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A Nonparametric Test of the Traditional Travel Cost Model

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STAFF PAPER

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Introduction

The travel cost model of recreation demand has been used to study the services provided by recreation sites for over 30 years.[1] Numerous assessments have been made of alternative ways of implementing the travel cost model (TCM) and of its performance according to a variety of criteria. The vast majority of these assessments are "parametric" in nature, i.e., they are based at least in part on specific assumptions regarding functional forms and error distributions in demand equations. Recently, Adamowicz and Graham-Tomasi proposed a "nonparametric" approach to testing the TCM based on an examination of the consistency of recreation data and the TCM with revealed preference axioms of rational choice. The nonparametric approach has the advantage of expurgating from the test procedure potentially confounding parametric assumptions.

In an empirical application of the methods they propose, Adamowicz and Graham-Tomasi (AG-T) found that recreation data on prices and quantities for Bighorn sheep hunting in Canada, when combined with a particular form of the TCM, generally were consistent with the axioms of rational choice. Very few violations of revealed preference axioms were identified, and when they did exist, a measure of the severity of the violation showed them to be "small." The version of the TCM they tested involved a separability assumption across trips, so that different trips were taken to be independent choices. While this separability assumption often is invoked in travel cost analyses based on the "discrete choice" model (e.g. Bockstael et al. 1987a), it is not imposed in the traditional TCM, in which the choice is the number of visits over a recreation season.

In this paper we provide a nonparametric test of the traditional TCM. We examine a multi-site model with choices made regarding the number of trips to take to each site over an entire recreation season. We employ the data on Bighorn sheep hunting used in AG-T. However, we find much weaker consistency of these data with the axioms of choice than did AG-T; here, violations are numerous and "large." Subject to some qualifications which we discuss below, this result calls into question the correspondence between actual recreation choices and their representation in the version of the traditional TCM we employ.[2]

There are two ways to interpret tests of consistency between recreation data and the axioms of choice. First, if it is maintained that individuals are rational, then one can test the details of the TCM. For example, use of the TCM requires a "price" for a recreation trip, including both money and time costs. This price is not an observed entity, and considerable debate surrounds its construction, particularly regarding the value of time. Observed inconsistencies between the recreation price-quantity data and the axioms of choice might then be due to an incorrect price inserted for trips.[3] The second interpretation rests on a maintained assumption that the prices and goods included in the data are correct. Then one can test for the rationality of the consumer choices in the data.[4] In this paper we adopt the former interpretation. We assume consumer rationality and examine the effects of alternative travel cost prices and model structure on consistency with the axioms of choice. In particular, we study methods for incorporating travel time into the travel cost variable, and the impact of changing the set of sites included in the consumer's choice set. We apply methods developed by Tsur (1989, 1990) to statistically test the severity of violations of revealed preference axioms under alternative conditions.

Regarding time values, there exists some ambiguity in empirical practice concerning whether both travel time and on-site time, or only travel time should be included. We assess choices with only travel time incorporated[5] and choices with both on-site and travel time included, where all time is valued at the wage rate. We find that there is a significant fall in the number and severity of violations when both travel and on-site time are included.

Regarding the choice set, the issue of how many sites to include in a travel cost model is vexing to the applied researcher. At the extremes are the single-site model and its well-known difficulties if there exist substitute sites (Rosenthal), and the full model, where all potentially interrelated sites are included. But how can this set be identified? If two groups of sites are separable in the utility function, then only those in one separable group need be included in any one estimation (Fletcher et al.) A necessary condition for a subset of the sites to constitute a separable group is that the group satisfy the axioms of choice (Varian, 1987). Certainly, if one set of sites leads to significant violations and another does not, it may be unwise to estimate parametric demands on the former set. Our procedure provides a method for identifying coherent groups of sites that seem to be less ad hoc than current practice.[6]

As AG-T note, the preferred way to test the traditional TCM using revealed preference methods is to have data on the season-long choices of a sample of individuals over several seasons, where there is sufficient interseasonal price variability to allow budget lines to cross. Here, we use a single season of data for a sample of individuals, and treat the sample data as if they were generated by a single consumer making several choices. Clearly, this is a shortcoming of the current approach. However, it is justified by two considerations. First, when one undertakes a parametric estimation of the TCM, or any other demand model, it is assumed that the individuals in the sample have the same demands, up to independent variables and error terms. Naturally, if this is the case, the data must behave as if it could have been generated by a single consumer.[7] Second, we conducted the same tests after stratifying the sample into different groups based on socio-economic variables, and found qualitatively similar results. While this is not entirely convincing, it leads one to believe that a TCM model with socio-economic demand "shifter" variables would encounter the same problems of consistency with revealed preference axioms for analogous subgroups of the sample as indicated by our results on the entire sample.[8]

The paper is organized as follows. In the next section we describe the parametric TCM we are testing and discuss some of the issues involved in its implementation. Then, we provide a brief presentation of revealed preference theory, and introduce the statistical techniques we employ. The following section describes our data and presents our results. A final section draws some conclusions.

