The impact of measurement assumptions upon individual travel cost estimates of consumer surplus: a GIS analysis

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Abstract The individual travel cost method is one of the most commonly applied approaches to estimating the recreational value (or 'consumer surplus') of open-access sites where the visitor does not have to pay an entrance charge for using the area. This paper presents a simple application of the method conducted using geographical information system (GIS) software. This approach permits analysis of the impact of various, commonly used, assumptions concerning the definition of visitor outset origins and routing to recreation sites. Results suggest that varying these assumptions can lead to substantial impacts upon estimates of consumer surplus to the extent that previously published studies may be subject to substantial error.

Key words Travel cost · Centroids · Geographical information system (GIS) · Recreation · Woodland

Received: 24 February 1999 · Accepted: 9 June 1999

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Introduction

The travel cost method is one of the most commonly applied approaches to estimating the recreational value of open-access sites where the visitor does not have to pay an entrance charge for using the area (Bockstael et al. 1991; Bateman 1993; Bockstael 1995). The method uses observations on the amount of travel time and travel expenditure (the latter being a function of travel distance from the outset origin to the site) to calculate the overall travel cost (TC). The most common 'individual' TC approach relates these travel costs to the number of trips made by a given visitor to the site. By extending this analysis across a statistically significant sample of visitors we can observe the expected negative relationship between travel costs and visits. This defines a 'demand curve' for visits, integration of which gives a measure of the recreational value of the site in question. This measure is known as 'consumer surplus' as it indicates the amount of value that visitors have for the site in excess of the direct purchase cost (say an entrance fee) which they have to pay for its use (in the case of an open-access site this entrance fee is zero).
The measurement of travel times and distances therefore supplies the basic information for TC analyses of the value of open-access recreational sites. In their assessment of common application errors, Bockstael and Strand (1987) identify measurement problems as a major source of both the over- and underestimation of benefits within the TC model[1]. Indeed, they conclude their analysis by offering a warning "against the current practice of assuming all error is associated with omitted variables" (p. 19). This preoccupation with the omitted variables problem is reflected in the gradual shift over the past 20 years or so away from the Clawson–Knetsch zonal TC approach, which examines

[1] Randall (1994) provides a detailed analysis of the various problems facing the TC researcher in the accurate determination of travel costs. Indeed, his underlying criticism is that such costs are inherently unobservable, being essentially subjective as they vary according to visitors' assessments of alternatives and hence opportunity costs. Randall's conclusion is therefore that the TC method cannot be used as a stand-alone approach to the estimation of recreational benefit values

the per capita visit rate from any given area to the site (Clawson and Knetsch 1966), in favour of applications of the individual TC method (Brown and Nawas 1973)[2]; however, the potential for measurement error affects both variants.

One source of such error concerns the simplifying assumptions which analysts are often forced to make regarding the measurement of travel time and distance. For example, rather than using the actual origins from which individual visitors began their journey, researchers are often only able to use some approximation to such outset points. The individual TC studies conducted by both Mendelsohn et al. (1992) and Loomis et al. (1995) use the centre points (or 'centroids') of the US county in which visitors started their journey as trip-origin locations rather than the actual address from which the journey began. This can be a substantial and inconsistent simplification. For example, in the Loomis et al. study, median county size ranged from 1181 to 3925 km^2 (calculated from US Census Bureau 1995) across the various states considered. In this instance, we would expect that the difference between the actual outset origin and the corresponding centroid would increase with the size of the county.

In an earlier study using a zonal TC model, Sutherland (1982) examined the impact of using circular centroids of either 10- or 20-mile width to calculate visitor travel time and distance. Sutherland found that this increase in scale resulted in a substantial rise in resultant consumer surplus estimates. While the individual TC method does not use zones to calculate the dependent variable (visits), nevertheless, as we can see from the previous examples, in measuring an individual's travel time or distance a simplifying assumption is often made that the individual's journey starts from some convenient outset point such as the centre of a researcher-specified area, rather than from the actual home or holiday address from which the journey actually began. Assessment of the potential error this simplification induces in welfare estimates constitutes a major objective of this paper[3].

