WELFARE MEASURES FROM DISCRETE CHOICE MODELS
IN THE PRESENCE OF INCOME EFFECT

Andrew Daly[ab], Gerard de Jong[acd], Nicolás Ibáñez[a], Richard Batley[a], Michiel de Bok[c]

a: Institute for Transport Studies, University of Leeds
b: RAND Europe
c: Significance
d: NEA

1.   INTRODUCTION

Welfare evaluation is central to the appraisal of transportation projects and many countries rely on a formal calculation procedure to obtain consumer surplus change, often as an input to a more general Cost Benefit Analysis. In transport planning practice, it is commonplace to derive consumer surplus change by means of a two-stage procedure, as follows. First, data on the discrete choices of individuals are analysed by means of a Random Utility Model (RUM), producing forecasts of choice probability under a 'do something' scenario (e.g. a price change). Second, these forecasted probabilities are aggregated to the market-level (e.g. reflecting demand over a period of time, for a population of travellers); then referencing against current market demand (or demand in a 'do nothing' scenario), one can derive a linear approximation to the change in consumer surplus arising from the price change. Following this procedure, the latter metric is referred to as the 'rule-of-a-half', and is rationalised as an approximation to the change in Marshallian consumer surplus.

How good an approximation the rule-of-a-half offers will depend upon a number of factors (e.g. Nellthorp and Hyman, 2001), but those issues aside, there is an intuitive appeal in deriving consumer surplus measures directly from the underlying model of discrete choice behaviour. When RUM is of the logit or nested logit form, as is common in transport planning practice, then the 'logsum' measure is a natural candidate as a measure of consumer surplus change. More general models of the Generalised Extreme Value (GEV) family have measures that correspond to the logsum and this concept can be extended quite widely, e.g. to mixed logit and a very general family of models.   In this context, we might think of demand models predicting a continuous variation in demand as being derived from discrete choice models by estimating expected demand from an aggregation of choice probabilities.

Whilst RUM is, in principle, a (probabilistic) representation of the Marshallian demand, it is often implemented with additive income utility functions (i.e. AIRUM, as introduced by McFadden 1981), meaning that probability is invariant to changes in income and to uniform changes in price. How this manifests in terms of the income expansion path is debatable, but the usual rationale is that AIRUM is not subject to an 'income effect'. If one accepts this rationale then the logsum may be interpreted not only as the Marshallian consumer surplus, but alternatively (and entirely equivalently) as the Hicksian compensating variation (i.e. the minimum/maximum quantity of money that must be given to/taken from an individual in order leave him or her on the same indifference curve as before a price increase/reduction). That is

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to say, the Marshallian demand arises from both substitution *and* income effects, whereas the Hicksian demand arises entirely from a substitution effect.

In transport appraisal, it is usually taken that transport costs account for a minor proportion of income, such that an assumption of zero income effect may be defensible. Accepting this assumption, the logsum from AIRUM offers a reasonable approximation to the complete welfare effects. When a policy intervention has a non-negligible impact on incomes (e.g. extensive road pricing, changes to car ownership; or policies in developing countries more generally) however, AIRUM is less defensible, since it may omit significant welfare impacts associated with the income effect. We also note that, even in developed countries, non-linear cost effects may be found to be very significant (Daly, 2008). In such cases, the analyst would in principle wish to measure the Marshallian consumer surplus, but this can in practice be difficult. Where a policy intervention impacts upon the price of more than one good, it is well established that the Marshallian consumer surplus is dependent on the path of integration (i.e. the sequence of price changes), because the marginal utility of income is not constant. Hicksian measures (whether the compensating variation or the equivalent variation) are, by contrast, unique, but suffer from their own practical problems in that compensated demand curves are unobservable; market behaviour reveals the Marshallian demand, not the Hicksian. Reconciling these various challenges, and noting the duality between uncompensated and compensated demands, the usual procedure is to take the observed Marshallian demand, and from this infer the Hicksian consumer surplus.