The Utility Maximization Approach to Travel Cost Models

The travel cost model is founded in utility maximization. Suppose a representative recreationist has preferences represented by a utility function, U, over the number of trips to a set of recreation sites and the consumption of all other market goods. Assume that choices are made as if the consumer solves the following problem:

$$\max U(v_1,\ldots,v_J,z)$$

$$S.T. \quad 1) \quad hw+M=Y=c(v_1,\ldots,v_J)+pz$$

$$2) \quad T=h+\sum_{j=1}^{J} v_j(t_1^{\,j}+t_2^{\,j})+t_z,$$

where v_1 to v_J represent the number of trips to each of J recreation sites, z is a bundle of all other goods, Y is income, w is the individual's wage rate, h is time spent working, M is non-wage income, c is out-of-pocket costs per trip, p is a vector of prices of all other goods, T represents the total time available, t_1^j is travel time per recreation trip, t_2^j represents time spent on the recreation site per trip, and t_z is the time spent consuming all other goods. The constraint used here attempts to incorporate time explicitly in the budget, an approach first proposed by Becker, which is commonly applied in investigations of recreation demand (e.g. Smith et al.). Assuming that M=0, and substituting from (2) into (1), we have:

$$w(T-\sum_{j=1}^{J} v_j(t_1^{\,j}+t_2^{\,j})-t_z)=c(v_1,..v_j)+pz$$

The constraint now identifies that full income is equal to expenses. This identifies the full cost (c_j^*) of visiting a recreation site (j) as $c_j^*=w(t_1^j+t_2^j)+c_j$ with time variables valued at the wage rate, w, and c_j representing actual travel expenditures involved in visiting the site. This is a relatively simple treatment of the time issue. See Smith et al. and Bockstael et al. (1987b) for more elaborate models of time in the recreation decision.

The Costs of Time.

One of the most perplexing concerns in the travel cost literature is how to calculate the total variable cost of travelling to the recreation site. It has long been recognized that how time is valued has substantial impact on site valuation (Bishop and Heberlein). In the traditional travel cost model it is frequently assumed that all trips are homogeneous in length. Hence, the time requirements are fixed per trip. Time spent travelling and on-site are not treated as choice variables in the model. Wilman developed a utility-based model with goods and services requiring time, those not requiring time, and two measures of recreation site use: the number of visits of a given length to a site, and the number of round trips to the site. She showed that travel time could be valued as "travel time saved" while on-site time could be valued in terms of its scarcity value. Numerous elaborations of these time valuation approaches have appeared (e.g. Smith; Bockstael et al, 1987b). While it generally is recognized in the theoretical literature that both travel and on-site time values should appear, empirical practice is uneven in this regard. Those who choose to not include on-site time implicitly assume that its value is low relative to travel time and can be ignored in practice.

We approach this issue in a relatively simple manner. Both on-site and travel time are incorporated in our travel cost analysis, and both are valued at the same rate. Since the issue addressed here is the consistency of the travel cost model with choice theory and not the estimation of welfare measures, our approach can be used to illustrate the effect including time in the prices has on the degree of consistency of observed choices with the axioms of revealed preference theory. Thus, our analysis will attempt to identify how well the model represents economic behaviour with travel costs only, and with travel and time costs.

Goods Separability

The utility maximization problem identified in the previous section essentially involved two groups of goods: visits to a set of recreation sites with each site treated as a different good (v), and a group including all other goods (z) that could be consumed by an individual. It is possible, however, that the utility function could be separable over some sets of these goods. For example, if separability of recreation trips from all other goods is legitimate, the following restructuring of the utility function, U will represent the same preferences as the original function.

$$U(H(v),G(z)),$$

The advantage of separability is that the sub-utility functions can be examined independently. If v and z are separable, then maximization of each function (H and G) yields demands that are consistent with rational choice behaviour.

One important aspect of separability in the travel cost model concerns the alternative sites available to the consumer for the same recreational activity. At the limit, one could assume a separate utility function for each site. However, it seems likely that the demands for recreation at a site would be affected by demands at other sites. The most complex approach would be to group all sites together in the utility maximization model. Using this inclusive strategy would seem to ensure that demands have not left out important influences. However, we do not generally know what the full choice set is. Thus, we typically are working with some reduced choice set, which may or may not correspond to a separable set. Without knowledge of the structure of the utility function the decision to include or exclude sites is an untested assumption. Certainly estimation on choice sets which do not admit rational choices (when individuals are in fact rational) would seem an unwise strategy if estimation is to be consistent with economic theory. There has been little investigation into methods of determining the choice sets which are relevant. In this study, the concepts of revealed preference are used to examine if particular subsets of an overall set of sites are consistent with rational choice. This is a necessary condition for the set to be truly separable.

