DYNAMIC DISCRETE CHOICE ESTIMATION OF LIFETIME DEER HUNTING LICENSE DEMAND

by

Yusun Kim

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STATEMENT OF COMMITTEE APPROVAL

Dr. Carson Reeling, Chair

Department of Agricultural Economics

Dr. Nicole J. O. Widmar

Department of Agricultural Economics

Dr. John G. Lee

Department of Agricultural Economics

Approved by:

Dr. Nicole J. O. Widmar

I dedicate this thesis to God. He has been the source of my strength for two years. This work is also dedicated to my parents, Chulsoo Kim and Sunghee Ko. I never have been able to complete my Master's program without their endless love and encouragement. At the same time, this paper is dedicated to my brother, Chiyoung Kim, my sister-in-law, Soyoung Kim, and two nieces, Haeun Kim and Nael Kim. They have supported me all the time. I am truly thankful to my advisor, Dr.Reeling, under whose academic guidance I have made completed this thesis.

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ABSTRACT

The sales of deer licenses, one of the most important revenue sources for wildlife management at the Indiana Department of Natural Resources (IDNR), have been declining for a decade. To increase its funds, the agency is considering launching a new lifetime deer license, which would allow hunters to harvest deer (and possibly other species) each year for the rest of their lives in exchange for a large, up-front fee. The forward-looking nature of the decision to buy a lifetime license means hunters' choice behavior is necessarily dynamic. We estimate a dynamic discrete choice model using data from a discrete choice experiment (DCE) to capture this forward-looking choice behavior and to estimate hunters' preferences for different lifetime license designs. We find that our dynamic model better fits our data than a standard, static choice model. We also find that hunters prefer licenses that allow (i) harvest of antlered and antlerless deer to one that only allows harvest of antlerless deer and (ii) harvest of additional species beyond just deer. We use our model to estimate the price of lifetime licenses that maximizes IDNR revenues. This is the first study to estimate the value of lifetime deer hunting licenses using a dynamic approach. This dynamic approach can help improve the IDNR's decision-making to maximize its revenue and stabilize wildlife management funds.

CHAPTER 1. INTRODUCTION

Participation in deer hunting in Indiana has declined since 2011(IDNR, 2011 - 2017). This decline threatens deer management, which depends financially and ecologically on recreational harvests (Brown et al., 2000; Peterson, 2004; Schorr, Lukacs, & Gude, 2014), as well as wildlife research, habitat restoration, and maintenance of wildlife areas and public access sites. This is because the sale of deer licenses contributes significantly to revenues for the Indiana Department of Natural Resources (IDNR)—the state agency responsible for resource management. Indeed, the sale of hunting licenses accounts for 29% of IDNR funding, and deer licenses—which are relatively more expensive than other licenses—are the second-best-selling license type in Indiana.

The IDNR is considering offering a new type of license to increase agency revenues: a lifetime deer license. This license would give hunters the right to harvest up to three deer (one antlered deer and two antlerless deer or three antlerless deer) per season in exchange for paying a large up-front fee. Lifetime licenses may also include licenses for harvesting various other species in addition to deer (e.g., fishing or small game). These licenses may be attractive to customers who seek to avoid future deer hunting license price increases or who wish to give a lifetime license to a child or grandchild as a gift. Further, lifetime license revenues can provide the IDNR with stable funding for wildlife management.

Designing lifetime deer licenses is complicated for several reasons. First, setting the optimal price and attributes for lifetime licenses is challenging due to the lack of historical data that can be used for estimating demand. Indeed, the IDNR has not offered lifetime licenses for deer hunting since 2005, and the structure of these previous licenses was different from what is currently being considered. Second, the decision to purchase a lifetime license is inherently dynamic. Discrete choice experiments (DCEs) can be used to overcome the first complication. DCEs generate a hypothetical market in which consumers are asked to choose one of several mutually exclusive alternatives based on their preference (Hoyos, 2010). Defining alternatives as a set of attributes with one or more levels, researchers can analyze how each attribute and its level affect individuals' utility from their choices. Although DCEs are commonly used to estimate demand for hunting licenses (Mackenzie, 1990; Serenari, Shaw, Myers, & Cobb, 2018), standard DCEs implicitly assume that hunters are myopic. This does not hold for the choice of whether to buy a lifetime license, which is necessarily forward-looking. Applying dynamic optimization in a discrete choice setting may allow for a better explanation of choice behavior (Eckstein & Wolpin, 1989).

We develop a DCE that accounts for forward-looking behavior to estimate a model of hunter choice for different lifetime deer hunting licenses. The design of our experiment is inspired by the one-step-ahead conditional choice probability (CCP) approach of (Arcidiacono and Ellickson (2011); Hotz and Miller (1993)). Specifically, we show hunters a take-it-or-leave-it lifetime license offer. If the hunter chooses to purchase a lifetime license, he or she receives the same utility from that lifetime license each year for the rest of his or her life. If the hunter does not buy a lifetime license, he or she gets the level of utility that corresponds to the status quo combination of licenses he or she buys every year. Using this approach allows us to derive the present value of future utility a hunter receives from either of the choices—and hence hunters' choice probabilities—in closed form.

DCEs are commonly used to value attributes of big game hunting, including game animal density (P. Boxall & Macnab, 2011; P. C. Boxall, Adamowicz, Swait, Williams, & Louviere, 1996; Haener, Dosman, Adamowicz, & Boxall, 2001; Horne & Petäjistö, 2003; Hunt, Haider, & Bottan, 2005; Kerr & Abell, 2016) and the probability of successful harvest (Hussain, Zhang, & Armstrong, 2003; Mackenzie, 1990). Serenari, Shaw, Myers, and Cobb (2019) studied hunter's preferences over white-tailed deer hunting policy choices like bag limits and season length. This is similar to our research, but the authors do not estimate hunter preferences for lifetime licenses. To our knowledge, there are no prior studies that use DCEs to value lifetime hunting license attributes.

The rest of this paper is structured as follows. In the following section, we provide background on deer hunting in Indiana. Section 3 introduces a model of lifetime license choice and describes our data. In section 4, we explain our estimation procedure. Section 5 shows estimation results. Section 6 concludes.