The purpose of our paper is to advance methods for deriving Hicksian consumer surplus from RUM in contexts where the income effect is significant and the income expansion path non-linear. A range of alternative methods (e.g. simulation, representative consumer, analytic) have been proposed in recent literature. The paper reviews the theoretical and practical advantages of each, with a view to identifying the preferred method for implementation in transport appraisal. Following this review, the paper presents an illustration of the preferred method using an operational transport model, in this case the Dutch national model system LMS.

1.1 Some preliminary concepts

Define an alternative to be a vector $\mathbf{x} = (x_1,...,x_K)$, where x_k is the quantity of attribute k for $k = 1,...,K$. The consumer is invited to choose from a finite set of such alternatives, $T = \{\mathbf{x}_1,...,\mathbf{x}_N\}$. Following Block and Marschak (1960), RUM offers a statement of the probability of choosing an alternative n from T, thus:

> There is a random vector $\mathbf{U} = (U_1,...,U_N)$, unique up to an increasing monotone transformation, such that:
>
> $P(n|T) = \Pr(U_n \geq U_m)$ for all $n \in T$, $m \in T, m \neq n$
>
> where $0 \leq P(n|T) \leq 1$ and $\sum_{n=1}^{N} P(m|T) = 1$ (1)

In order to implement the above, convention is to specify utility as:

$$U_n = V_n + \varepsilon_n \tag{2}$$

such that the utility of alternative n can be dissected into a deterministic component V_n and a random error ε_n. Some function is then specified to relate deterministic utility to the price p_n and qualitative attributes $\mathbf{x}_n$ of the alternative. Common practice is to adopt the following simple function, which specifies utility as linearly additive in residual income $y - p_n$ (i.e. following the consumption of n) and attributes $\mathbf{x}_n$:

$$V_n = \alpha_0 (y - p_n) + \boldsymbol{\beta}\mathbf{x}_n \tag{3}$$

where α_0 is constant across the alternatives. We arrive thus at the notion of the Additive Income RUM, or 'AIRUM'. That is to say, probability in (1) is based on the difference in utility between alternatives n and m, such that where utility is additive in income (3), income will impart no influence on probability.

The utility of equation (3) is *conditional*, since it depends on the choice on alternative n. Moreover it is of course *indirect*, since is the utility resulting from decisions about consumption, so that it has both income and price among its arguments.

When assessing the welfare effects of a policy intervention, a typical interest is to forecast the change in consumer surplus arising from a change in the price of an alternative. In the context of RUM, consumer surplus will change only if the change in price induces a change in the probability of choice. Two methods of measuring the change in Marshallian consumer surplus are prevalent in RUM practice, referred to as the 'rule-of-a-half' and 'log sum' methods.

Rule-of-a-half

Let us consider an increase in the price of alternative $m \in T$, such that $p_m \to p_m + \Delta p_m$ where $\Delta p_m > 0$, holding all else constant. Introducing the subscripts 0 and 1 to represent the states before and after the price increase, define Q_0 and Q_1 to be the quantity of units consumed (of all $n \in T$) in the respective states, and $P_0(m|T)$ and $P_1(m|T)$ to be the probabilities of choosing m in the two states. The rule-of-a-half was proposed in the works of Lane et al. (1971) and Neuberger (1971), according to which the change in consumer surplus ΔCS_m arising from the price increase Δp_m, is given by:

$$\Delta CS_m = \tfrac{1}{2}\left[Q_1 P_1(m|T) + Q_0 P_0(m|T) \right] \Delta p_m \qquad \text{for all } m \in T \tag{4}$$

As discussed above, this formulation is best justified as an approximation to the change in Marshallian consumer surplus.

Log sum

Now consider the second method of measuring the change in consumer surplus - the 'log sum' method. Although the origins of this method are evident in Williams (1977), Small and Rosen (1981) were first to offer a full and definitive treatment, with McFadden (1981) applying this treatment specifically to AIRUM. Accepting our earlier interpretation of AIRUM, as embodying zero income effect, the log sum method may be rationalised as the Hicksian compensating variation of a price change, i.e. the minimum/maximum quantity of money that must be given to/taken from an individual in order leave him or her on the same indifference curve as before the price increase/reduction. When AIRUM does not apply, the logsum can only be seen as the Marshallian consumer surplus.