Study Plan

This paper provides a test of the traditional TCM using nonparametric demand methods and investigates a number of the issues described above. The traditional TCM should be tested by considering the choice of individuals over a season as a consumption bundle, and examining these choices for rationality over several seasons (AG-T). Here, we do not have data on individuals over seasons. To test the model we take consumption bundles consisting of a season of recreation choices and amalgamate these bundles over a number of recreationists, assuming that these are the choices made by one consumer. In other words, by maintaining an hypothesis that individuals are rational in the sense that their behaviour is consistent with a utility maximization model, and that individuals in the sample have the same utility function, the travel cost method is tested to see if the choices generated by the individuals are consistent with the utility function implied by the travel cost model. While the assumption of identical utility functions may seem overly restrictive, as we describe above, the TCM used in practice essentially makes this assumption. Thus we are testing the model as it is most commonly used.

The Theory of Revealed Preference

Samuelson (1938) suggested that the observed choices by individual consumers could be used to investigate maximizing behaviour based on principles of rationality. This idea led to the development of revealed preference approaches to consumer theory which take the observed choices and investigate whether these choices are rational in the sense of maximizing a preference relation, and which attempt to approximate the utility function which represents the preferences generating the data.

In order to "rationalize" choice behaviour, revealed preference theory begins with a consumption set X of consumption vectors x, a price vector p, and a family B of budgets with elements b. Each element b can be defined as $b=\{x: x \in X \text{ and } px \leq m\}$, where m is income. A set of consumption vectors, h, can be chosen from b, so that h(b) contains the bundles which are chosen by a consumer subject to that particular budget b. A "rational" consumer makes choices which maximize a **binary** preference relation R. Thus, rationality is defined by there being an R such that: $h(b)=\{x: x \in X \text{ and } \forall y \in b, xRy\}$ $\forall b \in B$ (Richter).

The Strong Axiom of Revealed Preference (SARP) (Samuelson 1950) contains the conditions necessary to test multi-valued demands for consistency with a variety of "economic" preference relations (Matzkin and Richter). Let the directly revealed preferred relation R_0 be defined by the statement $x_1 R_0 x_2$ if $p_1 x_1 \geq p_1 x_2$ and $x_1 \in h(b)$. Let H_R be the transitive closure[9] of R_0. The SARP states that if xH_Ry, and $x \neq y$, then yH_Rx will not occur.

A modification of the SARP is the generalized axiom of revealed preference (GARP) proposed by Varian (1982). This axiom involves the **strictly** directly revealed preferred relation, P_0. To define the GARP we say that x_1 is strictly directly revealed preferred to x_2, written $x_1 P^0 x_2$, if $p_1x_1 > p_1x_2$. The GARP is defined as $x_1H_Rx_2$ implies not $x_2P^0x_1$. Note that there is no requirement that $x_1 \neq x_2$. The GARP differs from the SARP in that it allows multi-valued demands, or the existence of "flat spots" on indifference curves.

Matzkin and Richter show that choice behaviour that is consistent with the SARP is sufficient to construct a concave utility function representing the consumer. Varian (1982) identifies that consistency of choices with the GARP is enough information to state that the demands could have been generated by a concave utility function. Therefore, examination of a set of consumer choice data for violations of the SARP or GARP provides information on the consistency of that data with the underlying theory of economic maximizing behaviour.

Testing Observed Choice Behaviour for Rationality

The examination of data for violations of revealed preference axioms is complicated by the fact that measurement errors can exist in data sets of choice behaviour gathered from a consumer. The data may exhibit violations of rationality while the unobserved true data chosen by the consumer are consistent with revealed preference axioms. Varian (1985) and Tsur (1989) investigate statistical tests of the question: are violations of the revealed preference axioms noted in observed choice data sets sufficiently large that it is implausible that the true data satisfy the axioms?

Varian (1987) suggested that one measure of the severity of the violations is the amount a consumer's budget would have to be perturbed in order to allow his/her choices to be consistent with the GARP. In formal terms, consider demand data (p_t, x_t) where p_t is a price vector and x_t a vector of choice occasion quantities for t, t=1,....,T, and a given set of numbers e_t, with $0 \leq e_t \leq 1$. Varian defines a directly revealed preferred relation as $x_1R_ex_2$ if and only if $e_1p_1x_1 \geq p_1x_2$. Let H_e be the transitive closure of this relation. If $e_t=1$, the usual direct revealed preferred relation holds. However, if $e_t=0$, the relation is invalid. Thus e_t, which is a scalar ranging from 0 to 1, is the amount of reduction in the budget required to just satisfy the axioms of choice. If the axioms are satisfied initially, $e_t = 1$ for all t. If the axioms are not satisfied, some e_t less than 1 can be found which results in satisfaction of the axioms. Varian (1987) referred to these e_t's as efficiency indices. In this paper we use these indices in testing choice data for violations of revealed preference axioms. In describing the results of these tests, we calculate an "error" which results from subtracting e_t from 1. This reverses the direction of the measurement, so $(1-e_t)=0$ reflects consistency with the axioms, while $(1-e_t)$ approaching 1 suggests a serious violation.