The use of single outset origins for large areas seems undesirable. However, problems may be exacerbated if the population within a large area is unevenly distributed, such as when the majority of people in a coastal county live near the sea [the Loomis et al. (1995) study considers a number of Californian counties in which this may be the case]. Here, a simple geographic centroid may significantly differ from one that is weighted by population. A further complication may arise when researchers assume constant road speeds or straight line distances, thereby ignoring the extent and quality of the road network which underpins true travel times and distances (see, for example, Rosenthal et al. 1986; Hof and Rosenthal 1987).

We can speculate upon the possible consequences of these various assumptions for TC estimates of consumer surplus. The impact of using straight lines rather than road distances would seem to be a straightforward reduction in the travel distance and time measures underpinning the travel cost variable. However, it may be that this reduction is not uniform across all visitors, in that the journeys of those coming from nearby origins are likely to be relatively more circuitous than those of individuals travelling from more remote origins. Such factors would result in straight-line approximations giving biased estimates of consumer surplus. The effect of using geographical- rather than population-weighted centroid origins is less deterministic and will vary from case to case depending upon the distribution of population within chosen areas. However, it is the choice of the size of the area for each centroid that is perhaps of most interest. When these are relatively small, centroid origins should provide a good estimate of true journey origin. However, as area size increases, this will only remain correct if true outset origins are randomly distributed across the areas represented by centroids. This is unlikely to be the case even if the population is evenly spread across the area (i.e. where geographical- and population-weighted centroids coincide). A central tenant of the TC method is that, ceteris paribus, the lower the cost (i.e. the closer an individual lives to a site) the more trips will be made. Therefore, in any such surrounding area, more visits will be made from outset origins nearer to the site than from those further away. This means that using centroid origins will systematically overstate the travel cost that visitors from that region are prepared to bear.

Furthermore, in relative terms, this overstatement will be greater for areas nearer to the site than for those further away. Consider a visitor whose true journey origin is 10 km from the site but who lives in an area with a centroid 20 km from the site. Here, we have a 100% error due to use of the centroid origin. However, a second visitor has a true outset origin some 100 km from the site which is in a similarly sized area with a centroid origin some 110 km from the site. The absolute error is identical but the relative error is only 10%. This situation will result in a systematic bias to the estimated demand curve relative to the true relationship (based on actual origins). Here, at lower travel costs, we substantially overpredict the number of visits and our consumer surplus estimate is biased upwards. The impact of this effect will be directly related to the centroid size used, i.e.

[2] Essentially, while the Clawson–Knetsch approach models zonal visit rates, the individual TC method used in this and most recent studies takes the number of visits made by an individual (or party) to a site in a given period (usually 1 year) as the dependent variable. For further discussion of this distinction see Bateman (1993), while for discussion of other variants of the TC approach, including multiple site 'random-utility' models, see Bockstael (1995)

[3] Brown et al. (1983) consider other measurement issues within the individual TC model, notably the impact of using calculated as opposed to stated, perceived estimates of the per mile expenditure costs of travel. An examination of these issues with respect to the case study presented here is given in Bateman et al. (1995a)

larger areas should lead to larger (more biased) estimates of consumer surplus.

Methods

Discussion with a number of recognised experts (see 'Acknowledgements') in the field of TC research suggests that a principal cause of such simplifying assumptions being adopted is limitations in the software packages used to calculate travel times and distances[4]. In order to avoid the restrictions regarding centroid definition imposed by such off-the-shelf packages, a TC methodology was developed employing the spatial analytic flexibility of a geographic information system (GIS) [specifically, Arc/Info Version 7.0.1 (Environmental Systems Research Institute 1994)]. This is a software package designed to manipulate, integrate, analyse and display spatially referenced data. In the context of TC studies it is particularly useful for matching sets of points (e.g. visitor origins) to areas (e.g. census units), deriving centroids for such areas, and calculating distances or travel times between specified locations. Further details regarding the development of our GIS-based TC methodology are presented in Bateman et al. (1996). In summary, the method developed permits the following flexibility:

1. Relatively precise actual journey origins (accurate, in this study, to 1 km) may be specified. (This of course depends upon the resolution of the data collected. Current work examines the feasibility and reliability of a 100-m referencing system.)
2. Alternatively, centroid journey origins may be used with any area being specified; these areas are not confined to existing administrative boundaries and may be user defined.
3. Centroid origins may be generated which are either geographical or population weighted.
4. Travel distance and travel time may be calculated either using straight lines or by reference to a digital road map. Where the latter approach is used, information on road quality and corresponding road speeds can also be incorporated to provide more accurate measures of travel distance and time.