The log sum method derives from an equality established between the maximal utilities arising before and after a price change. Considering the same price change as before, that is, the price increase Δp_m, this equality may be written:

$$\max_{n=1,...,N}\left[v_n\left(\mathbf{x}_n;y+cv-\left(p_n+\delta_{mn}\Delta p_m\right)\right)+\varepsilon_n\right]=\max_{n=1,...,N}\left[v_n\left(\mathbf{x}_n;y-p_n\right)+\varepsilon_n\right]$$

where cv represents the compensating variation, p_n is price in the before state, and

$$\delta_{mn}=\begin{cases}0 & m\neq n\\1 & m=n\end{cases} \tag{5}$$

For the price increase Δp_m, any compensating variation must be given to the individual, such that $cv\geq 0$. Note that (5) applies to any GEV form. If we assume that the random error is IID Gumbel, RUM takes on the logit form; then taking expectations of the maximal utilities over Q, (5) may be re-written as follows, the form of which provokes the terminology 'log sum':

$$\Delta E\left(CS_m\right)=E\left(cv\right)=\frac{\ln\left\{\sum_{n=1}^{N}\left[\boldsymbol{\beta}\mathbf{x}_n-\alpha p_n\right]\right\}-\ln\left\{\sum_{n=1}^{N}\left[\boldsymbol{\beta}\mathbf{x}_n-\alpha\left(p_n+\delta_{mn}\Delta p_m\right)\right]\right\}}{\alpha}$$

where p_n is price in the before state, and δ_{mn} is defined as in (5).

Both the rule-of-a-half and logsum measures can be extended by simple analogy to incorporate changes in the quality variables **x** as well as the prices of more than one alternative.

1.2   Structure of the paper

In the following section, we review the recent literature on methods for Hicksian evaluation, particularly focussing on the methods developed by McFadden and by Karlström, which seem to us the most relevant for current applications. Section 3

presents results from applications of various methods within the Netherlands National Model.

2. RELEVANT LITERATURE

While the logsum and rule-of-a-half methods to derive Consumer Surplus (CS) and, under the assumption of AIRUM, Compensating Variation (CV), have been used since the 1970's, it seems that the development of acceptable methods for CV did not take place until the 1990's. Small and Rosen (1981) and Hanemann (1984), well aware of the distinction, were able to offer only approximations for the CV but complete calculations for CS. Computation costs may have played a large role here.

As discussed in the Introduction, CS and CV are equivalent only under the assumption of AIRUM, where income appears additively in the conditional indirect utility functions with the same coefficient in each function. In consequence, changes in incomes have no effect on choice. More correctly, however, a change in price (or other aspects of an alternative) will not only have the 'substitution effect', but will also have an 'income effect'; these effects are not distinguished separately in the CS. While it can be argued that for many transport policies the impact on travellers' incomes should be negligible, this is not always the case and methods are required for those situations.

Practice, in the UK and elsewhere, seems to be consistent in its use of CS rather than CV (Bates, 2003, Mott MacDonald, 2006, CPB and NEI, 2000) A recent review (de Jong *et al*., 2007) found widespread use of CS, with a trend towards the use of logsum rather than rule-of-a-half measures, but very limited use of CV. However, a number of methods have been developed, which were discussed in papers in the late 1990's.

It is difficult to say in general to what extent benefits are wrongly estimated by using CS instead of CV. Cherchi and Polak (2007) indicate on the basis of simulation results that the difference can be large, but in general one would say that the only certain determination is to calculate both measures. However, methods for calculating CV have been developed only recently and are not yet widely understood. Two methods have been used in a small number of studies each, the methods of McFadden and of Karlström, which are described in the two following sections. Additionally, work by de Palma and Kilani (2003) suggests another approach that generalises Karlström's method in terms of analysing the complete distribution of CV instead of only its first moment. This latter approach may be interesting, but we know of no applications to date.