There are two ways to use the efficiency index to describe choice data. One is to find a single e_t that when applied to all observations, removes all violations of the GARP. This method is referred to as the Single Index Test. An alternative approach is to use the vector e_t which associates each observation with an error term, and find the vector which minimizes some measure of aggregate error, while still satisfying the axioms of choice. A useful aggregate function is the quadratic form:

$$\min \sum_{t=1}^{T} (e_t - 1)^2$$

This approach is termed a Multiple Index Test (Varian, 1987; Tsur, 1989).

The Single and Multiple Index tests provide measures of the degree of violation or the distance of the observations from a set of budgets which satisfy the axioms. However, they do not provide a statistical measure of the significance of these violations. A number of investigators have proposed statistical tests regarding the size of the errors based on the recognition that measurement error exists in the data (Varian 1985; Tsur 1989, 1990). The most practical of these tests was proposed by Tsur (1989). This test assumes normally distributed measurement errors and uses the efficiency vector to construct a test statistic, ρ, that characterizes the severity of violation. It is calculated according to:

$$\rho = \sum_{t=1}^{n} \frac{[\log e_t]^2}{n}$$

This value is then compared to the variance of the log of actual expenditures. If ρ is greater than the variance of the log of actual expenditures, then one may reject the null hypothesis that observed violations are due to measurement error and the true data structure satisfies revealed preference axioms.[10]

Data and Methods

Data used in this study concern Bighorn Sheep hunting in Alberta, Canada. The data were collected from 623 individuals who held licences during the 1981 hunting season; 226 individual hunters provided sufficient information to be used for the present study.[11] Table 1 presents a summary of their socioeconomic characteristics.

Our investigation of individual choices uses the numbers of trips taken to various hunting sites over the entire hunting season as the consumption bundle with a price vector consisting of money and time costs of a trip.

As mentioned above, we treat the choices of different hunters in one season as if they were several choices of one hunter on different choice occasions. Hence, the tests of rationality of the observed choices involved comparing the observed consumption bundle of one hunter at the prices he faced with the observed consumption bundles of other hunters at different prices.

Ten hunting sites are defined based on wintering zones of the sheep populations. Two of these sites merit comment. Site 6 is an area restricted to individuals using archery in hunting big game species. This site is established through hunting regulations and bow hunting is monitored by enforcement officers. Site 10 represents the Willmore Wilderness, an area with little or no developed access to the habitats where sheep and other game species are found.

The total price of a recreational trip consists of travel costs and time costs. In this study the total price (P) consisted of:

$$P = TCOST + (TTIME \times w) + (STIME \times w),$$

where TCOST represents the actual "out-of-pocket" costs of travel to the site including fuel etc., TTIME represents the estimated number of hours spent travelling, STIME represents the time (in hours) spent at the site, and w represents an estimate of the individual's hourly wage rate. Although many applied travel cost studies utilize only TTIME in measuring the opportunity cost of time, a number of studies have shown that ignoring the on-site time is invalid (e.g. Wilman). In this study the values of TTIME and TCOST are dependent on the distance between origins and sites. Therefore, incorporating TTIME with TCOST simply shifts the budget lines by a proportion of an individual's wage rate. Revealed preference tests rely on changes in slopes of budget lines; hence, we cannot distinguish between a model with and without travel time. However, the magnitude of STIME is not directly dependent on distance, and incorporating it in the price of a trip results in changing the slope of budget lines[12].

Distance was estimated by the shortest round trip distance between each hunter's origin or home and the 10 hunting sites (see Coyne for details). Travel costs were calculated by multiplying these distances by a mileage charge of 18 cents per kilometre, which represents the estimated costs of purchasing fuel and vehicle maintenance services on a unit distance basis in 1981 (Coyne). Table 1 provides a summary of the magnitudes and variability of these distances and costs. Estimates of the time costs consisted of three components: the number of hours spent travelling, the number of hours spent on-site, and hourly wage rates. Two methods of computing wage rates were used in this study. One method used reported income, the second used occupation data.

In order to calculate the costs of travel time the approximated hourly wage rates for each of the income and occupation categories were multiplied by the estimated number of hours spent by the hunters travelling between their homes and hunting sites (TTIME). These hours were derived using the distances between origins and sites described above and by assuming an average vehicle speed of 80 kph. The time spent by individuals at each site in days (STIME) was collected directly from the hunters through the hunter survey. Days were converted to hours assuming a day was 8 hours long. The opportunity costs of on-site time were derived by multiplying hours by the wage rate. In cases where a hunter did not visit a particular site during the season, an estimate of the on-site time costs he would have faced in choosing that site was derived by taking the mean number of hours he actually spent hunting at all sites during the year and multiplying this by his wage rate.