We now present an application of our methodology utilising a simple individual TC model[5] to illustrate the impact of each of these factors upon resultant consumer surplus estimates.

[4] In the USA a common package is PC Miler (ALK Associates 1992), while in the UK Routefinder (Service in Information and Analysis 1992) has been used. Both lack the ability to specify high resolution origins (e.g. PC Miler can only operate down to the zip code level) and employ complete road network data in the manner possible with a geographic information system (GIS)

[5] This study has been simplified to focus upon the magnitude of the measurement effect under consideration. The study implicitly assumes that substitute sites are randomly distributed; for further discussion of substitution impacts see Bockstael et al. (1991). Given this, the absolute magnitude of benefit estimates produced should be treated with some caution; however, it is their relative size that is of interest here

Case study: woodland recreation in East Anglia

During March and April 1993, a face-to-face survey of visitors was undertaken at Lynford Stag, a typical open-access woodland recreation site, located within Thetford Forest, East Anglia[6]. In total, 351 parties of visitors were interviewed, with respondents being asked a variety of questions, including outset origin. Other questions collected data on a variety of socio-economic, activity, purpose and attitudinal variables thought likely to influence the individual's trip generation function. Visitors were also asked to estimate travel distance and duration to allow comparison with the GIS-calculated measures of these values. Such a comparison allows further assessment of the degree of error associated with different levels of approximation of outset origin (see subsequent discussion of results).

The Ordnance Survey Gazetteer of Great Britain (Ordnance Survey 1987) was consulted to identify 1-km resolution grid references for the stated outset origins. As expected, these were clustered around the site, with roughly 90% of origins within 100 km of Lynford Stag. The 1-km origins form the base and most accurate estimates of journey outset from which welfare measures can be calculated. However, to address the issues under consideration we also defined a series of alternative centroid origins based on progressively larger areas. The smallest of these was the ward – a basic reporting unit of the UK Census. This varies in size according to population density, with rural wards generally more extensive in area than their urban counterparts[7]. However, wards are, typically, relatively small areas of between 2 and 4 km width. A set of larger zones was provided by UK district boundaries. These are substantial administrative areas which are generally of the order of the smallest of the US counties considered in the Loomis et al. (1995) study discussed above. Finally, we also used the regions represented by UK counties, which compare with the largest US counties considered by Loomis et al.

We therefore have four resolutions of zone: 1 km; ward; district; and county. Figure 1 illustrates both the visitors' 1-km outset origins and the corresponding county centroids Inspection of those counties in the immediate

[6] Arguably, all on-site surveys may be subject to endogenous stratification. Following Englin and Shonkwiler (1995) we address this possibility via the use of Poisson count models in related work concerning the transferability of TC estimates (Lovett et al. 1997)

[7] This does raise the possibility of heteroskedasticity problems; however, these were not central to the research question in hand

