwhelmingly support the recent regulation changes to increase the antlerless harvest and to impose antler restrictions that will improve the buck-doe ratios. These hunters do not have a problem with access to hunting land or finding good places to hunt and harvest deer. Finally, over 75% of these hunters report that helping to manage the deer population is important or very important to them as a reason to hunt, significantly higher than the category 1 and 2 hunters. Even more valuable to game managers would be a better description of these hunters, either through demographic variables or other recognizable traits and behaviors. If these hunters could be singled out in some way or better described through covariate analysis, it would be easier for game managers to tap into the category-4 hunters as partners in the effort to reduce deer densities in some areas.

Looking at the covariate results in Table 1.7, and keeping in mind the hunter category labels from Figure 1.1, there are several interesting results. Remember that the category 3 and 4 hunters are both Round-Earth Realists, separated only by their attitudes toward posted land. These Realists are most likely to believe that overabundant deer are causing damage to the forests and other land uses, and are thus more supportive of recent PGC regulations to increase the antlerless deer harvest. Does this awareness and acceptance of the problems caused by deer overabundance also translate into behavior? The covariate results above indicate these Round-Earth Realists have the highest percentage of participation in the early and late seasons (a proxy for avid hunters). Group 2 also has a higher percentage of hunters who purchase large numbers of antlerless tags (3 tags or more) and a higher percentage who take more than a single antlerless deer in a hunting season compared to the Flat-Earth Traditionalists. The Round-Earth Realists also have a higher percentage of hunters reporting the highest income bracket, possibly allowing for a higher willingness to pay for expanded hunting privileges. Round-Earth Realists also have a higher percentage of archery hunters, muzzleloader hunters, and hunters affiliated with a hunting camp than Flat-Earth Traditionalists.

The Latent Class Analysis of covariates that were *NOT* statistically significant across the attitudinal classes indicated two misconceptions currently held by many game management agencies. The first misconception is that a hunter's age, hunting experience, and possibly education level is relevant to their attitudes toward deer management and acceptable deer populations; older and less educated hunters will tend to be more of the Flat-Earth Traditionalists. The second misconception is that hunters who travel far off the beaten path and get deep in the woods to hunt are somehow more dedicated hunters and more likely to be Round-Earth Realists. Neither of these results was supported by the latent-class analysis. Covariates for age, experience, education level, and distances hunted from both dirt and paved roads showed statistically insignificant differences amongst attitudinal classes. These covariates were tried in the models as I tested numerous combinations of attitudinal questions, and were never close to being statistically significant predictors of any one latent class. In short, older and/or less educated hunters, as well as hunters who hunt near to roads, were no more likely or unlikely to fall into any single hunter category that the attitudinal latent class analysis determined was relevant.

At first glance, the overall results of the latent-class analysis are possibly disheartening to game managers. First, as supported by previous research on hunter motivations (Decker et al., 1980; Heberlein, 1991; Decker and Connelly, 1989) the majority of hunters do not view their role in controlling the deer herd as being of primary importance. Additionally, the majority of hunters do not consider deer damage to forests and other land uses as a problem. These hunters may recognize that deer *affect* forest regeneration, and adversely affect the populations of other animals and plants or cause conflicts with farms and highways. But they do not believe that the effects of the current high deer densities are *a problem*, or at least enough of a problem as to warrant higher antlerless deer harvests to reduce deer populations.

But a second glance may well lead game managers to a more upbeat conclusion. It should be encouraging to game managers that the Round-Earth Realists are a sizable portion of the overall hunting population. These Group 2 hunters, who seem to support recent efforts to reduce deer densities, are also the most avid hunters, hunt early and late seasons at higher percentages, and purchase tags and harvest multiple antlerless deer at higher percentages than the less supportive hunters in Group 1. The implication is that this smaller, more committed group of hunters may remain constant, or even grow with educational effort, in the larger context of slowly declining hunter populations. Enlisting these dedicated hunters in large-scale deer reduction efforts may be possible if innovative licensing and policies can be designed to take advantage of their concern for deer damage.

The latent-class analysis was useful in determining hunter categories, but did not provide clear-cut groupings of hunters who overwhelmingly shared the same attitudes and beliefs. A limitation of the model was that it was difficult to include most of the "Importance of Reasons for Hunting" questions simply because the majority of hunters rated all of the reasons as Important (I), or Very Important (VI). The LCM could not discern well among hunters unless there were clear differences in attitudes, such as the importance of hunting for venison or the importance of hunting to help manage game. Additionally, none of the model's L^2 statistics (equation (10)) were statistically significant at the 95% confidence level. Under the assumption that the L^2 statistic follows a chi-square distribution, the Latent Gold output includes a p-value for each model, with p-values greater than .05 indicating that the model provides an adequate fit (Vermunt and Magidson, 2005, p 108). The amount of association among the manifest variables that remained unexplained after estimating the latent-class categories was very high in all of my hunter models, and thus the associated p-values were not close to the required .05 level.

The most significant finding in this analysis, however, may be that it is almost impossible to type-cast hunters by their opposition or support for regulation changes, antlerless deer harvests, and attitudes towards an appropriate deer population level. Despite the wealth of demographic data provided by this survey, the best latent class models showed only 10-15% difference in the observable covariate levels in each category. For the hunter categories that were more likely to support the PGC's goals of reduced antlerless deer, literally dozens of hunters of that exact attitudinal profile did not support the recent PGC regulation changes to bring about reduced deer populations. This indicates that either; 1) there are critical, unobserved variables (that were not questions in this survey) that would better classify hunters into latent classes, or 2) that the complexity of the interactions between these hunter behaviors and characteristics is not being captured in a simple latent-class model with covariates. Hunters are individuals from across society whose attitudes can not be categorized easily. Hunting, and the love of hunting, is such a complex and personal activity that game managers will never be fully able to guarantee support for well-designed and well-intentioned regulations changes. It is possible to classify hunters based on their attitudes, but it is difficult to ascertain a hunter's subsequent class based on his demographics and behavior.

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APPENDIX 1.A - KQDC Hunter Survey (2004)

The first set of questions is designed to tell us a little about your hunting experience. Please fill in the appropriate space or circle the best answer for each question.

1. a. How many years have you been hunting deer? ______ years

   b. How many years have you hunted deer in Pennsylvania? ______ years

2. In addition to the general hunting licence, which other licenses did you have for the 2003 Pennsylvania deer hunting season? (Circle all that apply)

   1 – Archery License
   2 – Anterless License
   3 – Muzzleloader License

Now we are interested in learning about your hunting success during the last season, 2003.

3. a. Did you kill an antlered deer in 2003?

   1 – YES 2 – NO

   b. If YES, in what season did you kill this antlered deer? (Circle one)

      1 - Early (Archery)
      2 - Early Junior/Senior (Archery)
      3 - Firearm (Rifle/Pistol/Shotgun)
      4 - Late (Archery, Flintlock/Muzzleloader)

   c. Was this antlered deer killed on the KQDC deer management area?

   1 - YES 2 – NO

4. a. Did you kill an antlerless deer in 2003?

   1 - YES 2 – NO

   b. If YES, in what season did you kill this antlerless deer? (Circle one)

      1 - Early (Archery, Flintlock/Muzzleloader)
      2 - Early Junior/Senior (Archery, October Firearm, Flintlock/Muzzleloader)
      3 - Firearm (Rifle/Pistol/Shotgun)
      4 - Late (Archery, Flintlock/Muzzleloader)

   c. Was this deer killed on the KQDC deer management area?

   1 - YES 2 – NO

   d. How many antlerless deer did you kill in 2003?
   ______deer

5. a. If you could purchase additional **antlerless** permits at the current cost of $6.00 per permit, how many **antlerless** deer would you seek to harvest in a year?
_____ (number of
deer)

b. How many antlerless deer would you seek to harvest on the KQDC deer management area?
_____ (number of

6. a. If the price for additional **antlerless** permits doubled to $12.00 per permit, how many **antlerless** deer would you seek to harvest in a year? _____ (number of deer)

b. How many antlerless deer would you seek to harvest on the KQDC deer management area?
_____ (number of

7. How many days did you spend afield in each of the following 2003 hunting seasons? (If less than one complete day, please indicate this by writing in 1 day). Please fill in the number of days on the lines provided.

Hunting Season:	***Pennsylvania***	***KQDC***
	- - - - - - - - # of days	- - - - - - - -
1 - Early (Archery, Flintlock/Muzzleloader)	_____	_____
2 - Early Junior/Senior (Archery, October Firearm, Flintlock/Muzzleloader)	_____	_____
3 - Firearm (Rifle/Pistol/Shotgun)	_____	_____
4 - Late (Archery, Flintlock/Muzzleloader)	_____	_____

There are many ways to manage deer in Pennsylvania. How supportive are you of each of the following strategies for managing deer in Pennsylvania?

8. How supportive are you of...	Strongly Support	Support	Slightly Support	Neither Support, Nor Oppose	Slightly Oppose	Oppose	Strongly Oppose
a. Continuing the statewide antler restriction?	1	2	3	4	5	6	7
b. Continuing the concurrent antlered and antlerless seasons?	1	2	3	4	5	6	7
c. Continuing the deer management area approach for allocating **anterless** licenses as opposed to the traditional county-based system?	1	2	3	4	5	6	7

d. The Pennsylvania Game Commission's efforts to increase the antlerless deer harvest?	1	2	3	4	5	6	7

9. For each of the following statements, please indicate whether or not you agree, using the scale: (Circle one response per statement)

1 = STRONGLY DISAGREE (**SD**)
2 = DISAGREE (**D**)
3 = NEITHER AGREE NOR DISAGREE (**N**)
4 = AGREE (**A**)
5 = STRONGLY AGREE (**SA**)

Level of agreement with…	SD	D	N	A	SA
a. Public lands are more heavily hunted than private lands..	1	2	3	4	5
b. Public lands have higher deer densities than private lands.	1	2	3	4	5
c. Public lands have higher hunter success rates than private lands.	1	2	3	4	5
d. I hunt with the goal of harvesting an antlered deer only.	1	2	3	4	5
e. The number of deer has no effect on plant and animal communities.	1	2	3	4	5
f. There is enough public hunting land in PA to provide access for anyone who wants to hunt.	1	2	3	4	5
g. The quality of the hunting experience is higher on private lands than public lands.	1	2	3	4	5
h. Posting of private land has made it more difficult for me to find a place to hunt.	1	2	3	4	5
i. Over time, deer hunting pressure has decreased in the places I hunt.	1	2	3	4	5
j. It has become increasingly difficult for me to find a good place to hunt deer.	1	2	3	4	5
k. Deer damage to forests in Pennsylvania is a problem.	1	2	3	4	5
l. Keeping deer populations in balance with natural food supplies is necessary	1	2	3	4	5
m. I don't really care if I shoot an antlered or antlerless deer as long as I get a deer.	1	2	3	4	5
n. Posting has restricted my access to hunting on private lands.	1	2	3	4	5

9. For each of the following statements, please indicate whether or not you agree, using the scale: (Circle one response per statement)

1 = STRONGLY DISAGREE (**SD**)
2 = DISAGREE (**D**)
3 = NEITHER AGREE NOR DISAGREE (**N**)
4 = AGREE (**A**)
5 = STRONGLY AGREE (**SA**)

Level of agreement with…	SD	D	N	A	SA
o. Deer cause serious conflicts with other land uses, such as forestry, farming, highways, and other development.	1	2	3	4	5

Level of agreement with…	SD	D	N	A	SA
p. I would rather harvest a doe than no deer at all.	1	2	3	4	5
q. The higher the deer population, the better my hunting experience..	1	2	3	4	5
r. I hunt to harvest a trophy antlered deer.................	1	2	3	4	5
s. I can have a satisfying day of hunting without harvesting a deer..	1	2	3	4	5
t. I can have a successful season of hunting without harvesting a deer..	1	2	3	4	5
u. The number of deer has no effect on forest regeneration..	1	2	3	4	5

10. How important, would you say hunting is to you: (Circle one)

Not Very Important	Somewhat Important	Important	Very Important
1	2	3	4

11. How important are each of the following reasons for your participation in hunting – is each very important, important, neither important nor unimportant, unimportant, or very unimportant? (Circle one response per statement)

1 = NOT VERY IMPORTANT (**NVI**)
2 = SOMEWHAT IMPORTANT (**SI**)
3 = IMPORTANT (**I**)
4 = VERY IMPORTANT (**VI**)

Reasons for Hunting:	NVI	SI	I	VI
a. To get outdoors	1	2	3	4
b. To get away from my everyday routine...	1	2	3	4
c. To obtain venison....................................	1	2	3	4
d. To get a large **antlered** deer.	1	2	3	4
e. The challenge of hunting deer.................	1	2	3	4
f. To test my outdoor skills..........................	1	2	3	4
g. To be with my friends	1	2	3	4
h. To be with my family..............................	1	2	3	4
i. To return to traditional hunting spots.......	1	2	3	4
j. To help manage the deer population........	1	2	3	4

Now we'd like to know about your experiences hunting in the KQDC management area.

12. Have you ever hunted deer in the KQDC deer management area?

1 - YES 2 – NO

(If no, skip to ***Question 33.***)

13. How many years have you hunted deer in the KQDC deer management area?

_____ years

14. How many years have you hunted antlerless deer in the KQDC deer management area?

_____ years

15. Compared to other years, how much time did you spend hunting deer on the KQDC deer management area in the 2003 season? (Circle one)

1 - More time
2 - About the same amount of time
3 - Less time

16. How far do you travel from your home to hunt deer in the KQDC deer management area? (Please estimate distance to the nearest tenth of mile) _____ number of miles

17. Do you own, belong to, or use a camp in the KQDC deer management area? (Circle one)

1 - Own camp
2 - Belong to camp
3 - Use camp
4 - None of the above

18. In the 2003 hunting season, what was the maximum distance you hunted from a paved road in the KQDC deer management area? (Please estimate distance to the nearest tenth of mile)
_____ number of miles

19. In the 2003 hunting season, what was the maximum distance you hunted from an "open" (non-gated) dirt road in the KQDC deer management area? (please estimate distance to the nearest tenth of mile) _____ number of miles

20. Do you walk gated roads to access your hunting area in the KQDC? (Circle one)

1 - YES 2 – NO

21. How does the KQDC compare to other places you may hunt? (Circle one number per line)

On the KQDC:				About the Same			
a.	I see **more** hunters	1	2	3	4	5	I see **fewer** hunters
b.	I feel **more** crowded	1	2	3	4	5	I feel **less** crowded
c.	I see **more** deer	1	2	3	4	5	I see **fewer** deer
d.	I have a **better** chance of shooting a big buck	1	2	3	4	5	I have a **worse** chance of shooting a big buck
e.	My experience is **better**	1	2	3	4	5	My experience is **worse**

22. How likely do you think you will be to continue to hunt in the KQDC management area? Do you think it is very likely, somewhat likely, somewhat unlikely, or very likely?

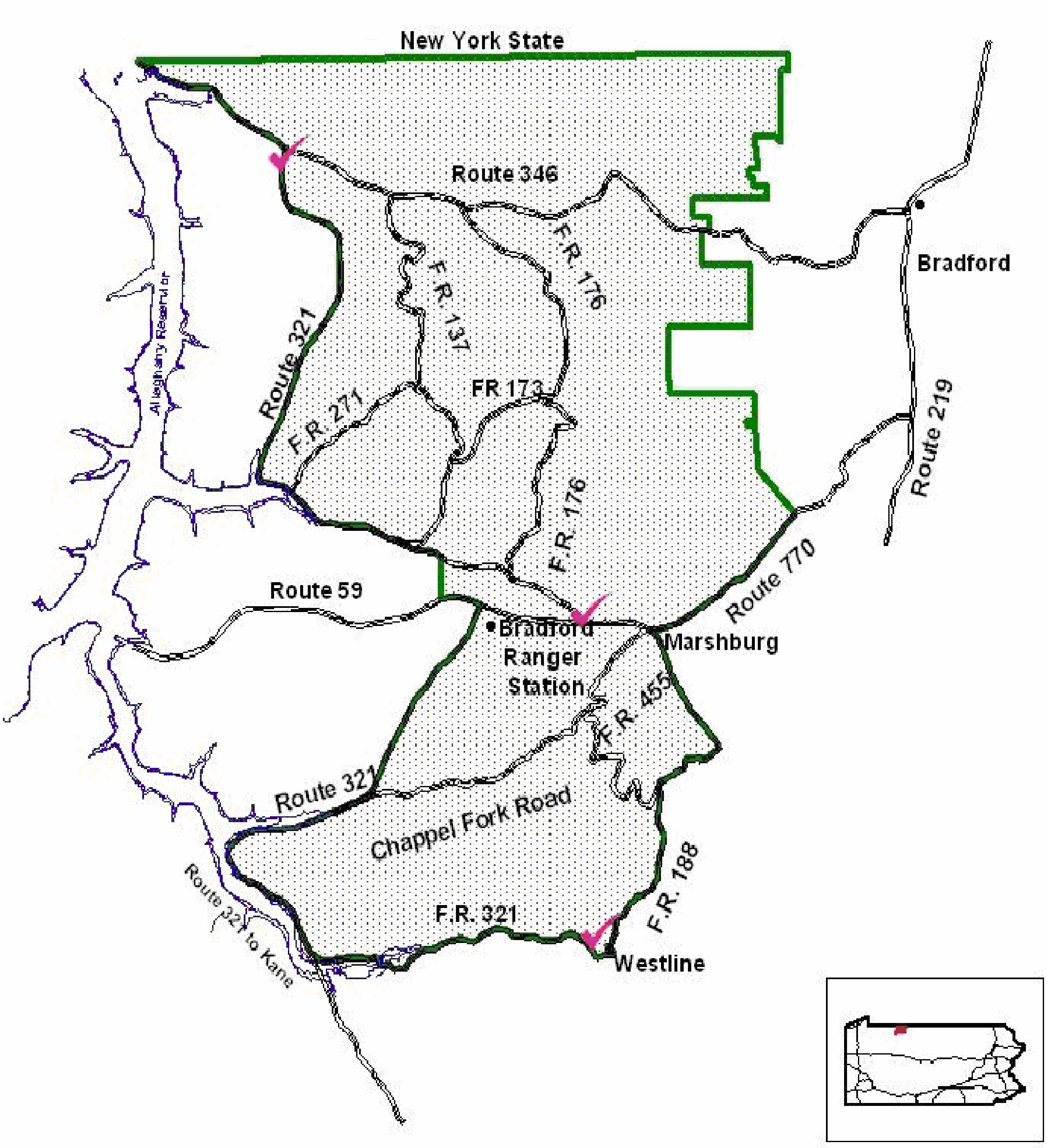
On the KQDC:	Very Likely	Somewhat Likely	Somewhat Unlikely	Very Unlikely	Don't Know
Next year	4	3	2	1	0
3 years from now	4	3	2	1	0
5 years from now	4	3	2	1	0

23. Which of the following statements best describes you? (Circle one)

    a. I am hunting in the KQDC management area mostly because of the opportunity to get an extra antlerless deer.

    b. I would hunt in the KQDC management area even without the opportunity to get an extra antlerless deer.

24. Where in the KQDC management area do you hunt? Please mark with an "X" on the Kinzua Quality Deer Cooperative map below the general area where you spend the most time hunting.



In the next series of questions, we are interested in learning more about your hunting style, experiences, and general opinions about hunting on the KQDC management area.

25. a. During the 2003 rifle season, how did you typically hunt on the KQDC? (Circle <u>one</u>)

1 – Drives with nine or less hunters
2 – Drives with ten or more hunters
3 – In ground stand
4 – In tree stand
5 – Stalking
6 – Small, quiet, pushes
7 – Other (please specify) ___________________________________

b. In your hunting experience on the KQDC management area in 2003, did you see more deer, the same number of deer, or less deer than you expected?

1 – More deer
2 – About the same number of deer
3 – Less deer

26. With enrollment of the KQDC in the Pennsylvania Game Commission's DMAP Program, are you now more likely, equally likely, or less likely to buy an antlerless license to hunt on the KQDC deer management area?

1 – More likely
2 – Equally likely
3 – Less likely

27. How did the DMAP program change the amount of effort **you** put into harvesting antlerless deer on the KQDC management area?

1 – More effort
2 – About the same effort
3 – Less effort

28. How did the DMAP program change the amount of effort your **group or camp** put into harvesting antlerless deer on the KQDC management area?

1 – More effort
2 – About the same effort
3 – Less effort
4 – Not applicable (I do not hunt from a camp or with a group)

29. How would each of the following affect your likelihood of hunting in the KQDC in the future? (Circle one response per statement)

1 = Much More Likely (**MML**)
2 = Somewhat More Likely (**SML**)
3 = Wouldn't Change (**WC**)
4 = Somewhat Less Likely (**SLL**)
5 = Much Less Likely (**MLL**)

My hunting on the KQDC management area would be:	MML	SML	WC	SLL	MLL
a. If there were a lot more deer.............	1	2	3	4	5
b. If there were a lot fewer deer.............	1	2	3	4	5
c. If the deer were larger bodied............	1	2	3	4	5
d. If my hunting partners did not want to hunt there…………………………..	1	2	3	4	5
e. If regulations became more complicated…………………………..	1	2	3	4	5
f. If I lost access to my hunting camp in the area………………………………	1	2	3	4	5
g. If, on average, the bucks had larger antlers ………………………………	1	2	3	4	5
h. If there were more hunters.................	1	2	3	4	5
i. If there were fewer hunters................	1	2	3	4	5
j. If access to KQDC lands became more difficult………………………………	1	2	3	4	5
k. If the habitat in my favorite hunting areas changed………………………	1	2	3	4	5

30. Please indicate how each of the following access issues affects your hunting experience in the KQDC area.

Access Issues:	Helps Experience	No Difference	Harms Experience
a. Gated roads	1	2	3
b. Lack of roads	1	2	3
c. Poor road conditions	1	2	3
d. Posting of lands	1	2	3
e. Gas and oil well access	1	2	3
f. Difficult terrain	1	2	3

31. Using a scale ranging from 1 (not at all crowded) to 9 (extremely crowded), on an average hunt in the KQDC deer management area, how crowded do you usually feel? (Circle one)

Not At All Crowded			Slightly Crowded		Moderately Crowded			Extremely Crowded
1	2	3	4	5	6	7	8	9

32. a. Which sources do you most often rely upon to get your news/information about KQDC management area? (Circle all that apply)

1 - Television
2 - Radio
3 - Newspapers
4 - Organization Newsletters
5 - Hunting Magazines
6 - Internet
7 - Talking to Others
8 - PGC Website
9 - The Hunting Regulation Booklet
10 - Other (please specify) ______________________

b. Of those you identified above as relying upon most often, which is the most important source? _____

Finally, we need to ask a few questions about you and your household. This information, as with all information provided in this survey, will be used for statistical analysis only and will remain strictly confidential.

33. In what year were you born? 19____

34. What is the highest level of formal education that you completed?

1 - Did not complete high school
2 - Completed high school or equivalent
3 - Some college or vocational training
4 - Completed college degree
5 - Graduate or professional training beyond college degree

35. a. How many people, including yourself, live in your household? _____ (number)

b. How many are under 18 years of age? _____ (number)

c. How many are over 65 years of age? _____ (number)

36. Would you say your health is:

1 – Excellent 2 – Good 3 – Fair 4 – Poor

37. How much difficulty do you have doing the following? Do you have a "great deal of difficulty," "some difficulty," or "no difficulty"? (Circle <u>one</u> response for each question)

How much difficulty do you have:		Great Difficulty	Some Difficulty	No Difficulty
a.	Going up and down stairs	1	2	3
b.	Kneeling or stooping.................................	1	2	3
c.	Lifting or carrying objects less than 10 pounds, like a bag of groceries	1	2	3
d.	Using your hands or fingers.......................	1	2	3
e.	Seeing, even with glasses...........................	1	2	3
f.	Hearing..	1	2	3
g.	Walking...	1	2	3

38. What is your zip code? ______

39. In what Pennsylvania county do you live?

____ (name of county)

Do not live in Pennsylvania _____

40. How would you describe your current place of residence?

1 - Large city
2 - Medium-sized city
3 - Small city
4 - Suburban
5 - Rural town or village
6 - In the country

41. Remembering that your answers are confidential, could you please tell me if your total household income from all sources before taxes in 2003 was more or less than $30,000? (Circle one)

a. LESS ? Was it more or less than $15,000?

1 – LESS 2 - MORE

b. MORE ? Was it more or less than $45,000?

1 – LESS 2 - MORE

Thank you very much for your cooperation! Please feel free to use the rest of this page or a separate letter to tell us any additional information or share any additional comments. Please return this questionnaire in the enclosed addressed envelope. No postage is necessary.

APPENDIX 1.B - KQDC Hunter Survey: Selected Summary Statistics

Question/Topic	Results or % of total
Demographic	
Average Age	47.7 years
Average years hunting	32.2 years
Mean travel distance to hunting area	76.6 miles
High School graduates	91.4%
College graduates	32.2%
Children under 18 years of age at home	39.7%
Live in a large or medium sized city	8.9%
Live in a small city or suburban area	31.3%
Live in a rural town, village, or in the country	59.8%
Income Data	
Refused to answer	9.6%
<$15,000 annually	5.2%
Between $15k-$45k annually	31.7%
>$45,000 annually	53.4%
Hunter Behavior	
Archery licensed	44.3%
Muzzleloader licensed	50.4%
Both archery and muzzleloader licensed	27.6%
Antlerless licensed	89.9%
Harvested a buck in 2003	29.2%
Own, belong to, or use a hunting camp	40.5%
Average # of days hunted during 12-day rifle season	4.9
Attitudinal Questions	
Support for statewide antler restrictions	68.1%
Agree that deer hunting pressure has decreased	50.6%
Agree that deer damage to PA forests is a problem	34.4%
Agree that a satisfying **day** of hunting can occur without a deer harvest	87.7%
Agree that a successful **season** of hunting does not require a deer harvest	56.1%
Reasons for Participation in Hunting (# answering “Very Important”, 4 on a 4-point scale)	
To get Outdoors	64.4%
To be with Family	48.7%
To obtain Venison	26.6%
To help manage the deer population	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 1.C - Covariate Categorical Variables, Summary Statistics

Variable	Levels	Population %
Darcher	1 – did not archery hunt in 2003	55.6%
	2 – archery hunted in 2003 season	44.4%
Dmuzhunt	1 – did not muzzleloader hunt in 2003	49.4%
	2 – muzzleloader hunted in 2003 season	50.6%
Dkillbuck	1 – did not harvest a buck deer in 2003	70.8%
	2 – harvested a buck deer in 2003	29.2%
DCampUse	1 – no hunting camp affiliation	59.5%
	2 – own, belong to, or use a hunting camp	40.5%
Dcollgrad	1 – not a college graduate	67.8%
	2 – graduated from college	32.2%
Dchildren	1 – no children under 18 at home	60.3%
	2 – children under 18 living at home	39.7%
YrsHunt	1 – have hunted less than 22 years	25.4%
	2 – hunted between 22 and 32 years	25.6%
	3 – hunted between 33 and 42 years	24.5%
	4 – hunted 43 years or more	24.5%
Age	1 – 13 to 34 years old	19.4%
	2 – 35 to 44 years old	20.7%
	3 – 45 to 51 years old	18.7%
	4 – 52 to 60 years old	21.5%
	5 - 61 to 84 years old	19.8%
Q4D (antlerless kill)	1 – Did not kill an antlerless deer	30.5%
	2 – killed one antlerless deer	35.0%
	3 – killed 2 or more	34.5%
Residence	1 – medium or large city	9.0%
	2 – small city or suburban	31.3%
	3 – rural town/village or in the country	59.7%
ScaledIncome	1 – refused to answer	9.7%
	2 – less than $45,000 annually	37.2%
	3 – more than $45,000 annually	53.1%
avidD	1 – did not hunt the early or late seasons	43.1%

	2 – hunted early/late seasons < 10 days	32.7%
	3 – hunted early/late seasons ≥ 10 days	24.2%
TagQty6	1 – stated demand of 0-1 tags at $6	26.9%
	2 – stated demand of 2 tags at $6	37.9%
	3 – stated demand of 3-15 tags at $6	35.2%
TagQty12	1 – stated demand of 0 tags at $12	25.1%
	2 – stated demand of 1 tag at $12	31.1%
	3 – stated demand of 2-8 tags at $12	43.9%
DirtRoadDist	1 – averaged 0.06 miles from a dirt road	24.1%
	2 – averaged 0.56 miles from a dirt road	17.5%
	3 – averaged 1.15 miles from a dirt road	32.5%
	4 – averaged 3.52 miles from a dirt road	25.9%
PaveRoadDist	1 – averaged 0.16 miles from a paved road	22.9%
	2 – averaged 1.48 miles from a paved road	30.5%
	3 – averaged 2.90 miles from a paved road	17.9%
	4 – averaged 6.80 miles from a paved road	28.6%

APPENDIX 1.D - Manifest Variables Used in the Final Model

(percentage of the total 702 hunters in parentheses)

8A. How supportive are you of continuing the statewide antler restriction?