CHAPTER 2. BACKGROUND

The IDNR's Division of Fish & Wildlife has been charged with conservation of land and wildlife populations since 1965 (IDNR; IDNR). The deer hunting season is composed primarily of three seasons: archery (early October to early January), firearm (mid- to late November), and muzzleloader (early to mid-December).[1] Currently, IDNR offers two types of licenses: a single-season license and a deer license bundle. Single-season licenses allow hunters to harvest a given number of deer—or a "bag limit"—in only one season. Bag limits vary by season but all permit harvest of at most one antlered deer. Single-season deer licenses cost $24 for residents. The deer license bundle allows hunters to harvest up to three deer (only one of which can be antlered) across any season. This bundle license was first offered in 2012 and costs $65 for residents. Additionally, hunters can purchase bonus antlerless deer licenses which allow harvest of antlerless deer in excess of license-specific bag limits, subject to county-level harvest quotas. The first bonus antlerless license costs $24. Subsequent licenses are sold at a discount. All license fees have remained the same since 2002 when IDNR increased the single-season deer license from $13.75 to $24.[2]

Funding for the Division of Fish & Wildlife is collected from two major sources: state funding and federal funding. State funding comes from primarily from sales of hunting, fishing, and trapping licenses and is spent to manage species for fishing and hunting. The amount of state funding was $9.3 million in 2020 (Indiana Department of Natural Resources). However, sales of all hunting, fishing, and trapping licenses have declined 11% from 2011 to 2017, and deer license sales have declined 44% over the same period.

[1] There are other seasons such as reduction zone and youth deer seasons, the dates for which can vary from year to year. However, relatively few hunters hunt during these seasons.
[2] There are additional transactions fee ($1) and an online fee ($1.99) for licenses purchased via the DNR's online portal.

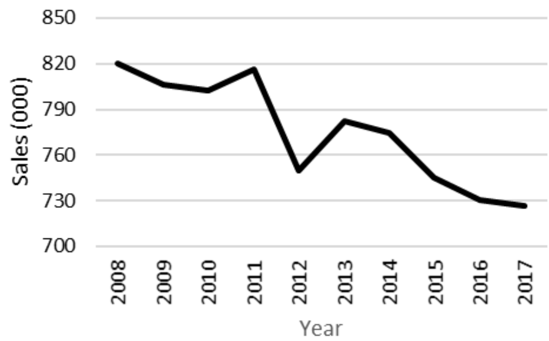

Figure 2-1. Sales of All Hunting, Fishing, and Trapping Licenses (left) and Deer Licenses (right) in Indiana, 2008–2017

This decline in deer license sales threatens the stability of state funding. To tackle this financial issue, IDNR announced hunting, fishing and trapping license fees for 2022-2023 would increase in December 2021.[3] Another solution IDNR is considering is to launch a new license: a lifetime deer license bundle. The lifetime deer license was previously offered for sale from 1981 to 2005 (IDNR). It took the form of a lifetime comprehensive hunting license, which covered all required hunting licenses and stamps—not just deer. In addition to a fishing or hunting license, a hunter with a lifetime comprehensive hunting license or lifetime comprehensive hunting and fishing license can harvest up to one antlered and one antlerless deer, depending on his or her equipment. Approximately 44,000 lifetime licenses were sold, about 59% of which were the lifetime comprehensive hunting license. The trend of sales of lifetime license had increased, especially in 2001. We assume that IDNR might announce that the agency would stop selling the lifetime license or increase its price in 2001. These lifetime licenses cost roughly 30 times the fee charged for their annual equivalents (JUSTIA, 2011). The average age of hunters who bought this license is 34 years old. Nearly 1,300 hunters bought multiple lifetime licenses, and 1,245 hunters had bought twice. We assume that they could buy them as a gift to their kids or grand kids. About 0.9% of total hunters with lifetime license had lived outside Indiana. Nearly all lifetime license buyers (99%) are male. The average of median income of lifetime license buyers was $58,126, ranging from $41,761 to $98,880.

[3] The prices we use in our analysis are the previous license fees, which correspond to those that prevailed during the course of the study.

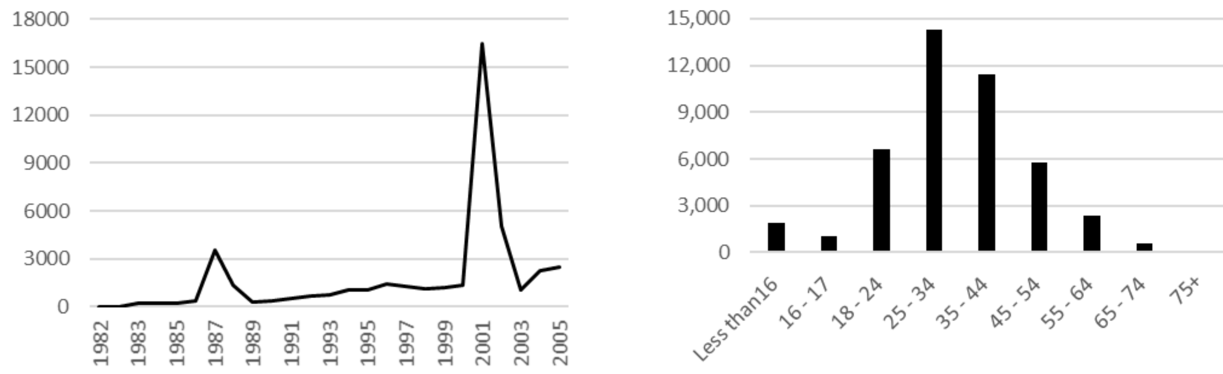

Figure 2-2. Sales of Lifetime Licenses (left) and Lifetime Sales in Each Age Group (right) in Indiana

Because (i) this license was different from the one IDNR is currently considering and (ii) there is no meaningful price variation across hunters who purchased this past license, we cannot use data from previous lifetime license sales to determine demand for the lifetime deer license bundles currently under consideration. We therefore propose a novel approach for estimating lifetime deer bundle demand.

CHAPTER 3. METHODS

This section is divided into two parts. First, we derive a dynamic model of lifetime license choice. Second, we describe the design of the DCE that we use to estimate this model.

3.1 A Model of Lifetime License Choice

A prospective hunter, indexed by i, who expects to hunt for T_i more years, faces a choice of whether to (i) buy a lifetime deer hunting license j at time t or (ii) forego a lifetime license in exchange for their *status quo* choice (e.g., an annual deer hunting license). Without loss of generality, let the status quo alternative be $j = 0$. Let the set of available lifetime licenses be $D^{H_{ijt}}$, where H_{ijt} denotes the hunter's "state." If the hunter has never purchased the lifetime license, then $H_{ijt} = 0$ and their choice set is $D^0 = \{0, 1, \ldots, J\}$. If the hunter purchases lifetime license $j \neq 0$, then $H_{ijt} = 1$ and their choice set collapses to $D^1 = \{j\}$ in future years since they never need to buy the status quo deer license again.