Results

Testing the Travel Cost Model

The first revealed preference test of the hunter data set involved a multiple index test on the entire sample with the value of time equal to zero. The results of this test are displayed in the first line of Table 2. Of the 226 choices of the sheep hunters, 181 (80%) constitute violations of SARP. Since the variance of the log of actual expenditures is less than ρ (Table 2) we reject the null hypothesis that the true data satisfy the SARP. The average error of the individual violations was 0.43; recall that a zero error represents perfect consistency with the SARP. Assuming that no type I errors of statistical inference are being committed, these results indicate a number of possibilities: 1) that the travel cost model is an incorrect representation of the economic behaviour of these recreationists; 2) that the model is accurate, but the prices used in the analysis are biased measures of true prices; 3) that there is significant heterogeneity among recreationists in the sample that is not being accounted for in this travel cost analysis; 4) that the utility function being tested does not contain the appropriate goods (sites), or 5) some other aspect of the test procedure is flawed. Two of these possibilities are investigated further below.

Incorporating the Values of Time in the Travel Costs

The other entries in Table 2 provide results of revealed preference tests incorporating the value of time based on wage rates determined from income or occupation information. The test results indicate a significant improvement in the consistency of the hunter choices with SARP when these values are included in the prices. According to Tsur's test, when on-site time is included using either method of computing wages, violations were insignificant. Second, using the income-based values provided closer consistency of the choices with SARP than using the occupation-based wage rate. Relative to no on-site time, the tests using income resulted in a reduction of violations (from 181 to 172), and much smaller mean errors (from about 0.43 to 0.16); tests using occupation did not reduce the number of violations, but their severity was reduced (to .30).

Figure 1 shows the distributions of errors from two tests; one incorporating no value of time and the other using a value of time based on income. These distributions reveal that, despite considerable improvement in consistency of the data with the SARP with positive time values, there are still relatively large individual errors associated with some individuals in the sample. Thus, while the mean errors were closer to zero, and Tsur's test indicates that they are not statistically significant, there remains a relatively high degree of inconsistency of observed choice behaviour with the axioms of rationality. Thus, one might search for alternative explanations for these deviations.

However, it is clear that when on-site time is incorporated in the travel cost the resulting prices better represent those faced by these sheep hunters, assuming that they are, in fact, rational and act as if they had a single preference ordering. These results are similar to those observed by Adamowicz and Graham-Tomasi using individual choices.

Tests of Separability in Hunting Site Choice

Typically, the analyst will not know the true set of recreation sites being considered when the choices are made. It is reasonable, then, that the analyst uses his or her judgement to define a coherent choice set that might constitute a separable group. Note that if one adds to such a separable group a choice that is not part of that group, then demands estimated for the expanded set will not correspond to utility maximization (unless, of course, the new group is also separable or constitutes the entire choice set).

For example, suppose the true set of goods is $\{ x_1, \ldots x_4 \}$ but the analyst does not have available information on x_4. If $\{ x_1, x_2 \}$ and $\{ x_3 , x_4 \}$ are separable groups, estimation of the demand system for $\{ x_1, x_2 , x_3 \}$ does not provide useful information for welfare analysis.

Regarding revealed preference tests, Varian (1983) showed that there are no testable restrictions on incomplete demand systems unless the data constitute a separable group. A necessary condition for separability is that the group satisfy the GARP. Thus, if one has data with a large number of violations on one choice set, and a much smaller number of violations on a reduced choice set, it might be concluded that the smaller set more closely corresponds to a separable group. Hence, a form of separability test which examines subsets of the data is performed to study alternative choice sets.

Two subsets of the set of ten sites were examined. The first subset was determined in an ad hoc fashion based on information about the sites. Two sites were removed from the original set: the bowhunting site (site 6) and the remote wilderness site (site 10). The 31 individuals who took trips to sites 6 and 10 were removed from the data set. The second subset was determined based on a cluster analysis of quality attributes related to the sites[13]. This subset contained sites

1 through 9 and the 26 individuals who hunted at site 10 were removed from the sample. A multiple index test was then conducted on the restricted choice sets. If the results of this analysis are markedly different from the full choice data set, then there is evidence that the appropriate sub-utility function operating over the site choice of recreational sheep hunters in Alberta is made up of these subsets rather than all 10 sites.