1 - strongly support, support, or slightly support	(68%)
2 – neither support nor oppose	(5%)
3 – strongly oppose, oppose, or slightly oppose	(27%)

8D. How supportive are you of the PGC’s efforts to increase the antlerless deer harvest?

1 - strongly support, support, or slightly support	(42%)
2 – neither support nor oppose	(9%)
3 – strongly oppose, oppose, or slightly oppose	(49%)

9H. What is your level of agreement with the following statement: Posting of private land has made it more difficult for me to find a place to hunt.

1 – strongly disagree	(6%)
2 – disagree	(22%)
3 – neither agree nor disagree	(18%)
4 – agree	(31%)
5 – strongly agree	(23%)

9J. What is your level of agreement with the following statement: It has become increasingly difficult for me to find a good place to hunt deer.

1 – strongly disagree	(7%)
2 – disagree	(31%)
3 – neither agree nor disagree	(19%)
4 – agree	(29%)
5 – strongly agree	(14%)

9K. What is your level of agreement with the following statement: Deer damage to forests in Pennsylvania is a problem.

1 – strongly disagree	(13%)
2 – disagree	(26%)
3 – neither agree nor disagree	(27%)
4 – agree	(25%)
5 – strongly agree	(9%)

9N. What is your level of agreement with the following statement: Posting has restricted my access to hunting on private lands.

1 – strongly disagree	(4%)
2 – disagree	(14%)
3 – neither agree nor disagree	(19%)
4 – agree	(41%)
5 – strongly agree	(22%)

9O. What is your level of agreement with the following statement: Deer cause serious conflicts with other land uses, such as forestry, farming, highways, and other development.

1 – strongly disagree	(9%)
2 – disagree	(22%)
3 – neither agree nor disagree	(26%)
4 – agree	(33%)
5 – strongly agree	(10%)

9T. What is your level of agreement with the following statement: I can have a successful season of hunting without harvesting a deer.

1 – strongly disagree	(11%)
2 – disagree	(21%)
3 – neither agree nor disagree	(12%)
4 – agree	(34%)
5 – strongly agree	(22%)

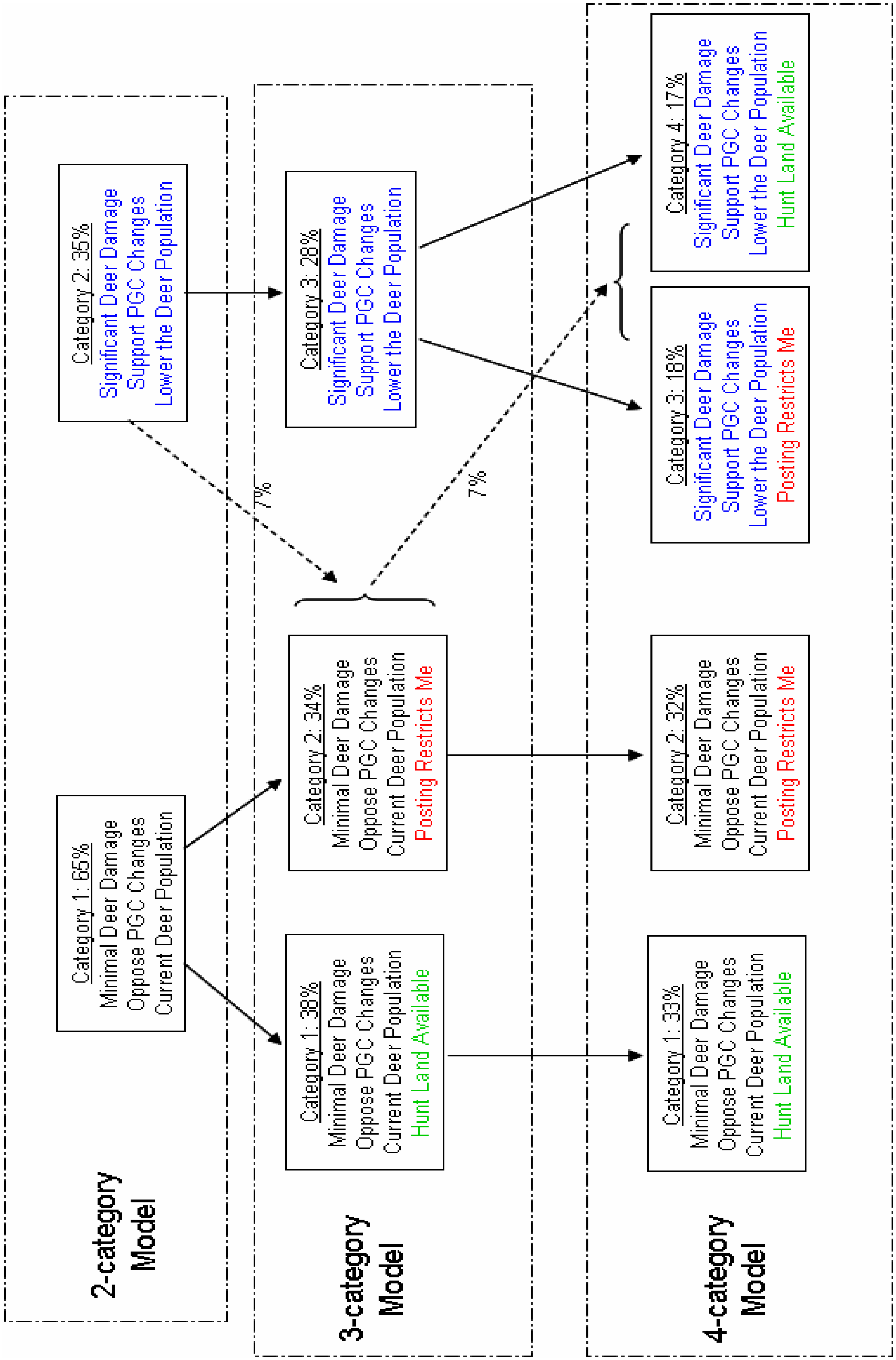
9U. What is your level of agreement with the following statement: The number of deer has no effect on forest regeneration.

1 – strongly disagree	(26%)
2 – disagree	(38%)
3 – neither agree nor disagree	(22%)
4 – agree	(10%)
5 – strongly agree	(4%)

11J. How important is the following reason for your participation in hunting: To help manage the deer population.

1 – not very important	(15%)
2 – somewhat important	(28%)
3 – important	(40%)
4 – very important	(17%)

APPENDIX 1.E - Hunter Category Breakout with Increasing Latent Classes



APPENDIX 1.F - Covariates, Results from Final Model

	Cat 1	Cat 2	Cat 3	Cat 4
Proportion of hunter population:	0.3242	0.3289	0.1760	0.1709

Covariate Variables (proportions listed are within a category)

	Cat 1	Cat 2	Cat 3	Cat 4
DCampUse				
1 – none	0.6663	0.6851	0.5626	0.5225
2 – own or use	0.3337	0.3149	0.4374	0.4775
Residence				
1 – medium or large city	0.0753	0.0817	0.1597	0.0709
2 – small city or suburbs	0.2744	0.3861	0.2991	0.2730
3 – rural	0.6503	0.5322	0.5412	0.6561
ScaledInc				
1 – refused to answer	0.1170	0.1113	0.0766	0.0517
2 – less than $45k	0.3865	0.4262	0.3225	0.3473
3 – more than $45k	0.4965	0.4626	0.6008	0.6010
QtyAt6 (tags purchased at $6 price)				
1 – 0 or 1 tag	0.3948	0.2522	0.1203	0.2162
2 – 2 tags	0.3183	0.4554	0.4233	0.3016
3 – 3 or more tags	0.2869	0.2924	0.4563	0.4822
avidD				
1 – no early/late seasons	0.4990	0.4346	0.3217	0.3942
2 – hunted <10 days	0.2826	0.3314	0.3995	0.3405
3 – ≥10 days	0.2184	0.2340	0.2788	0.2653

	Wald	p-value
DCampUse	15.2509	0.0016
Residence	10.5067	0.0150
ScaledInc	8.9120	0.0300
QtyAt6	37.7025	0.0000
avidD	14.1851	0.0012

Essay 2

Social Welfare Improvements from Changed Antlerless Deer Licensing Mechanisms

2.1: Background, Objectives, and Methodology

Monopoly power, and the possibility of prices different than those that would result from a competitive market, are often cited as a reason for regulation. Competitive equilibrium maximizes social welfare[4]; by distorting the competitive equilibrium while attempting to maximize their own profit, the monopolist reduces social welfare. Current white-tailed deer hunting regulations in the United States turn this argument on its head. In the case of antlerless deer management, it is *the regulations* that are distorting the market and reducing social-welfare; the monopoly power of the state game-management agencies provides the opportunity to bring the market closer to the competitive equilibrium. The improvements in social welfare in the market for antlerless deer may be sufficient to justify changing the current regulations.

Objectives

Essay 3 of this dissertation attempts to determine the dynamically optimal deer population, and associated deer density and annual deer harvests. Once that population and the appropriate harvest level is determined, there is an optimal static *allocation* of that appropriate harvest level, which is discussed here in Essay 2. The problem to be analyzed in this essay is straightforward. What are the estimated improvements in social welfare if current deer-harvest tag allocation systems are changed to reflect the fact that hunters (like all consumers) vary widely in their willingness to pay for deer tags? Policy-makers can then compare the advantages of the current system, including perceived equity and fairness, to the social-welfare improvements resulting from changes to the current system. The specific objectives of this essay are:

1. Develop a nonlinear programming model to maximize social welfare from the available antlerless deer herd.

2. Estimate demand curves for a discrete number of hunter types. An econometric model is developed and empirically estimated from hunter survey data in the state of Pennsylvania.

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[4] From Varian (1985), the classical measure of “Social Welfare” refers to the total net benefit (consumers’ plus producers’ surplus) from the market in question.

3. Use the estimated demand curves to optimize social welfare from the antlerless deer herd. Quantify the estimated improvements in social welfare from changing the current system to a more competitive-market outcome.

4. Discuss the policy implications of the results for deer-management agencies.

Methodology

The essay proceeds as follows. A typical antlerless deer management system, and the resulting economic inefficiency, is explained in Section 2. Section 3 creates a model of the deer management agency's problem: a constrained nonlinear program that is optimized for economic surplus. A review of the appropriate principle-agent and nonlinear pricing literature is conducted in Section 4. The theoretical justification for separating hunters by type, based on their willingness to pay for harvest, comes primarily from this nonlinear pricing literature. Section 5 then develops an econometric model to separate hunters in a Pennsylvania study into three types, using an ordered probit to first correct for endogeneity bias. Section 6 then combines the hunter types from the econometric analysis with the model of constrained social-welfare maximization to get empirical results of social welfare improvements. Finally, a discussion of the policy implications of the results is found in Section 7.

2.2: Inefficiency of Current Practices for Antlerless Deer Tags

Ohio, New York, New Jersey, Maryland, Maine, and Pennsylvania are all states with overabundant deer. 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, which entitles hunters to pursue game of all types, 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 rationed quota, on each hunter. Hunters are treated as equivalent in their desire for antlerless tags, with equal chances of receiving the allotted tags each 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.; Decker & Connelly). 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) across an entire state would be *theoretically* possible with an auction, or another competitive market mechanism, but is probably *practically* unrealistic considering coordination and transaction costs. However, 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 increase the total economic surplus from hunting and harvesting deer each season.

There exists a dichotomy in current deer-hunting laws and regulations that has been exposed by the decade-long trend of decreased hunter populations (see Appendix A) concurrent with an ever-expanding deer population. Along 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 (Riley et al.). In many areas, 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, 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 cannot purchase additional deer tags, and they cannot hunt deer without a tag. Thus, as game managers and biologists lament the fact that deer are not being harvested, the very hunters who would gladly continue hunting, killing deer, and getting utility from the experience are not allowed to do so.

A simple graphical analysis considering two hunter types can illustrate the possible economic inefficiency of the present antlerless deer harvest tag allocation system in Pennsylvania. Consider that the PGC has determined there should be a total of T* harvest tags sold this year to bring the deer herd to a pre-determined over-winter deer density.[5] Figure 2.1 represents aggregate demand curves for two hunter types. Hunters are identical within a Type, and for now assumed to be equiproportional in the total hunter population.

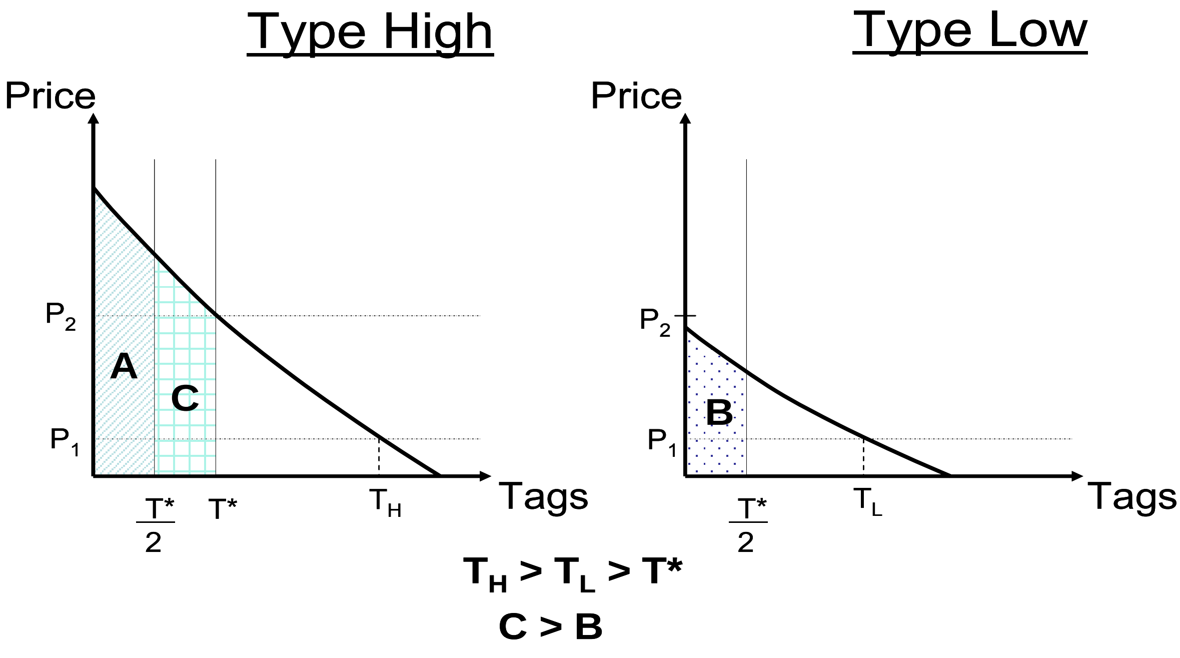

FIGURE 2.1: Both Hunter Types Exhaust Allocated Harvest

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[5] This concept is also covered in more detail in Essay 3.

The “Type High” hunters’ demand curve is everywhere higher than the “Type Low’s”, indicating a higher marginal willingness to pay for harvesting deer. Assuming a constant marginal cost of producing a harvest tag that is then normalized to zero, the current low price (\$6) of a harvest tag is represented by P_1 on each demand graph. At this low price, the quantity of tags demanded by each of the hunter types (T_H and T_L) exceeds T*. If the tags are awarded to hunters randomly, the effect will be half of the tag allocation going to each of the two hunter Types. Total economic surplus for all harvest tags is the sum of shaded areas A and B in the figure.

Now consider the welfare improvement if the PGC was not restricted to allocating the harvest tags randomly at one low price.[6] With the maintained requirement that the harvest target must still be met, what price should the PGC charge to maximize economic surplus? The price P_2 is the point on the Type High’s demand curve where all the tags are allocated to these serious hunters. At P_2, the Type Low hunters choose not to purchase any tags, and area B (formerly economic surplus) is “given up”. The gain in economic surplus, however, represented by area C on the left-hand Type High graph, more than makes up for the loss of Area B, so overall economic surplus from the available antlerless deer harvest is increased by $\Delta = (C - B)$.

A more likely scenario would be the situation illustrated in Figure 2.2. In this case, with our same Type High and Type Low typologies representing equal proportions of the total hunter population, the required tag allocation is now larger. In fact, neither hunter group would demand all of the (PGC optimally selected) T* tags even at a price of \$0. Maximum economic surplus would again be a “market price” where the harvest requirement was met, and harvest tags are allocated across groups to those hunters with the highest willingness to pay. Instead of the quota system where each group receives T*/2 of the tags, we again allow a market price, P2, to reduce economic surplus to the Type Low hunters. This reduction is equal to area D in Figure 2.2. The subsequent increase in tags demanded by the Type High’s when the quota is lifted, T_H, increases the

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[6] The restriction on the PGC to charge one low price for a harvest tag is a social norm and political restriction; in fact, the PGC is considering raising the prices of hunting licenses and deer tags as this essay is written in spring, 2006, and the political posturing and debate has already begun to keep hunting licenses stable at their current low levels.

Type High's economic surplus by area E, and thus increases overall economic surplus by $\Delta = (E - D)$.

This simple graphical representation could be expanded to more than two hunter types. It is more complicated (visually) if the proportion of hunters in the overall hunting population are not equal, as the total demand curves for the hunter types may cross. But the overall result remains the same if hunters are not equivalent in their willingness to pay for deer harvests; economic surplus is reduced by the current regulation that requires harvest tags to be sold, and randomly allocated, at one low price instead of the market clearing price.

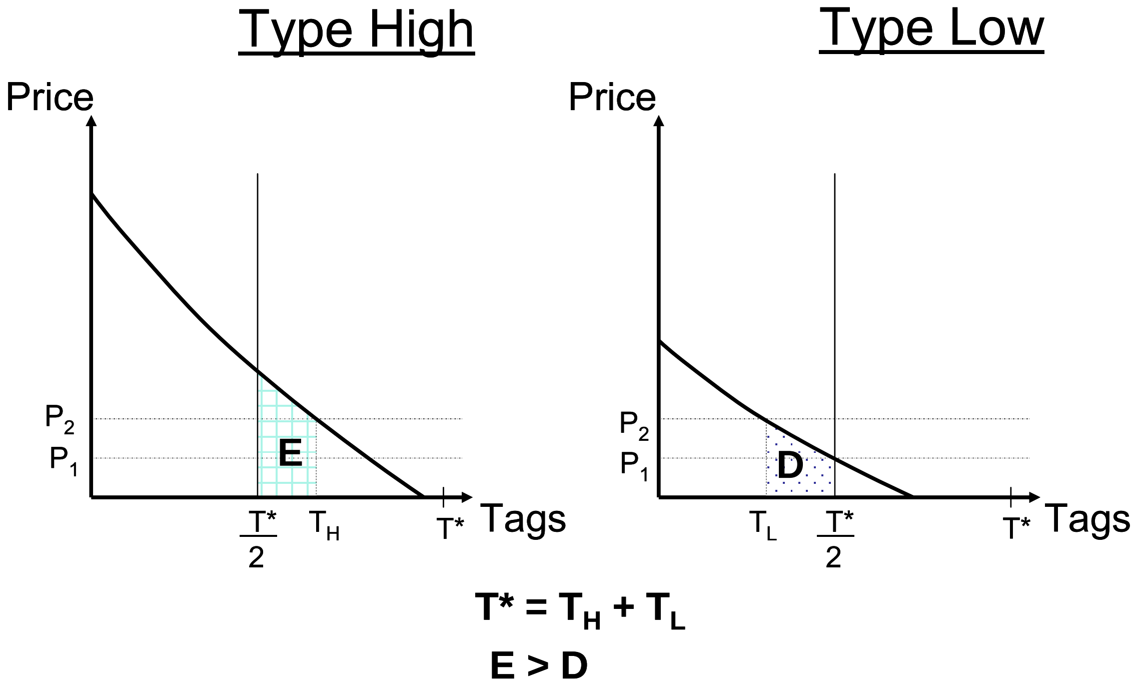

FIGURE 2.2: Neither Hunter Type Exhausts Allocated Harvest

If the willingness to pay for an antlerless deer tag is correlated with hunter skill and harvest success rates, then allocating the deer harvest tags to these higher-valuation hunters may 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. The issue, again, becomes finding a method of awarding tags to the hunters who most value them that is socially/politically acceptable to the majority of hunters. Unlimited tags are available in some suburban WMUs where hunting demand is low compared to the deer population. The rivalrous nature of a deer harvest would likely make this unacceptable where there are large numbers of Type Low Hunters, however. A few individual hunters taking an unlimited number of antlerless deer from the population will be frowned upon, unless those hunters are paying more for that privilege, which the current licensing system does not have a provision for.

2.3: A Model of Optimal Deer Tag Allocation

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 management of state game lands, wildlife enhancement and protection, and law enforcement, which can be considered public goods. The area underneath the hunter demand curves is thus an accurate measure of total economic surplus from the hunting and harvesting of the deer herd.[7] A management agency like the PGC is tasked to manage wildlife resources for the overall benefit of the people of Pennsylvania (DuBrock). The reality is that the PGC and other state management agencies are primarily funded through hunting and fishing license sales (Latham et al.), including antlerless deer tags.[8] I will model the PGC as a social-welfare maximizing agent, but maintain visibility in the empirical analysis of what affect my proposed regulation changes and better harvest tag allocation schemes have on overall PGC revenue.

Suppose there are M hunters in a deer-management agency's area of responsibility. Consider that there are a discrete number of hunter types, J, who differ by type based on two factors; their demand for antlerless deer tags, and their hunting success rates. A group of hunters of a single type is indexed by j, and all hunters of that type are assumed to have the same downward sloping demand for tags, $Q_j(P)$, or equivalently a downward sloping inverse demand specification $P(Q_j)$. I will assume that all hunters in the population have quasi-linear utility, an assumption which serves two purposes

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[7] This is very different from the economic surplus from the deer herd when all costs and benefits are considered. See note 2.

[8] Missouri is a rare exception among state wildlife management agencies. The Missouri Department of Conservation is funded through general tax revenue, and thus has less incentive to maximize hunting license sales.

(Varian). First, it allows consumer's surplus to serve as a legitimate measure of each hunter's welfare. Second, it allows individual utility functions to be aggregated in a social utility function, so total consumer's surplus can represent social welfare as well. Each hunter typology is a subgroup, m_j, of the total hunter population, so $\sum_{j=1}^{J} m_j = M$, with $m_j \neq m_i$ permissible. I must assume that the PGC can accurately estimate success rates, r_j, for the hunter types.

The economic surplus from a hunter of type *j*, ES_j, when faced with a price for an antlerless deer tag of P_j, can be determined directly from the number of tags he purchases at that price. Total economic surplus for a hunter of type *j* is then the area under the demand curve, or $ES_j = \int_0^{Q_j} P_j(Q_j)\, dQ_j$, and each of the m_j hunters of this type are assumed to receive this same economic surplus.

It may be feasible for a monopoly such as a game management agency to charge different prices to different consumers. We will examine the feasibility conditions for a nonlinear pricing scheme in Section 4. For now, however, it will be useful to consider that the PGC's control variable, price of harvest tags, is a vector **P,** whose elements p_1, p_2, …, p_J represent possibly different tag prices for different hunter types. The optimal number of antlerless deer tags to allocate each hunting season will depend upon the harvest target, H*, and the success rates of each of the hunter types, r_j, which I will assume to be constant. A more complex analysis could consider success rates for each hunter type as a function of harvest tags purchased, $r_j(Q_j)$, where I would assume $\partial r_j / \partial Q_j < 0$ for all j. The PGC's social-welfare maximization problem thus becomes:

$$\underset{(\mathbf{P})}{\text{Max}}: \sum_{j=1}^{J} ES_j \cdot m_j \tag{1}$$

$$\text{subject to: } \sum_{j=1}^{J} r_j \cdot m_j \cdot Q_j(p_j) = H^* \tag{1a}$$

$$Q_j(p_j) \geq 0 \qquad \forall\ j \tag{1b}$$

$$P \geq 0 \tag{1c}$$

The equality constraint (1a) indicates that the harvest target must be met. Equations (1b) and (1c) are simple non-negativity constraints on both tag prices and hunter demand; if price per tag exceeds a hunter type's reservation price, those hunters choose to purchase zero tags.

Solving the maximization problem for two hunter types yields an interesting result that can then be generalized to 3 or more types. Assuming an interior solution so that constraints (1b) and (1c) are strict inequalities, we can create a Lagrangian from equations (1) and (1a) with two hunter types, j = 1,2 and μ as the Lagrange multiplier;

$$\mathcal{L} = \int_0^{Q_1} p_1(Q_1)\,dQ_1 \cdot m_1 + \int_0^{Q_2} p_2(Q_2)\,dQ_2 \cdot m_2 + \mu[r_1 \cdot m_1 \cdot Q_1(p_1) + r_2 \cdot m_2 \cdot Q_2(p_2) - H^*]$$

and checking the first-order conditions yields

(FOC 1) $\partial\mathcal{L}/\partial p_1 = (\partial Q_1/\partial p_1) \cdot p_1(Q_1) \cdot m_1 - \mu \cdot r_1 \cdot m_1(\partial Q_1/\partial p_1) = 0$

$$p_1(Q_1) = \mu \cdot r_1$$

$$\mu = p_1(Q_1)/ r_1 \tag{2a}$$

(FOC 2) $\partial\mathcal{L}/\partial p_2 = (\partial Q_2/\partial p_2) \cdot p_2(Q_2) \cdot m_2 - \mu \cdot r_2 \cdot m_2 (\partial Q_2/\partial p_2) = 0$

$$p_2(Q_2) = \mu \cdot r_2$$

$$\mu = p_2(Q_2)/ r_2 \tag{2b}$$

Equations (2a) and (2b) indicate that at the optimum, the *marginal value per deer harvested* must be the same for each hunter type. Otherwise, the deer tags are being mis-allocated and overall surplus from the harvest target is less than it could be.

The simultaneous equations for μ from the two FOCs can also be set equal to each other to yield

$$\frac{p_1(Q_1)}{r_1} = \frac{p_2(Q_2)}{r_2}$$

or

$$\frac{p_1(Q_1)}{p_2(Q_2)} = \frac{r_1}{r_2} \tag{3}$$

at the optimum. Equation (3) is an interesting and powerful result. It says that the hunters who have higher success rates should not only pay higher prices for harvest tags, but that the ratio of the prices between hunter types should be the ratio of their harvest success rates. This result will be used to verify the nonlinear programming model results when hunter types are calibrated and optimal harvest tag prices are determined for multiple hunter types in a first-best world.

2.4: Relevant Principle-Agent and Non-Linear Pricing Literature

Numerous articles in the wildlife management literature discuss the need for game managers to be creative in using hunting to reduce deer densities (Riley et al.; Lauber and Brown; Brown et al.). As far as I know, analyzing the licensing of deer hunters as a nonlinear pricing (or monopoly principle-agent) problem has not been done. Using Pennsylvania to model the problem, the principal is the Pennsylvania Game Commission (PGC). For other states, the principal is the state's game management authority. The agents are hunters of various types (meat, sport, trophy) and skill levels/experience, creating a classic hidden information problem. Because the PGC is a monopoly seller of deer harvest tags, and because they also have the authority to prevent re-sale of those tags (which are printed with the name of the hunter and non-transferable), the principle-agent framework for the analysis fits a well-defined category of tractable problems

An excellent reference for all categories of nonlinear pricing is Nonlinear Pricing by Robert Wilson. The most applicable strand of the literature for my analysis is second-degree price discrimination using quantity bundling. Wilson credits Mirrlees as the basis of all subsequent theoretical literature on nonlinear pricing. The literature on optimal monopoly actions for principle-agent modeling starts with Mussa and Rosen (1984), who discussed monopoly pricing problems over a quality-differentiated spectrum of goods. Mussa and Rosen considered a situation in which the monopolist seller could not prevent resale. Maskin and Riley built a theoretical model for a monopoly principal selling a single product produced at a constant marginal cost. Unlike Mussa and Rosen, the products were identical quality. With a continuum of agents of different types, and either a finite or infinite number of types, Maskin and Riley showed that with a schedule of price-quantity pairs (a selling procedure), the principle's problem is tractable under very general assumptions on the agent's utility functions. Also in 1984, Goldman, Leland, and Sibley published a similar analysis of non-uniform pricing and quantity discounts as a method for monopolists to maximize firm profits. They considered non-resalable goods, and analyzed when income effects would affect the solution. Countervailing incentives were analyzed in 1995 by Maggi and Rodriquez-Clare. These authors discussed the importance of the quasiconvexity or quasiconcavity of the agent's utility on the private parameter for the nature of the optimal solution. Similarly, participation constraints when the agent's reservation utility depends upon their type were further analyzed by Jullien. Jullien identified conditions under which the optimal solution resulted in full participation by agents, which is likely to be a significant factor for deer licensing in Pennsylvania.