Let the single-period utility from choice j be $V(H_{ijt}) + \varepsilon(H_{ijt})$, which comprises a deterministic component, $V(\cdot)$, and a random, unobservable component, $\varepsilon(\cdot)$, assumed i.i.d. across individuals, attributes, and time periods. Hunters choose the alternative j each year that maximizes the present value of their lifetime indirect utility, $\sum_{\tau=t}^{T_i} \sum_{j\in D^{H_{ij\tau}}} d_{ij\tau}\left[V(H_{ij\tau}) + \varepsilon(H_{ij\tau})\right]\delta^{\tau}$, where $d_{ij\tau} = 1$ if the hunter chooses alternative j in period τ and zero otherwise and δ is the discount factor. This is the dynamic hunter's decision problem. Let the present value of utility the hunter receives conditional on choice $d_{ij\tau}$ be

$$(1) \qquad V(H_{ijt}) + \varepsilon(H_{ijt}) + \delta \int E\left(\max_{j' \in D^{H_{ij't+1}}} \{U(H_{ij'\,t+1})\}\right) f_j(H_{ij'\,t+1} | H_{ijt}) dH_{ij'\,t+1}$$

where $f_j(H_{ij't+1}|H_{ijt})$ is the probability of transitioning from state H_{ijt} to state $H_{ij't+1}$ given choice j and

$$U(H_{ijt}) = V(H_{ijt}) + \delta \int E\left(\max_{j' \in D^{H_{ij't+1}}} \{U(H_{ij'\,t+1})\}\right) f_j(H_{ij'\,t+1}|H_{ijt}) dH_{ij'\,t+1}$$

is the "conditional value function."

Given the random $\varepsilon(\cdot)$ terms, the probability the hunter chooses alternative j in period t is

(2) $$\pi_{ijt} = \Pr\left(U_{ijt} + \varepsilon(H_{ijt}) \geq U_{ij't} + \varepsilon(H_{ij't})\ \ \forall j' \neq j\right).$$

Generally, we can derive this probability by solving a dynamic programming problem using backward recursion (Arcidiacono & Ellickson, 2011). For a finite T_i, the final-period problem is just a static one: $E\left(\max_{j' \in D^{H_{ij't+1}}} \{U(H_{ij'T_i})\}\right)$, which we can solve using numerical integration methods. We can then work backwards to $t = 0$ using Bellman's principle of optimality. However, this process is computationally burdensome if the conditional value function does not have a closed form.

To solve this issue, we assume (i) these shocks have a type-1 extreme value distribution and (ii) the lifetime license is offered for only one period at the beginning of the hunter's decision problem; if they do not purchase the lifetime license in period 0, then they will never have the chance to purchase it ever again. Given the distributional assumption (i), we can write

(3) $$E\left(\max_{j' \in D^{H_{ij't+1}}} \{U(H_{ij't+1})\}\right) = \ln\left(\sum_{j' \in D^{H_{ij't+1}}} \exp\left(U(H_{ij't+1})\right)\right) + \gamma,$$

where γ is Euler's constant. Substitute equation (3) into (1) to get

(4)

$$U(H_{ijt}) = V(H_{ijt}) + \delta \int \left[\ln\left(\sum_{j' \in D^{H_{ij't+1}}} \exp\left(U(H_{ij't+1})\right)\right) + \gamma\right] f_j(H_{ij'\,t+1}|H_{ijt}) dH_{ij'\,t+1}$$

Assumption (ii) implies

$$f_j\left(H_{ij'\,t+1}\middle|H_{ijt}\right) = \begin{cases}1 & j' = j\\ 0 & \text{otherwise.}\end{cases}$$

We can use this information to rewrite (4) as

(4′) $$U\left(H_{ijt}\right) = V\left(H_{ijt}\right) + \delta[U\left(H_{ijt+1}\right) + \gamma]$$

Updating the time index and recursively substituting the result back into (4′) over T_i periods yields

(5) $$U\left(H_{ijt}\right) = V\left(H_{ij\tau}\right)[1 + A(T_i)] + \Gamma_i$$

where $A(T_i) = [(1+r)^{T_i} - 1]/[r(1+r)^{T_i}]$ is an annuity factor, and $\Gamma_i = \gamma A(T_i)$. The resulting choice probability (2) is

(6) $$\pi_{ijt} = \frac{\exp\left(U\left(H_{ijt}\right)\right)}{\sum_{j'} \exp\left(U\left(H_{ij't}\right)\right)}.$$

Note that Γ_i is constant for hunter *i* and hence falls out of choice probability (6).

3.2 Choice Experiment Design

We estimate (6) using data from a DCE. We define each license bundle as a combination of three attributes: bag limit, combination of licenses for other species, and price. Table 3-1 defines each attribute and its levels. The bag limit attribute takes two possible levels: one antlered deer and two antlerless deer or three antlerless deer. These levels correspond to the bag limits for the current annual deer license bundle, which allows hunters to harvest three antlerless deer or two antlerless and one antlered deer every year. The license combination attribute takes seven possible values comprising a deer license bundle plus any combination of a lifetime fishing license, lifetime hunting license,[4] and lifetime spring turkey license. These correspond to the three most popular sporting licenses sold in Indiana. Lastly, the price attribute takes seven possible values. These correspond to the present value of the cost of each license combination over 30 years at a 2.5% percent discount rate.(Brookshire, Eubanks, & Randall, 1983)

Table 3-1. Discrete Choice Experiment Attributes and Levels

Attribute	Definition	Levels
Bag limit	The number and sex of deer the hunter can harvest	3 antlerless 2 antlerless + 1 antlered
License combination	Other lifetime licenses included with the lifetime deer license bundle	Deer bundle Deer bundle + Fishing Deer bundle + Hunting Deer bundle + Spring turkey Deer bundle + Fishing + Hunting Deer bundle + Fishing + Spring turkey Deer bundle + Fishing + Hunting + Spring turkey
Price	The up-front cost of the lifetime license	\$500 / \$833 / \$1167 / \$1500 / \$1833 / \$2167 / \$2500

We used SAS to identify a D-efficient (*D* = 92.22) fractional factorial experimental design comprising five blocks of ten choice sets. Each choice set consists of two lifetime licenses comprising different combinations of the attributes in Table 3-1 and one "status quo" choice, representing the option to not purchase either lifetime license. Figure 3-1 shows an example of a choice set.