2.1 Method for calculating CV: McFadden's simulation approach

The first practical methods for calculating CV seem to have been introduced by McFadden (1996, 1999). In this work, McFadden sets out three possible procedures for calculating CV:
- bounds can be defined based on the utility changes of the originally chosen alternative (lower bound) and finally chosen alternative (upper bound) –

however these bounds can be quite wide, as is shown by Herriges and Kling (1999), and in any case one would prefer a best estimate. Besides, as McFadden (1999, p.255) notes, if the probabilities depend on income, then the upper bound depends itself on the CV, making necessary to find bounds for the upper bounds, which is clearly a serious a practical limitation;

– a 'representative consumer' approach can be used – however McFadden shows that there can be considerable bias in this approach, a finding not repeated by Herriges and Kling (1999) but which is confirmed by Cherchi *et al*. (2004);

– a simulation method can be used.

In the (1996, 1999) papers, McFadden then exploits the simulation method, but finds it to be less than totally satisfactory because of its computational burden. Essentially, the simulation method works as follows.

Given a representative sample of the consumer population, then for each member of the sample we need to solve the following equation for CV:

$$\max_j \left\{ V\left(x_j^0, y - p_j^0, \varepsilon_j\right) \right\} = \max_j \left\{ V\left(x_j^1, y + CV - p_j^1, \varepsilon_j\right) \right\} \tag{4}$$

where V is the conditional indirect utility function for each alternative;

the 0 and 1 superscripts represent conditions before and after a change;

x represents the non-price characteristics of the alternatives;

p represents the prices; and

ε is a random utility component.

An important assumption in this approach is that the values of the random component, i.e. the individual's departure from the average, is unchanged between the before and after situations. It may be noted that specific distributional assumptions are not required, i.e. the approach can be used with effectively any form of choice model, though McFadden (1999, p.266-272) particularises the analysis to distributions of the utilities within the Multivariate Extreme Value (MEV) type.

The procedure works by making a draw t of the random components: ε_t. Then by enumerating the alternatives in the base situation it is straightforward to find

$$V_t^0 = \max_j \left\{ V\left(x_j^0, y - p_j^0, \varepsilon_{jt}\right) \right\} \tag{5}$$

This is the base utility and the function of CV is to return the consumer to this utility level after the changes in price and/or characteristics. For each of the alternatives j we therefore need to solve for CV_{jt}

$$V_t^0 = V\left(x_j^1, y + CV_{jt} - p_j^1, \varepsilon_{jt}\right) \tag{6}$$

Then the required solution to the CV for draw t is simply $CV_t = \min_j \{CV_{jt}\}$ and the overall solution can be obtained by repeating the sampling for many t's and averaging.

The problems with this method are, according to both McFadden and Herriges and Kling, that sampling has to be used and that iterative numerical methods have to be used to solve equation (6) repeatedly. Sampling from complex GEV distributions for many alternatives can present an issue, but for the most common mixed multinomial and multinomial logit models the procedure is straightforward. Modern computers – even just 10 years after the writing of these papers – then make light work of the sampling, while the solution of equation (6) can be facilitated in most cases by noting that the majority of indirect utility functions used in practice take the separable form

$$V(x, y - p, \varepsilon) = V^*(x) + M(y - p) + \varepsilon \tag{7}$$

where V^* is the utility contribution of all the non-price, non-random aspects of the alternative; and
M is the contribution of the monetary aspects.

Then, if non-satiation with respect to income applies, i.e. M is strictly monotonically increasing, the inverse function M^{-1} exists and we can solve equation (6) immediately

$$CV_{jt} = -y + p_j^1 + M^{-1}\left(V^*(x_j^1) + \varepsilon_{jt} - V_t^0\right) \tag{8}$$

When this step is possible it appears that McFadden's method is quite practicable. It has been used in a small number of practical studies (e.g. by McFadden and Herriges and Kling), largely concerned with environmental evaluations.