Maskin and Tirole analyzed the principle-agent problem when there exists a common value in the respective utility parameters. For my purposes, this is likely to be the case, as the PGC currently wants to increase deer harvest, and hunter utility is assumed to increase with deer harvest as well. Mas-Collell, Whinston and Green explain in detail that the revelation principle allows us to restrict attention to the category of solutions where truth-telling is the optimal strategy for each agent (Ch. 23). Participation constraints are also restricted to the individual rationality of the agents, which for my purposes simply indicates that hunters can choose not to purchase a license once they are offered by the PGC.

Another portion of the academic literature that is relevant to this analysis are those papers that developed the social welfare implications of nonlinear pricing. A summary of this literature by Keating and Gates stated "nonlinear pricing arrangements can have positive or negative implications for social welfare depending on the competitive environment, the objective of the firm, the specific pricing options employed, and the demand characteristics of the customers" (p.35). Profit-maximizing firm's use of nonlinear price structures and the potential effects on social welfare were developed in Spence, Roberts, Schmalensee, Katz, Cooper, Varian (1985), Wilson, McAfee et al., and Armstrong. The distributional distortions and inequitable changes in consumer surplus that may occur from a nonlinear pricing schedule are analyzed here for each hunter type.

A contribution of my application of nonlinear pricing theory will be to consider non-monetary goals of the monopolist. Much of the literature considers the utility of the monopolist to be linear or quasi-linear in firm profit. In my analysis, the monopolist is concerned about welfare-maximization of a constrained resource. The objective function is overall economic surplus, and additionally the monopolist can not "produce" a product at a specified (usually constant) marginal cost. The deer harvests are optimally determined through another process, and the monopolist management agency should then allocate them in the manner that maximizes the welfare from society's scarce resource, the deer herd.

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 econometric 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 airlines distinguishing business and personal travelers from the days of the week they fly, 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. This situation is similar to book sellers who can distinguish among customers with a slightly differentiated product (hardcover vs. paperback) released at staggered times.

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 $e_{\text{actual}} < e_{\text{low}} < e_{\text{high}}$ for each type. So any nonlinear pricing scheme developed for the PGC must be one in which 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). Paragraph 1 on page 502 of Mas-Colell, Whinston and Green explains, because of the observability of the payoff, (which in this case is the hunter's deer harvest), that this allows the PGC "contract" or license scheme to also specify effort, e. See Appendix B for a summary of this discussion in MWG (1995).

The theoretical basis for separating hunters by type comes directly from "Monopoly with Incomplete Information" by Maskin and Riley (1984). An adaptation of their analysis, including their Figure 1 which illustrates the concept of separating consumer types with quasi-linear utilities, is included at Appendix C. Maskin and Riley's paper is used here only to justify the separation of hunter types. Those author's go on to show the profit-maximizing price-quantity bundles for a monopolist, in both the first-best (perfect information) and second-best (agent-only information) scenarios. Game managers, and specifically the PGC, *are not* profit-maximizing firms for the purpose of this analysis. The PGC receives a large portion of its revenue from hunting license sales, and indeed is likely to care about any licensing mechanism that reduced its revenue significantly. But the PGC mission statement, goals, and population management plan for white-tailed deer (2003a and 2003b) all indicate that the PGC attempts to manage the deer herd for the benefit of all members of the Commonwealth. Deer population goals are set to ensure damage to forests is minimized, not to create the maximum number of deer for hunters. For this reason, the PGC is assumed to be a social-welfare maximizing agency. The deer herd is a finite resource that must be managed like any other resource, with the largest benefit to society being the optimal use of that resource.

So what is the purpose of separating hunters with incentive-compatible price-quantity bundles if it is not profit maximization for the PGC? First, it is a means of justifying the violation of the fairness doctrine whereby all hunters have the same chance of receiving a first (and subsequent) harvest tag. Serious Hunters who harvest more than their "fair share" of the deer population, making those deer unavailable for other hunters, will be forced to pay larger and larger prices for subsequent harvests, possibly making it more palatable for Casual Hunters to accept. Second, in areas where current hunter demand is not great enough to reduce deer densities to game-manager-selected appropriate levels, a system that allows Serious Hunters to harvest more deer benefits society as a whole by reducing the damage from overabundant herds. Third, overall economic efficiency will be increased if a licensing mechanism that separates hunters by their valuation of a deer harvest is used. This system will more closely resemble a competitive market outcome than the current quota system.

2.5: Empirical Analysis of Hunter Types

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 antlerless deer 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 D.

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. A histogram of the remaining 632 hunter responses at the \$6 price is shown in Figure 2.3.

Creating "hunter types" from Figure 2.3 is subjective. First, multiple hunters indicated a desire for between 1-10 tags (excluding the lone hunter who desired 15), so if each quantity level is considered its own type, there are 10 hunter types. On the opposite extreme, we could consider that there are only 2 hunter types, our aforementioned Type High and Type Low categories, and then logically but arbitrarily select a cutoff quantity that separates the groups. For example, the histogram data could be used to designate any hunter who desires 3 or more tags at a price of $6/tag as a Type High Hunter, and those hunters who only want 2 or fewer tags at a price of $6/tag as Type Low Hunters. Dummy variables could be created for this somewhat arbitrary designation. Assuming the Pennsylvania hunter population truly has only 2 hunter types, our designation in this manner is a form of measurement error. We can not expect to correctly identify all of the actual Type High Hunters from this single proxy variable; thus we have induced measurement error in our dummy variable classification.

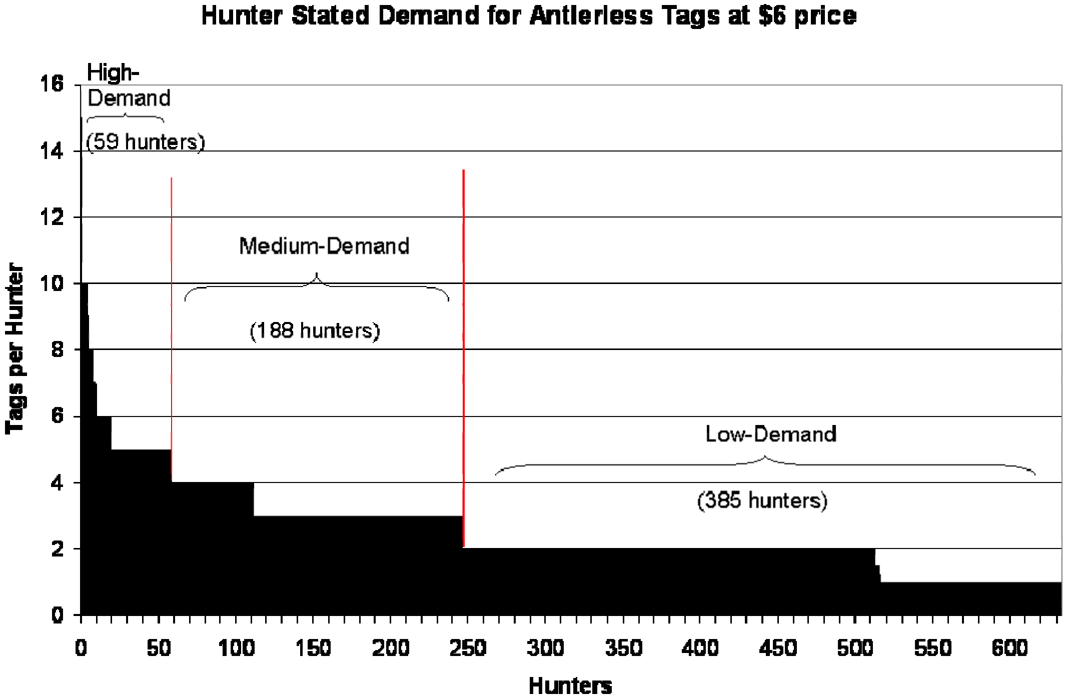

FIGURE 2.3: Histogram of Hunter Stated Demand

For the remainder of this analysis, I chose to illustrate the technique with three logical hunter types. From Figure 2.3, the hunter types were created logically (but arbitrarily) as indicated. 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 could then be conducted on a simple demand specification for all *i* hunters, allowing the demand intercept to vary by hunter type:

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

This specification forces the demand curves of higher types to be everywhere steeper than the demand curves of lower types, an important assumption of the model. The argument could be made that this assumption is invalid for some deer hunters, i.e. those who value their first antlerless deer very highly, but then place no value on a subsequent antlerless deer harvest in the same hunting season. I will assume these hunters are few in number relative to the entire hunter population, which is necessary for the analysis to continue toward a tractable solution.

The specification in equation (4) is problematic for two reasons. First, there is sample selection bias in the model because only the hunters who demand antlerless harvest tags at the current price of $6/tag are included. Hunters who may demand antlerless tags at lower prices have been omitted because of the survey methodology. Data on these hunters (or more specifically, these non-hunters) would be required to correct for this sample selection bias, but none currently exists.

The second issue with using the specification in equation (4) is the bias introduced from the endogeneity of the hunter dummy variables. Using the histogram of stated demand for tags (Figure 2.3) to categorize hunters, and then using that demand-based categorization to estimate overall demand equations, surely biases our estimated coefficients. A method is needed whereby hunters are *categorized based on characteristics other than stated demand* for antlerless tags. Once categorized, the stated demand for tags can be used to estimate an overall demand curve as in equation (4) without endogenous sample selection biasing the coefficients. This method is limited by the ability of the demographic and behavioral characteristics in the KQDC data to accurately categorize hunters. I have made an attempt to remove the endogeneity by developing instrumental dummy variables for hunter type with an ordered probit.

An Ordered Probit

Logically, there is a combination of characteristics that create a hunter that is more enthusiastic, skillful, and willing to pay for subsequent antlerless deer harvests. Using the previous separation of hunters from the histogram in Figure 2.3, a temporary ordinal dummy variable called Dummy Hunter Type (DHT) was used; 0 for low-demand hunters, 1 for medium-demand hunters, and 2 for high-demand hunters. Independent variables from the KQDC data set that were used to predict the hunter category are explained in Table 2.1, with higher numbers and dummy category 1 variables all postulated to predict higher-demand hunters.

Table 2.1: Independent Variables in Ordered Probit

Variable	*Definition*	*Range of Values*
DOEHARV	Number of antlerless deer harvested in 2003	0,1,2,3,4,5,6,7,9
EARLY	Days spent afield during early (archery, muzzleloader) season in 2003	0 - 40
FIREARM	Days spent afield during firearms deer season in 2003	0 - 12
LATE	Days spent afield during late (archery, muzzleloader) season in 2003	0 - 18
D9P	Agree or strongly agree with the statement: "I would rather harvest a doe than no deer at all."	1: agree 0: disagree/neutral
D9T	Disagree or strongly disagree with the statement: "I can have a successful season of hunting without harvesting a deer	1: disagree 0: agree/neutral

The econometric model to be tested is thus:

$$\mathrm{DHT}_i = \alpha_0 + \alpha_1\mathrm{DOEHARV} + \alpha_2\mathrm{EARLY} + \alpha_3\mathrm{FIREARM} + \alpha_4\mathrm{LATE} + \alpha_5\mathrm{D9P} + \alpha_6\mathrm{D9T} + \mu_i \qquad (5)$$

with the subsequent estimated coefficients, $\hat{\alpha}_j$, used to predict the ordinal hunter category for each of the 632 antlerless deer hunters in the survey, $\mathrm{D\hat{H}T}_i$. The full LIMDEP results for this ordered probit model are in Appendix F. The overall model and the estimated coefficients on DOEHARV, FIREARM, and D9P were statistically significant, and importantly all of the independent variable coefficients were appropriately signed. The cross-tabulations of the model predictions are shown below in Table 2.2 for a discussion.

Table 2.2: Ordered Probit Cross-Tabulation of Predictions

		+++++++++	**Model Prediction**	+++++++++
Initial Quantity	*Initial Designation*	$D\hat{H}T_{Low}$	$D\hat{H}T_{Med}$	$D\hat{H}T_{High}$
385	*DHT = 0; Low*	355	29	1
188	*DHT = 1; Med*	115	69	4
59	*DHT = 2; High*	17	22	20
Total: 632		**487**	**120**	**25**

LIMDEP categorizes hunters based on the highest probability of being in one of the three possible categories. Compared to the original designation, where we used 59 high-demand hunters and 188 medium-demand hunters based on our arbitrary designation from the histogram, our probit model with this "highest probability categorization" designates only 25 high-demand and 120 medium-demand hunters. This is a recognized problem with ordered probit predictions in an unbalanced sample (Greene, 2003). Because high-demand and medium-demand hunters are a small proportion of the total hunter population, the threshold probabilities are less likely to be met for these categories compared to the low-demand hunter category. The suggested solution (Greene) is to adjust the threshold values for inclusion in these lower density categories. Using the predicted probabilities from the ordered probit, for each hunter's likelihood of being in each category, the threshold probabilities were adjusted to maintain as closely as possible the original numbers of hunters in each category. The new hunter groups, listed below in Table 2.3, now contain hunters who most closely represent our low, medium, and high demand designation without actually using stated demand to categorize the hunters.

Table 2.3: Ordered Probit With Corrected Thresholds

		+++++++++	**Model Prediction**	+++++++++
Initial Quantity	*Initial Designation*	$D\hat{H}T_{Low}$	$D\hat{H}T_{Med}$	$D\hat{H}T_{High}$
385	*DHT = 0; Low*	301	76	8
188	*DHT = 1; Med*	73	94	21
59	*DHT = 2; High*	9	19	31
Total: 632		**383**	**189**	**60**

Using these predicted values from the ordered probit to re-designate hunters with a dummy variable for high-demand, $\hat{D}_{High}$, and medium-demand, $\hat{D}_{Med}$, as appropriate, these instrumental variables are now uncorrelated with the error term in the OLS specification:

$$Q_i = \gamma_0 + \gamma_1 \cdot \hat{D}_{High} + \gamma_2 \cdot \hat{D}_{Med} + \gamma_3 \cdot \ln(P) + \varepsilon_i \qquad (6)$$

The regression results (see Appendix E) showed a reasonably high goodness of fit (adjusted R-square of .2965) and statistical significance for all variables at any significance level. The demand specification for these three hunter types, indexed by *j*, varies only by the first coefficient once the intercept and dummy variable coefficient are combined:

$$Q_j = \gamma_j - \gamma_3 \cdot \ln(P) \qquad j \in \{high, medium, low\} \text{ and } \gamma_3 > 0 \qquad (7)$$

which leads to the inverse demand specification:

$$P = \beta_j \cdot \exp(-\beta_3 \cdot Q_j) \qquad \text{where } \beta_3 = 1/\gamma_3 \text{ and } \beta_j = \exp(\gamma_j / \gamma_3) \qquad (8)$$

Total Marshallian Economic Surplus (ES) for each of the three hunter types can be calculated as the area under the inverse demand curve from zero to Q_j, or

$$ES_j = \int_0^{Q_j} \beta_j \cdot \exp(-\beta_3 \cdot Q_j)\, dQ_j \qquad = \qquad \beta_j/\beta_3(1 - \exp(-\beta_3 \cdot Q_j)) \qquad (9)$$

Using these coefficient estimates from the OLS regression allowed me to calculate and graph inverse demand curves for hunters of each type (see Figure 2.4).

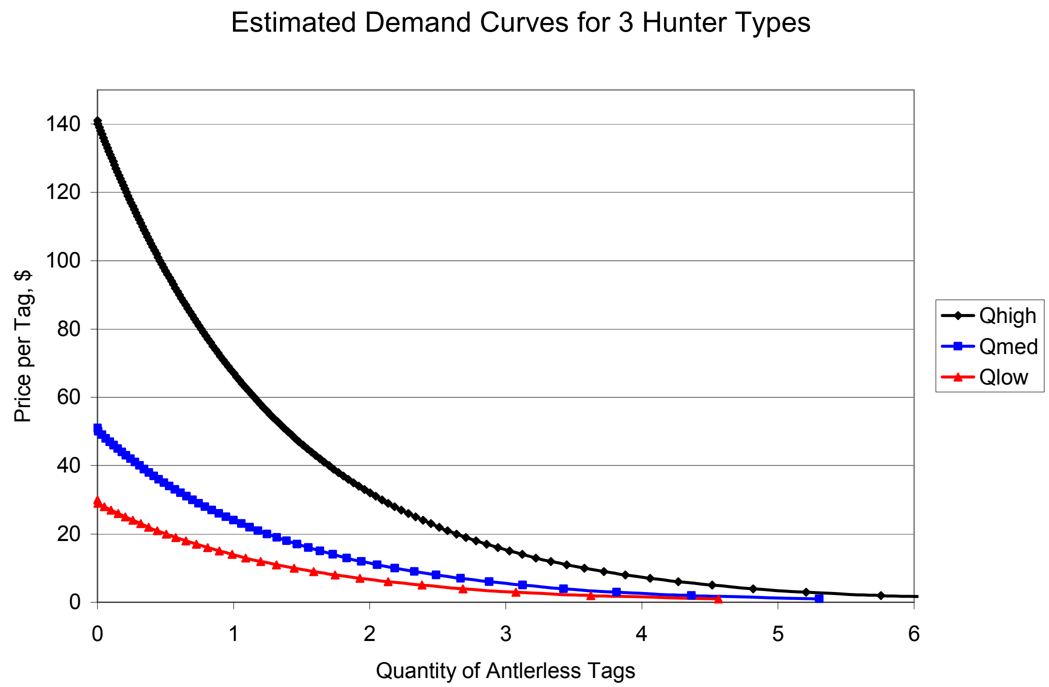

FIGURE 2.4: Estimated Demands for 3 Hunter Types

This simple model of only three hunter types is illustrative for the purposes of estimating increased economic efficiency from a re-allocation of harvest tags. 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 at Penn State. 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 2.4 indicates that the willingness to pay for a marginal deer tag varies substantially by hunter type, as expected. I will assume that representative hunters within a category (low, medium, or high) are identical in their demands for tags. To remove the integer problem, I must allow harvest tags to be purchased in fractional amounts in the analysis that follows. The assumption will be that the average hunter within a group, when many hunters exist, can be modeled as receiving fractional harvest tags. Examining the relative numbers of hunters within each category of types in the KQDC sample revealed the following breakdown of the hunters who hunt antlerless deer:

High-Demand Hunters:	9.5%
Medium-Demand Hunters:	29.9%
Low-Demand Hunters:	60.6%

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 general hunting license population in Pennsylvania of 1,018,248, with approximately 50% of the hunters not interested in hunting antlerless deer at all, leaves the following approximations for my created antlerless hunter categories in 2003 for the state of Pennsylvania:

High Demand Hunters (m_{high}):	48,370 hunters
Medium Demand Hunters (m_{med}):	152,230 hunters
Low Demand Hunters (m_{low}):	308,530 hunters

An analysis of hunter success rates, r_j, for these different hunter types was needed as well. Comparing the hunter-reported antlerless harvest in 2003 with the number of antlerless tags hunters *stated* they would purchase at the current price of $6 was used to approximate hunter success rates (antlerless deer harvested per tag purchased) for each hunter type. This estimation was imperfect, as 21 hunters had success rates over 100% using this method, so success rates over 100% were rounded down to 100%. A more detailed analysis is found in Appendix G. The resulting success rates obviously decrease as subsequent tags are purchased by each hunter type, but were steady at low quantities. The final results were checked to ensure that each hunter type had final quantities of tags at or below the threshold where success rates started to decrease dramatically. Success rate estimated for the designated high-demand hunters was 100% for each tag up to a total of 3 tags. Success rates dropped to 90.6% for the medium-demand hunters up to a total of 2 tags, and only 52.2% for the low-demand hunters for their first tag. Considering *all* of antlerless tags purchased by the hunters in the KQDC survey, the overall success rate per tag purchased would have been 51.7% for the hunters in our sample. This is significantly greater than the 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. This implies that the hunters in our sample may be higher skilled and/or more dedicated than the average Pennsylvania hunter.

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, the assumption that success rates vary by hunter type, but remain constant *within* the type category for subsequent tags, works well at the recommended optimal tag quantities. A better model would allow success rates to decrease as each hunter type purchases subsequent tags, but the available data did not allow for a good estimate of this decreasing function.

2.6: Economic Surplus Improvements From a Price-Rationed Allocation of Tags

I built a nonlinear programming simulation model using LINGO®, from Lindo Systems Inc., to determine the prices and optimal tag allocations under different scenarios. The LINGO® computer code for one set of parameters is found at Appendix H**.** The exogenous variables were set at rounded approximations for Pennsylvania hunters already determined:

Total hunters who hunt antlerless deer: 500,000

Required annual antlerless deer harvest: 350,000 to 600,000, with PGC recommended harvest of 450,000 highlighted as a baseline for comparison.

Predicted success rates:

r_{high} = 100%
r_{med} = 91%
r_{low} = 52%

Percentages of each hunter type in the total hunter population would determine hunter numbers:

m_{high} = 10% of total antlerless hunters
m_{med} = 30% of total antlerless hunters
m_{low} = 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 total hunter populations decline. The *relative* effect on economic surplus was the same however, when going from the current system of license sales to market-based improvements.

2.6.1: The Current System (politically constrained outcome)

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 political or social norm constraint gives all hunters 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 is obviously larger when the desired annual harvest target is larger.

Table 2.4: Current System with $6 harvest tags

Desired Harvest	***Total Economic Surplus***	***PGC Revenue***	***CS_{high}***	***CS_{med}***	***CS_{low}***
350,000	$16,525,609	$3,065,693	$4,665,495	$4,428,427	$4,365,993
400,000	$17,169,949	$3,503,650	$4,744,513	$4,497,209	$4,424,578
450,000	**$18,079,991**	**$3,941,606**	**$4,929,466**	**$4,655,036**	**$4,553,883**
500,000	$19,195,226	$4,379,562	$5,202,102	$4,882,322	$4,731,240
550,000	$20,463,404	$4,817,518	$5,546,659	$5,162,151	$4,937,075
600,000	$21,839,476	$5,255,474	$5,949,549	$5,479,941	$5,154,511

These results can serve as a basis for comparison with different pricing policies for antlerless harvest tags. Notice from Table 2.4 that the current system “divides up” the economic surplus from antlerless deer fairly evenly between four groups; the PGC, and each of our three hunter types.

2.6.2: 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. If all hunters were identical, in both their preferences and harvest success rates, this would be a market-clearing price and a competitive market result, which we know would be the most efficient use of the deer herd. Because hunter’s willingness to pay and harvest success rates vary by type, however, charging a single price for harvest tags that just meets the management authority’s harvest target will not be efficient. What price will result, and how much total economic surplus could be improved, was tested in the simulation and compared to the current system described above. The output from the LINGO solutions over the range of reasonable deer harvest targets is provided below in Table 2.5.

Table 2.5: Optimal Single-Price to Meet Harvest Target

Desired Harvest	***Optimal Price per Tag***	***Total Economic Surplus***	***PGC Revenue***	***Δ Surplus***	***Δ Surplus (%)***
350,000	$21.39	$17,035,040	$9,098,281	$509,431	3.1%
400,000	$19.20	$18,514,950	$9,570,046	$1,345,001	7.8%
450,000	**$17.24**	**$19,843,620**	**$9,850,316**	$1,763,629	9.8%
500,000	$15.48	$21,036,490	$9,973,329	$1,841,264	9.6%
550,000	$13.90	$22,107,460	$9,968,299	$1,644,056	8.0%
600,000	$12.48	$23,068,970	$9,860,181	$1,229,494	5.6%

The efficiency gains from allowing the PGC to charge a single, market-clearing price for antlerless tags are not trivial. At the harvest goal of 450,000 antlerless deer (an average annual harvest total for Pennsylvania, but a number lower than that recommended by foresters to reduce damage from deer browsing; see Latham et al.), the economic surplus would be increased by 9.8%. Comparison of Table 2.4 and Table 2.5 indicates that the major beneficiary of this system is the PGC. Revenue from harvest tags increases significantly, possibly providing an incentive to wildlife management agencies to consider this market-clearing price for antlerless tags. If wildlife belongs to society, the PGC is now capturing more of the value that hunters place on the antlerless deer resource as society's managing agent. If this increased revenue is spent to benefit society by improving wildlife habitat, securing more public lands, or even compensating farmers and foresters harmed by deer browsing, it is arguably a true overall improvement in social welfare.

But there is a political disadvantage of this increased price, as the theoretical literature of the equity/distributional effects of nonlinear pricing predicted. The distribution of these economic surplus gains is not equitable across hunter types, and in fact there is an *overall loss* in consumer surplus to both medium-demand and low-demand hunters. The output in Table 2.6 below shows that these hunters lose large portions of consumer surplus from hunting antlerless deer when the price per tag increases from the current $6/tag to the recommended optimum that just meets the harvest target.

Table 2.6: Consumer Surplus Changes with Single Market-Clearing Price

Desired Harvest	*Optimal Price per Tag*	*ΔCS high-demand hunters*	*ΔCS (loss) medium-demand hunters*	*ΔCS(loss) low-demand hunters*
350,000	$21.39	$668,372	($2,279,291)	($3,912,242)
400,000	$19.20	$875,658	($1,945,516)	($3,651,532)
450,000	**$17.24**	$962,092	($1,698,958)	($3,408,216)
500,000	$15.48	$945,967	($1,524,599)	($3,173,866)
550,000	$13.90	$843,259	($1,409,203)	($2,940,781)
600,000	$12.48	$667,846	($1,341,064)	($2,701,993)

The results of the market-clearing price simulation also indicate that when the PGC is allowed to charge a single price that rations deer tags to those hunters who value them most, many formerly low demand hunters do not choose to purchase a tag. For example, at a desired harvest of 450,000 deer, our demand specification for low-demand hunters indicates that only 212,172 harvest tags are desired by our estimated 300,000 low-demand hunters. Thus, if tags are sold in discrete units, roughly 88,000 formerly low-demand hunters do not chose to purchase an antlerless deer tag at the optimal price of $17.24. In other words, the ranks of antlerless deer hunters shrink significantly from the current estimate of 500,000 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.; Alsheimer). 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 valid reason for maintaining low prices on deer tags.

2.6.3: First-Best Outcome: Hunter Types Pay Different Prices

From equation (1) derived earlier, with perfect information the PGC should solve the non-linear programming problem:

$$\underset{(\mathbf{P})}{\text{Max}} : \sum_{j} \{\beta_j/\beta_3[1 - \exp(-\beta 3 \cdot Q_j(p_j))]\} \cdot m_j \qquad j \in \{\textit{high}, \textit{medium}, \textit{low}\} \tag{6}$$

$$\text{subject to: } \sum_{j} r_j \cdot m_j \cdot Q_j(p_j) = H^* \tag{6a}$$

$$Q_j\,(p_j) \geq 0 \qquad \forall\ j \tag{6b}$$

$$p_j \geq 0 \qquad \forall\ j \tag{6c}$$

$$r_j,\ m_j \text{ given} \qquad \forall\ j \tag{6d}$$

One might assume 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 because of the variance in harvest success among hunter types, this may not be the case. The analysis of the Langrangian in Section 3, and the resulting optimal price ratio derived in equation (3), indicated that it is the marginal value per harvest that must be considered when optimizing economic efficiency. Depending on the parameters for each hunter type's demand function, it may indeed be optimal for more harvest tags to be sold to low-demand hunters. The prices that each hunter type should be charged to maximize social welfare from the deer herd are found by solving the system of equations represented in equations (6) – (6d) above in the LINGO® nonlinear program. The optimal price for low-demand hunters is P_{low}; for medium-demand hunters is P_{med}; and for high-demand hunters is P_{high}. The results are summarized in Table 2.7 below, with total economic surplus gains compared to the current system of \$6 harvest tags that are randomly rationed.