[4] In Indiana, the hunting license is effectively a small game hunting license and allows harvest of sixteen species, including rabbits, squirrels, turtles, frogs, red and gray foxes, coyotes, raccoons, opossum, striped skunks, quail, pheasants, crows, doves, woodcocks, waterfowl, and migratory birds. Hunting licenses do not allow harvest of deer.

Q2.1 Please imagine that you face the following three deer hunting license choices. Which license would you be most likely to purchase? Please choose between License A, License B, or No choice. You may only indicate one choice per choice set.

Choice	License A	License B	No choice
Deer bundle bag limit	3 antlerless	2 antlerless + 1 antlered	I would not buy either of these licenses
Lifetime licenses included	Deer bundle + Fishing + Hunting + Spring turkey	Deer bundle + Fishing + Spring turkey	
Price	$1,500	$1,167	
I would choose:	□	□	□

Q2.1-1 If you chose "No choice" for Q2.1, why did you not choose either license?

□ I would buy one or more single-season licenses instead (check all that apply):

□ Deer – bundle □ Deer – archery □ Deer – firearm □ Deer – muzzleloader
□ Deer – other □ Annual fishing □ Spring turkey □ Hunting

□ I would buy a lifetime license if it were cheaper than the price shown above.
□ I do not go hunting frequently enough.
□ Other (please specify):______________________________

Figure 3-1. Example of choice set from resident mail survey

A follow-up question (as in Q2.1-1 in Figure 3-1) was also given to the respondents who choose "No choice" to gather information about why they did not choose one of the given lifetime licenses. In particular, we ask respondents to report which single-season licenses they would purchase instead of the lifetime licenses. We use this information later to calculate the price of the no choice, *status quo* alternative.

3.3 Sampling and Data Collection

The DCE was embedded in a survey which comprised three parts. The first part contained questions asking about respondents' hunting experience and their opinions on Indiana deer hunting. The second part presented respondents with the DCE. The last part collected respondents' demographic information. We used a mail survey. This survey was designed following the survey design methods outlined in Dillman (2007).

We sent the mail survey to a random sample of 2,500 Indiana residents who had purchased a deer hunting license in the past five years. The survey comprised two separate mailings. The first mailing took place in mid-January 2021 and included a cover letter, the survey, and a prepaid return envelope. Reminder postcards were sent approximately 10 days after the initial mailing, followed by a second survey mailing approximately one week thereafter. We received 487 completed surveys. We removed 11 surveys with suspected protest responses. We considered these protest responses due to the presence of obviously misleading responses and/or offensive comments written in the survey. This response behavior is indicative of respondents objecting to or rejecting the premise of the survey (Champ, Boyle, & Brown, 2017). About 75% of those with protest response are male, their average age is 58 years old, and the average income is $69,500. The median education level is high school or equivalent. Our final sample for the resident survey includes 476 responses for a response rate of 19 percent. Table 3-2 compares the demographics for our sample of respondents to the population of Indiana deer hunters in Indiana. We found that the percentage of male hunters or young hunters (age 18-24) from the sample hunters are statistically different from that from population hunters at 5% level. The ratios of all hunter groups divided by specific income levels are also statistically different from the population income groups except for the group with income ranging from $30,000 - $39,999.

In any voluntary survey, there can be a nonresponse bias among survey respondents. Nonresponse bias occurs when the respondents who did not fill out the mail survey are different from the hunters who did (Dillman, Smyth, & Christian, 2014). Nonrespondents often have lower educational levels, lower incomes, and have lower interest in the subject of survey (Filion, 1975). Since the years of experience of wildlife activity does not affect the probability respondent rate (Fisher, 1996), we assume that the hunters who does not response are determined by demographic characteristics and this fact can lead to the results of our choice model to be interpreted as maximum effect.

In addition to nonresponse bias, our responses may be influenced by a unique feature of Indiana state law. Normally, hunters who own their own farmland are not required buy a deer license under what is known as a “landowner exemption.” Landowner preferences may be systematically different from non-landowners, and hence we may need to control for landownership status in our estimates. We drew our sample from a list of people who had recently purchased deer licenses, and hence only 5.7% of sample respondents have a landowner exemption. We included these respondents in our data since they still might buy a lifetime deer license as a gift for a grandchild or for another hunter in the future.

Table 3-2 Demographics of the Resident Hunter Populations and Samples

Characteristics	Resident	
	Population	Sample
Gender		
Male	87.20	84.21*
Female	12.69	14.92
Other	0.11	0.42*
Age		
Less than16	0.02	-
16 - 17	0.06	-
18 - 24	7.43	12.29*
25 - 34	21.39	22.03
35 - 44	23.08	22.46
45 - 54	19.34	17.37
55 - 64	16.07	17.37
65 - 74	8.48	6.78
75+	4.14	1.69*
Income		
< $20,000	0.42	4.51*
$20,000 - $29,999	2.53	4.74*
$30,000 - $39,999	8.36	7.00
$40,000 - $49,999	15.59	9.03*
$50,000 - $74,999	47.87	19.86*
$75,000 - $99,999	19.57	23.48*
$100,000 - $149,999	5.10	18.51*
$150,000 +	0.54	12.87*

* = the sample proportion is statistically different from the population proportion at the 5 percent level.

CHAPTER 4. ESTIMATION

We now describe our estimation procedures. The expected number of remaining hunting years, T_i, plays an important role in estimating the choice probability (6). We apply three approaches to estimate T_i for each resident hunter. First, we perform survival analysis to estimate T_i as a function of hunters' demographic characteristics using population data for Indiana hunters. Second, we use life expectancy data from the US Centers for Disease Control and Prevention to determine an upper bound on T_i given each hunter's current age. Lastly, we estimate T_i using directly from our survey data using full-information maximum likelihood estimation (FIML).