Table 3 reports the results of the tests of the subsets and the entire set of sites. The subsets are examined using prices with and without the incorporation of the value of time. When the subsets are examined using prices without the value of time, all show significant violation of the axioms of choice. When the value of time is incorporated all sets appear to be consistent with the axioms of choice based on Tsur's test. It appears that the value of time assumption is much more important than the site choice definition in this context. This very limited test indicates that recreationists choose among sites that vary markedly in their characteristics. One implication of this result is that analysts should be more rather than less inclusive in their definition of choice sets. It also indicates that remaining violations in our data are due to reasons other than an ill-specified choice set.

Discussion

Our initial test of the traditional TCM with no on-site time value resulted in a large number of significant violations of rationality. The results suggested one of two possibilities: 1) that sheep hunters were not rational in the sense of maximizing a utility function; or 2) that the model used was incorrect. Under a maintained hypothesis of rational choice by hunters, we explored modifying the model to include the opportunity cost of on-site time. The results suggest that the traditional travel cost model more closely represents the underlying economic maximizing behaviour when these time costs are incorporated.

We also studied the possibility that the observed violations of rationality occurred because the tests involved an inappropriate set of available sites. Two different subsets were considered. In one case two sites were chosen by considering "obvious" differences between various characteristics of the sites. In the other case only one site was removed based on statistical analysis of the attributes of the sites. The hypothesis of rationality was investigated with these restricted choice sets. Both the restricted and the complete sets of choices were consistent with the axioms when values of time were considered in the sense that remaining violations were not statistically significant according to Tsur's (1989) test. After incorporating the value of on-site time, the remaining violations appeared not to be due to misspecification of the choice set.

The number of violations of the SARP found in this sheep hunter data set are relatively large when compared with the number of violations found in other applied studies testing revealed preference conditions. For example, Adamowicz and Graham-Tomasi found about 2-5% of trips taken by individual sheep hunters violated the axioms. However, their analysis utilized individual trips as the level of analysis, not the entire choice of trips by a hunter over the hunting season. Other researchers, utilizing time series data have found few violations (e.g. Tsur (1989); Swofford and Whitney; Chalfant and Alston). Naturally, applying the theory of individual choice to aggregate time series is not entirely convincing as a test of individual rationality. The current study is one of few revealed preference studies which indicates significant violation of the axioms of choice. Among the weaknesses of our effort is our treatment of single choices by many individuals as if they were many choices by a single individual. However, our goal is to test a model of choice and not the choices per se and the model assumes that a single preference ordering underlies cross-section observations.

The large number of violations we find casts doubt on the simple traditional travel cost model we test. The number of violations of the axioms of choice are substantial and some violations are quite large. Future research efforts should focus on important questions surrounding non-market demand estimation. For example, demand heterogeneity may be the factor producing the apparent inconsistency with the axioms. Alternately, further study of separability issues may reveal the reason for the degree of inconsistency we find. These separability issues include the set of sites considered, the sets of goods included in the demand functions (eg. disaggregating travel costs into distance and lodging), and the potential separability of trips in one time period versus another (eg. seasonal demands). Applying nonparametric demand theory to these problems could provide a promising direction in this area of economic enquiry.

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Table 1. Socioeconomic Characteristics of the Sample of Bighorn Sheep Hunters Used to Investigate the Travel Cost Model.

Socioeconomic Characteristic	Mean, % or Median	Standard Deviation
Age (Years)	35.02	10.90
Sex (Percent Male)	98.6	
Income (Median)	$31,123	
Education (Years)	12.70	2.77
Big Game Hunting Experience(Years)	17.68	11.20

NUMBER OF TRIPS AND TRAVEL COSTS BY SITE FOR ALL HUNTERS

Site:	1	2	3	4	5	6	7	8	9	10
Mean Travel Cost	56.09	47.05	47.72	42.57	45.97	48.65	50.84	66.08	84.97	108.3
Std. Dev.	44.36	38.33	34.93	32.12	30.43	28.29	26.64	25.45	32.25	39.74
Trips	94	88	32	33	43	21	38	36	12	26

Table 2. Results of the Multiple Index Revealed Preference Tests Applied on the Entire Sample (N=226) of Hunters.

Value of Time	Results of Multiple Index Test		Number of Violations of SARP (% Total)	Mean of Individual Errors[a]
	ρ	Var.[b]		Mean
None[c]	1.14	0.94	181 (80)	0.43
Wage rate based on income[d]	0.21	0.84	172 (76)	0.16
Wage rate based on occupation[d]	0.75	1.21	181 (80)	0.30

[a] This represents the mean of one minus each individual hunter's efficiency index term in the perturbation vector. This error is the minimum amount by which each individual's budget has to be perturbed to be consistent with the SARP.

[b] Refers to the variance of the log of expenditures.

[c] In this test, ρ>Var; therefore the choices of hunters were not consistent with SARP and represented a statistically significant violation.

[d] The wage rates as discussed in the text were applied to each individual hunter in the estimation of the value of time.

Table 3. Results of the Multiple Index Revealed Preference Tests Used to Investigate Site Choice Sets by Bighorn Sheep Hunters (see text for details on choice sets).