Table 2.7: First-Best Pricing of Harvest Tags

Desired Harvest	P_{low}	P_{med}	P_{high}	***Economic Surplus***	**Δ *Surplus***	**Δ *Surplus (%)***
350,000	\$15.55	\$27.22	\$29.91	\$17,643,160	\$1,117,551	6.8%
400,000	\$13.96	\$24.44	\$26.85	\$19,060,920	\$1,890,971	11.0%
450,000	**\$12.54**	**\$21.94**	**\$24.11**	**\$20,333,790**	\$2,253,799	12.5%
500,000	\$11.26	\$19.70	\$21.65	\$21,476,570	\$2,281,344	11.9%
550,000	\$10.11	\$17.68	\$19.43	\$22,502,560	\$2,039,156	10.0%
600,000	\$9.07	\$15.88	\$17.45	\$23,423,690	\$1,584,214	7.3%

Economic surplus improvements are around 12%, or roughly \$2.2 million annually for the mid-range of desired harvests. As indicated from the earlier analysis, the optimal prices are in the ratio of the harvest success rates. High-demand and medium-demand hunters should be charged higher prices for their harvest tags because they take more deer out of the allowable harvest allocation *per tag purchased*. This leaves fewer deer to be allocated to the low-demand hunters, so hunters with higher success rates should optimally pay more. Efficiency is lost when hunters with different WTP and different success rates pay the same price. A comparison of the total economic surplus in Table 2.7 with the previously calculated total economic surplus in Table 2.5, where a single-market clearing price was used, shows this clearly.

If the PGC knew each hunter's type, and could charge different prices when the hunter came to purchase harvest tags, the results of the first-best model could be implemented and would be an example of monopoly price discrimination. As the literature on monopolies suggests, the monopolist seller (in this case, the PGC as society's manager of wildlife) would be expected to accrue large portions of what was formerly consumer surplus in the market for antlerless deer. This analysis is summarized in Table 2.8 below by comparing the first-best outcome with the current system. The losses in consumer surplus are large for low and medium-demand hunter types, and subsequent increases in PGC revenue, indicates clearly that consumer surplus would indeed be captured by the monopolist seller if the PGC had information about each hunter's type and WTP for antlerless tags.

Table 2.8: First-Best Pricing Compared to Current System

Desired Harvest	***ΔCS (loss) for High-Demand Hunters***	***ΔCS (loss) for Medium-Demand Hunters***	***ΔCS (loss) for Low-Demand Hunters***	***Δ PGC Revenue***
350,000	($315,467)	($3,142,088)	($2,828,129)	$7,403,237
400,000	($63,474)	($2,834,790)	($2,448,827)	$7,238,060
450,000	$68,787	($2,600,282)	($2,122,494)	$6,907,784
500,000	$98,931	($2,426,230)	($1,834,664)	$6,443,308
550,000	$42,358	($2,301,655)	($1,572,474)	$5,870,932
600,000	($87,484)	($2,216,793)	($1,324,487)	$5,212,976

Fortunately for hunters, the PGC currently has no way to distinguish an individual hunter's WTP for deer harvest tags. This hidden information prevents the PGC from implementing the first-best perfect price discrimination results in Table 2.7.

2.6.4: Second-Best Pricing: Bundling of Harvest Tags

One method of charging different prices for harvest tags without knowledge of each hunter's type would be bundling the tags in discrete price-quantity pairs. A single tag would be one price, $P_1 = P_{low}$; a two harvest tag bundle would be $P_2 = P_{med} + P_1$, and a three-tag bundle would be $P_3 = P_{high} + P_2$. In this manner, the PGC can create marginal prices for tags that vary. This bundling of tags would be an example of second-degree price discrimination described in the literature (Wilson). To avoid the integer problem again, and get an approximation of social-welfare and distributional affects, I will assume that fractional tags are possible at the price for the next full tag in the bundle; for example, a hunter can purchase 1.4 tags at a price of P_2 if his demand curve supports that purchase.

The issue with bundling of tags becomes finding a separating equilibrium price scheme. From the demand curves in Figure 2.4, the low-demand and medium demand hunters have very little vertical distance between their respective demand curves after a quantity of 1 tag per hunter. Additionally, due to the much greater success rate of the medium-demand hunters (91% > 52%), it was always optimal for the medium-demand hunters to purchase *fewer* tags than the low-demand hunters in the perfect-information scenario. Thus, a pooling equilibrium exists between medium demand and low-demand hunters, because it is always better for the medium-demand hunters to withhold their information about their own type, and "pretend" to be low-demand hunters and purchase low-tag bundles. High-demand hunters, however, are better off in a separating equilibrium from the other hunter types because of their much higher WTP for tags.

The result of this method of selling tags is that total economic surplus increases over the current system of rationing tags. Total economic surplus improvements are slightly less than the first-best outcome because of the efficiency losses due to hidden information. A comparison of the efficiency gains from bundled tags compared to the current rationing system is below in Table 2.9, as well as a description of the best price-tag bundles for various desired harvest levels.

Table 2.9: Second-Best Pricing (Bundling) of Harvest Tags

Desired Harvest	*1-Tag Bundle Price*	*2-Tag Bundle Price*	*3-Tag Bundle Price*	*Economic Surplus*	*Δ Surplus*	*Δ Surplus (%)*
350,000	$20.08	$50.98	$81.88	$17,185,450	$659,841	4.0%
400,000	$18.03	$45.77	$73.51	$18,649,990	$1,480,041	8.6%
450,000	**$16.19**	**$41.10**	**$66.01**	**$19,964,860**	$1,884,869	10.4%
500,000	$14.53	$36.89	$59.25	$21,145,340	$1,950,114	10.2%
550,000	$13.05	$33.12	$53.19	$22,205,180	$1,741,776	8.5%
600,000	$11.72	$29.74	$47.76	$23,156,710	$1,317,234	6.0%

These total economic surplus gains are around $1.9 million annually at mid-range harvest targets, and very near to the first-best results. Increases in social welfare from the limited deer herd resource of over 10% are possibly worth considering, especially since this second-best pricing scheme requires no knowledge of hunter types and is incentive compatible with the hunter's own purchasing decisions.

Another benefit of this second-best pricing scheme, however, is that consumer surplus is largely maintained by hunters instead of becoming revenue for the PGC. The hidden information, whereby only the hunters know their own type, allows them to retain much of the consumer surplus from deer harvests they receive under the current rationing system. Compared to the current system, where tags are rationed through a random allocation process, this marginal pricing of tags allows *prices* to ration the tags more equitably amongst those hunters who value them most. High-demand hunters benefit from price rationing of tags over the current system, as shown in Table 2.10 below. Medium-demand hunters lose consumer surplus compared to the current system, but not nearly as much as they did if the PGC could perfectly price discriminate and charge them their marginal price for each tag. Medium-demand hunters also gain at the expense of low-demand hunters because of the pooling effect, where they purchase the same bundles of tags as low-demand hunters.

Table 2.10: Second-Best Pricing (Bundling) of Harvest Tags Compared to Current System

Desired Harvest	***ΔCS for High-Demand Hunters***	***ΔCS (loss) for Medium-Demand Hunters***	***ΔCS (loss) for Low-Demand Hunters***	***Δ PGC Revenue***
350,000	$663,733	($2,044,991)	($3,733,381)	$5,774,480
400,000	$809,183	($1,709,535)	($3,439,677)	$5,820,070
450,000	$846,452	($1,464,084)	($3,171,991)	$5,674,489
500,000	$791,906	($1,293,078)	($2,920,471)	$5,371,761
550,000	$659,830	($1,182,795)	($2,676,208)	$4,940,953
600,000	$462,681	($1,121,139)	($2,431,142)	$4,406,832

Likewise, the increases in PGC revenue are still significant, but not as large as the scenario where perfect information allowed the PGC to perfectly price-discriminate among hunters (compare the last column of Table 2.8 with the last column of Table 2.10 above).

2.7: Discussion

Bundling of antlerless tags, as described in this analysis, may be acceptable to most hunters. Because deer are a rivalrous good for consumptive uses, some low-demand hunters are justifiably concerned about high-demand 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 two, 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 the PGC when changes in the annual harvest target levels are warranted would be the prices of the bundled tags.[9] The initial years of this proposed licensing method may require detailed hunter surveys in certain areas of the

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[9] Annual deer populations fluctuate due to winter-mortality rates and other random shocks.

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 "bundled harvest tags" purchase data, with slight changes in single 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.

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 (Decker and Connelly), 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; more analysis of how success rates decrease for subsequent tags would improve the current model as well. But again, the success rates used here are not an unreasonable approximation based on overall historical success rates in the state of Pennsylvania.

The econometric method utilized for estimating demand curves for a discrete number of hypothesized hunter types has advantages and disadvantages. The method allows the researcher to set an initial proportion of hunter types in each category that seems reasonable. Using an ordered probit to predict individual hunter categories has the advantage of correcting for endogeneity bias, and is best if there is confidence in the ability of the available behavioral and attitudinal data to accurately predict hunter categories. The predictive ability of the ordered probit was low for the high-demand and medium-demand hunters because of an unbalanced sample, so the proportion of hunters in these categories was adjusted by changing the probability threshold values. The final

OLS demand model indicated a willingness to pay for the first full antlerless deer tag of roughly $110 (the area under the high-demand hunter demand curve up to a quantity of 1 tag). Even for the most dedicated/serious of hunters, a WTP for one tag of $110 for the first antlerless deer tag may seem unreasonable to some hunters and game managers. Nonresident hunting licenses in Pennsylvania are $101; this gets you an *antlered deer* tag and additional wildlife licenses. A nonresident antlerless deer tag is an additional $26. If there are hunters from surrounding states who are willing to pay those prices to hunt antlerless deer in Pennsylvania, I assume that there are residents of Pennsylvania who are willing to pay those prices as well, but probably only a select few (less than 10%) as was modeled in this analysis.

Importantly, this analysis indicates the possibility for significant increases in total economic surplus from antlerless deer hunting if the PGC was allowed to change the current system of rationing tags at a price of $6 per tag. At a desired annual harvest of 450,000 antlerless deer, the increase in economic surplus would be approximately $2.25 million each year if hunter types were known. Because hunters can not be forced to reveal their type, setting a low price for tags and then rationing the tags because of the excess demand at that price is a legitimate method of distributing tags. The methods examined in this analysis considered using prices to ration the tags, instead of the current system. In each method tested, 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 via multiple mailings as is done now, 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 price for tags that clears the market at the desired harvest rate is the possible effect on overall hunter numbers, and the opposition to any price-rationing scheme from low-demand hunters who will lose consumer surplus they cuurently enjoy under the rationing system.

The optimal single price for a desired harvest of 450,000 antlerless deer was $17.24, seemingly not a price increase that would place the tags out of reach for even the lowest income hunters. Total economic surplus would be improved by approximately $1.7 million annually, or 9.8% over the current system. But if the demand curves are to be believed, this may result in thousands of currently low-demand hunters not purchasing 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.

I was able to develop an incentive compatible licensing scheme with bundling (second-degree price discrimination), whereby the first tag was sold for one low price and subsequent tags were bundled at higher prices, and then analyze the resulting improvements in social welfare. The resulting improvements in economic surplus from this pricing system and bundling of tags were 8%-10% relative to the current system, not trivial at large desired harvest rates. High-demand hunters actually receive more consumer surplus under tag bundling than they do under the current rationing system. 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 improvements in total economic surplus would justify changing the current selling practices. As noted in Table 2.9, high-demand and medium-demand hunters will pool together and purchase the same tag bundles, and both groups will lose some of the consumer surplus they enjoy under the current rationing system. 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 total 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 or bundled tags as a way of allocating antlerless deer tags. But the resistance to changing the current system from lower-demand hunters may be significant, and the relatively small increases in overall social welfare may not be worth the fight.

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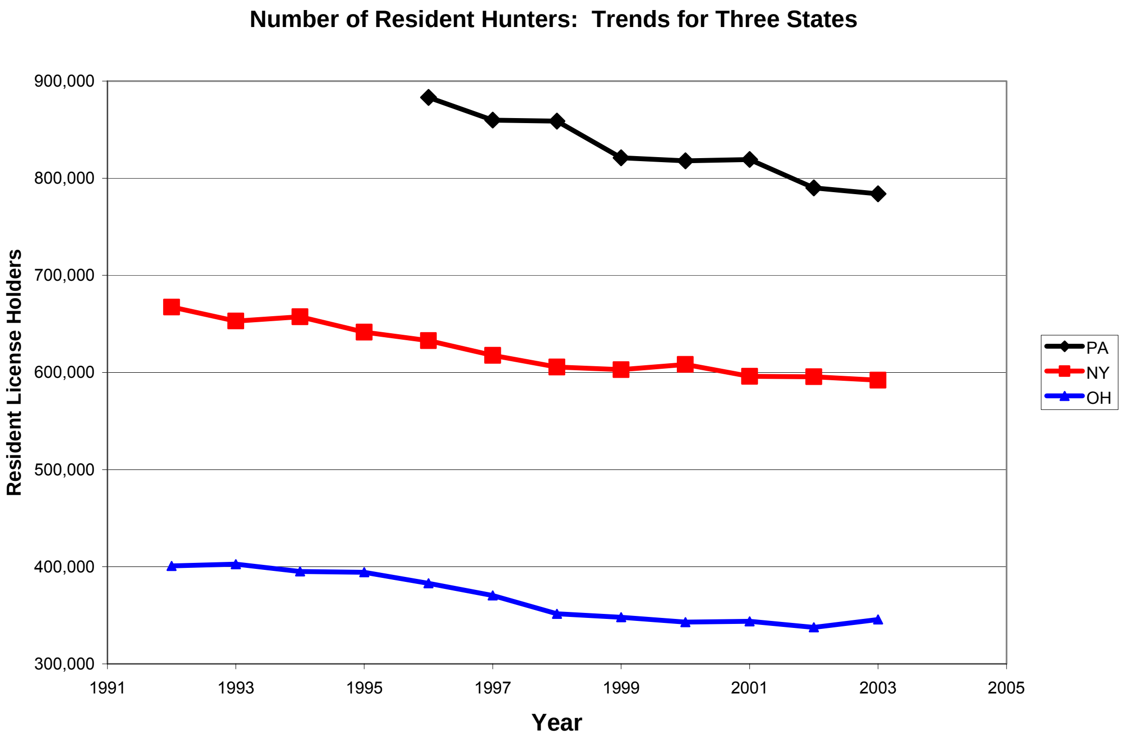
APPENDIX 2.A - Hunter Trends for Selected States



Resident Licenses Sold[10]

Year	PA	NY	OH	NJ
1992		667,301	400,749	84,261
1993		652,913	402,638	80,617
1994		657,304	395,261	77,058
1995		641,493	394,441	73,942
1996	883,091	632,802	382,919	70,190
1997	859,936	617,727	370,487	66,863
1998	858,914	605,589	351,628	63,897
1999	820,931	602,872	347,974	59,707
2000	817,970	608,234	343,078	60,085
2001	819,232	596,094	343,827	56,574
2002	789,959	595,554	337,539	54,106
2003	783,955	592,006	345,818	52,315

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[10] Data provided by respective state game management agencies.

APPENDIX 2.B - MWG (1995) Equivalence, with Hunting Scenario

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 $f(\pi \mid e)$. 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 $e(\theta)$ that the hunter should take and a compensation scheme $w(\pi \mid \theta)$ (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 $e(\theta)$ 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 $\pi(e)$. 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 $\pi(e)$, and give him a payment of $-\infty$ 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 2.C - Maskin and Riley (1984) Adapted to Hunter Typologies

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

The PGC monopolist produces a single "product" (the right to a deer harvest) at a constant marginal (administrative and production) 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):

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

where q is the number of deer tags purchased from 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

$$R_s = T_s - cq_s. \qquad (2)$$

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 principal) 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 $<q_s, R_s>_{s \in S}$, offered to each of the hunters

Maskin and Riley's Figure 1 (see Figure 2.5 below) illustrates how the PGC could separate hunter types with the appropriate 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 payment to the PGC, 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 2.5 Note that at $\langle q, R \rangle$ the slope of the corresponding indifference curve is

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

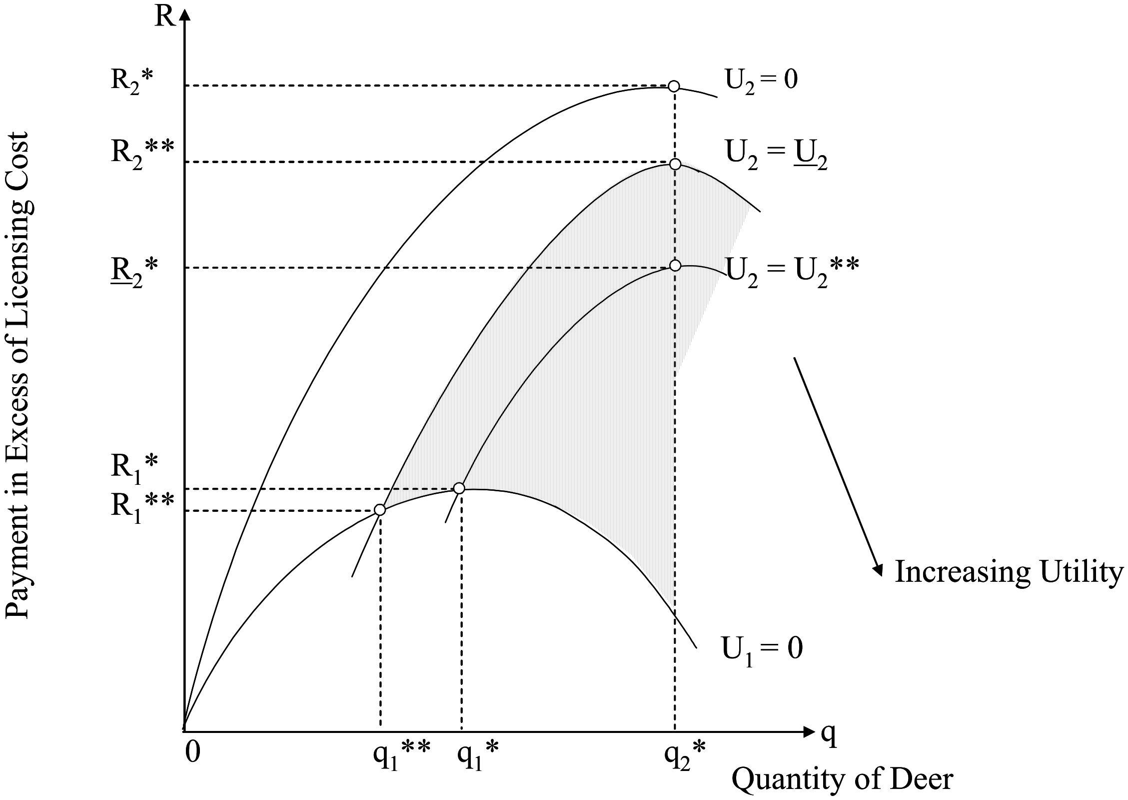

FIGURE 2.5: Adapted from Maskin and Riley (1984)

Therefore, at any point $\langle q, R \rangle$ 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, 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 $R_1^* + cq_1^*$.

APPENDIX 2.D - KQDC Hunter Survey: Selected Summary Statistics

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 2.E - OLS Results, Ordered Probit Dummy Variables

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

Regression Statistics	
Multiple R	0.546093
R Square	0.298218
Adjusted R Square	0.296547
Standard Error	1.225767
Observations	1264

	df	SS	MS	F	Significance F
Regression	3	804.484616	268.161539	178.476318	1.98573E-96
Residual	1260	1893.156144	1.502505		
Total	1263	2697.640759			

	Coefficients	St Error	t Stat	P-value
Intercept	4.562671	0.217284	20.998607	3.49124E-84
ln(P)	-1.354124	0.099481	-13.611929	1.81231E-39
Dhigh	2.132898	0.120343	17.723534	6.29852E-63
Dmed	0.740835	0.077048	9.615251	3.5988E-21

APPENDIX 2.F - Model 2 Ordered Probit LIMDEP ® Results

```
--> ORDERED;Lhs=DHT;Rhs=ONE,DOEHARV,EARLY,FIREARM,D9P,D9T;Marginal
Effects;Keep=HTHAT$
+---------------------------------------------+
| Ordered Probability Model                   |
| Maximum Likelihood Estimates                |
| Model estimated: Mar 16, 2006 at 09:46:27AM.|
| Dependent variable                 DHT      |
| Weighting variable                None      |
| Number of observations             632      |
| Iterations completed                12      |
| Log likelihood function      -460.7371      |
| Restricted log likelihood    -558.6736      |
| Chi squared                   195.8730      |
| Degrees of freedom                   5      |
| Prob[ChiSqd > value] =        .0000000      |
| Underlying probabilities based on Normal    |
|    Cell frequencies for outcomes            |
|  Y Count Freq  Y Count Freq  Y Count Freq   |
|  0   385 .609  1   187 .297  2    59 .093   |
+---------------------------------------------+
+---------+--------------+----------------+--------+---------+----------
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of X|
+---------+--------------+----------------+--------+---------+----------
          Index function for probability
Constant    -1.49089566      .15153827    -9.838   .0000
DOEHARV       .51986423      .04638729    11.207   .0000    1.32278481
EARLY         .01155945      .00692162     1.670   .0949    4.79667722
FIREARM       .03498929      .01453304     2.408   .0161    4.89398734
D9P           .33572466      .13641841     2.461   .0139     .79588608
D9T           .05625223      .10708353      .525   .5994     .33860759
          Threshold parameters for index
Mu(1)        1.35244954      .08876390    15.236   .0000

+-----------------------------------------------------+
| Marginal effects for ordered probability model      |
| M.E.s for dummy variables are Pr[y|x=1]-Pr[y|x=0]   |
| Names for dummy variables are marked by *.          |
+-----------------------------------------------------+
+---------+--------------+----------------+--------+---------+----------
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of X|
+---------+--------------+----------------+--------+---------+----------
          These are the effects on Prob[Y=00] at means.
Constant        .000000   ......(Fixed Parameter).......
DOEHARV      -.19883850      .01799841   -11.048   .0000    1.32278481
EARLY        -.00442128      .00264839    -1.669   .0950    4.79667722
FIREARM      -.01338276      .00555901    -2.407   .0161    4.89398734
*D9P         -.12365167      .04785234    -2.584   .0098     .79588608
*D9T         -.02156872      .04115182     -.524   .6002     .33860759
          These are the effects on Prob[Y=01] at means.
Constant        .000000   ......(Fixed Parameter).......
DOEHARV       .14503595      .01306310    11.103   .0000    1.32278481
EARLY         .00322495      .00193138     1.670   .0950    4.79667722
FIREARM       .00976160      .00405809     2.405   .0162    4.89398734
*D9P          .09400356      .03772148     2.492   .0127     .79588608
*D9T          .01565844      .02973353      .527   .5985     .33860759
          These are the effects on Prob[Y=02] at means.
Constant        .000000   ......(Fixed Parameter).......
DOEHARV       .05380255      .01429864     3.763   .0002    1.32278481
EARLY         .00119633      .00081048     1.476   .1399    4.79667722
FIREARM       .00362116      .00200821     1.803   .0714    4.89398734
*D9P          .02964810      .01616865     1.834   .0667     .79588608
*D9T          .00591027      .01162247      .509   .6111     .33860759
```

```
+-----------------------------------------------------------------------
| Summary of Marginal Effects for Ordered Probability Model (probit)
+-----------------------------------------------------------------------
Variable|    Y=00    Y=01    Y=02   Y=03   Y=04   Y=05   Y=06   Y=07 |
-----------------------------------------------------------------------
ONE         .0000   .0000   .0000
DOEHARV    -.1988   .1450   .0538
EARLY      -.0044   .0032   .0012
FIREARM    -.0134   .0098   .0036
*D9P       -.1237   .0940   .0296
*D9T       -.0216   .0157   .0059
+-----------------------------------------------------------------------
|   Cross tabulation of predictions. Row is actual, column is predicted.
|   Model = Probit    .  Prediction is number of the most probable cell.
+-------+-------+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| Actual|Row Sum|  0  |  1  |  2  |  3 |  4 |  5 |  6 |  7 |  8 |  9  |
+-------+-------+-----+-----+-----+-----+-----+-----+-----+-----+-----
|      0|    385|  355|   29|    1|
|      1|    188|  115|   68|    5|
|      2|     59|   17|   23|   19|
+-------+-------+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|Col Sum|    632|  487|  120|   25|   0|   0|   0|   0|   0|   0|   0|
+-------+-------+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

APPENDIX 2.G - Success Rate Estimation for Each Type

Low-Demand Hunters: 383 total

Tag Number	Hunters who Purchased at least this number of Tags	Hunters who harvested at least this number of Deer	Implied Success Rate
1	383	200	52.2%
2	276	6	2.2%
3	83	0	0%
4	27		
5	9		
6	4		
7	3		

Medium-Demand Hunters: 189 total

Tag Number	Hunters who Purchased at least this number of Tags	Hunters who harvested at least this number of Deer	Implied Success Rate
1	189	189	100%
2	181	164	90.6%
3	113	37	32.7%
4	46	0	0%
5	19		
6	4		
7	2		
8	2		

High-Demand Hunters: 60 total

Tag Number	Hunters who Purchased at least this number of Tags	Hunters who harvested at least this number of Deer	Implied Success Rate
1	60	60	100%
2	58	60	100%
3	52	60	100%
4	39	33	84.6%
5	31	11	35.5%
6	12	3	25.0%
7	4	2	50.0%
8	3	1	33.3%
9	3	1	33.3%
10	3	0	0%

APPENDIX 2.H - Model 1, LINGO® Nonlinear Optimization Code

```
! Finding the Single-Price Optimum;

MAX = (MLOW*(BETALOW*GAMMA3*(1-@EXP(-
1*BETA3*QLOW))))+(MMED*(BETAMED*GAMMA3*(1-@EXP(-
1*BETA3*QMED))))+(MHIGH*(BETAHIGH*GAMMA3*(1-@EXP(-1*BETA3*QHIGH))));

M=800000;

GAMMALOW=4.56267;
GAMMAMED=5.30351;
GAMMAHIGH=6.69557;
GAMMA3=1.35412;

BETALOW=@EXP(GAMMALOW/GAMMA3);
BETAMED=@EXP(GAMMAMED/GAMMA3);
BETAHIGH=@EXP(GAMMAHIGH/GAMMA3);
BETA3=1/GAMMA3;

RLOW=.52;
RMED=.91;
RHIGH=1;

MLOW=.6*M;
MMED=.3*M;
MHIGH=.1*M;

HSTAR=450000;

QLOW=GAMMALOW-(GAMMA3*@LOG(PLOW));
QMED=GAMMAMED-(GAMMA3*@LOG(PMED));
QHIGH=GAMMAHIGH-(GAMMA3*@LOG(PHIGH));

QLOW>0;
QMED>0;
QHIGH>0;

PLOW>0;
PLOW<BETALOW;
PMED>0;
PMED<BETAMED;
PHIGH>0;
PHIGH<BETAHIGH;

(RLOW*MLOW*QLOW)+(RMED*MMED*QMED)+(RHIGH*MHIGH*QHIGH)=HSTAR;

PGCREV=(MLOW*QLOW*PLOW)+(MMED*QMED*PMED)+(MHIGH*QHIGH*PHIGH);