4.1 Estimation of Expected Remaining Hunting Years: Survival Analysis

We use survival analysis to estimate T_i following Klein and Moeschberger (2003). Let T_i be a random variable. Three essential functions describe the distribution of T_i: the probability density function (PDF), or the unconditional probability a hunter stops purchasing hunting licenses at time t; the survival function, or the probability of a hunter buying a deer license at least to time t; and the hazard rate, or the probability the hunter stops buying a license at time $t + \Delta t$. In this study, we assume that T_i follows a Weibull distribution (Emmert-Streib & Dehmer, 2019; Hintze, 2007).[5] The Weibull distribution is suitable for data exhibiting a monotone hazard rate (Cleves & Cleves, 2008), which accords well with the fact that hunters stop participating as they get older.

The PDF, hazard rate, and survival function for the Weibull distribution are

$$g(t|\mathbf{Z}_i) = \lambda \exp(\mathbf{Z}_i'\boldsymbol{\beta})\, t_i^{\lambda-1} \exp\big(-\exp(\mathbf{Z}_i{}'\boldsymbol{\beta})\, t_i^{\lambda}\big)$$

$$h(t|\mathbf{Z}_i) = \lambda \exp(\mathbf{Z}_i{}'\boldsymbol{\beta})\, t_i^{\lambda-1}$$

$$S(t|\mathbf{Z}_i) = \exp\big(-\exp(\mathbf{Z}_i{}'\boldsymbol{\beta})\, t_i^{\lambda}\big)$$

where $\mathbf{Z}_i$ is a vector of hunter i's personal characteristics, $\boldsymbol{\beta}$ is a vector of parameters estimated using maximum likelihood methods in STATA (code: streg), and λ determines the shape of the hazard function. If $\lambda < 1$, $h(t)$ is monotonically decreasing. If $\lambda = 1$, $h(t)$ is constant. If $\lambda > 1$,

[5] As a robustness check, we also estimated a survival model assuming T_i follows an exponential distribution. This model assumes that hazard rate is constant, which means the probability a hunter quits buying a license is the same at each time t. The exponential distribution does not fit our data well—the value of Akaike and Bayesian Information Criteria were lower for the Weibull distribution. Furthermore, the exponential model does not fit hunters' life cycle since, intuitively, hunters should be more likely to stop participating as they reach old age.

$h(t)$ is monotonically increasing. We expect that $\lambda > 1$ since the probability individuals stop hunting increases with *t*.

We estimate the survival model using license purchase data from the IDNR database. We observe every license purchased by each unique hunter in the state over the period 2014–2021. We also observe hunters' characteristics, including age, gender, residence status, (i.e., a dummy variable indicating whether or not they are Indiana residents),[6] and address. We estimate income as the median income of the census block group in which the hunter lives. Table 4-1 summarizes the data. A test of proportions finds that there are differences between residents and non-residents—in particular, nonresident hunters are younger and richer than resident ones.

[6] We include data of nonresident hunters only for the survival analysis.

Table 4-1. Demographics of Resident and Nonresident Hunters Registered in the IDNR Database (All Figures are Percentages)

Characteristic	Total (n=132,171)	Resident (n=121,064)	Non-resident (n=11,106)
Residence			
Resident	91.6	-	-
Non-resident	8.4	-	-
Gender			
Male	87.31	87.2	95.55*
Female	12.58	12.69*	4.41
Other	0.11	0.11*	0.04
Age			
Less than 16	0.02	0.02	0.06
16 - 17	0.06	0.06	0.04
18 - 24	6.99	7.43*	3.36
25 - 34	20.36	21.39	27.73*
35 - 44	21.97	23.08	30.22*
45 - 54	18.31	19.34*	17.67
55 - 64	15.19	16.07*	12.81
65 - 74	8.02	8.48*	6.46
75+	9.10	4.14*	1.65
Income			
< $20,000	0.40	0.42	0.4
$20,000 - $29,999	2.40	2.53	2.49
$30,000 - $39,999	7.92	8.36	7.95
$40,000 - $49,999	14.76	15.59*	14.21
$50,000 - $74,999	45.30	47.87*	41.57
$75,000 - $99,999	18.57	19.57	20.79*
$100,000 - $149,999	4.91	5.10	10.56*
$150,000 +	5.74	0.54	2.00*

* = the proportion is statistically greater than the other group at the 10% level.

The average number of years of hunting experience for hunters registered in the IDNR database is 10.1 years, ranging from 1 to 17 years (Table 4-2). Nonresident hunters have slightly greater experience than residents. The data is left truncated at 2014; hunters that we observe starting in 2014 may have hunted deer before 2014, but we do not observe their actual starting date. We can adjust the likelihood function to account for left truncation in STATA.

Table 4-2. Years of Hunting Experience for Resident Hunters Registered in the IDNR Database

	Observations	Mean	Std. Dev.	Min	Max
Total	361,474	10.1	5.3	1	17
Resident	356,408	10.0	5.3	1	17
Nonresident	5,066	11.5	4.2	1	17

We use this data to estimate two survival models. The first, referred to as "model 1," uses only a constant and four covariates, including hunter i's age in 2020 (age_i), a binary variable equal to one if hunter i is male and zero otherwise ($male_i$), a binary variable equal to one if hunter i lives in Indiana and zero otherwise ($resident_i$), and the median income of the census block group in which the hunter lives ($income_i$). The second model, or "model 2," is similar but adds quadratic and cubic terms for age and income along with interactions between male and the other variables.[7]

Table 4-3 shows the estimated hazard ratios and coefficients for models 1 and 2. All variables are statistically significant at the 5% level except income for model 1. The estimator for λ is 1.88 for model 1 and 1.89 for model 2, providing evidence that the hazard is not constant in either model. This is in line with our expectations. The results from model 1 show that, all else equal, a resident male hunter is less likely to stop hunting compared to a nonresident male, reducing the risk of stopping hunting by 8% but model 2 shows that a resident male hunter is 7% less likely to stop hunting compared to the nonresident male hunter. Meanwhile, model 1 indicates that male hunters have 49% less risk to quit hunting than resident female hunters, model 2 shows that resident hunters have 46% less risk to stop hunting. We found that older hunters are more likely to quit hunting. However, Model 2 shows that the hazard rate is a cubic function with respect to age and income. Before a hunter is 47 years old, the hazard rate increases slowly, but after that age it increases exponentially. A hunter's income has negative effect on the hazard ratio overall, although this effect is very slight.

[7] We also estimated models featuring all possible interactions. Model 2 has the third lowest BIC (562,124.4). The two models that outperform model 2 include a statistically insignificant interaction term on age and residency. The predicted remaining hunting years from model 2 does not differ meaningfully from the two models with lower BICs.