An important application is that by Morey, Sharma and Karlström[1] (2003) who appraise a proposal for improving access to health care in Nepal (similar calculations using a transport model can be found in section 3 of the present paper). The model differentiates the marginal utility of income by two groups, each of which has conditional indirect utility functions linear in income. First, they show that the logsum calculation used for CS gives a close approximation to CV for this model, because very few individuals would shift income group as a result of this policy. Second, they randomly assign specific income levels to individuals conditioned on their membership of a specific income group and apply McFadden's simulation method. Proceeding in this way they calculated the full CV and found that it was indeed close to the logsum calculation. Finally they compared these outcomes with income effect to those from a no-income effects model and found substantial differences.

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[1]   We list the co-authors because they are relevant here.

2.2   Method for calculating CV: Karlström's formula

Karlström's formula appears to have originated in a working note completed in 1998 which has been developed into a paper (still unpublished) by Karlström and Morey in 2004. A published general theory underlying the method is given by Dagsvik and Karlström (2005), which goes on to discuss the distribution of CV in the population and how more accurate values can be obtained by conditioning on initial and current choices.

The objective is to provide a direct calculation of the CV without specific simulation and that can be applied to any form of RUM. Simulation would still be necessary if the RUM form requires it (e.g. for mixed multinomial logit). The key result is presented as Theorem 1 in Karlström and Morey, giving the expected value of the income m required after the change (i.e. the original income *plus* the CV) as

$$E(m) = \sum_i \left\{ \mu_{ii} P_i(\mu_{ii}) - \int_{\underline{\mu}}^{\mu_{ii}} y \frac{\partial P_i(y)}{\partial y} dy \right\}$$

where μ_{ii} is the income required in the new state that would keep the consumer at
   the same level as in the original state, if he chose alternative i both before
   and after the change;
   $P_i(y)$ is the probability of choosing alternative i in a model in which
   alternatives other than i are given utility equal to the maximum of their utilities
   before and after the change at income level y, while i is given the initial
   quality attributes of the alternatives and income level;
   $\underline{\mu} = \min_k \{ \mu_{kk} \}$.

Now, in this formula, μ_{ii} is just the change in utility between the old and new states of alternative i, expressed in terms of the price of that alternative. Because of the assumption that the random terms do not change, this utility is calculated quite easily and because of the assumption that utility is monotonically decreasing in the price of the alternative, it is readily converted into a monetary equivalent.

Another requirement for this calculation is that income and price appear in the utility functions only in the form $(y - p)$, so that the income increase required to compensate a price change is simply the amount of that price change. Strictly, this is a requirement to maintain consistency with the generally accepted microeconomic framework applying to consumer behaviour in a discrete choice context (see, for instance, Jara-Díaz, 2007, p54), but is not commonly accepted as a requirement for choice modelling.

The first term in the Karlström formula is then just the income that would be needed to compensate those choosing i, assuming that the choices they would make before compensation were the same as before the change and compensation. But this is an upper bound and the full compensation calculation needs to take account of the fact that some consumers would change behaviour in consequence of the change in the alternatives and the compensation: this is the function of the second term.

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An intuitive understanding of the second term may be helped by thinking that the derivative represents the number of people who switch away from i when their compensation when choosing other alternatives increases by dy.

The main problem is the calculation is the function P. However, because of the assumption that the error terms do not change, a simple maximum function applied to the before and after utilities is correct. If the differentials can be derived in closed form then the integration is usually relatively easy to evaluate, as it is one-dimensional.

Karlström and Morey state that they obtain the same answer as the McFadden simulation, provided enough draws are taken in the simulation.

An application made by Franklin (2006) may be the first published use of Karlström's method, applied to the issue of tolling on a proposed new bridge near Seattle. Unfortunately, a linear (AIRUM) model fits the data considerably better than a non-linear model, which means the results are of little practical importance.

Finally, a paper by Zhao, Kockelman and Karlström (2008) looks at the important theoretical issue of the correlation of the error terms in the base and forecast contexts. The finding is that the issue is not of purely theoretical interest as the mean value of Compensating Variation and, most particularly, the distribution of CV within the population, depend on the assumption made about the correlation of these error terms. This is unfortunate, as it seems difficult to make any definitive statement about these error terms. The analysis is based on the application of a multinomial logit form to choices between free and tolled routes. Income does not participate in the model and cost, which is limited to the toll, is associated with a positive marginal utility of income. In this scenario no simulation would be needed to calculate the mean of the distribution of CV, which for this case has to be identical regardless of the correlation for the random terms before and after the policy intervention.