CSLOW=(BETALOW*GAMMA3*(1-@EXP(-1*BETA3*QLOW)))-(PLOW*QLOW);
LOWTOTCS=MLOW*CSLOW;
CSMED=(BETAMED*GAMMA3*(1-@EXP(-1*BETA3*QMED)))-(PMED*QMED);
MEDTOTCS=MMED*CSMED;
CSHIGH=(BETAHIGH*GAMMA3*(1-@EXP(-1*BETA3*QHIGH)))-(PHIGH*QHIGH);
HIGHTOTCS=MHIGH*CSHIGH;
```

Essay 3

Policy Options for Overabundant Deer: Are Socially Optimal Deer Densities Possible?

“Control of the size and composition of the kill in sport hunting cannot transcend the ability and willingness of hunters to conform.” (McCullough, p.236)

3.1: Introduction, Objectives, and Methodology

White-tailed deer (*Odocoileus virginianus*) are a highly valued wildlife resource. Over 10 million Americans over the age of 16 hunt deer each year, and these hunters are estimated to spend $10.7 billion annually in deer-hunting related expenditures (U.S. Fish and Wildlife Service). However, deer are not an unambiguous good. The Insurance Institute for Highway Safety estimates that each year there are more than 1.5 million deer-vehicle accidents in the United States annually, causing $1.1 billion dollars in vehicle damages, injuring approximately 10,000 motorists, and killing approximately 150 people (Dombrowski). Damage from deer browsing to agriculture and the saw-timber industry is estimated in the hundreds of millions of dollars annually (Conover). For years, forest scientists and ecologists have voiced concern over the damage that large deer populations can cause to ecosystems in general, and forest habitats in particular. The recognition of problems related to the size of the deer population have led to calls for management agencies to take action to reduce deer densities in some areas. The issue of increased deer densities has recently hit the mainstream media, with two editorials in the New York Times (NYT editorial; and Kristof) and a front-page article in the Wall Street Journal (Sterba) indicating that sport hunting and other methods should be used to decrease the deer populations below current levels.

Deer population levels are traditionally controlled by harvest restrictions on sport hunters. Reducing population levels under the traditional approach would simply require increasing the allowable harvest of female (antlerless) deer. Yet the number of deer hunters in some states is steadily decreasing, especially in the northeast United States (see Appendix A). For example, the number of resident licenses to hunt deer dropped from a peak of 712,000 in 1984 to 621,000 by 1997 in New York State, and only 592,000 by 2003 (NYS DEC). New York and Pennsylvania are both states whose game-management agencies have publicly admitted they are attempting to reduce deer densities statewide even as hunter populations are decreasing. Concurrent with this decrease in hunters has been an anecdotal (but generally accepted) decrease in the *hunting effort*, by which is meant a combination of hunting fewer hours, hunting only in good weather, and hunting only in easily accessible areas. Reduced hunter numbers and hunter effort imply reduced harvests and subsequently growing deer stocks, increasing the damages caused by deer.

White-tailed deer stocks were much smaller at the beginning of the 20th century than they are today. At that time total hunting effort, as determined by both the numbers of hunters and the effort per hunter, was relatively large. Concern for conservation of the species led to hunting regulations to protect the deer herd from being extirpated. Antlerless deer harvests began only after deer populations started to increase rapidly in the mid-1900s. Riley et al. explained how regulated recreational hunting of antlerless deer became the primary method by which white-tailed deer numbers were managed, and discusses how this method is still very effective where hunters are putting forth sufficient effort. Control of deer populations is not possible, however, if hunter numbers and hunter effort are too low over a specific area of deer habitat. Suburban areas with weapons discharge prohibitions, national parks, and even large areas of private land excluded from hunting access have had to resort to culling and other expensive methods of deer management. This essay is interested only in analyzing areas of deer habitat that *are* open to sport-hunting, but traditional hunting methods are not resulting in optimal deer densities.

All other things being equal, and absent quality concerns such as stunted or starving deer, hunters would prefer larger deer stocks. As self-interested consumers of deer through sport-hunting, most hunters would enjoy deer populations and deer densities that are at or near the ecological carrying capacity, K, of the habitat. Higher deer densities reduce the effort necessary to harvest a deer, as well as adding to the enjoyment of hunting by making deer and deer sign more abundant. The majority of deer hunters do not consider the negative externalities of high deer densities, however (Luloff et al.). The managing agency tasked with selecting the socially optimal level of deer densities (in Pennsylvania, the PGC) must consider these negative externalities, and balance those against other societal objectives.

The purpose of this essay is to investigate a policy option for large areas of deer habitat for which hunter effort is not sufficient to reach the harvest goals of the management agency. New York, Pennsylvania, Ohio, Maryland, Maine, and New Jersey have been unable to reduce deer populations to the desired levels with traditional sport hunting. Modeling hunters as utility-maximizing consumers of deer, and hunter effort as costly, a policy of payments to hunters for harvesting antlerless deer using Pennsylvania data will be analyzed using a discrete-time dynamic program. The resulting recommended deer densities, harvest levels, and payments will be tested for their sensitivity to calibrated parameters. A final policy recommendation will be based on the results of the model.

Objectives

Economists view deer populations as a renewable resource, a composite asset that provides both benefits and costs to humans over time. As with any other asset, the economic goal of deer management should be to achieve the deer population that optimizes the value of the asset over time. Horan et al. (1999) state that: "A common assumption in the bioeconomic resource management literature is that economic efficiency is the goal of policy makers" (p 191), and list numerous examples (Bjorndal; Clark; Neher; Conrad (1995); Montgomery and Adams). Using this assumption, if all costs and benefits of a deer population for a given habitat are considered, the dynamically optimal deer density for that habitat can be determined.

This essay seeks to determine the optimal management of deer using a bioeconomic model that recognizes three important factors. First, deer hunters can not be *directed* to harvest deer on a large scale. They must have the proper incentives to harvest more deer if the socially optimal deer densities demand it. Second, deer harvest is a nonlinear function of hunter effort, implying that the marginal cost to society of reducing deer densities is increasing. And third, deer damage is not a linear function of deer density, with marginal damage increasing above certain threshold levels of deer density (DeCalesta and Stout). A realistic policy to use sport hunting to reduce deer densities below their current levels, if optimal, should be analyzed in all of its complexity. This essay develops a bioeconomic model of optimal deer densities. The specific objectives of this essay are:

1. Compute the economically efficient deer population/density, annual harvests, and hunter effort
2. Test the sensitivity of the results to the calibrated parameters of the model.

3. Recommend a policy alternative for game-management agencies attempting to reduce deer densities with sport hunting effort.

Methodology

A dynamic optimization of the social welfare provided by the white-tailed deer population will indicate the optimal deer density and hunter effort that management agencies should attempt to achieve. My methodology considers the following interactions explicitly. First, hunter effort is costly and exhibits decreasing marginal effectiveness at lower deer densities. Second, deer damage is a piecewise linear function of deer density. Third, payments for an antlerless deer harvest are the managing agency's control variable as an incentive to induce hunting effort.

Section 2 discusses the economic, social, and legal considerations that must be considered in addressing the problem of deer overabundance, and the general policy context of increasing hunter effort. Section 3 develops a theoretical model of both social welfare maximization and hunter utility that defines overabundance. Section 4 then develops the specific hunter utility function to be used in this analysis, and introduces the factors that increase hunter effort and deer harvest. In Section 5, the dynamic programming problem to determine optimal deer densities, modeling the policy of payments to hunters for harvesting antlerless deer, is then developed. Data and parameters from the state of Pennsylvania are used to calibrate the model in Section 6, but the technique is applicable to any sizeable area of deer habitat where the deer density currently exceeds the social carrying capacity of the habitat. Results and optimal path analysis of the base case scenario for Pennsylvania are discussed in Section 7. Sensitivity analysis for the parameters of interest is conducted in Section 8. An estimated "regional model" for a state game agency with multiple areas of responsibility, and where deer damage and hunter utility vary by region, is outlined in Section 9. The policy implications of the results are discussed in Section 10, along with suggested areas of future research.

Models of renewable natural resources, especially forests and fisheries, are well-developed in the literature. The goal for the management of these renewable resources, whether publicly or privately owned, is to determine the harvest rates (or rotation age) that maximize the value of the resource considering all of the appropriate costs and benefits (Van Kooten and Bulte). Terrestrial wildlife analysis is less-widely covered, but a large literature does exist (see Horan and Bulte; Zivin et al.; Chavas and Holt; Skonhoft; Bulte and Horan; Skonhoft and Solstad; Van Kooten et al.; Brock and Xepapadeas; Ready et al.; Rosen). Within the literature on deer-management policy specifically, of particular importance is Rondeau and Conrad, who modeled an optimal deer management scheme for an isolated deer population. A limitation of their model for the purposes of this study is their model does not consider the benefits of deer to hunters as a source of utility from hunting and harvesting, which is a considerable value where recreational hunting is allowed. This essay adds to the deer management policy literature by including stock dependent hunter utility and non-linear hunter effort in the net benefit function of the deer herd.

3.2: The Challenge of Deer Overabundance

Solutions to the problem of large-scale deer overabundance are complicated by institutional challenges commonly referred to as the human dimensions of wildlife management. One complication is the practice of state ownership of wildlife resources (Bean; Lueck; Huffman) and the concept that wildlife belong to the public in general. State ownership of wildlife, by itself, is not the cause of the overabundance problem. Indeed, State ownership would seem to be justified for deer management due to the public goods nature of deer (Shuhmann and Schwabe). For example, hundreds of commuters may enjoy seeing deer in a farmer’s fields on their drive home from work. The viewing value is nonrivalrous and nonexcludable. The farmer, who may enjoy the viewing value of the deer as well, is paying the costs (in lost farm productivity) of the deer herd in his fields, while the commuters are free-riding. If the farmer was able to select his own optimal quantity of deer, it may be less than the efficient amount considering the public good viewing value of the deer. The problem of overabundance stems from the fact that the state has imperfect control over the amount of hunter effort, as well as where that hunter effort is applied.

State ownership of deer was originally justified to alleviate the open-access problem that may occur if no state control existed (Van Kooten and Bulte). The public goods nature of deer only applies to the non-consumptive benefits that deer provide, such as viewing values and existence values. Consumption of deer through recreational hunting is indeed rivalrous and excludable. Limited hunting seasons and harvest limits were created to control individual hunters who do not consider the effects of their own harvest choices on the reduction in resources for others. The constraints on hunter's time and effort that traditional hunting regulations impose are not helpful in solving an overabundant deer population if it exists.

State ownership of the deer herd is accepted through legal precedent and tradition, but private land ownership rights add another complication. Wildlife may be publicly owned, and controlled by state game management agencies, but large land owners can easily restrict the public's access to that wildlife resource by enforcing their private property rights. Economic optimization may direct an optimal harvest and hunter effort level, but if hunters are not allowed access to the habitat by private landowners, no harvest can occur and sub-optimal deer densities will result.[11]

The second complication when searching for policy solutions to overabundant deer is the general concept of externalities; simply put, the costs and benefits of deer do not accrue to the same members of society (Cornes and Sandler). Distributional and equity issues when considering the costs and benefits that deer provide quickly become overwhelming. Depending upon whether an individual primarily receives the benefits from the deer herd (hunters, photographers, wildlife watchers) or primarily incurs the costs (farmers, silviculturalists, gardeners), the desired prescribed deer density level will be vastly different. These conflicting interests are evident in the emotional debates surrounding any attempt to change deer management techniques and deer populations (Curtis and Hauber; Kirkpatrick and Turner; Rutberg).

The final institutional complication when modeling policy solutions for deer overabundance is the consideration of how game management institutions behave in practice (Walters). Game management agencies are bureaucracies like any other, with both their constituents and internal members divided into "power blocks or factions" with narrow self-interests (Allison). Public Choice Theory suggests that "policy makers seem to be particularly concerned with the economic welfare of politically powerful interest groups with a direct economic interest in the use of resources, and equity issues" (Horan

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[11] Anderson and Hill's book is a more complete analysis of how most of these complications could be overcome with private property rights and markets for wildlife. For this essay, however, state ownership and control of deer populations is assumed to continue for the foreseeable future.

et al., p.192). Although a rich literature exists on the topic[12], this essay considers that the economic stakeholders concerned with deer populations are numerous and diverse enough that the eventual policy outcome will closely represent the social-welfare maximizing result.

A scientific complication when optimizing deer stocks is accurately measuring the costs and benefits of the deer herd. Non-market valuation techniques must be used in any case, leading to disagreements about the assumptions and methodology chosen (Van Kooten and Bulte). This essay attempts to avoid a discussion of the available techniques for evaluating the costs and benefits of deer and simply uses literature already available on the topic (Conover; Drake; Ritz and Ready; Decker and Connelly) and then analyzing the sensitivity of the results to the parameters used in the model.

3.2.1: Policy Considerations to Increase Hunter Effort for Antlerless Deer

In this analysis, I am concerned with the economics of *antlerless* deer harvest to control deer populations on a large scale. Antlered deer (bucks) are still valued highly enough by hunters that they can easily be controlled at or below recommended biological levels through traditional hunting. Thus, throughout the remainder of this paper, "deer harvest" and "deer overabundance" refers to antlerless deer unless otherwise stated.

The first policy consideration when antlerless deer harvests are below desired levels should be to extend the deer seasons to ensure that hunters are not time-constrained in their hunting effort. An obvious criticism of the Pennsylvania deer season is that hunting is not allowed on Sundays. The opportunity cost of hunters' time is lower on Sunday, and many hunters would be able to expend more hunter hours if the option of hunting on Sunday existed. These "blue laws" in Pennsylvania and other states, however, are a political reality that can only be changed slowly through political effort. Another criticism of the Pennsylvania deer season is that the rifle season is only 2 weeks long. Deer hunters in Pennsylvania currently have the option to archery hunt over a 50-day season, rifle hunt over a 12-day season, and muzzleloader hunt over a 22-day season (Pennsylvania Hunting and Trapping Digest, 2005) so arguably hunters are not time constrained. Again, for the purposes of this model we are determining an optimal

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[12] See the previously mentioned article by Horan et al. for a list of relevant public choice literature.

outcome assuming that the deer habitat under analysis contains un-constrained hunter effort hours.

A second policy consideration often mentioned would be reduced price, or zero-price, hunting licenses and harvest tags. In general, hunting licenses and harvest tags in states with overabundant deer are already low priced. The fees are designed to cover administrative costs and conservation officer salaries, not as a method of reducing demand for hunting licenses. In New York State, for example, a resident deer hunting license is only \$19, and up to 2 antlerless deer tags are awarded based upon WMU for no additional charge (www.dec.state.ny.us). Hunter surveys in Pennsylvania have shown that 9%-10% of hunters who purchase hunting licenses each year do not even hunt, indicating that license fees are not a significant deterrent to hunting effort (Luloff et al.). Compared to estimated hourly wages of w = \$20, the additional hunting effort expected from zero-price hunting licenses would be minimal.

A policy option that has been used successfully in small, controlled areas and specific deer habitat is professional culling. Using culling to reduce deer densities on *large* tracts of land where sport hunting is allowed poses numerous problems. First, the number of sharpshooters and professional cullers required for a regional or statewide effort at deer reduction simply do not exist. Although technically possible, it would also be politically infeasible to allow cullers to use more effective killing methods (baiting, spotlighting) than hunters themselves, and then pay them to remove the deer, making it more difficult for traditional hunters to find and kill deer. The only large-scale source of manpower available to reduce deer densities are hunters themselves, and as discussed earlier, socio-political norms serve as a constraint on the methods that could be used to cull deer on a large scale.

So what policy option exists whereby hunters could be compensated for their hunting effort, and given incentives to harvest more antlerless deer? A variant of the professional culling concept would be to compensate hunters for antlerless deer harvests. Traditional hunting methods would be used, which may be less efficient than pure culling with bait and spotlighting, but these traditional methods are already socially acceptable. Numerous authors have suggested that incentives and encouragement of some type are needed for hunters to harvest more antlerless deer. Riley et al. recommend a "paradigm shift…from one of protection of a scarce resource to one of managing the impacts of deer" (p.459). These authors also suggest that "hunting may become… more a community service or civic duty should the (negative) impacts of deer be broadly recognized." Brown et al. stated that "regulations need to give hunters incentives to shoot antlerless deer voluntarily or simply require them to do so" (p.797).

Whether a compensating payment to hunters for each antlerless deer harvested would be socially acceptable (both to hunters and non-hunters) is debatable. Many hunters would probably consider it a "bounty," and an affront to their sport, and may not even accept a payment. Concurrently, many non-hunters may object strongly to hunters being "rewarded" for participating in a sport that they love and enjoy already. The strongest opposition may come from animal-rights activists and a vocal minority of citizens who already object to hunting on moral and ethical grounds. Using taxpayer funding to pay hunters to kill additional animals would be highly objectionable to these people, even if the damage that deer cause to the forest ecosystems is well understood and the benefits of reduced deer densities is properly explained. Some form of incentive must be provided to hunters to reduce deer densities, or the current situation of overabundant deer will continue to confound game managers.

One method of stealth compensation for additional deer harvests may be allowing harvested animals to be sold for consumption. This practice is widely followed in Europe, and has been suggested as a policy alternative in the United States (Finley). The state of Missouri currently compensates hunters who donate deer to their statewide "Hunters for Harvest" program, where butchers process donated deer for low-income families, as a method of partially compensating hunters for their time spent harvesting deer that the hunters do not want to consume themselves. The $35 payment is small, but the program has increased in popularity every year since its inception (Murphy). The value of a harvested antlerless deer could be generally estimated from substitute protein (beef, pork, chicken) prices and average antlerless deer carcass weights, but would probably not exceed $100 per animal (Finley and author calculations).

For the purposes of this paper, a compensating payment to hunters for antlerless deer harvests is assumed to be possible and easily implemented. Hunters would be required to show their harvested deer at game-management agency check-stations, and receive payment for each harvested deer. As a policy to reduce deer densities in areas where hunter effort is currently not sufficient to do so, a model of optimal deer densities can then be tested.

3.3: A Theoretical Model to Define Overabundance

3.3.1: Societal Optimum

Consider the problem of a management agency (in this specific case, the Pennsylvania Game Commission, or PGC) that seeks to maximize the economic efficiency of its deer herd. Using a general population model (Clark) that ignores age and sex variations in the population, the deer stock at any time *t* is expressed as X(t)[13]. Dynamic economic analysis of large mammal populations that have also represented animal populations in this simplified manner include Horan and Shortle (whales), Zivin et al.(feral pigs), Horan and Bulte (elephants), Rondeau (wolves, grizzlies, beaver, and deer), and Rondeau and Conrad (deer). The agency controls the deer density by allowing harvests, H(t). Hunters achieve deer harvests through hunter effort, E(t).

The benefits of the deer stock have both a consumptive and non-consumptive element. The consumptive element of the net benefits from the deer herd accrues to hunters when deer are harvested. Consumptive benefits can be represented by a composite hunter utility function, U(H(t),E(t)), which is continuous and twice differentiable. I will assume that $U_H > 0$, $U_{HH} < 0$, $U_E < 0$, and $U_{EE} = 0$, where subscripts indicate partial derivatives. Thus, hunters receive positive utility from harvested deer at decreasing rates, but negative utility from expending hunter effort at a constant marginal opportunity cost of time. Non-consumptive benefits of the deer stock (viewing, photography, existence, bequeath) are represented by the function N(X(t)). I will assume N(X) is strictly concave with N(0) = 0, $N_X > 0$, and $N_{XX} < 0$. Likewise, the damage inflicted by deer can be represented by a composite damage function, D(X(t)). The elements of this damage function are described later, but should capture the numerous ways that deer can cause harm to biodiversity, crops, forests, automobiles, human health,

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[13] Nonlinear demographic theory for the management of animals (Getz and Haight) considers complications of age-structure, gender ratios, and harvest values (males preferred to females, as with white-tailed deer) to create more realistic population stock models. Multispecies ecosystem effects, spatial effects and diffusion, and seasonal effects are all discussed by Clark (chapters 7, 9, and 10). I accept the imprecision of the general population model that represents the stock, X(t), as a simplification for the dynamic optimization.

etc. The damage from deer is an increasing and convex function, with $D(0) = 0$, $D_X > 0$, and $D_{XX} \geq 0$.

The evolution of the deer stock over time is represented by

$$\dot{X} = F(X(t)) - H(t) \qquad (1)$$

The growth function, $F(X)$, incorporates the deer herd's natural fecundity and mortality rates (Clark). Letting K represent the habitat's carrying capacity, I will assume $F(X)$ is strictly concave for $0 \leq X \leq K$, as well as $F(0) = F(K) = 0$.

Harvest of deer is modeled as a production function, with hunting effort, E, and the deer stock, X, as the productive inputs, and the deer harvest, H, as the output. In general, the production function for deer will be a concave function of deer density and hunter effort

$$H(t) = H(X(t),E(t)) \qquad (2)$$

with strictly positive first partial derivatives ($H_X > 0$, $H_E > 0$) and strictly negative second partial derivatives ($H_{XX} < 0$, $H_{EE} < 0$), to ensure decreasing marginal productivity of hunting effort over all deer densities.

A pareto optimal management plan for the PGC would be one in which the paths of hunter effort, deer harvest, and deer stock maximize the discounted social value of the net benefits of the deer population (Leonard and Van Long). Suppressing the time indices for ease of notation, and with δ the social discount rate, the economically optimal plan solves:

$$\underset{(E)}{\text{Maximize}} \int_0^\infty e^{-\delta t} [U(H(X,E),E) + N(X) - D(X)]\, dt \qquad (3)$$

$$\text{subject to:} \quad \dot{X} = F(X) - H(X,E) \qquad (3a)$$

$$X \geq 0;\ H(X,E) \geq 0 \qquad (3b)$$

$$X \geq H(X,E) \qquad (3c)$$

$$X(0) = X_0, \text{ given} \qquad (3d)$$

The optimal plan can be characterized using the maximum principle (Pontryagin et al.). The current value Hamiltonian for the game-manager's problem is:

$$\mathcal{H} = [U(H(X,E),E) + N(X) - D(X)] + \lambda[F(X) - H(X,E)] \qquad (4)$$

with λ as the costate variable.

Non-consumptive values of deer for the non-hunting population are large, but constant, as long as there is a viable population of deer greater than zero (Conover). If it is reasonable to assume that these non-consumptive values are large enough to never make it optimal to extirpate the deer herd, i.e. that $X(t) > 0$ for all time periods, then I will consider $N_X = 0$ over the range of deer stock considered here. The solution to the game management agency's problem with boundary condition X_0 given, represented by equations (3) – (3d), will define a set of functions that maximize social welfare: $E^*(t)$, $X^*(t)$, and $\lambda^*(t)$.

With the reasonable assumption that the $N(X)$ function is constant over positive deer densities, $N(X)$ can be removed from the Hamiltonian in equation (4), and the necessary conditions for an optimal solution (Leonard and Long) are

$$\partial \mathcal{H}/\partial E = [(U_H \cdot H_E) + U_E] - \lambda(H_E) = 0$$

$$\Rightarrow U_H + U_E/H_E = \lambda \tag{5}$$

$$-\partial \mathcal{H}/\partial X = \dot{\lambda} - \delta\lambda = -[(U_H \cdot H_X - D_X)] - \lambda(F_X - H_X)$$

$$\Rightarrow \dot{\lambda} = (D_X - U_H \cdot H_X) + \lambda(\delta + H_X - F_X) \tag{6a}$$

$$\Rightarrow \delta = \frac{\dot{\lambda}}{\lambda} + \frac{U_H \cdot H_X - D_X}{\lambda} + (F_X - H_X) \tag{6b}$$

$$\partial \mathcal{H}/\partial \lambda = \dot{X} = F(X) - H(X,E) \tag{7}$$

With the current stock of deer estimated by the management agency, represented by equation (3d), an additional transversality condition that guarantees convergence of the solution is necessary (Rondeau):

$$\lim_{t \to \infty} X(t)\lambda(t) = 0 \tag{8}$$

indicating that the discounted value of the deer stock goes to zero over an infinite time horizon.

The interpretation of the necessary conditions is as follows. Equation (5) indicates that the costate variable, $\lambda(t)$, (the discounted shadow price of a deer) along the optimal path is the combination of the dollar-valued marginal utility potentially received from harvesting the deer and the marginal disutility of the effort required for that harvest. Equation (6b) has been arranged as an arbitrage condition, consisting of three components. These components represent returns or losses from the deer stock that the management agency must compare to the opportunity cost of capital, δ. The first component is the return on the value of the deer stock because of the increase or decrease in the shadow price, or the rate of capital gain. The second component represents the benefits due to marginal harvest minus the marginal damage of the stock. The third component is the natural growth rate of the stock reduced by the increased harvest that growth will allow. At the optimum, the manager will balance society's rate of return with these three components of the return on the deer stock, and be indifferent between them. Finally, equation (7) indicates that the stipulated law of motion will be met along the optimal path.

A phase-diagrammatic analysis in the hunter effort – deer stock (E – X) plane can assist in elucidating the possible solutions of the general problem. Characterizing the optimal steady state deer stock and hunter effort requires additional manipulation of the first-order conditions in equations (5) – (7). Recognizing that U_H, like $U(\cdot)$, is a differentiable function of deer stock and hunting effort as well, $U_H(H(X,E), E)$, we can totally differentiate equation (5) to get another expression for $\dot{\lambda}$:

$$\dot{\lambda} = U_{HH}\{H_X \cdot \dot{X} + H_E \cdot \dot{E}\} + U_{HE} \cdot \dot{E} - 2\{U_E(H_{EE} \cdot \dot{E} + H_{EX} \cdot \dot{X})/(H_E)^2\} \tag{9}$$

Then, substituting λ from equation (5) into equation (6a) gives the expression

$$\dot{\lambda} = (D_X - U_H \cdot H_X) + [U_H + (U_E/H_E)](\delta + H_X - F_X) \tag{10}$$

And setting equation (9) equal to equation (10) yields:

$$(D_X - U_H \cdot H_X) + [U_H + (U_E/H_E)](\delta + H_X - F_X) = U_{HH}\{H_X \cdot \dot{X} + H_E \cdot \dot{E}\} + U_{HE} \cdot \dot{E} - 2\{U_E(H_{EE} \cdot \dot{E} + H_{EX} \cdot \dot{X})/(H_E)^2\} \tag{11}$$

Collecting terms and simplifying yields the differential equation for the control variable that must hold for the optimal hunter effort,

$$\dot{E} = \frac{(D_X - U_H \cdot H_X) + [U_H + (U_E/H_E)](\delta + H_X - F_X) - \dot{X}\,[U_{HH} \cdot H_X + 2\{U_E \cdot H_{EX}/(H_E)^2\}]}{U_{HH} \cdot H_E + U_{HE} - [2\{U_E \cdot H_{EE}/(H_E)^2\}]} \tag{12}$$

and the previously known equation of motion for the deer stock, equation (7).

The representation of the solution in a phase diagram will involve separating the phase space into regions where we know the trajectories of the variables over time. The separatrices represented by $\dot{E} = 0$ and $\dot{X} = 0$ will define these regions. The costate variable, $\lambda(t)$, for the manager's optimal control problem may be either positive or negative. Zivin et al. and Rondeau indicate that animals with both stock benefits and damages, and harvest (control) costs and benefits, can have positive or negative shadow prices even in an optimal program. The result is that there are often multiple equilibrium candidates, and as Rondeau shows clearly, probable discontinuities in the $\dot{E} = 0$ isocline. A qualitative analysis of the optimal solution, however, will be beneficial in defining the conditions for overabundance.

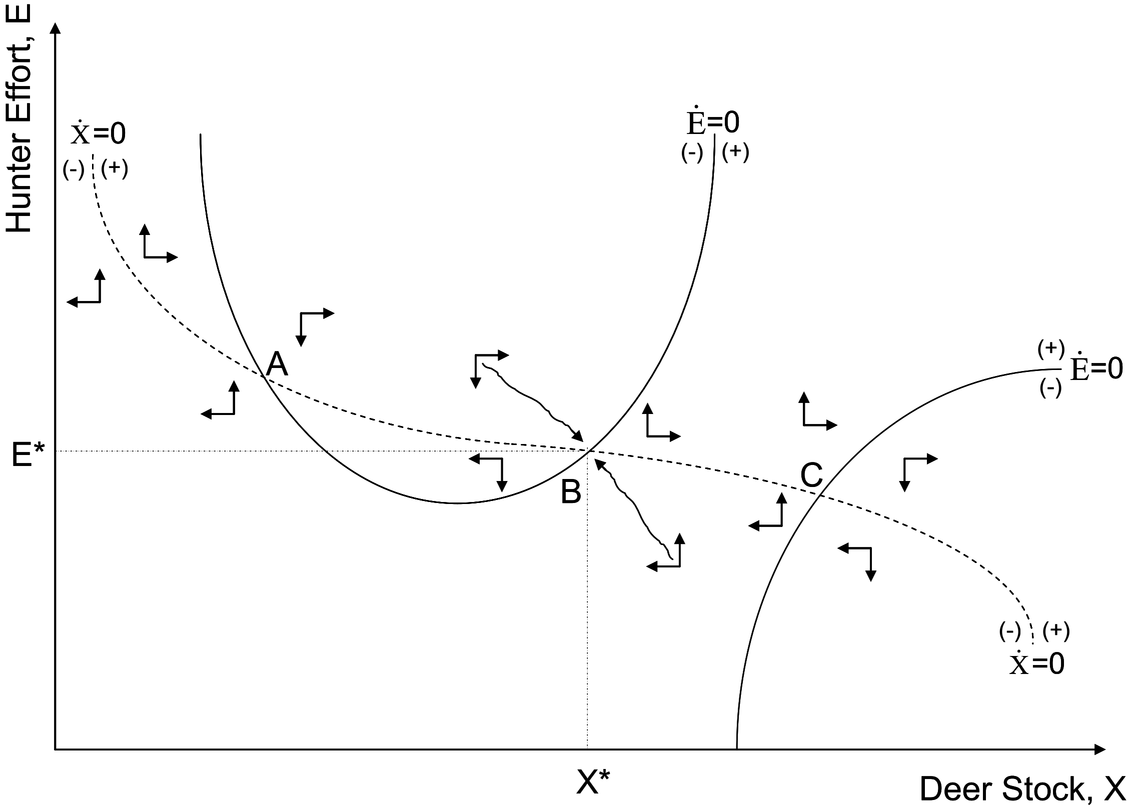

FIGURE 3.1: Example Phase Diagram in the Effort-Stock Plane

Figure 3.1 shows an example phase diagram for the PGC's optimization problem. There are three possible equilibrium (points A, B, C) of which point B is a saddle point, indicating a stable equilibrium. There is also a discontinuity in the $\dot{E} = 0$ isocline. This stable long run optimum indicates an optimal deer stock, X*, and hunter effort level, E*, indicated in Figure 3.1, and thus an optimal shadow price for the marginal deer, λ*. From our production function in equation (2), the optimal harvest of deer is easily determined as well, H*(X*, E*). The goal of the PGC, as a social-welfare maximizing management agency, should be to use hunting regulations and manage hunter effort so that deer stocks and deer harvests each year are as close to the optimal X* and H* as possible. But traditional management tools, under conditions of reduced hunter populations and hunter effort, may not be sufficient.

3.3.2: Hunter Selected Harvest vs. Societal Optimum

Consider the stock of deer that currently exists, X_{real}, and its relationship to the long run optimal deer stock, X*. In reality, hunting effort level can not be directed by the PGC. Deer are harvested each fall by sport hunters who can choose their own effort levels subject to constraints enforced by the PGC. If there are N total hunters, for now assume they are identical in their tastes and skill levels, and are represented by a single composite hunter whose total harvest each year is the sum of all hunter harvests, H. The utility that our composite hunter receives is from our earlier optimization model; U(H(t),E(t)), which is continuous and twice differentiable with $U_H > 0$, $U_{HH} < 0$, $U_E < 0$, and $U_{EE} = 0$. It will be more clear to represent this utility function as a separable and money-valued combination of two components: the benefits of the deer harvested, B(H), where $B_H > 0$ and $B_{HH} < 0$; and the cost of hunter effort, C(E), which is assumed to have a constant opportunity cost of time, w; $C(E) = w \cdot E$.

Myopic hunters will consider each fall's hunting season as a constrained utility maximization problem. Since hunting licenses and deer tags must be purchased prior to hunting season, they are sunk costs and are not considered in the marginal effort decision. The composite hunter is assumed to know the stock of deer/deer density that currently exists, $X = X_{real}$. Hunters will choose hours of hunting effort, E, to maximize their own utility subject to regulatory constraints placed upon them by the game management authority. These constraints include deer season lengths of D total daylight hours, and allowable harvests which we assume the deer manager has set to H*.

Again, harvest of deer for the representative hunter can be modeled as a concave production function H = H(X, E). The hunter then maximizes

$$\underset{(E)}{\text{Max}} : B(H(X,E)) - w \cdot E \tag{13}$$

$$\text{subject to: } H(X,E) \leq H^* \tag{13a}$$

$$E \leq D \tag{13b}$$

The method of Lagrange can be used to solve this constrained maximization problem. The hunter's Lagrangian is

$$\mathcal{L} = B(H(X,E)) - w \cdot E + \mu_1(H^* - H(X,E)) + \mu_2(D - E) \tag{14}$$

with the necessary first order conditions

$$\partial\mathcal{L}/\partial E = B_H \cdot H_E - w - \mu_1 \cdot H_E - \mu_2 = 0 \tag{15}$$

$$\mu_1 \geq 0; \qquad (H^* - H(X,E)) \geq 0; \qquad \mu_1(H^* - H(X,E)) = 0 \tag{16}$$

$$\mu_2 \geq 0; \qquad (D - E) \geq 0; \qquad \mu_2(D - E) = 0 \tag{17}$$

and the general solution can fall into one of four categories:

Case (A): constraint (13a) is binding; $\mu_1 > 0$

Case (B): constraint (13b) is binding; $\mu_2 > 0$

Case (C): both constraints are binding; $\mu_1 > 0$ and $\mu_2 > 0$

Case (D): neither constraint is binding; $\mu_1 = \mu_2 = 0$

Case A and Case C will result in an optimal deer harvest. The N hunters will each harvest h* deer, resulting in a total harvest of H*. Case B is problematic, in that hunters would choose to make more hunter effort, but the hunting season length is too short. Because constraint (13a) is not binding, we know that optimal harvest H* has not been reached, but we do not know how much more hunting effort there will be. Regardless, the management agency's own regulation (season length) is keeping hunters from attempting to reach the optimal harvest level.

Now consider Case D, where neither constraint (13a) nor (13b) is binding. First order condition (15) informs us that the hunters' will choose effort as expected, where the marginal benefit of effort equals the marginal cost of effort, or

$$MB_E = B_H \cdot H_E = w$$

Figure 3.2 represents Case D graphically. The assumptions on the concavity of both the benefits of harvest function and the harvest production function guarantee concavity of the marginal benefit of effort, MB_E, function as well. Hunters will continue to expend hunting effort until the marginal benefit of the next hunting hour just equals the marginal cost of their time, w. This hunter-selected total harvest rate, H^S, results in too few deer harvested ($H^S < H^*$) compared to the socially optimal harvest. Hunters do not consider the shadow price of the deer in society's optimization problem, λ^*. Damage costs would make $\lambda^* < 0$ for low deer densities, so society would be better off if hunters continued their hunting effort until MBE = (w + λ*). The PGC's constraints are indicated in Figure 3.2 as well, indicating that both constraints are slack and $\mu_1 = \mu_2 = 0$.

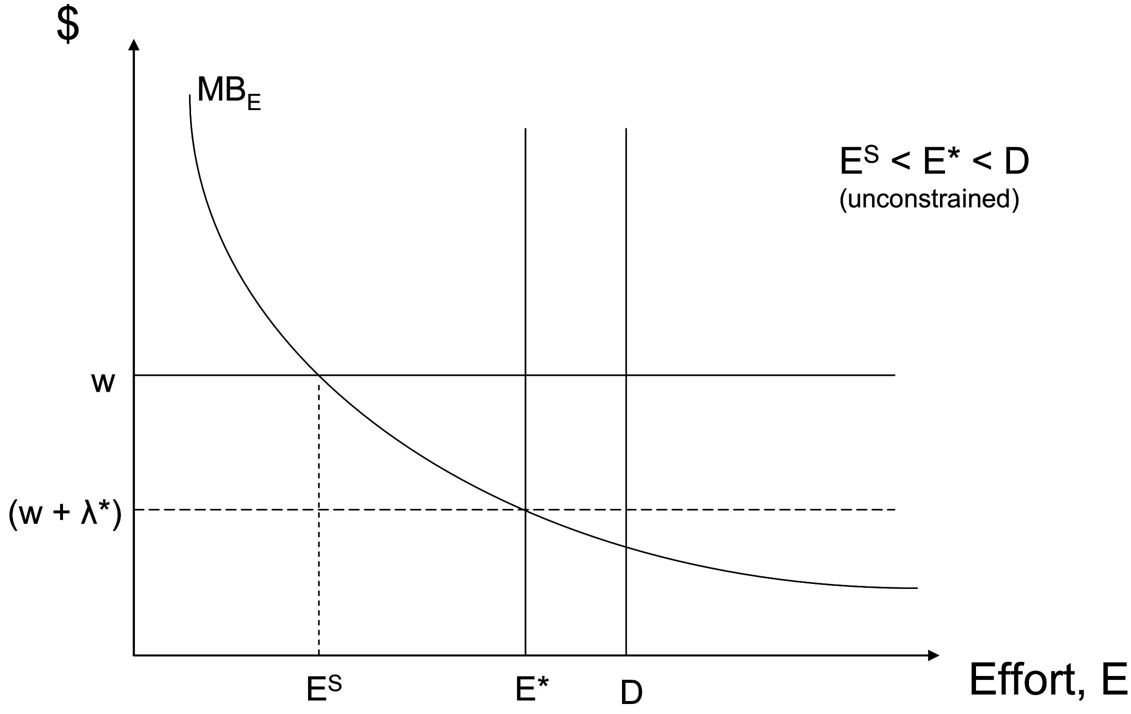

FIGURE 3.2: Hunter Selected Effort

It is important to note that in the Case D scenario, the average hunter's hunting effort is lower than what is needed to reach the social-welfare maximizing harvest level. Even though hunters are unconstrained by hunting season length or allowable harvest tags, the hunting effort they select, E^S, does not match the social-welfare maximizing path determined by equation (12). It is this scenario that game managers in many areas of the northeastern United States are concerned about (Riley et al.; Lauber and Brown; Brown et al.). Total hunter effort, even when hunting season lengths are long and antlerless harvest tags are available in large numbers, is less than the social optimum. After seasons of lower than optimal harvests, the deer stock exceeds the social optimum, $X_{real} > X^*$. This condition formally represents deer overabundance. A policy to address the problem of deer overabundance would be paying hunters to harvest antlerless deer, which will be modeled and tested in the subsequent sections of this essay.

3.4: From General to Specific: Developing a Hunter Utility Function

The recent report of the Deer Management Forum (DMF) (Latham et al.) was an attempt to introduce some of the adverse impacts of the deer herd (forest flowers, song birds, biological diversity) into deliberations on proper deer densities. A key assumption of the authors of the DMF study is that recreational hunting could be used to maintain deer densities much lower than the deer densities that currently exist (p.162). VanDeelen and Etter provide evidence that this assumption of constant hunter effort is untenable. Deer harvested in large enclosures in 6 different hunter effort studies showed clearly that hunter hours per deer killed increase significantly at low deer densities. Figure 3.3 shows the relationship between deer density and hunter effort from one of the studies analyzed by VanDeelen and Etter. Riley et al. confirmed that hunter effort declines significantly at reduced deer numbers, a behavioral response to the significantly increased hours needed to attain a valuable harvest, and those authors discuss the challenges this will create for proper ecosystem management at reduced deer densities. Overabundant deer is most likely a symptom of reduced hunter effort in the northeastern states, and current licensing practices are being modified to attempt to increase deer harvest where it is needed to decrease overabundant deer populations.

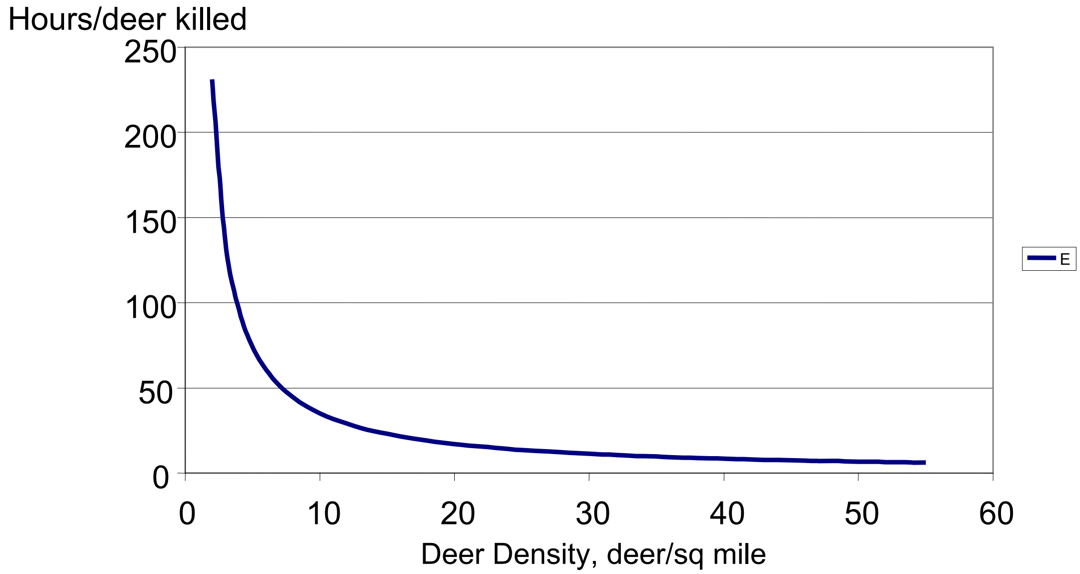

FIGURE 3.3[14]: Hunter Effort Hours to Harvest One Deer

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[14] Adapted from Van Deelen and Etter (2003), the graph is a smoothed plot of actual data points.

Typical functional forms for harvest production could be either proportional "harvest per unit effort" formulas such as equation (18a), or an exponential production function such as equation (18b) (Conrad, 1999; Conrad and Clark).

$$H = qEX \tag{18a}$$

$$H = X(1 - e^{-qE}) \tag{18b}$$

The more realistic functional form for deer habitat would be equation (18b), where effort levels approaching infinity result in harvest levels approaching the current stock, which is assumed to be finite. The renewable resource literature on fisheries and wildlife has developed a catchability coefficient that I will consider in a similar manner as a "huntability coefficient." The huntability coefficient, q, should be considered as a combination of factors that determine the efficiency of hunters in harvesting deer. Terrain, available refugia such as swamps or posted land, hunter skill, and hunting rules and regulations can all affect the q coefficient, but studies estimating this variable for deer hunting do exist (see for example Van Etten et al.; Holsworth; Roseberry and Klimstra).[15]

Consider the benefits to hunters of a certain population of deer. For any deer density, X, there would be an associated level of deer activity and deer sign (droppings, hoof-tracks, etc.) that would increase with deer density. Hunters would value increased deer density for the increase in deer activity, but more importantly, for the increased probability of harvesting a deer during hunting season. Expected harvest for the average hunter, using the assumptions on the production functions explained previously, would be increasing in deer density and hunting effort. Hunting effort is costly, however, in that foregone wages, w, are given up for each hunting effort hour expended. Because deer seasons occur during daylight hours and during weekdays, I will use the average wage rate as a hunter's opportunity cost of time. A separable utility function could be modeled in the form:

$$U(H,E) = \alpha \cdot H^{\beta} - w \cdot E \qquad 0 < \alpha < \infty, \qquad 0 < \beta < 1 \tag{19a}$$

which combined with the production function in equation (18b) yields

$$U(X,E) = \alpha \cdot [H(X,E)]^{\beta} - w \cdot E \tag{19b}$$

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[15] These authors found huntability coefficients for deer (under different conditions) of q=.004, .006, and a range of .0006-.0016 respectively, using a proportional harvest per unit effort formula like equation (18a).

The utility of a harvested deer would depend upon the harvest parameter, α, which will vary based upon the "value" hunters place upon a harvested deer, but is assumed (by the $0 < \beta < 1$ restriction) to be decreasing in subsequent intra-seasonal harvests, and also decreasing in the hours of hunting effort, E, required to harvest the deer.

Assuming hunters are free to choose their hunting effort level, what effort do they select? If unrestricted by regulations, hunters will maximize their utility from equation (19b) with respect to effort, or set

$$\partial U/\partial E = \alpha\beta[H(X,E)]^{\beta-1}\partial H/\partial E - w = 0 \qquad (20)$$

The optimal effort level is thus a function of the (known) parameters (α, β, q, w) and pre-hunt deer density, X. Optimal effort from the hunter's perspective, E^S, is thus a function of deer density, where

$$E^S(X) = E \text{ that solves equation (20) for all } X \in \{ 0 < X \leq K \} \qquad (21)$$

With utility-maximizing hunters choosing their effort levels, equations (18b) and (21) imply an optimal harvest level for hunters that they self-select, H^S, as well,

$$H^S(X) = H(X, E^S(X)) \qquad (22)$$

Game management agencies usually have some criteria that they have selected to determine desired deer populations. In Pennsylvania, the PGC goal is "an over-winter deer population that forests can support without adversely affecting tree regeneration" (DuBrock, p 3). By estimating the pre-hunt deer density that exists, the game management agency then determines "harvest goals" for each of the wildlife management units (WMUs) they are responsible for. We can call these harvest goals H*. Up until recently, game managers were confident that unrestricted hunter effort levels would exceed the necessary effort to reach the harvest goal, or $H^S > H^*$. Short hunting seasons and limited numbers of antlerless deer tags were originally designed to limit the hunting effort allowed by hunters, and keep the antlerless deer harvest from exceeding the selected harvest goal. But as early as the late 1970s, this paradigm started to change. Traditional gun-hunting seasons were adjusted and lengthened, archery and muzzleloader seasons were added, and special youth and senior hunts were added in many states to increase the antlerless deer harvest. Even when the number of antlerless harvest tags available to hunters became basically unlimited, some states "found out very quickly that you reach a saturation point in (antlerless) license demand" (Dubrock, p.5). An examination of the hunter utility model just developed can explain this phenomenon.

3.4.1: Increasing Hunter Selected Effort (E^S) and Harvest (H^S)

Consider a one square mile (OSM) tract of deer habitat in Pennsylvania. The habitat is some combination of forest, farm fields, and human development that contains a certain number of deer, X. Because we are using a OSM area, X will be considered a deer density, in deer/sq mile, for the model that follows. On the first day of deer season, before any deer have been harvested, there is a level of hunting effort, E, measured in hunter hours, that would be expected to be necessary to harvest a deer. As the hunting season continues, deer are removed from the population through harvest, and the remaining deer become more wary of hunters and more difficult to kill. Thus, we would expect larger and larger amounts of hunter hours to be required for subsequent deer harvests. An exponential production function where $H = X(1 - e^{-qE})$, as in equation (19b), models this behavior well, indicating decreasing marginal productivity of hunter effort from:

$$\partial H/\partial E = qX\cdot e^{-qE} \qquad (23)$$

The selection of an appropriate huntability coefficient, q, is critical for an accurate analysis. Game managers in most states already have good estimates of the factors that influence the efficiency of hunters in taking deer. But from equation (23) we can see that marginal harvest increases with the huntability coefficient for all deer densities, $X > 0$ and hunter effort levels, $E > 0$.

The hunter utility function, equation (19b), should be thought of as a composite hunter, made up of all the hunters expending hunter effort on our OSM tract of land. The benefits to this composite hunter of antlerless deer harvests are represented by the $\alpha\cdot[H(X,E)]^{\beta}$ term in equation (19b), with decreasing marginal benefits of harvested deer because of our $\beta < 1$ assumption. Additional effort increases deer harvest at a decreasing rate from equation (23), and the costs of effort are assumed constant at the opportunity cost of the hunter's time, w. Thus, hunters will continue to expend hunting effort as long as the marginal benefits of that effort exceed the marginal costs. Combining equation (20) and equation (23) indicates that hunters continue to expend hunting effort when

$$w \le \alpha\beta[H(\cdot)]^{\beta-1}qX\cdot e^{-qE} \qquad (24)$$

I can use equation (24) to analyze what circumstances will result in low hunter harvests. First, all things being equal, an increase in the opportunity cost of time will result in lower equilibrium harvest levels. If real wage rates in the United States increase over time, hunters will hunt fewer hours. Lower "valuation parameters", α and β, will also reduce hunter harvest. Because the utility function represents a composite hunter, the recent reduction in overall hunter numbers, ceteris paribus, has reduced the α parameter for sure, and possibly the β parameter as well. As noted already from equation (23), a reduction in hunter efficiency, q, will also reduce hunter harvest. An aging hunter population, more posted land that creates refugia for deer during hunting season, bad weather, and other factors could all result in a reduced q, and thus low harvests at hunter-chosen effort levels.

Raising q, or improving hunter efficiency, would result in greater hunter-selected harvest rates. New York State recently opened all or parts of ten forested counties in the Allegheny Plateau region of New York to rifle hunting.[16] Previously, by tradition and for safety reasons, the hunting regulations in these counties allowed only shotgun-hunting for deer. The greater range and accuracy of rifles will increase the huntability coefficient, q, and result in higher "hunter-determined" harvests of antlerless deer in these counties where deer are overabundant. There are numerous other methods of increasing the huntability coefficient; allowing baiting to draw deer to areas where they can be more easily killed is one. But socio-political norms serve as constraints upon what hunters and game managers are allowed to consider when increasing q.

3.5: An Empirical Dynamic Model of Optimal Deer Densities

When a game management agency selects a target deer population (or more accurately, a target deer density), what should they consider? Currently some biological/ecological criteria such as minimizing damage to forest habitat, or ensuring a specific level of over-winter deer survival rates, is used. As already mentioned, the PGC chooses to target post-hunt densities of deer that do not adversely affect tree regeneration. A fairly sophisticated analysis of pole-timber, saw-timber, and seedling/sapling forests is made for every WMU in the state, and a specific "maximum" post-hunt deer density is determined (Diefenbach et al.). This density goal is then compared with constantly

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[16] see http://www.dec.state.ny.us/website/dfwmr/wildlife/guide/legalimp.html

updated pre-hunt deer density estimates, hunter success rates, and recent license sales to determine the "best" number of tags to sell to hunters (DuBrock).

What these current systems of selecting the target deer populations ignore is two-fold. First, all of the other externalities from deer are seemingly ignored in the analysis. Deer-vehicle accidents (DVAs) on highways, crop and orchard destruction, and costs to society of Lyme disease are several of the additional costs to an overabundant deer herd. The Deer Management Forum analysis (Latham et al.) argued strongly that damage to forest biodiversity occurs at relatively low deer density levels, and should be considered as well, and called for even lower deer density targets than the PGC currently uses. What the DMF nor the PGC currently consider, however, is the second ignored component of selecting an optimal deer population; the cost in increased hunter effort to harvest deer at lower deer densities. The social welfare maximizing deer densities should be determined while taking these additional costs into consideration.

3.5.1: The Benefits of the Deer Population

In general, the deer population in a given area creates value in several ways. Viewing values, existence values, bequeath values, and other vicarious-use values are all discussed by Conover (1997) and hypothesized to be "for the most part, independent of population levels" (p.303). I will make the assumption in this analysis that as long as deer populations are not driven to near-extinction levels, these non-use values are constant over the range of deer densities considered. From our earlier formulation in equation (3), N(X(t)) becomes a constant, and can be removed from the optimization for interior solutions.

The large and estimable component of antlerless deer value, then, is the value hunters place on deer for sport and consumption. The utility hunters receive, as individuals and as a group, is assumed to increase with the deer population but at a decreasing rate. As discussed in the development of equations (19a) and (19b), more deer in the woods increase a hunter's chances of both seeing deer and deer sign, and of actually harvesting a deer. With hunting effort being costly, however, we developed the general utility function in equation (19b) as a concave function of deer density, X, and hunter effort, E. The policy option we are testing adds an additional component to hunter utility. Hunters receive a payment, p, for each deer harvested as an incentive to harvest more antlerless deer. The hunter utility model is now:

$$U(X,E) = \alpha\cdot[H(X,E)]^{\beta} - w\cdot E + p\cdot H(X,E) \tag{25}$$

Here I must address the fact that numerous studies (Decker and Connelly; Ward et al.) have indicated that hunters get satisfaction primarily from the non-harvest aspects of hunting. Hunters' motivations for hunting are primarily companionship with friends and family, enjoyment of nature and the outdoors, and to challenge and test their outdoor skills. Similar to the vicarious-use values just discussed, these hunter valuations should only change when the deer density is pushed toward extinction levels. As long as there is a viable deer population to hunt, these non-harvest values are assumed to be large and constant for the average deer hunter over a large range of positive deer density. Arguably, companionship with friends and family and the enjoyment of nature may be improved at larger deer densities (more deer sighted, better hunting stories to share). I will make the assumption that the α parameter in equation (19b) captures these non-use values at positive harvest values, and no additional component of hunter utility is required.

3.5.2: The Damage Costs of the Deer Population

The damage caused by a deer herd is significant, and varies almost as much by the human activity in the area where the deer are found as it does from the density of the deer herd itself. Deer in large tracts of non-lumber forest, with few nearby roads, crops, ornamental plants, or orchards, do not cause direct economic damage. They may reduce the quantity and variety of the plant and animal species (ferns, birds, and small mammals) that they browse, or that compete with them for food, and a value can be placed on this reduced biodiversity. Indeed, if deer densities are high enough to remove certain plant and animal species from the habitat completely, the analysis may get quite complicated, but for the most part deer only cause damage because of their effect on human activity. A damage function can be calibrated based on a deer herd's effects on the following: automobile accidents, farm crops, nurseries and orchards, residential plantings, Lyme disease prevalence, forest lumber, and forest biodiversity. Again, damage will be assumed to be a convex function of deer density, D(X), and the assumption that $D_X > 0$

and $D_{XX} \geq 0$ for $0 < X < K$. The damage function can be linear, nonlinear, or piecewise linear (kinked).

3.5.3: Deer Population Dynamics

The growth rate of an un-hunted deer herd, after considering natural mortality by predation, sickness, accidents, and winter starvation, is astounding. McCullough studied the enclosed deer herd at the Edwin S. George Reserve in southeastern Michigan, where an initial population of 6 deer grew to over 160 deer in only 6 years. Using the basic logistic growth function for deer and other K-selected species,

$$F(X) = rX(1 - X/K) \qquad (26)$$

estimated natural growth rate parameters, r, usually vary from $.4 < r < .8$ based on the natural habitat conditions and mortality factors. Again, the growth parameter for the deer habitat being analyzed, and the estimated biological carrying capacity, K, can be calibrated from historical data.

The timing of the hunting harvest, occurring traditionally over a short period in late fall, lends itself to a simple difference equation that explains deer population dynamics. Letting a *t* subscript delineate between time periods, the density before the deer are hunted, X_t, is reduced by the hunters' harvest, H_t, in any one time period. The remainder of the population after the fall harvest, $(X_t - H_t)$, grows according to the parameters in the logistic equation (26), resulting in the subsequent years' deer density, X_{t+1}.

3.5.4: The Social Optimum

The model outlined in Section 2, and the optimal control problem of equations (3)-(3d), was useful for analyzing the problem of overabundance. Shadow prices of deer along an optimal path may be positive or negative (see Zivin et al.; Rondeau) and the nonconcavity of the Hamiltonian that results introduces complexities in equilibrium analysis. For empirical analysis, the PGC's optimization problem can be analyzed more conveniently as a discrete time dynamic programming problem. The timing of deer harvests described above in Section 5.3 makes this formulation realistic, so the dynamic programming problem will be described and then analyzed from here forward.

The first-best solution for the PGC would occur if they could direct hunters to apply hunting effort to harvest the appropriate number of deer from the given population each year. Based on the selected production function, the PGC is in effect directing hunter effort. Using the exponential production function, directed effort is a function of deer density and the directed harvest

$$E(X,H) = [\ln(X) - \ln(X-H)]/q \qquad (27)$$

There would be benefits to the hunters from harvests, but also a cost to hunters from their harvest effort. Notice that the payments to hunters for antlerless deer harvest in the utility function (25) would come from some form of taxation or reduction in welfare for others, and these payments are a "wash" to society as a whole. Obviously this ignores the welfare distribution issues and possible inefficiencies associated with this wealth transfer, but for now we are concerned only with getting the optimal harvests (and thus deer density) to maximize overall social welfare. Again using the *t* subscript to indicate an annual time period, the PGC should select the harvest rates of deer, H_t, to solve

$$\underset{(H_t)}{\text{Maximize}} \sum_{t=0}^{T} \rho^t \left[\alpha\cdot(H_t)^\beta - w\cdot E(X_t,H_t) - D(X_t)\right] \qquad (28)$$

subject to:

$$X_{t+1} = X_t - H_t + F(X_t - H_t) \qquad (28a)$$

$$X_t > 0 \qquad \forall\, t \qquad (28b)$$

$$0 \le H_t < X_t \qquad \forall\, t \qquad (28c)$$

$$X_0 \text{ given} \qquad (28d)$$

where ρ is the annual discount factor.

Equation (28) summarizes all the benefits and costs to society that the game management agency can control by directing harvest. Remember that there are large non-harvest values, both to society and to hunters, from the deer herd being maintained at some positive level. These benefits are considered constant as long as the deer herd is not driven to extinction, thus giving us the constraint in equation (28b), and allowing us to ignore them in the maximization equation (28). The equation (28a) constraint is the equation of motion that determines how the deer herd changes from one time period to the next, and equation (28c) directs that the annual harvest is nonnegative and again it is (by assumption) not optimal to extirpate the deer herd.

The solution to equation (28) can be determined empirically by a dynamic program. Selecting an appropriately distant T, a terminal condition V(T,X) = 0 will be justified.[17] Mathematica® 5.2 programs (Wolfram) were developed to solve the following Bellman equation, after parameter calibration,

$$V(t, X_t) = \max_{(H_t)} \{\rho^t [\alpha\cdot(H_t)^\beta - w\cdot E(X_t,H_t) - D(X_t)]\} + V(t+1,X_{t+1}) \qquad (29)$$

with the constraints on deer herd growth given by equation (28a) and a V(t,0) = 0 constraint to ensure it is never optimal to exterminate the herd. Thus, the present value function $V(t, X_t)$ represents the maximum possible net present value at period t for a deer density X_t, given that the PGC will again direct the optimal deer harvest H_t for all subsequent years as well. The baseline program code is found in Appendix B. Rondeau and Conrad (2003) were the inspiration and previous example in the literature for the Bellman equation solution method used in this analysis.

3.5.5: Modeling the Policy Option: Payment for Harvest as an Incentive

Calculating the optimal harvests, H_t, considering the costs and benefits of the deer herd is only the first step. The dynamic program represented by equations (28)-(28d) assumed that the game managing agency could *direct* an appropriate harvest by hunters. This is of course not the case. Utility-maximizing hunters will select an effort level each year to solve the utility maximization problem represented by equation (25), which now includes a payment for harvest

$$\partial U/\partial E = \alpha\beta[H(X,E)]^{\beta-1}\partial H/\partial E - w + p = 0 \qquad (30)$$

Thus the second step for the game management agency is to select the appropriate payment for an antlerless deer harvest. Knowing the optimal harvest required, H*, will direct the amount of hunter effort, E*, that is optimal. With estimates of the parameters of the hunters' utility function, each year the game management agency will set

$$p(t) = \alpha\beta[H_t^*]^{\beta-1}\partial H^*/\partial E^* + w \qquad (31)$$

and this payment will serve as the proper incentive to induce hunters to harvest the dynamically optimal number of antlerless deer.

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[17] T=50 was originally chosen. Analysis of all possible initial deer densities resulted in convergence to a steady H_t within 4 -7 years. Subsequent analysis used T=10, saving computational time, with no change to the results.

3.6: Calibrating the Model for the 'Average' Deer Habitat in the State of PA

Chapter 12 of the Report of the DMF (Latham et al.) recommended creating comparison areas for analysis that are 10 square miles (TSM) in size. The empirical iterations required to solve the Bellman equations in Mathematica® were capable of handling TSM areas without extremely long processing times. Carrying capacities, deer damage functions, and logistic growth models can be calibrated over any area of deer habitat based on available data. My model calibrates composite hunter utility for an average 1 square mile (OSM) area, and then scales the resulting utility parameters up for the appropriate TSM area.

Using data for an entire state to create an "average" section of deer habitat, considering the variation in habitat, deer density, deer-caused damage, and hunter aptitudes and valuations, may seem to be of little value. But it is illustrative of the technique that should be followed by game management agencies when selecting optimal deer densities and harvest targets, over any region of deer habitat where sport-hunting is allowed. It is also illustrative of the average improvements in social welfare that may be possible with the recommended policy of paying hunters for antlerless deer harvests. If, as is generally accepted, average deer densities in Pennsylvania are too high under current policies, then what does the model indicate deer densities, annual hunter harvests, and estimated payments, p, should be at the optimum?

3.6.1: Deer Density and Natural Growth

The estimated population of deer in Pennsylvania over the last decade has ranged from 1.2-1.6 million animals. We will use 1.4 million deer to calculate the average "pre-hunt" density of deer, X, in our model. Pennsylvania has approximately 26,560 square miles of forest (Diefenbach et al..), which the PGC uses to set over-winter density goals. This implies an average pre-hunt deer density of 52.7 deer/mi^2 of forested habitat. However, Pennsylvania has approximately 37,838 square miles of undeveloped land (farmland and forest combined) (Ritz and Ready). This figure implies an average deer density of 37 deer/mi^2 of potential habitat. Which figure to use for an appropriate estimate of average deer density is irrelevant as long as other parameters are calibrated to be consistent with this initial condition. I have selected **X = 45 deer/mi^2** as an appropriate average pre-hunt deer density that currently exists in Pennsylvania, implying deer habitat of (1,400,000/45) = **31,110 mi^2** for the later analysis.

In 2003, the PGC reported hunter harvests of 464,890, or almost exactly 1/3 of the pre-hunt density (1,400,000/464,890 = .332). For an average square mile of deer habitat, this implies a **pre-hunt density of 45 deer/mi^2**, a **harvest of 15 deer/mi^2**, and a subsequent **post-hunt density of 30 deer/mi^2**. This estimate matches well with the PGC's data, which showed that post-hunt, or over-winter, deer densities in Pennsylvania varied between 29-34 deer/mi^2 from 1987-1994 (Diefenbach et al.). Since the deer harvest in Pennsylvania in 2003 was typical for recent deer seasons, we can now use these results to estimate the parameters in the logistic growth function.

DeCalesta and Stout give a good summary of research estimates of the biological carrying capacity, K, for white-tailed deer in various habitats. Analysis of suburban areas with parks such as Irondequoit, NY, and other protected areas with large unfarmed open space such as Saratoga National Historical Park, has estimated maximum deer densities as high as 156 deer/mi^2. Mixed forest and abandoned farm fields such as McCullough's analysis of the George Reserve deer herd indicated estimates of K = 98 deer/mi^2. For pure hardwood forests, such as DeCalesta and Stout's own study in Pennsylvania, maximum carrying capacities were roughly 65 deer/mi^2. A good average for Pennsylvania, where habitat is a mixture of forests, abandoned fields and active farm crops, would be the George Reserve estimate of **K = 98 deer/mi^2**.

Ignoring the variability in estimated deer populations and harvests, and assuming that a pre-hunt, harvest, and post-hunt population of 45, 15, and 30 deer/mi^2 is sustainable in Pennsylvania year after year, an estimated natural growth rate, r, can now be calibrated. Using equation (26), we see that the annual growth from the *post-hunt* density of 30 deer/mi^2 must be enough to replace the deer that were harvested by hunters, 15. Thus,

$$F(30) = 15 = r\,(30)(1 - 30/98) \Rightarrow r = 15/20.82$$

$$\mathbf{r = .72}$$

3.6.2: Damage Function

Numerous studies have attempted to quantify the damage that white-tailed deer cause to humans and ecosystems. Ritz and Ready used available data to determine the marginal damage of a deer in Pennsylvania as \$150-\$232. An updated analysis by Drake et al. was also useful for this analysis, but these authors failed to consider forest damages, which are significant. Considering first the *non-forest* damage caused by the deer herd in Pennsylvania, I estimate the annual total damage for Pennsylvania's 31,110 mi^2 of deer habitat to be:

Table 3.1: Non-forest Damages from Deer in PA

Deer-Vehicle Collisions[a]	\$92,700,000
High-Value Agriculture (orchards, vegetables)[b]	\$17,506,294
Grain Crops (corn, soybeans, wheat, oats)[b]	\$25,738,984
Lyme Disease[a]	\$17,850,000
Residential Ornamental[b]	\$25,700,000
Nursery Stock Depredation[b]	\$4,303,200
Total Annual Non-forest Damage	\$183,798,478

[a]-Ritz and Ready midpoint [b]-Drake et al.

Thus the annual damage caused by deer on a square mile of deer habitat is (183,798,478/31,110) = \$5,908.02. These damages are assumed to be proportional to the deer density, creating a linear damage function, $D_{nf}(X)$, originating from the origin in the "Damage-Density" plane. For reasons that will be clear later, I can use the over-winter (post-hunt) deer density that prevails in Pennsylvania to get the first component of the damage function, the dashed line shown in Figure 3.4. The slope of the non-forest damage curve $D_{nf}(X)$, represents the marginal damage from additional deer, or β_1 = \$196.93/deer.

The damage *to forests* by deer browsing is not assumed to originate at the origin. Deer effect the regeneration of economically valuable hardwood lumber species, but only above a certain "threshold" deer density level estimated at roughly 11 deer/mi^2. Above the level of 20 deer/mi^2, the regeneration of certain hardwood timber species becomes almost impossible without fencing or other methods of preventing deer browsing. Likewise, deer browsing has a negative effect on non-timber forest vegetation, understory, bird and insect populations, and small mammal density as well, but only when deer density rises above about 11 deer/mi^2. Research by Tilghman, DeCalesta, and DeCalesta and Stout all indicate that deer browsing has no effect on species richness or abundance below these threshold levels. Complicating the analysis of forest damage is the question of *when* the majority of the damage caused by deer browsing occurs. The

PGC assumes that the damage to hardwood timber and forest vegetation occurs primarily in the winter months, so *post hunt* densities are what is important when determining damage caused by deer browsing.

The best estimate of annual timber losses for the state of Pennsylvania due to deer browsing is \$75 million (Ritz and Ready, p.19). Chapter 5 of the DMF report (Latham et al.) explains in detail the role of deer in altering forests, but unfortunately does not estimate the damage to forest biodiversity in dollar terms. What is the value of the non-timber damage to forest biodiversity? Is it zero, because the deer are simply creating a new forest habitat (Sterba)? Is it equal to or greater than the damage to timber as the DMF report implies, but if so, who is willing to pay to reduce it? I will assume initially that the non-market value of deer damage to all other (non-timber) forest species and overall biodiversity is ½ the timber damage estimate, an additional \$37.5 million annually, at current deer densities found in Pennsylvania. Sensitivity analysis will indicate that this forest damage parameter has a large effect on optimal equilibrium deer densities. The combined \$112,500,000 forest damage over our estimated 31,110 mi^2 of deer habitat results in (112,500,000/31,110) = \$3,616.20 of damage annually per square mile. Assuming these damages are "zero" below a deer density of 11 deer/mi^2, and the current annual damage estimates were measured at the over-winter deer density of 30 deer/mi^2, the second component of our estimated deer damage function is $D_f(X)$, the lower blue line in Figure 3.4. The slope of this function is the marginal damage of an additional deer to forests above the threshold level, or β_2 = \$190.33/deer.

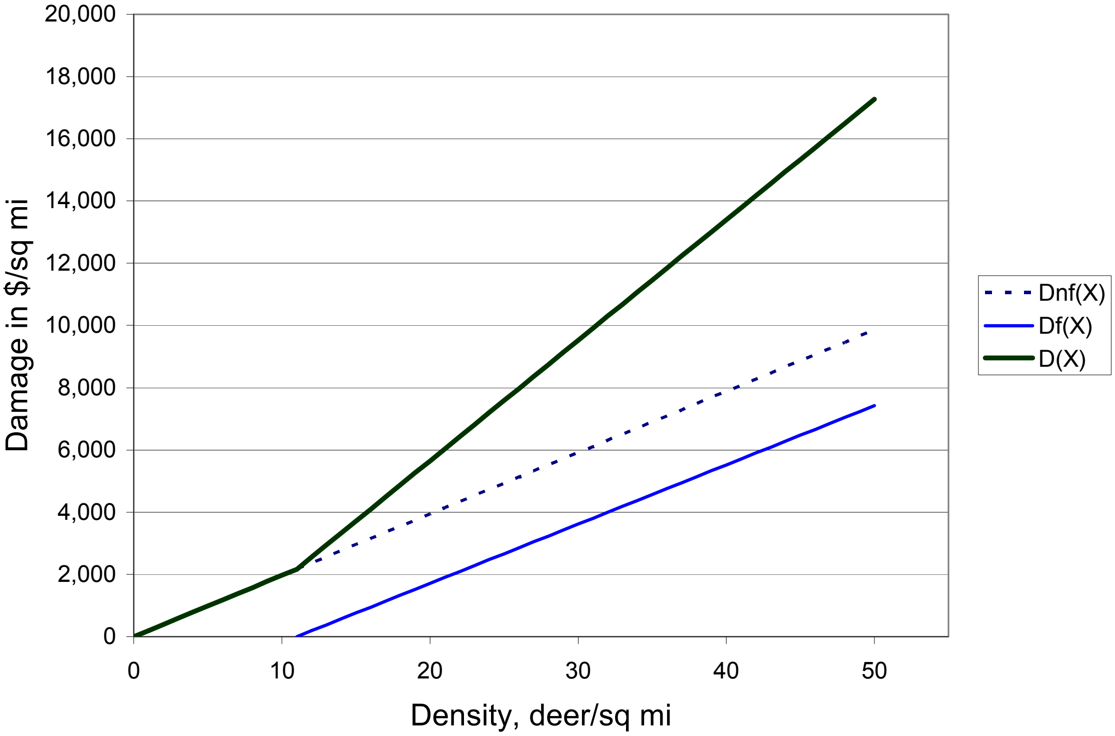

FIGURE 3.4: Piecewise Linear Deer Damage Function

The non-forest and forest damages of Figure 3.4, when combined, result in a piecewise linear damage function, D(X), shown as the heavy solid line in Figure 3.4. The D(X) function has a slope of β_1 = 196.93 from the origin to a density of 11 deer/mi^2, and a slope of β_{tot} = (196.93+190.33) = 387.26 thereafter, indicating a total **marginal damage of $387.26/deer** above a density of 11 deer/mi^2. If accurate estimates of hardwood-tree damages above the critical level of 20 deer/mi^2 were available, an additional “kink” could be added at that density and calibrated across the ranges of deer density expected in Pennsylvania. The calibration of the damage function using over-winter density should not be of concern. As described earlier, the “steady-state” that currently exists in Pennsylvania has an estimated 45 deer/mi^2 in the summer and fall, all eating crops and getting hit on the highways and spreading Lyme disease via deer ticks. Then, after a relatively quick harvest in late fall, the current post-harvest deer density of 30 deer/mi^2 spends the winter damaging the forests, getting hit on highways, and eating ornamental shrubbery to survive the winter. The spring births replenish the deer stock, and the cycle repeats itself. So the current annual damage estimates can be estimated as proportional to either the pre-hunt or post-hunt deer density, as long as it is applied consistently.

3.6.3: Hunter Utility from Harvests

Of the studies referred to earlier that attempted to estimate a huntability coefficient (q) from hunts in enclosed areas, lower efficiency was generally associated with larger enclosures. This is to be expected. If deer can "escape" to areas of lower hunting pressure, hunters will be less successful in harvesting them. The largest of the studied areas, the Crab Orchard National Wildlife Refuge, indicated a range of q from .0006-.0016 (Roseberry and Klimstra). Hunters in this study were restricted to using shotguns, and hunting only from stand locations, which would reduce hunter efficiency compared to Pennsylvania's use of rifles and allowed hunter movement. However, the deer in the Crab Orchard study had not been hunted in over 24 years, which would likely push the huntability coefficient higher than deer that are annually hunted. Studies on deer hunted in other enclosures indicated huntability coefficients that ranged from .004-.006 (Van Etten et al.; Holsworth), but again these coefficients are most likely high compared to Pennsylvania because there were no refugia for the deer to escape to. I have chosen a huntability coefficient for my initial analysis of **q = .001**. A sensitivity analysis will show that the optimal deer density depends critically on the assumed q. A higher q indicates more efficient hunters; more efficient hunters can harvest deer with less (costly) hunter effort, while still enjoying the harvest value of the deer. Efforts to *increase q* will result in lower optimal deer densities.

Our exponential production function, $H = X(1 - e^{-qE})$, implies a deterministic level of hunter effort that would harvest H = 15 deer/mi^2 from an initial pre-hunt density of X = 45 deer/mi^2. With q = .001, solving for effort, E, from equation (18b) we see that hunter effort in Pennsylvania must be

$E = [\ln(45) - \ln(45-15)]/.001$

$\mathbf{E = 405.4\ hrs/mi^2}$

Is this effort level reasonable? We can use available data to estimate the average amount of hunter effort on a 1-mi^2 area of Pennsylvania deer habitat in a single hunting season. From PGC data, there were 836,270 (resident and non-resident) big-game and sportsmen licenses sold in 2003. From survey data (Luloff et al.) and the PGC's own estimates (DuBrock), approximately 92% of hunters who purchase a license actually hunt deer, for a rough estimate of 769,386 actual deer hunters. In a survey of hunters in northern

Pennsylvania in 2004, the average hunter hunted 4.6 days of the rifle hunting season and spent an average of 5 hours each day actually hunting (Ward et al.). This is (769,386 * 4.6 * 5) = 17,695,878 hours of total hunting effort over the 31,110 square miles of deer habitat, for an average estimated amount of hunting effort of $E = 568.8$ hrs/mi^2. Of course, many of these hunters may be hunting exclusively for antlered deer, which are generally more elusive and more time consuming to hunt. So as a rough estimate, 405.5 hours of hunting effort per square mile of habitat would be a reasonable amount for our analysis.

An accurate opportunity cost of time for a hunter would be the average wage rate. For an annual salary of \$40,000, a hunter who works (50 wks/yr * 40 hrs/wk) = 2000 hrs per year has an opportunity cost of time of $w = \$20/\text{hr}$.[18] Many hunters of course make significantly more than \$40,000 per year in annual salary, but alternatively many hunters are retired or are school-age children who would have a lower opportunity cost for the workday daylight hours spent hunting. Thus I will use **w = \$20/hour** as an initial average opportunity cost of time.

To calibrate the parameters α and β in the hunter utility function, I have to assume that the current deer harvest in Pennsylvania is made by utility-maximizing hunters *un-constrained by season length*. This assumption deviates significantly from the analysis in essay 2, where certain high-demand hunter types were assumed to be restricted from purchasing tags through the rationing system that currently exists. I now assume that hunters have been able to hunt all of the antlerless deer they want, and have selected to stop hunting on their own. Thus, the current "per area" harvests levels and effort hours are at the maximum point of the utility function, $\partial U/\partial E = 0$, as in equation (20). The marginal productivity of effort, $\partial H/\partial E$, comes from equation (23) at our calculated effort level, huntability coefficient, and pre-hunt deer density.

$$\partial H/\partial E = qX\cdot e^{-qE} = (.001*45)e^{-(.001*405.5)} = 0.02999 \qquad (32)$$

and selecting elasticity parameters over the range of $\beta = 0.3\text{-}0.8$, we get utility parameter pairs that satisfy $\partial U/\partial E = \alpha\beta(15)^{\beta-1}(.0299) - 20 = 0$, as shown in Table 3.2 below.

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[18] The Bureau of Labor Statistics website reported the mean annual salary from November, 2004 data for all occupations in Pennsylvania as \$36,970. see http://www.bls.gov/oes/current/oes_pa.htm

Table 3.2: Utility Parameter Pairs, Calibrated

α	β
14,790.5	0.3
8,461.2	0.4
5,163.2	0.5
3,281.9	0.6
2,145.7	0.7
1,432.1	0.8

I expect decreasing marginal value from deer harvests for hunters; otherwise, we would expect to see as many hunters on the final day of hunting season as we do on the first day in areas with liberal tag limits. For some individual hunters, the marginal value drops sharply after the first deer. In fact, many hunters will only shoot one deer even if offered the chance for more. For some hunters, subsequent deer are nearly as valued as the first, and they will continue hunting and harvesting all season. Our OSM "composite hunter" consists of an average of (769,386/31,110) = 24.7 hunters, so the marginal utility from the first few deer probably is relatively large, but then starts to level off at some low value as more and more deer are harvested per square mile of deer habitat. I have selected to use the elasticity parameter **β = .5** and the subsequent valuation parameter **α = 5,163.2** for the initial model, and conduct sensitivity analysis for these utility parameters to see how the optimal results vary.

3.7: Results of a Statewide Model: The Base Case

Using the parameters for an "average" 1-square-mile (OSM) area of Pennsylvania deer habitat as explained in the previous section, the Bellman equation from equation (29) was coded in Mathematica® and solved. To solve the problem numerically required that deer densities and deer harvests be in discrete units. As with all discrete-time first order difference equations, there were instances in which the solution cycled rather than converged (Chiang). To reduce this possibility, and to determine more accurate optimal densities and harvests, the model parameters were scaled up to encompass a ten-square mile (TSM) area of deer habitat. The solution was then scaled back down to OSM recommendations for ease of understanding. The results, compared to the current steady-state situation, are described in Table 3.3 below. It is interesting to note that this "base case" steady-state post-hunt (over-winter) deer density is very near the PGC-recommended over-winter density of 21 deer/mi^2 of *forested land* in Pennsylvania (Diefenbach), but this is merely coincidental.

Table 3.3: Comparison of Current to Optimal Steady States

	Current Steady-State	Optimal Steady-State
Pre-Hunt Deer Density	45 deer/mi^2	33.2 deer/mi^2
Post-Hunt Deer Density	30 deer/mi^2	21.2 deer/mi^2
Annual Deer Harvests	15 deer/mi^2	12.0 deer/mi^2
Social Welfare from deer herd	\$2,364.62/mi^2	\$2,799.86/mi^2
Payment to hunters for Harvests	\$0	\$198/deer

Annual Statewide Improvement in Social Welfare from Optimal Policy:	\$13,540,200
Annual Total Payment to Deer Hunters to Achieve Optimal Policy:	\$73,920,500

The Bellman equation also indicates an optimal path for the annual deer densities, harvests, and payments offered for the harvest of an antlerless deer to achieve the maximum value, or maximum societal welfare, from the deer herd. Payments vary slightly each year due to the discrete nature of a deer harvest, but stay in roughly the same range over the 8 years it takes to reach the new steady-state. These paths are illustrated in Figure 3.5.

These results indicate that the current situation in Pennsylvania, with deer herds that average 30 deer/mi^2 of habitat and hunters only choosing to harvest 15 deer/mi^2 each hunting season, is indeed suboptimal. Self-interested hunters do not consider the externalities of a large deer herd. Optimal post-hunt deer densities are closer to 21.2 deer/mi^2 of deer habitat, once the damages caused by deer are considered. Note however that the deer densities do not approach the 11 deer/mi^2 recommended by the Report of the Deer Management Forum and others, to protect the biodiversity of forests. The cost in hunter effort to reduce deer densities to levels approaching 11 deer/mi^2 is prohibitive, suboptimal for social-welfare maximization, and unrealistic when you consider that liberal deer tag limits are already unable to keep deer densities lower than the current 30 deer/mi^2 in many areas.

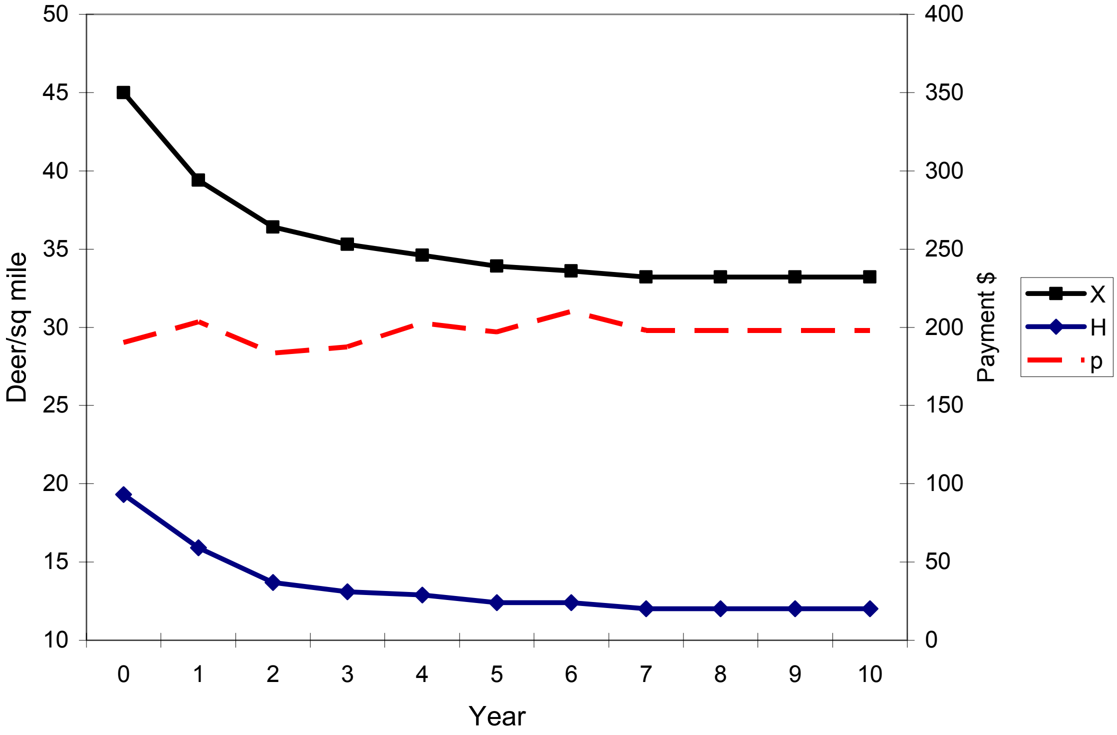

FIGURE 3.5: Optimal Path to Steady State

The annual improvement in social welfare of $13.5 million is significant. This improvement comes from the reduction in deer damage due to lower density levels, when the hunter effort required to hunt deer at lower densities is considered. I would recommend consideration of the policy of paying hunters to harvest antlerless deer based on this large improvement in social welfare. The large payment to hunters for harvesting deer may be a concern for policy-makers, however. As discussed earlier, in the social-welfare accounting these payments are not a cost to society; they are simply a wealth transfer from some members of society (taxpayers) to others (hunters). These payments may be justified due to the reduction in deer-vehicle accidents, forest damages, timber and crop damages, and other externalities from deer. But payments of almost $74 million each year to hunters may be difficult politically if the money comes from the general tax revenue of the state, instead of from the people most harmed by deer damage.

3.8: Sensitivity Analysis

Sensitivity of the results to the estimated model parameters can be made by comparing three results: recommended post-hunt deer densities, annual improvements to social welfare compared to the current steady-state, and total payments to deer hunters under the policy. All of the models tested move quickly to the new steady-state if the optimal policy (p and H) is followed. In fact, the base-case scenario took the longest (year 0 thru year 7) to reach steady-state of any of the models tested, with the majority of models requiring only until year 4 or year 5 to reach the indicated optimal steady-state.

3.8.1: Utility Parameters

The marginal utility of a harvested deer can either decrease quickly after the initial deer (low β parameters) or more slowly (higher β parameters). Calibrating the α parameter at current deer harvests and hunter effort levels found in Pennsylvania then indicates how much "value" hunters place on a harvested deer, and thus their consumer surplus after the cost of their hunter effort is considered. These utility parameters have very little effect on recommended deer densities, however, as indicated in Table 3.4. As we will see later, the damage deer cause, D(X), compared to the efficiency of hunters in taking deer, q, determines optimal deer densities.

Table 3.4: Utility Parameter Sensitivity Analysis

Assumed β	(post-hunt) Optimal deer density	(annual) Payment to hunters	(annual) Increased Welfare
.3	22.2 deer/mi^2	$53,694,500	$12,597,000
.4	21.7 deer/mi^2	$63,375,400	$13,031,500
.5	21.2 deer/mi^2	$73,920,500	$13,540,200
.6	21.2 deer/mi^2	$80,059,900	$14,254,100
.7	20.7 deer/mi^2	$91,670,700	$14,944,600
.8	20.0 deer/mi^2	$106,221,000	$15,670,400

What the assumption of utility parameters *does* affect is the required payment to hunters to induce the optimal harvest each year. Assuming a low β parameter, for hunters in Pennsylvania to be currently harvesting 15 deer/mi^2 indicates that they value a harvested deer *very* highly. Thus, additional deer hunting effort can be induced at relatively low payments, because the chance of harvesting additional deer is almost enough incentive alone. Assuming high β parameters indicates that deer harvests are not as valuable to hunters who currently harvest 15 deer/mi^2, so inducing more effort will take larger payments. The small changes in annual social welfare improvements that occur with different utility parameters are shown in Table 3.4 as well.

3.8.2: Deer Damage

I somewhat arbitrarily selected "½ the timber damage", or \$37.5 million, for the *non-timber* forest damage in the base case. The damage to forest biodiversity and non-timber vegetation may be higher, so another arbitrary value of "equal to total timber damage" was tested and the results assessed. Using \$75 million as the non-market value of the biodiversity damage to forests, the slope of the $D_f(X)$ function in Figure 3.4 increases to $\beta_2 = 253.77$. Calling this scenario "Increase 1", the results in Table 3.5 indicate that the optimal over-winter deer density drops to18.2 deer/mi^2 with this additional damage considered.

Table 3.5: Deer Damage Sensitivity Analysis

Damages	(post-hunt) Optimal deer density	(annual) Payment to hunters	(annual) Increased Welfare
Base Case	21.2 deer/mi^2	\$73,920,500	\$13,540,200
Increase 1[a]	18.2 deer/mi^2	\$103,030,000	\$33,339,200
Increase 2[b]	18.2 deer/mi^2	\$103,030,000	\$32,590,400
Increase 3[c]	15.1 deer/mi^2	\$135,427,000	\$58,735,800

[a] increase biodiversity damage to \$75 million; $\beta_2 = 253.77$

[b] increase automobile damage to \$150 million; $\beta_1 = 258.33$

[c] increase both biodiversity damage to \$75 million and automobile damage to \$150 million

Gary San Julian, an Extension Wildlife Specialist at Penn State, estimates the annual damage caused by deer on Pennsylvania highways at \$150 million (Drake et al.). Using \$150 million as the value of deer-vehicle collision damage in Table 3.1, the slope of the $D_{nf}(X)$ function increase to $\beta_1 = 258.33$. Using this change in DVC only, and calling the results "Increase 2" in Table 3.5 indicates the optimal deer density is again 18.2 deer/mi^2. Finally, an analysis of both of these damage estimate increases combined, probably a conservative "worst case damages" scenario, indicates an optimal post-hunt deer density of 15.1 deer/mi^2.

The final column in Table 3.5 indicates that higher estimates of deer damage, resulting in lower optimal deer densities, subsequently make the optimal steady-state improvements in social welfare that much larger. Hunters are reducing deer damage at higher rates through their hunting effort. Of course, the incentive (payment for harvests) needs to be that much greater to induce this increase in effort, so the payments to hunters increase as well.

3.8.3: Opportunity Cost of Time, w

Higher wages, or just a higher opportunity cost of time, will make the effort required to harvest a deer more costly, and all else being equal, reduce the net benefit to hunters from hunting and harvesting deer. The reduction in deer damages will increase social welfare, but the increased cost of hunter effort will decrease social welfare. An increase in w will *decrease* the optimal hunter effort level, and as real wages have increased over time this is arguably what has reduced hunter effort in many areas of the United States.

The results from different assumptions about hunter's opportunity cost of time, w, are summarized in Table 3.6. The optimal deer density is very sensitive to the hunter's assumed wage, w. In fact, if hunter's opportunity cost of time is assumed to be $30/hr or more, optimal over-winter deer densities are *higher* than the current 30 deer/mi^2. The hours of (now more costly) effort that hunter's have to spend to harvest deer are more valuable than the damage that those deer cause. The historical trend of increasing real wages, without an equivalent increase in the "value" of a harvested deer, will probably make the damage from overpopulated game species such as white-tailed deer a reality.

Table 3.6: Opportunity Cost of Time Sensitivity Analysis

w	(post-hunt) Optimal deer density	(annual) Payment to hunters	(annual) Increased Welfare
15	15.1 deer/mi^2	$101,570,000	$45,528,200
20	21.2 deer/mi^2	$73,920,500	$13,540,200
25	26.9 deer/mi^2	$30,635,000	$1,231,180
30	31.0 deer/mi^2	$(-)	n/a

3.8.4: Hunting Efficiency, q

The model shows that the optimal deer densities are also very sensitive to the assumed huntability coefficient, q. Like wages, the assumed efficiency of deer hunters in harvesting deer dictates how "costly" a deer harvest is to society. If huntability coefficients are low, hunters must spend many hours stalking deer, and be compensated by larger payments, p, to continue hunting and harvesting. Likewise, if huntability coefficients are high and hunters are efficient at killing deer, they can more easily reduce deer densities, and not have to be compensated as much for doing so. The base case model tested a q = .001, but average hunter hours per square mile of deer habitat in

Pennsylvania (E = 568.8 hrs/mi^2) indicated that huntability coefficients as low as q = .000713 are reasonable. As mentioned earlier, deer hunted with rifles in a one-mile^2 fenced enclosure showed huntability coefficients as high as q = .004 (Van Etten et al.), but the deer could not escape easily so this number is considered above what is reasonable for Pennsylvania deer habitat.

Testing the results over a range of huntability coefficients indicated that higher assumed hunter efficiency results in lower optimal deer densities, as expected. But what was not expected was the dramatic increases in overall social welfare, and the dramatic decreases in payments, p, needed to reduce deer densities to optimal levels (see Table 3.7). These two affects, when combined, may make the policy of a payment for antlerless deer harvests more acceptable to political leaders and policy-makers considering methods to reduce overabundant deer. Notice also that optimal deer densities are pushed to the "threshold level" of 11 deer/mi^2, where damages to forests begin, at huntability coefficients of q = .002 or greater.

Table 3.7: Assumed Huntability Coefficient, q, Sensitivity Analysis

(assumed) q	(post-hunt) Optimal deer density	(annual) Payment to hunters	(annual) Increased Welfare
.00071	29.9 deer/mi^2	$1,459,600	$232,239
.00100	21.2 deer/mi^2	$73,920,500	$13,540,200
.00125	16.5 deer/mi^2	$96,464,900	$37,140,900
.00150	12.8 deer/mi^2	$107,786,000	$62,145,000
.00200	11.0 deer/mi^2	$91,710,700	$103,260,000
.00300	11.0 deer/mi^2	$61,141,200	$145,141,000

3.8.5: Scenario Analysis

The results in Table 3.7 dictated an analysis of the following scenario. In the base case, the huntability coefficient q = .001 and the hunter effort required to harvest the current 15 deer/mi^2 was used to determine the parameters of the hunter utility function. With the assumed functional form in equation (19b), utility maximization by hunters under the current situation in Pennsylvania indicates a "value parameter" of $\alpha = 5163.15$ (see Table 3.2). What if game managers now take steps to increase the huntability coefficient? Hunters value a harvest the same, but now steps are taken to improve hunter efficiency. These steps may include efforts to encourage land owners to open posted land to hunting, or allowing hunting methods and techniques not currently acceptable or legal.

In any case, what are the results (combined with a payment for antlerless harvests) of increasing q?

The results in Table 3.8 indicate that steps taken to improve hunter efficiency by only 15%-35% will have the desired results, at much lower costs to taxpayers for harvest payments. Improvements of huntability to .00135 or higher result in unconstrained hunters *harvesting more deer* than is socially optimal, the historical scenario that hunting laws and restrictions were designed to regulate. Overall social welfare would be improved by over $20 million annually, with no payment for antlerless harvests needed.

Table 3.8: Improvement to Hunter Efficiency

improved q	(post-hunt) Optimal density	Required p	(annual) Payment to hunters	(annual) Increased Welfare
.00100	21.2 deer/mi^2	$198.01	$73,920,500	$13,540,200
.00115	20.7 deer/mi^2	$88.63	$32,537,400	$17,016,100
.00125	20.0 deer/mi^2	$38.73	$13,858,000	$18,798,400
.00135	19.3 deer/mi^2	(-$3.78)	n/a	$20,327,400
.00150	18.6 deer/mi^2	(-$65.09)	n/a	$22,420,100

These results indicate that options to increase q should be explored, whenever possible, as a method to encourage increased deer harvests in deer habitat where current hunter effort is inadequate. Allowing rifle hunting in all or parts of 10 New York counties was discussed earlier. New York has also recently changed the regulations to allow the transfer of doe management permits (harvest tags) from one hunter to another. Both of these changes are attempts to increase the efficiency of hunters, equivalent to an increase in q. Game managers should become more creative in their attempts to increase q, as my analysis indicates that even small increases in the huntability coefficient will lead to large increases in social welfare, and smaller required payments for harvest as well.

3.9: A Multiple Region Model

A more likely situation for game managers than the statewide model we have examined so far is one where deer densities and hunter effort vary by region. There will be a large region of deer habitat where hunter effort is low, and complaints from some stakeholders about high deer densities are occurring. Simultaneously, there will be neighboring areas of deer habitat where hunters are still hunting in large numbers and deer densities are low, and thus deer are causing few conflicts with non-hunters. The technique outlined in this analysis should be used by game managers to select the socially optimal deer densities, based on the parameters specific to the different regions. The control variable is the payment offered for an antlerless deer harvest *specific to each region*.

For an illustration of this technique, 3 different regions were modeled from the total area of Pennsylvania that represent the differentiated areas of deer habitat found in Pennsylvania: Timber forests (59%), Farmland/non-Timber woodland (25%), and Suburban habitat (16%) (from Diefenbach, 1997). The statewide damages from the deer herd were divided amongst these regions based on the types of damages reported and measured. For example, all of the timber damage was applied to the forest region, and all of the grain crops and high-value agriculture damage was applied to the farmland region. Other parameters that differed by region, including carrying capacity, huntability coefficient, and current deer densities, are outlined in Table 3.9 below.

Table 3.9: Regional Variance in Calibrated Parameters

	(value parameters)					(damage slopes)	
Region	q	β	α	K	r	$\beta 1$	$\beta 2$
Forest	.001	.5	4,216	65 deer/mi^2	.62	85.6	222.9
Farm	.002	.5	2,581	98 deer/mi^2	.72	202.0	0
Suburbs	.0005	.5	3,111	98 deer/mi^2	.22	187.9	0

The results from each of these regions are illustrative of what the PGC should expect when optimizing deer densities when the damages from deer, the huntability coefficients, and the deer's natural growth rates all vary by region. For example, the parameters for the Suburbs region were built to indicate immediate proportional damage from both deer-vehicle collisions and residential ornamental landscaping. But due to safety considerations and available refugia, the huntability coefficient was very low and even a large number of prospective hunters in suburban areas does not inflate the value parameter per OSM area very high. Thus, the expected payment ($661/harvest) and optimal post-hunt deer density (28.5 deer/mi^2) would be the highest of the 3 regions described. A comparison of the optimal results by region is in Table 3.10.

Table 3.10: Regional Comparison of Optimal Steady State

Region	Required p	Annual Harvest	Post-hunt Optimal deer density
Forest	$286.14	8.6 deer/mi2	19.9 deer/mi2
Farm	$107.27	11.8 deer/mi2	20.7 deer/mi2
Suburbs	$661.95	4.4 deer/mi2	28.5 deer/mi2

An obvious concern when delineating regions within a state, where payments for antlerless deer harvest are much higher in some regions than in others, would be ensuring that the harvests occurred in the appropriate region. For example, an ingenious hunter could hunt in a nearby farming region where deer are plentiful and more efficiently harvested, then claim he harvested the deer in a suburban region in order to collect the higher harvest payment. For this reason, hunting seasons may have to be staggered by region. As occurs now, game wardens and other hunters would police areas where the season is not open. Once the 2-week season ended in the high-payment suburbs, the 2-week season in the forested region would begin, and a subsequent hunting season for farmland regions would be last. This practice would ensure that hunters did not "save" harvested deer for presentation at check stations for a harvest payment during subsequent seasons.

3.10: Policy Implications and Discussion

My results support the general consensus that the current deer densities in Pennsylvania are too high, when the damages caused by deer are considered. Hunter effort (the only realistically available method of controlling deer populations on a large scale) and hunter populations are declining in most areas. Because hunters are free to choose their own effort levels, there must be an incentive for them to hunt if the value they place on the next harvested deer does not justify the hunter effort required to successfully find and kill that deer. Because hunter effort is costly, both to the hunter and to society, the socially optimal deer densities must balance all relevant costs and benefits while considering the growth rates and carrying capacities of the deer habitat. The estimated gains in annual social welfare from properly managing deer densities are large, and policies that would create these significant gains should be considered.

The sensitivity analysis scenarios indicate clearly that increasing hunter efficiency should be the first step for an overpopulated deer herd. This benefits hunters and society both. Policy-makers are of course constrained by safety, hunting tradition, and social acceptance alike when they consider methods of improving the huntability coefficient. Ignoring areas where sport hunting is not allowed due to safety concerns or an anti-hunting public, what creative methods may be used to increase q? Rifles, transferable harvest tags, and increased access to refugia have already been mentioned. Expanded shooting hours (before sunrise and after sunset), hunting with dogs (allowed in some southern states, but not in the northeast), and hunting over bait (allowed in many mid-western and southern states) may be several reasonable ways to increase q. More questionable methods may include allowing spotlighting, hunting from vehicles, or hunting with night vision devices in specific areas. The author is not advocating any of these currently illegal methods of hunting, but using them to illustrate how creative ideas and techniques may be necessary to increase q.

Once all acceptable methods of increasing hunter efficiency are implemented, and the dynamic programming method indicates the optimal deer densities and payments to hunters for harvest, policy makers still have to consider the acceptability of the payment to both hunters and the non-hunting public. The base case indicated a payment of \$198 per antlerless deer. This dollar amount seems reasonable as a method to increase hunter effort, and may even encourage casual hunters or former hunters to become more serious about taking antlerless deer. The amount seems less reasonable, however, from the perspective of non-hunter and taxpayer acceptance. The damages from deer outlined in this analysis are significant, easily topping \$300 million annually in the State of Pennsylvania alone. But paying hunters to reduce current deer densities *reduces* the damage caused by deer, it does not eliminate that damage. And the majority of deer damage accrues to a fairly specific group of people; farmers, forest owners, and those unfortunate enough to strike a deer on the highway. Paying hunters almost \$200 for the harvest of an antlerless deer adds up quickly, and may not be acceptable to the average citizen who is uneducated about the damage caused by overabundant deer.

Once again, creative policy can possibly overcome this resistance to paying hunters as an incentive to harvest more deer. One possibility is two antlerless deer seasons, separated by a few weeks in late fall. The first season would be much the same as deer are hunted now; two weeks, no payment for harvest, traditional hunting methods. Only after hunters have taken as many antlerless deer as they choose to without a payment for harvest would the second season begin. This second hunting season, separated in time from the first, would then pay hunters for antlerless deer harvest. The payment for harvest will only be made on the additional 3-4 deer/mi^2 that the payment would induce. The majority of deer, shot by hunters in the first season at the rates they are currently hunted (15 deer/mi^2 at current densities) would not require a payment, greatly reducing the overall wealth transfer from the payment policy. As long as large numbers of hunters did not act strategically and "wait for the second season" to harvest their antlerless deer, this system would result in optimal deer densities but at lower annual payments to hunters.

A second creative policy to provide the appropriate payment to hunters that may be less offensive to non-hunters would be paying hunters for antlerless deer donated to butcher shops. The Share the Harvest program (and others) already described does just that, but using privately donated funds, and at low (currently $35 per deer) rates (Murphy). Hunters willing to donate deer to approved butcher shops, which would then process the deer for food kitchens and aid to poor families, could be paid $200 in the base case scenario, or the appropriate amount dictated by the methodology outlined in this paper. This payment would be more acceptable to the general public, and the funds could come from the social welfare funds used to feed needy people, while having the desired effect of giving hunters the incentive necessary to harvest more deer per square mile. The management effort to coordinate this type of program may be excessive, however.

A final consideration for the policy of paying hunters to harvest deer is the effect that it will have on future hunter numbers. In fact, at its most basic level, the reduced hunter numbers and reduced hunter effort described at the beginning of this paper is the root cause of the deer overpopulation problem. More hunters (and thus higher α parameters) create higher equilibrium hunter effort levels and greater harvests. If the demand existed in all areas, there would be no need to offer an incentive for hunters to harvest more deer. So what a payment for antlerless harvests does to increase or decrease hunter numbers in the long term is important.

My opinion is that a reasonable payment will encourage more hunters to hunt, get friends and family involved in hunting, and encourage hunters to take seriously the "harvest aspects" of the enjoyment of hunting. Hunters will be less likely to pass up that doe that walks by the first few days of hunting season, waiting for the buck that may be following, if a significant payment for harvest is at stake as well. Hunters who are reluctant to kill antlerless deer that are far from a road or in difficult terrain may reconsider letting a deer pass as well, considering a payment to the hunter will be a partial compensation for the time and effort of dragging out the deer. Older and more skilled hunters will be encouraged to share their knowledge and secrets of success with younger hunters who are enjoying hunting, but would like to harvest more deer.

A criticism of paying hunters who harvest antlerless deer is that it will create a class of "bounty hunters" who do not hunt for the enjoyment of the sport, but simply to collect the harvest payment. Although possible, it is not likely that someone who was not a hunter, or at least interested in becoming a hunter already, would take up sport hunting for a $200/deer payment. Vehicles, rifles, and hunting equipment are large upfront costs of hunting, as is the time to become hunter certified, practice with a rifle, and learn scouting, tracking, and hunting skills. If there is no enjoyment from hunting and harvesting deer already, the payment for harvest alone will not justify the effort and hours required to be successful at harvesting a deer. The payment will be an additional incentive for *those who hunt already* to take more deer. If they are compensated for their effort and time as an incentive to provide the public good of reducing the deer density to socially optimal levels, that should be considered a justifiable and appropriate use of public money.

3.10.1: Extensions to the Model

Possible improvements to the technique in this essay are numerous. One criticism of the model is that it ignores the stochastic nature of annual deer harvests and deer natural growth rates. An error distribution may be added in a more complicated numerical simulation, replicating any one of many sources of uncertainty in both hunter success rates and deer population growth rates. Monte Carlo simulations may be useful to analyze the game management agency's optimal target harvests considering that deer mortality and hunter success could fluctuate significantly.

A second refinement of this model would consider deterministic reductions in the annual hunter populations, continuing the trends of the last decade. Payments for harvest would logically need to increase if hunter populations decrease further. Predicting hunter populations (especially once a payment for antlerless deer harvest is implemented) was considered too ambitious for this baseline analysis, but would be easier once several years of data are collected under this proposed policy of paying hunters for harvests. A trend of decreasing timber forest and farmland areas, and increased areas of suburbia, would be valuable as well, and possibly easier to predict than hunter population trends.

Another refinement of the model would be a spatial analysis that considered hunter effort that disperses in proportion to the difference between harvest payments offered between regions. An estimate of the average hunter's willingness to leave his traditional hunting area, and the travel costs between regions would be required. It is realistic to think, however, that hunter effort that responds to high payments for harvest in one region may leave inadequate hunter effort in other regions. The resulting harvests and post-hunt deer densities may be sub-optimal if hunter effort is easily transferred between regions.

One final improvement to the methodology used here would be to consider hunter types explicitly. Hunter types could vary (as in essay 2 of this thesis) by their willingness to pay for a harvest tag; by their opportunity cost of time, w; or by their hunter skill, efficiency, or huntability coefficient, q. If estimates of the proportions of these hunter types in the overall hunting population were available, a more detailed analysis would be possible and may lead to more accurate recommendations for deer density and the hunter payments for harvest necessary to achieve those densities.

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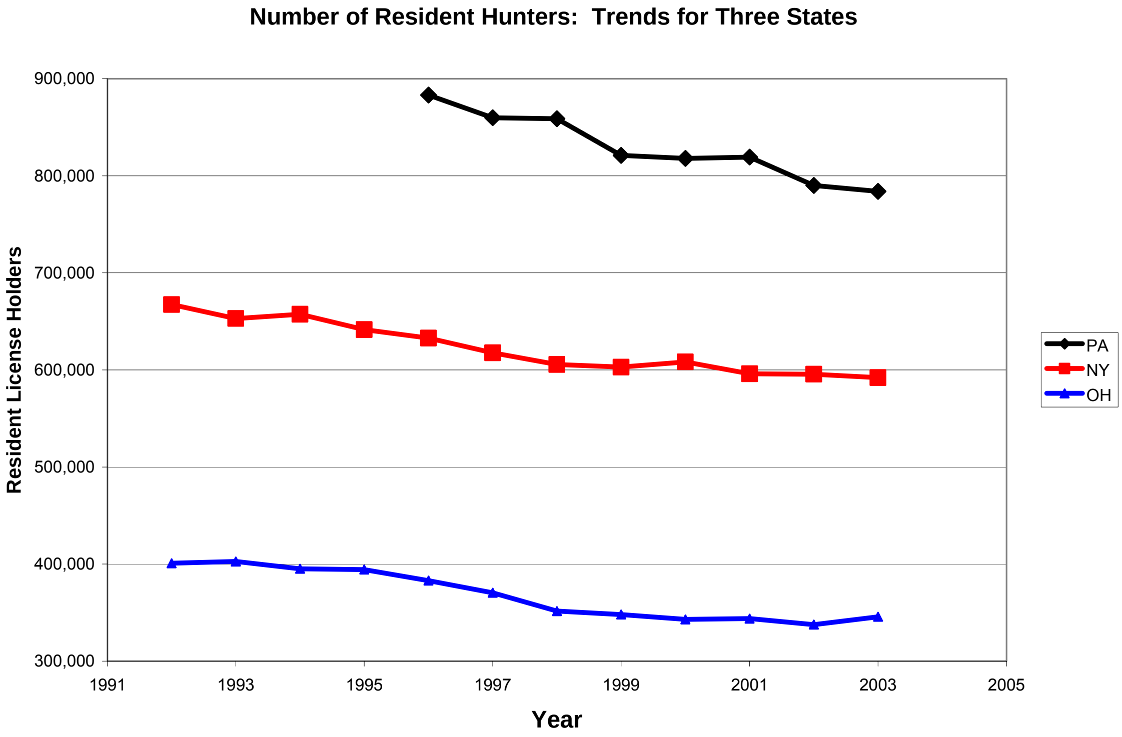
APPENDIX 3.A: Hunter Trends for Selected States



Resident Licenses Sold[19]

Year	PA	NY	OH	NJ
1992		667,301	400,749	84,261
1993		652,913	402,638	80,617
1994		657,304	395,261	77,058
1995		641,493	394,441	73,942
1996	883,091	632,802	382,919	70,190
1997	859,936	617,727	370,487	66,863
1998	858,914	605,589	351,628	63,897
1999	820,931	602,872	347,974	59,707
2000	817,970	608,234	343,078	60,085
2001	819,232	596,094	343,827	56,574
2002	789,959	595,554	337,539	54,106
2003	783,955	592,006	345,818	52,315

---

[19] Data provided by respective state game management agencies.

APPENDIX 3.B: Mathematica® Code