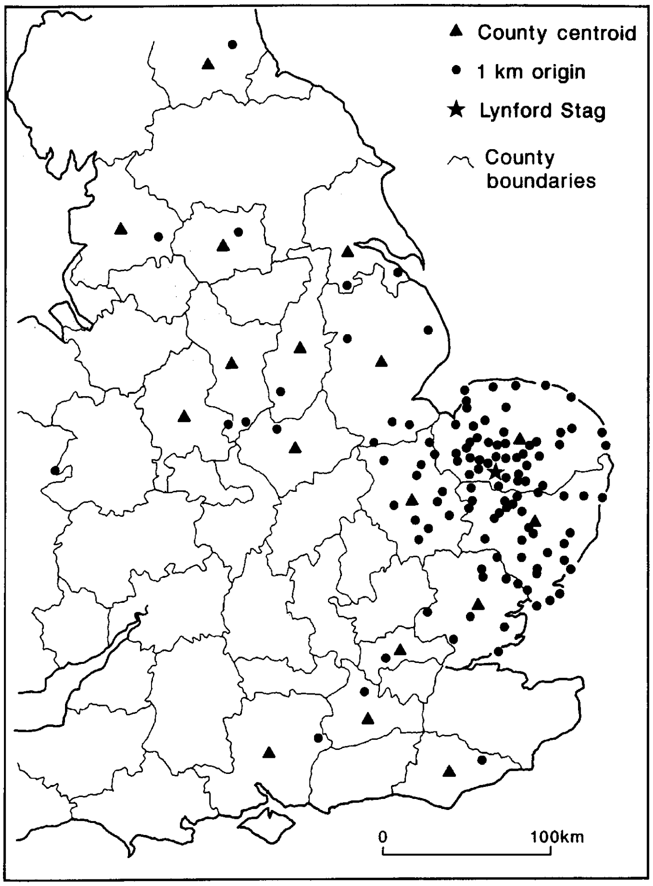

Fig. 1
Comparison of 1-km resolution journey outset origins with county geographical centroid outset origins

vicinity of the site clearly shows that the majority of visitors actually set out from points, indicated by the 1-km origins (note that in Fig. 1 some of those that are very close to each other have been amalgamated to ease inspection), that are closer to the site than the county centroid origins. This is likely to be the case irrespective of the size or location of the area used to simplify the calculation of outset origins. However, the relative error caused by this effect is much greater for zones close to the site than for more distant areas. This systematic bias is likely to result in an overestimate of consumer surplus as discussed previously. The GIS was then used to calculate both geographical- and population-weighted centroids for all four scales of zone (an exception here were the 1-km origins where data on population distribution were not available at a level of detail that would make weighted adjustments meaningful).

At each of the four resolutions, travel costs were calculated from all journey origins to the site. Two approaches were tested here, the first assuming simple straight-line routes and constant speed – the approach of Rosenthal et al. (1986) and Hof and Rosenthal (1987) – while the second approach used information on road availability, quality and road speeds. This latter method recognises that site accessibility increases with the availability of high-quality, direct road routes to the site, and declines for areas where this is not the case (for further discussion, see Bateman et al. 1995b, 1996)[8].

The various travel cost measures obtained from these permutations of calculations were then entered into a series of trip generation functions. Statistical tests indicated that defining the dependent variable as the natural logarithm of the number of visits made by a household to the survey site per annum produced the best fit to the data[9] (such a semi-log form is typical of those used throughout the US and UK literature). To ensure comparability across results, this functional form and the predictor variables (derived through standard exploratory tests) were kept constant across these analyses in order to ensure that any differences in results were attributable solely to changes in the type of centroid used to derive outset origins. The predictor variables were as follows: travel cost; household size; whether respondent is on holiday; whether respondent is working; whether respondent lives near site; respondent's rating of the scenery; whether respondent is a taxpayer; whether respondent is a member of the National Trust; whether the main reason for visit is dog walking. All the variables were significant at the 5% level; for further information and a variable sensitivity analysis using the 1-km outset origin model alone, see Bateman et al. (1996).

Following theoretical and empirical arguments (Smith and Desvousges 1986; Balkan and Kahn 1988; Willis and Garrod 1991a,b), trip generation functions were estimated using limited-dependent variable, maximum likelihood (ML) techniques (Maddala 1983), thereby allowing explicit modelling of the truncation of non-visitors (and so precluding the prediction of negative visits, a problem where ordinary least squares estimation is employed). Here, we write our general trip generation function as per Eq. (1):

$$\ln VISIT_i = \beta X_i + e_i \qquad (1)$$

where i indexes individuals; X_i is our vector of independent predictor variables (as defined previously) with coefficient vector β; and e_i are disturbances assumed to be independent, identically distributed $N(0,\sigma^2)$. Given this model, the ML estimator is based on the density function of $\ln VISIT_i$, which is truncated normal as given in Eq. (2):

$$f(\ln VISIT_i) = \begin{cases} \frac{(1/\sigma)\phi[(\ln VISIT_i - \beta X_i)/\sigma]}{(1-\Phi[-\beta X_i/\sigma])} & \text{if } VISIT_i > 0 \\ 0 & \text{otherwise} \end{cases} \qquad (2)$$

[8] This paper also presents a comparison of travel times calculated using the GIS (with allowances made for varying road quality and congestion) with those stated by visitors in answer to direct questions. Results show that stated and calculated measures are highly similar, giving further support to our automated, GIS-based approach

[9] Sensitivity analysis of the impacts of alternative functional form, estimation method and truncation options is presented in Bateman et al. (1995a)

Goodness of fit measures were given by log likelihood values, while consumer surplus estimates were then derived in the usual manner (Willis and Garrod 1991a) and standard errors were used to construct 95% confidence intervals for the travel cost coefficient, upper and lower limits being used to estimate confidence bounds for consumer surplus.

