COST-BENEFIT ANALYSIS AND DISTRIBUTIONAL CONSEQUENCES OF AN AREA LICENSING SCHEME FOR STOCKHOLM

Farideh RAMJERDI
Senior Researcher
Institute of Transport Economics
Oslo - Norway

1. INTRODUCTION

The objective of this work is to evaluate the role of income effect at the level of mode choice for Stockholm and the consequence on the measures of users' benefit. For this purpose travel to work data will be used. The main idea for the focus on travel to work is that one can assume fixed origin and destination for this travel purpose. Results, i.e. alternative mode choice models will be used in the evaluation of users' benefit from a cordon toll policy in Stockholm.

2. DESCRIPTION OF TRAVEL TO WORK DATA IN STOCKHOLM

The Stockholm Travel Study 1986/1987 has been employed in this study. The data collection is described, for example by Algers, Daly, and Widlert (1989).

Table 2.1 Frequency of Mode Choice and Socio-Economic Characteristics of Low-, Medium-, and High Income Groups

Income in 1000 SEK/year	Low $0<GP\leq 95$	Medium $95<GP\leq 130$	High $GP>130$
sample size	372.00	481.00	378.00
gross personal income	69.66	109.38	185.70
disposable personal income	50.77	75.35	115.65
gross household income	154.17	206.97	276.98
no. of female workers	283.00	241.00	82.00
no. of part time workers	170.00	43.00	14.00
workers with access to car	254.00	368.00	388.00
Frequency of Mode Choice			
mode chosen: car	111.00	213.00	242.00
mode chosen: transit	176.00	205.00	109.00
mode chosen: slow	85.00	63.00	27.00

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Table 2.1 presents the socio-economic characteristics of the individuals in the sample along with their frequency of mode choice in three income strata. Because of a larger proportion of part time workers in low income stratum, one can deduce that the differences between wage rate of low- and high income strata not to be as large as their income differences. Frequency of choice of slow mode (walk and bicycle) and public transportation is higher among low income group, while car mode choice increases with income.Examination of data shows that distance to work increases with increase in income.Furthermore, total car cost for mode choice car decreases with income mainly due to tax deduction for travel to work cost.

3. MEASURES OF USERS' BENEFITS IN TRANSPORT SYSTEM, A BRIEF REVIEW

When income does not appear in the specification of utility in the mode choice model, the resulting equations represent both the market and compensated demands. In this case all measures of users' benefits, which will be explained briefly coincide. Therefore, introducing income creates some ambiguity in the welfare analysis, which naturally depends upon the specific form preferences have been captured through a demand model.

Consumer surplus is a widely used tool in applied welfare economics. The basic idea is to evaluate the value to consumer, ie, his willingness to pay accompanying a change in the price of a good. Because price changes affect consumer welfare, an evaluation of this effect is often the key input to public policy decisions.Even though consumers' surplus is quite a controversial concept, it is a widely used concept and there is substantial agreement on the correct quantities to be measured. That is the amount the consumer would pay or need to be paid to be just as well off after the price change as he was before the price change, or the Hicksian compensation variation measure. An alternative measure which takes ex post price change utility as the basis of compensation is Hicksian equivalent variation measure (Hausman, 1981). The primary condition for the market measure of consumer surplus to correspond to the Hicksian compensation variation is to have constant marginal utility of income.

Even though disaggregate demand models have long been popular, especially in the transportation field, only recently has research been made to use methods of applied economics in discrete choice situations (for example, Williams (1977), McFadden (1975), Small and Rosen (1981)).

There has been a renewed interest in the application of conventional cost-benefit analysis to such models (for example, Small (1983), Hau(1985), Jara-Diaz et.al.(1987)).

Jara-Diaz and Videla (1987), compare more strict measures of consumer benefit that have been derived for mode choice models. They summarize that these approaches provide logit formulation of the mode choice if the random component is assumed to be Gumbel probability distribution; and furthermore the different measures of user benefit coincide and are given by:

$$UB = N/\mu \quad \text{Ln} \ \Sigma \ \exp Vi \qquad (1)$$

where N is the number of individuals in the population and μ is the marginal utility of income and Vi is the conditional indirect utility function of mode i.

If income effect should be included in the specification of the indirect utility function, marginal utility of income will not be independent of prices and qualities of modes. With this formulation the different measures of users' benefit do not coincide and hence a Hicksian measure is called for.

4. DETECTION OF INCOME EFFECT IN MODE CHOICE

Jara-Diaz and Videla (1987) provide a theoretical framework for the detection of income effect in mode choice. In this paper we summarize their main conclusions.