```
Clear [X,q,α,h,H,mc,tc,hTC,β1,β2,r,k,δ,ρ,hTB,w,v,y,jj,opt,n,f,x,dens]
Clear [temp,harvopt,harvpath,phden,ahden,prehuntdens,afterhuntdens]
Clear [alpha,xstart,xend,toteff,eff,u,β,uwrteff]
Clear [optSSS,chTC,chTB,chNB,cdamage,cNPV,impNPV,deltaNPV]
"First step is to Calibrate parameter values from known (Pennsylvania) data
points";
h[xstart_,toteff_] = xstart*(1-Exp[-q*toteff]);
u[xstart_,toteff_] = alpha*((xstart*(1-Exp[-q*toteff]))^β)-(w*toteff);
uwrteff[xstart_,toteff_] = ∂toteff u[xstart,toteff];
"Calibrate q for the average 1-sq mile (OSM) parcel in Pennsylvania";
xstart = 45;
xend = 30;
toteff = 405.4;
q = (Log[xstart]-Log[xend])/toteff//N
"Or, use a historically accurate q from other sources of between .001 and .008";
"Calibrate α based on the wage rate and selected 'decrease in subsequent
harvest' factor";
w = 20;
β = .5;
uwrteff[xstart,toteff]
α = alpha/.Solve[uwrteff[xstart,toteff]□0,alpha][[1]]
"Enter all other parameter values from known or selected information";
T = 10;
β1 = 196.93;
β2 = 190.33;
xforest = 110;
r = .72;
k = 980;
δ = .04;
ρ = 1/(1+δ);
f [x_] = r*x*(1-(x/k));
Do [v[T+1,j] = 0,{j,0,k}]
damage = Table[If [i≤xforest,β1*i,(β1*i)+(β2*(i-xforest))],{i,0,k}];
For [t = T, t > -1, t = t-1,
  H [t,0] = 0;
  v [t,0] = 0;
  For [n = 1,n < (k+1),n = n+1,
    hTC = Table[If[H□n,50000000,(Log[n]-Log[n-H])*w*10/q],{H,0,n}];
    jj = Table[(ρ^t)*((α*10((h/10)^β))-hTC[[(h+1)]]-damage[[n-h+1]])+v [t+1,Round
[n+ f [(n-h)]-h]], {h,0,n} ];
    opt = Flatten[Position[ jj, Max [jj]]];
    H [t,n] = opt[[1]]-1;
```