Results

Comparison of stated travel distance and time with GIS-derived measures showed that there was no significant difference (at $P < 0.88$) for our most accurate (1-km resolution) origin measures. However, as centroids of progressively larger areas were used as the basis for simplifying individuals' journey outset origins, so the resultant measures of distance and travel time began to substantially exceed those stated by visitors during the site survey. Significant differences were found for both district ($P < 0.03$) and county ($P < 0.01$) centroid outset origins. These results in themselves suggest that our central hypothesis may be well founded.

Full results from our analysis are presented in Table 1. Consider first our assessment of the impact of using straight-line as opposed to road-based measures of travel cost. Here, we can see that, irrespective of the type of centroid used to define outset origin, the straight-line measure consistently produces lower estimates of consumer surplus. This is as expected and simply reflects the underestimate of true travel cost produced by straight-line approximations. Nevertheless, the degree of difference, ranging up to 20%, is substantial.

As far as the impact of using geographical- as opposed to population-weighted centroid origins is concerned, we can see that, in this study, there is very little difference in the consumer surplus estimates obtained. It is feasible that in extreme cases where, for example, areas are elongated or population is highly clustered in one part of an area, then use of geographical- rather than population-weighted centroids may be misleading. However, this is clearly not a major issue in the present study.

Finally, the effect of changing the size of areas can be examined and here we see the most substantial impacts of the various assumptions that can be made regarding centroid origins, with results fully in line with our prior expectations. The move from defining outset origin by 1-km grid reference point to ward level centroid has virtually no impact upon welfare estimates. This is not surprising given that wards often cover just a few square kilometres. However, when we move to using district centroids the biases discussed with respect to Fig. 1 begin to become noticeable, with travel cost coefficients altering as expected and welfare estimates substantially inflated. This effect becomes dominant when we change to our largest, county-level centroid origins. Here, consumer surplus estimates increase substantially to the point that those based upon the most accurate outset origins (the 1-km and ward centroids) are less than half of the comparable measure obtained using the county-level centroids.

Given their similarities in functional form and predictor variables, it is unsurprising that differences in the degree of explanatory power between models (indicated by log likelihood values) are small. Nevertheless, relative differences suggest that, as expected, models based upon more accurate outset origins provide a superior prediction of visit numbers. The removal of variation induced

Table 1
Results of the individual time cost (TC) model for different specification of time and distance in the travel-cost variable. Note (all models): petrol costed at 8 p/km; time costed at 43% of wage rate; identical functional form and variable list. Sensitivity analysis on the 1-km model is presented in Bateman et al. (1996)

Model			TC coefficient	Standard error	T-value	Log likelihood	Annual CS/HH (£)	Annual CS/HH 95% UCL (£)	Annual CS/HH 95% LCL (£)
Area[a]	PWC/GWC[b]	RD/SLD							
1 km	GWC	RD	−0.0281334	0.00914719	−3.08	−455.08	422.97	1166.06	258.34
		SLD	−0.0343321	0.0104276	−3.29	−454.32	346.60	856.45	217.26
Ward	PWC	RD	−0.0280613	0.00925375	−3.03	−455.21	424.06	1199.07	257.57
		SLD	−0.0343684	0.0105582	−3.26	−454.46	346.24	870.21	216.11
	GWC	RD	−0.0284978	0.00923917	−3.08	−455.02	417.56	1145.39	255.32
		SLD	−0.0337608	0.0105273	−3.21	−454.61	352.47	906.47	218.76
District	PWC	RD	−0.0235753	0.00906603	−2.60	−456.70	504.75	2049.57	287.81
		SLD	−0.0268869	0.0104250	−2.58	−456.74	442.58	1843.77	251.47
	GWC	RD	−0.0236146	0.00913093	−2.59	−456.78	503.91	2081.07	286.66
		SLD	−0.0280577	0.0104679	−2.68	−456.42	424.11	1578.06	244.97
County	PWC	RD	−0.0140468	0.00837676	−1.68	−459.12	847.13	5017.41	390.59
		SLD	−0.0141129	0.00941977	−1.49	−459.46	849.18	2674.14	366.41
	GWC	RD	−0.0133633	0.00831721	−1.61	−459.23	890.46	4049.62	401.13
		SLD	−0.0144076	0.00937061	−1.54	−459.35	825.92	3005.85	363.08