3.   EMPIRICAL APPLICATION

In our empirical example we apply a transport model that has been used very extensively in practice, the Dutch National Model System, LMS. First, we shall briefly describe this transport model (also see Gunn, 1998 or Daly and Sillaparcharn, 2008). The LMS was first developed in the 1980's and has been used since for several policy documents on transport policy and for the evaluation of large transport projects. It is a forecasting model for the medium to long term (the forecast year often being 20-30 years ahead), with a focus on passenger transport (freight traffic appears only in assignment of an exogenous OD truck matrix to the road network). The model covers the whole of The Netherlands and some neighbouring areas, distinguishing more than 1,300 zones. The LMS consists of random utility submodels at the household or person level for:
- Licence holding, constrained to exogenous forecasts;
- Car ownership, constrained to exogenous forecasts;

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- Tour frequency by travel purpose.

- Mode and destination choice: there are eight of these models, one for each of eight travel purposes. The modes distinguished are: car-driver, car passenger, train, bus/tram/metro, non-motorised.

- Departure time choice by travel purpose.

The model system is applied in a pivot-point fashion, whereby the demand models produce growth factors for the changes between the base year and forecast year for each origin-destination movement by mode, purpose and time of day, and a given base matrix represents the traffic pattern in the base year. Then, the OD car driver demand matrices are assigned to the road network and after initial assignment there is a feedback to mode, destination and departure time choice (iterative application). The model has been updated regularly and a new version is currently under development.

In our application we focus on welfare measures from the LMS mode-destination choice models for commuting only. Just as in the models in the Morey et al. (2003) application in Nepal discussed above, which had linear cost, the LMS has different cost coefficients by income class (in LMS applications we use five income bands each with a different travel cost coefficient). Contrary to the Nepal model, costs appear in a logarithmic fashion (as $\beta\log(d+p_n)$, where d is a small amount and p is the travel cost of alternative n). Both these departures from AIRUM (cost coefficient by income band, log of cost) imply that logsum changes from the LMS mode and destination choice models will contain an approximation of the income effect. Differences in the marginal utility of income between income groups and between costs changes of different magnitude are included whereas the effects of households shifting income group because of the policy measure are excluded. Given that we have a limited number of income categories, the latter effect is probably small (this effect could be quantified by simulating an exact income level within each group). In this section we show such outcomes for an increase in car costs, and compare these to the logsum change from a 'reduced LMS' (no income effects model). Exact income effects calculated using the Karlström method will follow later.

In the runs with LMS, we use results for 2020 from the existing Transatlantic Market (TM) scenario that was used in Zondag et al. (2007). This scenario has a modest economic growth (1.9% yearly GDP growth), modest population growth (up to 17 million inhabitants) and modest demand for housing (housing stock increases by 0.5% per year) and employment locations (stabilisation of number of workers). The logsum changes are calculated by comparing a model run with road user charging (here: a flat rate increase on the car costs of 32.3 %) with a model run for the same scenario without the flat rate increase in car cost. The outcomes are given in Table 1.

In the first column of Table 1 we can see that the change in the logsum when using the existing LMS (so with approximate income effect) produces disbenefits for commuters and for all travel purposes together. Overall, the negative effect of the road charge does not outweigh the positive travel time benefits from reduced congestion. But please note that the government obtains a large sum of money from the charging, which has not been taken into account in the logsum change. Road

user charging in The Netherlands will be combined with a large reduction in car purchase tax and car ownership tax, or removing these completely. The benefits to car users from this reduction in fixed car costs will probably exceed the disbenefits shown in Table 1. The existing LMS results also show that the highest income group has the largest disbenefits, simply because this category will contain most households in 2020.