Table 4-3. Weibull Survival Model Estimates

	Model 1					Model 2				
Variables	Hazard ratio	Std. Err.	Coefficient	Std. Err.	z	Hazard Ratio	Std. Err.	Coefficient	Std. Err.	z
age	1.0113	0.0002	0.0113	0.0002	66.01	1.2965	0.0068	0.2597	0.0053	49.19
age^2						0.9943	0.0001	-0.0057	0.0001	-49.08
age^3						1.0000	8.09E-07	0.0000404	8.09E-07	49.96
income	1.0000	1.09E-07	0.0000	1.09E-07	1.26	1.0000	9.42E-07	-0.0000169	9.42E-07	-17.98
$income^2$						1.0000	1.03E-11	0.0000	1.03E-11	18.55
$income^3$						1.0000	3.46E-17	-4.98E-16	3.46E-17	-14.41
male	0.5113	0.0033	-0.6709	0.0064	-104.90	0.7722	0.0698	-0.2585	0.0903	-2.86
resident	0.9210	0.0174	-0.0823	0.0189	-4.35	1.3364	0.1120	0.2900	0.0838	3.46
age_male						1.0020	0.0005	0.0020	0.0005	3.93
inc_male						1.0000	3.11E-07	-2.35E-06	3.11E-07	-7.55
male_res						0.6980	0.0601	-0.3595	0.0861	-4.18
Constant	0.0045	0.0001	-5.4135	0.0267	-202.66	0.0002	1.89E-05	-8.7529	0.1195	-73.23
λ	1.880516	.0050808				1.893784			.0051006	

Obs	361474	χ^2	12747.7	Obs	361474	χ^2	15974.2
Prob > χ^2	0.000	BIC	565286.9	Prob > χ^2	0.000	BIC	562124.4

We use the estimated survival models from Model 2 to calculate the median remaining hunting years for the population of hunters. The median remaining hunting years for resident hunters ranges from 16.2 years to 26 years. The remaining hunting years is shorter for hunters older than 65 than for those younger than 65 (Table 4-4).

Table 4-4. Remaining Hunting Years for Sample Hunters from Survival Analysis

	Observations	Median	Std. Dev.	Min	Max
Total	440	16.2	2.5	7.2	26.0
> 65 years old	30	13.2	1.5	7.2	15.8
< 65 years old	410	16.5	2.4	7.8	26.0

4.2 Estimation of Expected Remaining Hunting Years: Life Tables

Next, we use life tables from the Center for Disease Control and Prevention (CDC) to estimate expected hunting years for hunters (Wei R (2012)). Life tables show individuals' life expectancy conditional on reaching a particular age, stratified by gender and race. We used Indiana life tables to estimate remaining hunting years for residents. In using life tables, we implicitly assume that hunters hunt for the rest of their lives. Hence, this approach likely overestimates hunters' true remaining hunting years. Table 4-5 summarizes our estimates.

Table 4-5. The Expected Hunting Years for Sample Hunters from Life Table

	Observations	Mean	Std. Dev.	Min	Max
Total	440	36.2	12.9	9.9	60.1
> 65 years old	30	12.9	1.8	9.9	16.6
< 65 years old	410	37.9	11.6	20.0	60.1

4.3 Full Information Maximum Likelihood Estimation

As an alternative to estimating remaining hunting years outside our model, we can estimate T_i inside our model using full-information maximum likelihood (FIML). Let T_i be a random variable following an exponential distribution with density $y(T) = \Theta(\mathbf{Z}_i)\exp(-\Theta(\mathbf{Z}_i)T)$, which has a nonnegative support and is often used in duration analysis (Holmes, Illowsky, & Dean, 2017). We assume the parameter $\Theta(\mathbf{Z}_i) = e^{\mathbf{Z}_i{}'\boldsymbol{\theta}}$ such that the distribution of T depends on $\mathbf{Z}_i$, a vector of hunter's demographic variables including age, income, gender, and residency status, and a parameter vector $\boldsymbol{\theta}$ to be estimated.

4.4 Choice Model Specification and Estimation

We write the present value of indirect utility in equation (5) as $U_{ijt} = \mathbf{X}'_{ijt}\boldsymbol{\alpha}[1 + A(T_i)] + \mu p_{ijt}$, where $\mathbf{X}_{ijt}$ is a vector of lifetime license characteristics, including an alternative-specific constant for the opt-out alternative, $\boldsymbol{\alpha}$ and μ are marginal utility parameters, and p_{ijt} is the price of license j from the DCE. The log-likelihood for the survival and life table models is

$$\ln L = \sum_{i\times j\times t} \frac{\exp\left(U_{ijt}\right)}{\sum_{j'} \exp\left(U'_{ij}t\right)}.$$

Given T_i—which is determined outside the model—and the discount rate is (r) is 0.025 (Brookshire et al., 1983), we can estimate $\boldsymbol{\alpha}$ and μ using a standard conditional logit model after multiplying the attribute data $\mathbf{X}_{ijt}$ by the annuity factor.

For the FIML model, the probability a hunter chooses an alternative j is

(7)

$$\int_{T\geq 0} \Pr\left(U_{ijt} + \epsilon_{ijt} > U_{ij't} + \epsilon_{ij't} \ \ \forall j' \neq j\right) y(T)dT = \int_{T>0} \pi_{ijt} y(T)dT$$

Note that (7) is the standard conditional logit choice probability weighted over the possible values of T. The log-likelihood corresponding with (1) is

$$\ln L = \sum_{i\times j\times t} d_{ijt} \ln\left(\int_{T>0} \pi_{ijt} f(T)dT\right),$$

with gradient

$$\frac{\partial \ln L}{\partial \boldsymbol{\alpha}} = \sum_{i\times j\times t} d_{ijt} \frac{\int_T \left(\partial \pi_{ijt}/\partial \boldsymbol{\alpha}\right) y(T)\, dT}{\int_{T>0} \pi_{ijt} y(T)\, dT} = 0$$

$$\frac{\partial \ln L}{\partial \mu} = \sum_{i\times j\times t} d_{ijt} \frac{\int_T \left[\partial \pi_{ijt}/\partial \mu\right] y(T)\, dT}{\int_{T>0} \pi_{ijt} y(T)\, dT} = 0$$

$$\frac{\partial \ln L}{\partial \boldsymbol{\theta}} = \sum_{i\times j\times t} d_{ijt} \frac{\int_T \pi_{ijt} [\partial y/\partial \boldsymbol{\theta}]\, dT}{\int_{T>0} \pi_{ijt} y(T)\, dT} = 0,$$

where

$$\frac{\partial \pi_{ijt}}{\partial \boldsymbol{\alpha}} = \pi_{ijt} \left(\mathbf{X}_{ijt}[1 + A(T)] - \sum_{j'} \mathbf{X}_{ij't}[1 + A(T)] \pi_{ij't} \right)$$

$$\frac{\partial \pi_{ijt}}{\partial \mu} = \pi_{ijt} \left[p_{ijt} - \sum_{j'} p_{ij't} \pi_{ij't} \right]$$

$$\frac{\partial y}{\partial \boldsymbol{\theta}} = e^{-\Theta(\mathbf{Z}_i)T} [1 - T\Theta(\mathbf{Z}_i)] \mathbf{Z}_i \Theta(\mathbf{Z}_i).$$