```
    v [t,n] = (ρ^t)*((α*10((H[t,n]/10)^β))-hTC[[(H[t,n]+1)]]-damage[[n-
                              H [t,n]+1]])+v[t+1,Round[n+f[(n-H[t,n])]-H[t,n]]];
    Clear [hTC]]]
Hstar = Table [H[0,i],{i,1,k}];
"Track an optimal path for any starting deer density";
Clear
[dens,harvopt,harvpath,phden,ahden,effopt,temp,prehuntdens,afterhuntdens,
effortopt];
dens = 500;
For [t=0, t < T+1, t = t+1,
  harvopt [t] = Hstar [[dens]];
  phden [t] = dens;
  ahden[t ] = dens-harvopt[t];
  effopt[t] = (Log[phden[t]]-Log[ahden[t]])/q;
  temp[t] = Round[dens+ f[(dens-harvopt[t])]-harvopt[t]];
  dens = temp[t]]
harvpath = Table[harvopt[i]/10,{i,0,10}]//N
prehuntdens = Table[phden[i]/10,{i,0,10}]//N
afterhuntdens = Table[ahden[i]/10,{i,0,10}]//N
effortopt = Table[effopt[i],{i,0,10}]//N
Clear
[dens,harvopt,harvpath,phden,ahden,effopt,temp,prehuntdens,afterhuntdens,
effortopt];
dens = 450;
For [ t=0, t < T+1, t = t+1,
  harvopt[t] = Hstar[[dens]];
  phden[t] = dens;
  ahden[t] = dens-harvopt[t];
  effopt[t] = (Log[phden[t]]-Log[ahden[t]])/q;
  temp[t] = Round[dens+f[(dens-harvopt[t])] -harvopt[t]];
  dens = temp[t]]
harvpath = Table[harvopt[i]/10,{i,0,10}]//N
prehuntdens = Table[phden[i]/10,{i,0,10}]//N
afterhuntdens = Table[ahden[i]/10,{i,0,10}]//N
effortopt = Table[effopt[i],{i,0,10}]//N
"Calculate Payment, p, to induce these Harvests and Densities";
"dU/dE = 0, with optimal harvest and effort, defines proper payment";
p = Table[w/(q*prehuntdens[[i]]*Exp[-q*effortopt[[i]]])-(α*β*((harvpath[[i]])^(β-1))),
{i,1,10}]
"The Optimal Steady-State Surplus for a 1-sq mile area of deer habitat is:";
optSSS = ((α*((harvpath[[10]])^β))-((Log[prehuntdens[[10]]]-
         Log[afterhuntdens[[10]]])*w/q)-damage[[afterhuntdens[[10]]*10+1]]/10)
"Compare to current steady-state surplus with no payments to hunters";
cSSS = (α*((xstart-xend)^β)-((Log[xstart]-Log[xend])*w/q)-
         damage[[((xend*10)+1)]]/10)
"Improvement in annual surplus per OSM tract of habitat is:";
```