Data Set	Value of Time[a]	ρ	Variance[b]	% Choices Violating SARP	Mean Error[c]
10 Sites[d]	0	1.140	0.946	80	0.4289
9 Sites(site 10 removed)[d]	0	1.157	0.877	81	0.4368
8 Sites(sites 6 & 10 removed) [d]	0	1.110	0.871	81	0.4319
10 Sites	full wage	0.208	0.844	76	0.1585
9 Sites (site 10 removed)	full wage	.214	0.837	77	0.1680
8 Sites (sites 6 and 10 removed)	full wage	0.199	0.843	75	0.1621

[a] Values of time were calculated using income derived wage rates category (see text).

[b] Refers to the variance of the log of expenditures.

[c] Refers to the mean of one minus the individual efficiency index from the perturbation vector.

[d] The test results for these samples represent significant violations of the axioms of revealed preference because ρ >variance.

1. see McConnell; Smith 1989; or Fletcher et al. for overviews of the travel cost model.

2. The analysis in AG-T with independent trips concerns revealed preference tests on the bundles of goods which make up the cost of a trip. The goods they test usually are aggregated into one good, called a "trip," in the TCM. Here, we aggregate these goods into a good called trips, and test consumption bundles consisting of trips. Hence, the two tests are conceptually distinct. There is no inconsistency between the current results and those of AG-T, since the goods they test are not a subvector of those tested here.

3. Of course, violations also might be due to other things; see AG-T and below for more discussion of the test procedure and its assumptions.

4. If consumers are not rational, then the derivation of the TCM from utility maximization cannot be "correct." We mean here that the TCM technique implies data which happen by coincidence to be close to true data, whatever this truth may be. Hence, the parametric analysis and the nonparametric one are conceptually separate, and we ask if it is possible for them to be consistent with one another.

5. Our specification does not allow us to distinguish different values of time, since changes in the wage rate merely shift budget lines parallel to one another and changes in revealed preference violations require that there be a change in slope. In AG-T, it was possible to test different values of time. They found that including time led to fewer violations, but that there was no difference between time valued at 1/2 versus the full wage. The magnitude of violations was slightly smaller when using the full wage. Note too that, for the same reason, in this paper we cannot distinguish between a model with only travel time and one with no time value included.

6. Epstein (1982) and LaFrance and Hanemann (1989) discuss incomplete demand systems while Hanemann and Morey (1992) discuss incomplete demand systems and welfare analysis. LaFrance and Hanemann show that the incomplete demand system provides a basis for analysis comparable to the theory for complete demand systems (i.e., the subsystem is integrable to a sensible expenditure function) as long as, inter alia, the submatrix of Slutsky substitution terms for the incomplete system is negative definite and a certain price index for the demands not in the incomplete system exists (see LaFrance and Hanemann, Theorem 1). The properties of this price index are equivalent to the separability of the utility function in the incomplete system of goods and other goods (LaFrance and Hanemann, p. 265). The relationship between revealed preference axioms and the conditions for weak integrability of incomplete demand systems advanced by LaFrance and Hanemann is the subject of further research.

7. Note that this is a different issue than whether aggregate demand data could have been generated by a single representative consumer with a budget constraint including aggregate (or average) income.

8. Stratification is more general than including demand shifters, since entirely different demands can arise for different strata. Naturally, including shifter variables with polynomials of interaction terms can closely approximate the stratified demands. The use of revealed preference approaches to identify strata is an area for further research. Some preliminary results on stratification can be found in Boxall.

9. If $x_1R_0z_1$, $z_1R_0z_2$, ...$z_kR_0x_2$ for some finite number of bundles z_k then x_1 is revealed preferred to x_2. This relation can be expressed as $x_1H_Rx_2$ and H_R is referred to as the transitive closure of R_0.