We estimate α, μ, and **θ** using MATLAB.

CHAPTER 5. RESULTS

5.1 Estimation Results

Table 5-1 shows estimation results for resident hunters when expected remaining hunting years are estimated via survival analysis, life tables, and FIML. All parameters are statistically significant at 5% level and the signs are the same across all models. The coefficients from the FIML model have the smallest values; the exception is the one for price, but its magnitude (-0.0016) is not significantly different from those in the life table (-0.0015) and survival analysis models (-0.0014). The Akaike Information Criterion (AIC) is the smallest for the FIML model, which means this model fits the choice data best.

The signs of all coefficients in all models are largely as expected. The coefficient on the opt-out variable is positive, indicating that, all else equal, hunters prefer not buying a given lifetime license to choosing their status quo option–buying annual hunting licenses. Hunters also prefer licenses that allow them to harvest an antlered deer to one that only allows harvest of antlerless deer. Combining licenses for other species—except for spring turkey—in addition to a deer license gives hunters greater utility. The coefficient of the deer, fishing, hunting, and spring turkey license combination has the greatest magnitude among all license combinations.

We also estimate the distribution of hunters' expected remaining hunting years directly with the FIML model. We assume this distribution depends on hunters' demographic characteristics, including age, income, and gender, given by a binary variable equal to 1 if the hunter is male. All variables are statistically significant at the 5% level except for the male binary variable. The signs of those variables are in line with our expectations. Note that the exponential distribution has a mean of $1/\Theta(\mathbf{Z}_i)$. This means, for example, that the positive coefficient on a hunter's age implies older hunters have fewer expected remaining hunting years, all else equal. Wealthier hunters, by contrast, have more expected remaining hunting years, all else equal.

Table 5-1. Estimated Resident Utility Functions

Variable	FIML		Life Table		Survival Analysis	
	Parameter	Std. Err.	Parameter	Standard error	Parameter	Standard error
Utility function parameters						
Opt out	0.0129	0.0041	0.0180	0.0045	0.0394	0.0079
Bag limit (base = 3 antlerless)						
1 antlered, 2 antlerless	0.0558	0.0033	0.0680	0.0027	0.1119	0.0046
Combined licenses (base = deer bundle only)						
Deer bundle + fishing	0.0181	0.0044	0.0219	0.0047	0.0351	0.0081
Deer bundle + hunting	0.0155	0.0042	0.0189	0.0048	0.0303	0.0083
Deer bundle + spring turkey	0.0143	0.0043	0.0172	0.0049	0.0247	0.0085
Deer bundle + fishing + hunting	0.0400	0.0047	0.0477	0.0047	0.0752	0.0082
Deer bundle + fishing + spring turkey	0.0266	0.0042	0.0296	0.0047	0.0448	0.0081
Deer bundle + fishing + hunting + spring turkey	0.0519	0.0049	0.0612	0.0047	0.0977	0.0081
Price	-0.0016	0.0001	-0.0015	4.74E-05	-0.0014	4.73E-05
Expected remaining hunting years parameters						
Constant	-7.6410	0.7775				
Age	0.1041	0.0159				
Income	-1.39E-05	2.92E-06				
Male = 1	-0.2769	0.2867				
Log-likelihood	-3,368.9		-3,421.8		-3,528.7	
No. of observations	12,698		12,698		12,698	
AIC	6,764		6,862		7,075	

5.2 Maximized Lifetime License Price Estimation

We use our estimated model to calculate the price of the lifetime license which maximizes IDNR funds for wildlife management. We assume that IDNR offers hunters only one type of lifetime licenses out of the seven possible types created from all possible combinations of license attributes. Hunters then make a choice: they either (i) buy the offered lifetime license *j* or (ii) do not buy it and instead choose their status quo alternative, indexed by 0. We used Excel Solver to estimate the maximized price of each license type. The objective function is the average revenue from hunters,

$$\max_{p_j} \frac{1}{N} \sum_{i} \pi_{ij} p_j$$

where N is the number of hunters and π_{ij} is the probability hunter i chooses to buy the offered license j, calculated from (6) and (7).

We used the data of registered hunters in the IDNR database. To calculate the probabilities of a hunter's choices given a lifetime license, we used each hunter's annuity factor derived from the survival analysis, life tables, or the estimated coefficients from the FIML model. Table 5-2 shows the expected revenue-maximizing prices of each lifetime license. The price of each lifetime license varies according to the hunter's preference on combined license with other species, ranging from $902.45 to $1077.89 for FIML model, ranging from $984.72 to $1,220.73 for survival analysis model and $1,138.03 to $1,625.13 for the life table model. The expected revenue-maximizing price of the lifetime deer bundle license is the lowest in each of the three models. We found from the results of three models that the lifetime license with all species brings the highest average revenue from each hunter and the expected revenue-maximizing price is the highest out of seven lifetime licenses. It is important to interpret them as the maximum price since the coefficients from FIML model are estimated using sample hunters with nonresponse bias.

Table 5-2. The Estimated Expected Revenue-Maximizing Lifetime License Price

	FIML		Life Table		Survival Analysis	
Lifetime License	Price	Avg. revenue per hunter	Price	Avg. revenue per hunter	Price	Avg. revenue per hunter
Only deer license						
1 antlered, 2 antlerless	902.45	276.76	984.72	317.03	1138.03	421.30
Combined licenses with 1 antlered 2 antlerless						
Deer bundle + fishing	957.36	330.89	1059.95	391.04	1290.74	570.81
Deer bundle + hunting	949.05	322.71	1049.02	380.31	1268.25	548.83
Deer bundle + spring turkey	945.27	318.99	1042.91	374.31	1242.64	523.78
Deer bundle + fishing + hunting	1032.84	404.98	1161.90	490.93	1496.74	771.89
Deer bundle + fishing + spring turkey	985.49	358.54	1088.90	419.44	1337.66	616.65
Deer bundle + fishing + hunting + spring turkey	1077.89	449.09	1220.73	548.43	1625.13	897.12

5.3 Robustness Check

We conduct several robustness tests on our model.