Let X be a vector of continuous goods other than trips and P the vector of associated prices. Let Qj be a vector of modal attributes qij, and Cj the cost of using jth alternative of the M available modes. Let us now consider a utility function defined in the space (X,Qj). An individual chooses X and j such that

$$\max_{\substack{X \in x \\ j \in \{1,\dots,M\}}} \{ U(X,Qj) / PX' + Cj \leq I \} \equiv \max_{j \in M} [\max_{X} \{ U(X,Qj) / PX' \leq I - Cj \}] \qquad (2)$$

where I is money income.

We assume that the utility U is separable in X and Qj. This implies that the level of satisfaction attained from consuming a bundle X is independent of modal characteristics. In this case we can write the utility function as:

$$U\{X,Qj\} = U1(X) + U2(Qj) \qquad (3)$$

It can be shown that the optimization problem formulated in (2) is a set of functions X (P,I-cj) that generates the conditional indirect utility function Vj

$$Vj = V1(P,I-Cj) + U2(Qj) \qquad (4)$$

A second order Taylor expansion of V1 in I-Cj around (P,I) provides

$$Vj = V1(P,I) - \mu(P,I)\ Cj + \frac{1}{2}\frac{\delta\mu}{\delta I}\ Cj^2 + U2(Qj) \qquad (5)$$

where μ is the marginal utitily of income and by construction $\delta U/\delta I = -\delta U/\delta C$ which is the conditional version of Roy's identity in discrete choice.

From equation (5) it is clear that the linear-in-cost version of Vj implicitly assumes that the marginal utility of income μ is not a function of income and, therefore mode choice is not influenced by income but only by Cj and Qj.

We can hypothesize that μ should decrease with individual income, i.e. an additional money unit is more valuable for people with less income.

They suggests a specification to test for the presence of income effect in mode choice. They suggests a more flexible specification of utility namely

$$Vj = Aj + \alpha\ Cj + 1/2\ \beta\ Cj^2 + U2(Qj) \qquad (6)$$

Following properties are constructed:

1) $\mu j = \delta Vj / \delta I = -\alpha - \beta\ Cj$
2) $\delta\mu j / \delta Cj = -\beta < 0$ or $\beta > 0$
3) $\beta(Ii) > \beta(Ik) \quad Ik > Ii$
4) $\alpha < 0$
5) $\mu(Ii) > \mu(Ij) \quad$ for $\quad Ii > Ij$

5. APPLICATION

The proceeding framework will be applied to work trip in Stockholm. To establish a reference for discussion we first estimated a simple mode choice model, linear in cost and time, for travel to work. Estimation was based on three modes; car, public transportation and slow mode (walk, bicycle). We assume a generic cost coefficient for cost variable. Table 5.1 presents the result of estimation. This model yields a marginal utility of income ($\mu j = -\delta Vj / \delta Cj$) of .03351 for car and public transport users and a subjective value of time is 19.27 Kr/hr.

Table 5.1 Estimated Coefficients for Simple Mode Choice Model. Personal income = 0.0 excluded

Alternatives: 1 car; 2 public transport; 3 slow mode

Variable *	Parameter Value	t-value
Constant, 2	-.6058	(-1.9)
Constant, 3	.9221	(2.1)
In vehicle travel time, 1,2	-.01076	(-2.1)
Total cost, 1	-.03351	(-5.7)
Dummy, car used during work,1	2.132	(9.2)
Dummy, destination inner city,1	-.6126	(-2.9)
Car competition, 1	-.3785	(-3.0)
Walking and waiting time, 2	-.02360	(-3.9)
Dummy, 1 for intra-zonal trip,2	-1.266	(-2.0)
Dummy, 1 for intra-zonal trip ,3	.5752	(1.4)
Distance < 4 km, 3	-.3649	(-5.6)
Distance > 4 km, 3	-.3411	(-6.2)
Sample size: 1231		
Log likelihood:		
zero coefficients -1255.89		
with constants only -1110.94		
final value -682.45		
p2 w.r.t. zero .4568		
p2 w.r.t. constants .3859		

* All times are in minutes, and all costs are in SEK

The first step in the detection of income effect as formulated in previous section is to test for the significance of β in eq (6). This was done by adding variable $(cost)^2$ in simple mode choice model. The coefficient for $(cost)^2$, β, is significant (t-value = 3.0) and has the right sign (positive). This implies that the marginal utility of income can depend on income and hence β should be a function of income. Therefor income stratification will be necessary. Separate models for different income strata are estimated. Results are as shown in table 5.2.