Table 1. Outcomes of logsum change calculation in 2020 for road user charging, excluding road- and purchase tax reduction[2]

	Benefits flat rate in m. € /year (2005 price level) compared to reference	
	Existing LMS	Reduced LMS (no income effects model
Commuting:		
Income category 1	-7	-3
Income category 2	-11	-6
Income category 3	-35	-19
Income category 4	-56	-36
Income category 5	-343	-232
Total for commuting	-451	-296
All travel purposes	-2720	

To compute the logsum change without income effect, we re-estimated the LMS mode destination choice model for commuting on the original data:
- One cost coefficient instead of five
- Linear cost instead of logarithmic cost.

It may be noted that with these changes the model satisfies the AIRUM requirement.

The remainder of the specification stayed the same, but the other coefficient values also changed (though only by small amounts) because of this change in the representation of cost. We call this the 'reduced LMS'. The cost coefficients and the final log likelihood value of both commuting models are presented in Table 2.

In Table 2 we only show the cost coefficients for the two different specifications for commuting. In total there are about 40 coefficients. A model with just one coefficient for logarithmic costs performs better than the model with one coefficient for linear costs, and the model with five coefficients for logarithmic costs gives a further (very significant) improvement in the loglikelihood value. Higher incomes are less sensitive to cost changes (decreasing marginal utility of income).

Table 2 Estimation results for commuting (only cost coefficients shown)

	Existing LMS		Reduced LMS	
	Coefficient for log cost	t-ratio	Coefficient for linear cost	t-ratio
Income category 1 (lowest)	-0.974	(-33.8)		
Income category 2	-0.895	(-37.3)		
Income category 3	-0.800	(-36.3)		
Income category 4	-0.645	(-29.7)		
Income category 5 (highest)	-0.613	(-27.9)		
All income categories			-0.0397	(-15.9)
Log-Likelihood	-130711.4		-131515.2	

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[2] The benefits for car users from the abolishment of road taxes and a 25% reduction of purchase taxes for 2020 in the TM scenario, are estimated at about 3.9 billion Euro a year over all travel purposes.

The logsum change from the LMS without income effect is in the second columm of Table 1. It gives a substantially smaller disbenefit (-34%) from the policy (not including the effect of the corresponding reduction in fixed car costs) than the full LMS. Including the income effect (in an approximate way) in this application thus makes a difference. We also plan to calculate the exact compensating variation for this application using Karlström's formula.

4.   SUMMARY AND CONCLUSIONS

The appraisal of transportation projects in many countries relies on the calculation of consumer surplus change, usually applying the 'rule of half'. In calculating consumer surplus, it is attractive to use measures that are consistent with the demand model being used. When this model is of the logit form, the 'logsum' measure is a natural candidate as a measure of consumer surplus change.

However the logsum and analogous measures do not provide exact welfare measures when the policy being evaluated has an impact that is not negligible with respect to the incomes of travellers. Such circumstances certainly arise in many applications for developing countries, but are also relevant in developed countries when policies that would change car ownership or implement extensive road pricing are being considered. Non-linear cost functions, found to be important in many contexts (Daly, 2008), also imply an income effect and thus in principle require a more sophisticated appraisal measure than rule-of-a-half or the logsum.

The paper discusses Hicksian measures of benefit that are more appropriate when 'income effect' may be relevant. Methods have been developed in recent literature to derive such measures from discrete choice models. The most promising of these methods for practical work seem to be McFadden's simulation method and Karlström's formula.

Besides the review of the theoretical and practical issues involved in deriving income-compensated welfare measures from discrete choice models, the paper also presents new results from runs using an operational transport model, in this case the Dutch national model system LMS. This showed that for the simulation of road user charging in The Netherlands (using a high flat rate per kilometre), the difference between a welfare evaluation with and without income effects was substantial (more than 30%).

In conclusion, it is argued that it is important to make methods available for making welfare analyses consistent with the latest advances in choice modelling. Inconsistency between these stages of analysis is unacceptable because of its implications for the appraisal of projects, but it is not always an easy task to maintain the same assumptions about utility functions and the distribution of preferences in the population. The literature indicates that different approaches can indeed lead to different results which could affect the funding of important projects.

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