```
impSSS = optSSS - cSSS
"Pennsylvania-wide, there are 31,110 OSM tracts of deer habitat";
"Improvement in annual surplus for entire state (annually) would be:";
deltaSSS = impSSS*31110
"Total annual payment to hunters for harvesting deer would be:";
payment = harvpath[[10]]*31110*p[[10]]
```

APPENDIX 3.C: Variable List

Symbol	Definition	Base Case Value or Functional Form
X_t	Deer Density	45 deer/mi^2
H_t	Deer Harvest	15 deer/mi^2
t	Time period	Subscripts for annual variables
q	Huntability	.001
E	Effort	Hunter hours
W	Wage	$20/hr (opportunity cost of time)
α	Value parameter	
β	Elasticity parameter	
U	Hunter Utility	
E^S	Indirect (optimal) effort	$E^S(X)$
H^S	Indirect (optimal) harvest	$H^S(X,E^S(X))$
δ	Discount rate	.04
ρ	Discount factor, $1/(1+\delta)$	.961538
F(X)	Natural growth function	$rX(1-X/K)$
r	Growth rate parameter	.72
K	biological carrying capacity	98 deer/mi^2
β_1	Non-forest damage slope	\$196.93/deer/mi^2
β_2	Forest damage slope	\$190.33/deer/mi^2
D(X)	Total Deer damage	Kinked
$D_f(X)$	Forest deer damage	linear
$D_{nf}(X)$	Non-forest deer damage	linear
OSM	One Square Mile	of deer habitat
TSM	Ten Square Miles	of deer habitat
p	Payment for harvest	$/antlerless deer

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Northeastern Agricultural and Resource Economics Association (NAREA)
Association of Graduates, USMA
Armor Association
Phi Kappa Phi
Association of the United States Army