Our baseline assumption is that our survey respondents are forward-looking when evaluating lifetime license purchase decisions. Our first robustness check tests whether this holds by comparing our dynamic model estimates against a static model. Here, utility is specified as in (5) but $A(T_i) = 0\ \forall i$.

We also implicitly treat the opt-out price as zero such that the lifetime license prices respondents saw during the choice experiment would represent increases in expenditure relative to their status quo. In reality, a rational respondent should weigh the price of a lifetime license against the present value of their expected annual expenditures on the single-season licenses they buy in their status quo setting. We calculate respondents' status quo expenditures from the follow-up question we described in Figure 3.1 and treat this as the opt-out price instead.

Table 5-3. Robustness Checks

	Current Model	R1	R2	R3
Dynamic/static	Dynamic	Static	Dynamic	Static
Opt-out price	Zero	Zero	Non-zero	Non-zero

Table 5-4 shows the AICs from each model, and detailed results are shown in the appendix. The models with zero opt-out price have the lowest values among the four models. This result shows that the current model fits the data best relative to the other models. Under non-zero opt-out prices, the AICs increase even for the dynamic model.

Table 5-4. Akaike Information Criteria for Each Robustness Check

	Current Model	R1	R2	R3
Static	-	7,137	-	7,188
Survival analysis	7,075	-	7,848	-
FIML	6,764	-	6,819	-
Life table	6,862	-	8,099	-

CHAPTER 6. CONCLUSION

The sales of deer licenses in Indiana have been declining for a decade, leading to a lack of funding for wildlife management at the IDNR. A lifetime deer license is being considered to increase agency funds. Hunters are highly likely to have different decision-making processes when they purchase a lifetime license compared to a single-season one. We used a dynamic discrete choice model to capture hunters' forward-looking choice behavior and estimate hunter utility from different lifetime license designs. We also estimate the license price which maximizes IDNR revenue.

We find that our dynamic model better explains hunters' lifetime deer license purchase behavior than a standard, static model. Based on the result from MLE model, we conclude that, all else equal, resident hunters prefer licenses that allow harvests of both antlered and antlerless deer as well as licenses that allow harvests of other species. However, resident hunters are not willing to pay more for lifetime deer licenses combined with a lifetime spring turkey license than they are for a lifetime deer license combined with hunting. The license structure that gives residents the greatest utility is one that allows harvest of one antlered and two antlerless deer and includes a lifetime fishing, hunting, and spring turkey licenses. The price of the lifetime license with three antlerless deer that is the key price to maximizes DNR revenue is from $902.45 to $1077.89.

Our work is the first study to estimate the value of lifetime deer hunting licenses. The results from this work can contribute to decision making that will increase funds for wildlife management. Indeed, there are many states in the U.S (e.g., Illinois, South Carolina, Texas, or Oklahoma) that provide lifetime licenses for other species such as fishing and hunting. This work can provide a useful approach to set the best price considering the unique preferences for each states' hunters.

APPENDIX. ROBUSTNESS CHECK RESULTS

Appendix 1. Survival Model

	R 1		R 2		R 3	
Variable	Parameter[a]	Standard error	Parameter[a]	Standard error	Parameter[a]	Standard error
Utility function parameters						
Opt out	0.6143	0.1095	0.1316	0.0069	0.7314	0.1080
Bag limit (base = 3 antlerless)						
1 antlered, 2 antlerless	1.5441	0.0640	0.0925	0.0042	1.5290	0.0637
Combined licenses (base = deer bundle only)						
Deer bundle + fishing	0.4762	0.1125	0.0386	0.0077	0.4777	0.1120
Deer bundle + hunting	0.4130	0.1159	0.0244	0.0078	0.4111	0.1154
Deer bundle + spring turkey	0.3421	0.1181	0.0217	0.0080	0.3397	0.1175
Deer bundle + fishing + hunting	1.0240	0.1138	0.0547	0.0077	1.0098	0.1132
Deer bundle + fishing + spring turkey	0.6213	0.1122	0.0402	0.0076	0.6186	0.1118
Deer bundle + fishing + hunting + spring turkey	1.3422	0.1126	0.0874	0.0077	1.3350	0.1121
Price	-0.0013	0.0000	-0.0005	3.14E-05	-0.0013	4.73E-05
Log-likelihood	-3559.6461		-3914.7584		-3585.0222	
No. of observations			12,698			
AIC	7137.292		7847.517		7188.044	

[a] All estimates are significant at the 1% level.

Appendix 2. Life Table and FIML Model

	R 2			
	Life Table		FIML Model	
Variable	Parameter[a]	Standard error	Parameter[b]	Standard error
Utility function parameters				
Opt out	0.0819	0.0038	0.0164	0.0041
Bag limit (base = 3 antlerless)				
1 antlered, 2 antlerless	0.0518	0.0024	0.0567	0.0035
Combined licenses (base = deer bundle only)				
Deer bundle + fishing	0.0229	0.0043	0.0182	0.0045
Deer bundle + hunting	0.0123	0.0044	0.0156	0.0043
Deer bundle + spring turkey	0.0134	0.0044	0.0144	0.0044
Deer bundle + fishing + hunting	0.0277	0.0043	0.0403	0.0048
Deer bundle + fishing + spring turkey	0.0232	0.0042	0.0271	0.0043
Deer bundle + fishing + hunting + spring turkey	0.0491	0.0043	0.0528	0.0050
Price	-0.0002	2.18E-05	-0.0015	5.17E-05
Expected remaining hunting years parameters				
Constant			-7.5544	0.7741
Age			0.1052	0.0163
Income			-1.44E-05	3.03E-06
Male = 1			-0.2643	0.2872
Log-likelihood	-4040.5736		-	
No. of observations	12,698			
AIC	8099.147		6818.969	

[a] All estimates are significant at the 1% level.

[b] All estimates are significant at the 1% level except for Male

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