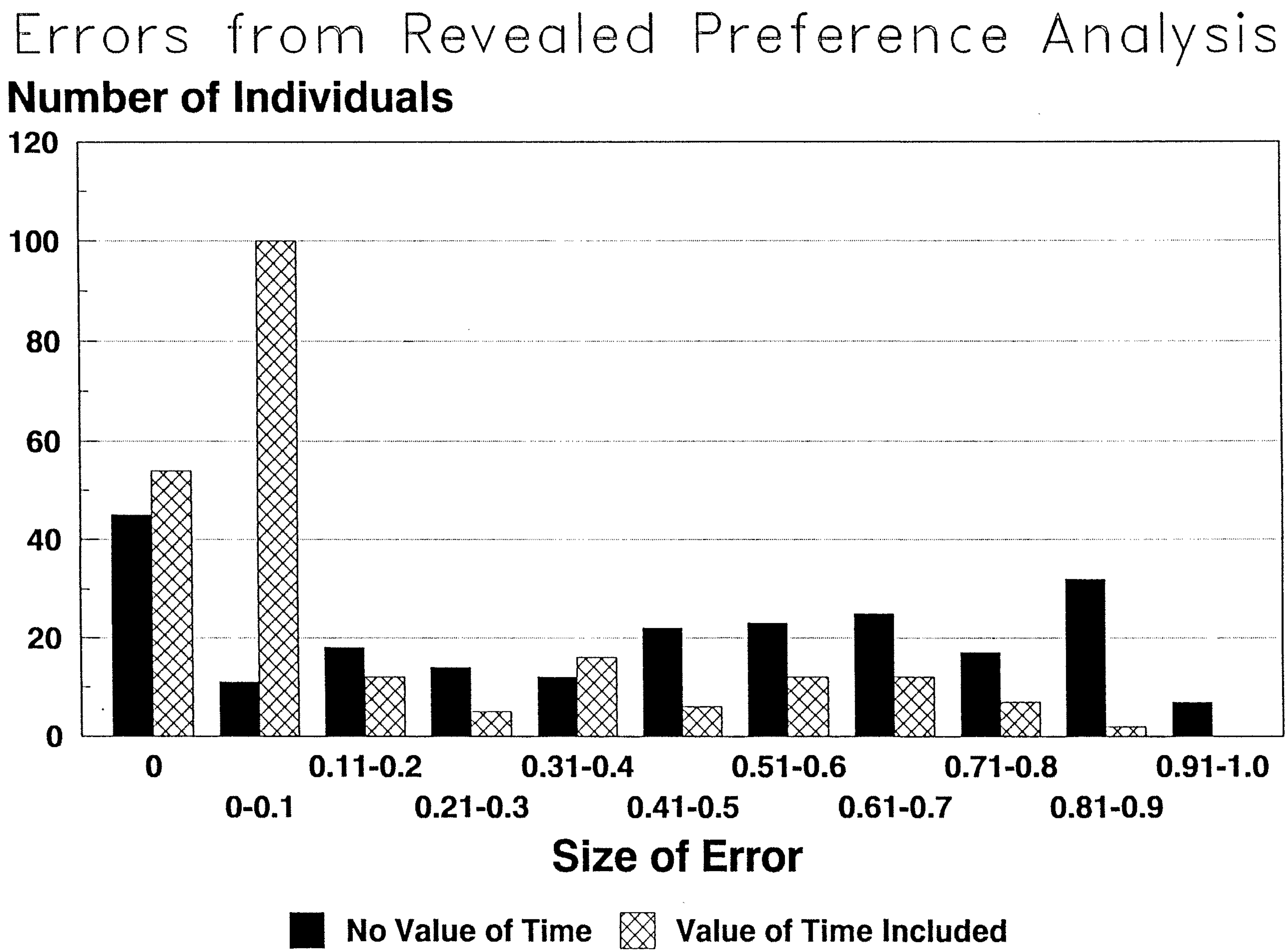
10. Tsur's test is approximate in that it assumes a parametric structure (i.e. a normal distribution)

for the distribution of errors. This assumption is inconsistent with the spirit of nonparametric demand analysis, in which no a priori structure is to be imposed on the preferences underlying observed choice behaviour. Tsur (1990) has developed procedures to test data for violations of the GARP utilizing no parametric assumptions on the distribution of measurement errors. He shows that the ρ derived from the parametric form of his test is very close to the ρ derived from the distribution free test. We use the normal form, since it is much easier to compute.

11. See Adamowicz (1988) for a more complete description of the data.

12. It would be useful to separate travel time and travel cost from the on-site time and examine only these two elements. However, the data available constrain us to time and travel costs which are both a function of distance. The use of on-site time here is also somewhat artificial since on-site time may be considered a choice variable in a different type of consumer optimization problem. We treat on-site time as exogenous. This allows the value of on-site time to be incorporated into the budget easily.

13. Cluster analysis was used to examine the 10 sites based on average distance to each site, sheep population, hunter congestion, and previous year's harvest of sheep. These data were transformed to a percentage of the maximum value of each variable (i.e. $[Var_a/Var_{max}]*100$). We tried two clustering methods: average linkage and complete linkage (Sas Inc.). Euclidean distance was used to compute the distance matrix. Since our sample size was small (n=10) relative to the number of variables (n=4), cluster analyses proceeded using various combinations of three variables. These analyses consistently revealed that site 10, the remote wilderness site, is significantly different from the rest of the sites. Therefore, a new subset of sites excluding site 10 was examined.


Errors from Revealed Preference Analysis
Number of Individuals
120
100
80
60
40
20
0
0
0-0.1
0.11-0.2
0.21-0.3
0.31-0.4
0.41-0.5
0.51-0.6
0.61-0.7
0.71-0.8
0.81-0.9
0.91-1.0
Size of Error
No Value of Time
Value of Time Included