[a] Indicates relevant centroid used in each model. Each centroid is to 1-km resolution accuracy
[b] *PWC* Population-weighted centroid; *GWC* geographical-weighted centroid; *RD* road distance; *SLD* straight-line distance; *CS/HH* consumer surplus per household (*UCL* upper confidence limit; *LCL* lower confidence limit)

by the move from more to less accurate outset origins (i.e. from centroids of small to large areas) also results in a broadening of the confidence intervals around consumer surplus estimates. This means that differences between these estimates are not statistically significant. However, given that most decision makers will be interested in best (central) estimates, these results do give some cause for concern.

Discussion and conclusions

We have used a GIS-based individual TC model to examine the impact of certain common simplifying assumptions regarding journey outset origin, routing, and consequent travel cost measures. Inspection of Table 1 shows that common assumptions regarding these measures can have substantial impacts upon TC estimates of consumer surplus. The use of journey origins from the centre points of large areas can lead to a substantial inflation of central welfare estimates. This finding is of considerable note given that a number of individual (and zonal) TC studies in the literature adopt such measurement strategies. However, this study also gives a clear indication of best practice for such TC analyses, while demonstrating practical means of achieving this. Use of accurate journey origins, and road rather than straight-line distances, not surprisingly produces improved trip generation functions and more defensible estimates of the welfare benefits of open-access recreational sites. Clearly, if researchers wish to inform the policymaking process then the use of accurate base data is vital if TC methods are to provide defensible benefit estimates.

Finally, we would note that the potential improvements which application of GIS techniques may bring to TC studies extend well beyond the scope of this paper. In particular, the analytical flexibility afforded by a GIS could be used to substantially improve the operation of Clawson–Knetsch zonal TC models, to the extent that they might well out-perform the individual TC model employed above. A GIS can be used to interpolate and integrate Census and related data to yield small-zone, socio-economic variables (such as unemployment rate, car-ownership, etc.) to supplement already improved travel time and distance measures (Brainard et al. 1999). Similarly, a GIS can also incorporate remote-sensed and other land cover data (Lake et al. 1998) so that distances and travel times to alternative recreation sites (not necessarily restricted to the type under analysis, for example in the above application coastal beaches might be considered alongside other woodlands) may be calculated. These measures, in turn, can be readily manipulated to create weighted substitute availability variables. The overlay of GIS map layers detailing travel time, travel distance, socio-economic variables and substitute availability should allow the definition of small-area homogeneous zones within which these variables are roughly constant. Such zones would avoid many of the problems inherent in early Clawson–Knetsch studies, and the variables produced may, we suspect, provide superior predictors of site use to those in present-day individual TC models. Furthermore, the standardisation and automation of data collection through such techniques allows analyses to be more readily transported between sites, so enhancing the potential for successful benefit transfers[10] (Lovett et al. 1997; Bateman et al. 1999; Brainard et al. 1999). Further investigation into the potential of such analyses is the subject of ongoing research.

Acknowledgements This research was funded primarily by the Economic and Social Research Council (grant no. L320223002) and by the Nature Conservancy Council for England (English Nature: grant no. FIN/NC10/01). Assistance was also provided by the University of East Anglia/School of Environmental Sciences Research Promotion Fund and CSERGE. This research was undertaken in part while Ian Bateman was on study leave at the Department of Resource Management, Lincoln University, New Zealand, and Andrew Lovett was on study leave at the Centre for GIS and Modelling, University of Melbourne, Australia. We are very grateful to both these institutions. Helpful comments and encouragement from Nancy Bockstael, Michael Hanemann, Nick Hanley, Alan Randall and Ken Willis are gratefully acknowledged; remaining errors are the sole responsibility of the authors.

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