Examination of table 5.2 indicates that α and β for the three separate models have the correct signs. Furthermore β decreases with income and α increases with income. One can calculate μ for each income stratum and the corresponding t-values from the variance- covariance matrices of the coefficients, as shown in table 5.3

Table 5.2 Estimated Coefficients for Simple Mode Choice Model Including $(cost)^2$ for Different Income Strata

Alternatives: 1 car; 2 public transport; 3 Slow mode Variable *	0<I<95	95<I<130	130<I
Constant,2	.3587(0.6)	-.9109(-1.9)	-2.419(-3.7)
Constant,3	1.047 (1.4)	.4224 (0.6)	1.021(1.0)
Time,1,2	-.0026(-.3)	-.0053(-0.7)	-.0421(-3.7)
Total cost,1	-.0940(-2.9)	-.0748(-3.6)	-.0385(-1.5)
Total cost sq,1	.635E-3(1.4)	.857E-3(2.9)	.519E-4(0.1)
Dummy, car use at work,1	3.20 (4.1)	2.06 (4.7)	1.81 (5.1)
Dummy, dest. inner city,1	.082 (.2)	-.732(-2.3)	-.578(-1.5)
Car compet.,1	-.1455 (-.6)	-.4211(-2.2)	-.7314(-2.8)
Walk/wait time,2	-.0444(-3.5)	-.0225(-2.5)	-.0094(-0.9)
Dummy, int.z.,2	-1.40(-1.6)	-1.65(-1.4)	-
Dummy, int.z.,3	.902 (1.3)	.587 (0.9)	.159(0.1)
Dist <4 km, 3	-.2807(-2.7)	-.3121(-3.1)	-.7054(-4.5)
Dist >4 km, 3	-.4606(-3.4)	-.3277(-4.0)	-.2926(-3.2)
Sample size:	372	481	378
Log likelihood:			
initial value	-363.68	-489.51	-402.71
constant only	-352.10	-428.98	-294.01
final value	-211.73	-276.39	-168.54
p2 w.r.t. zero	.4178	.4354	.5815
p2 w.r.t. cons.	.3987	.3557	.4268

Average cost used for the calculation of μ is based on average costs of travel by car and public transport for the given income strata and mode share in that income stratum. Note that value of μ for high income stratum is almost equal to μ calculated from a simple mode choice model and that μ for low income stratum is almost twice as large as the high income group.

Table 5.3 Marginal Utility of Income

Income group	μ(Cj)	C	μ(C)	(t-stat)
0<I<95	.09043-.001270Cj	10.8	.07671	(1.80)
95<I<130	.07482-.001714Cj	9.5	.05854	(2.26)
130<I	.03847-.000104Cj	8.3	.03761	(1.13)

One can calculate t-statistic to test for the statistical significance of the difference between marginal utility of income of different income groups. Based on these t-statistics it is difficult to accept that μi's are in fact different.

It can be shown that income elasticity πi is proportional to $\mu i I$. While μi decreases with income in proportion similar to 2/1.5/1, disposable personal income increases similar to 1/1.5/2, or similar income elasticities for the three income groups considered.

We also calculated the subjective value of time and it's t-statistics for different income groups as shown in table 5.4. The expected subjective value of time specially for low and medium income strata are very low if indeed they should be a reasonable proportion of wage rate. As discussed earlier the differences between average disposable income within income stratum are larger than wage rate differences because of the larger number of part time workers in lower income groups. The t-statistics for the subjective value of time, svt, are fairly low.

Table 5.4 Estimated Subjective Value of Time

Income group	svt, Kr/hr	t-statistics
0<I<95	2.015	.072
95<I<130	5.434	.061
130<I	67.179	.035

In addition to the difficulty in accepting that the are differences in the value of μi's, the subjective values of time that yield from these models are difficult to accept both based on value and on their t-statistics.

6. AN ALTERNATIVE APPROACH

In 1978, Train and McFadden (1978) provided a theoretical treatment of how income and price should enter in the specification of the utility functions for a discrete choice model. The inclusion of a variable that represents modal cost (price) divided by individual wage rate, in the specification of utility in disaggregate demand modelling, comes from their analysis. Jara-Diaz and Farah (1987) suggest expenditure rate, i.e. the amount the individual earns per unit of available time, to replace wage rate. Furthermore they suggest that the usual linear specification of representative utility which results from the

Train and McFadden approach to be inadequate. They develop a general specification of conditional indirect utility function using expenditure rate. One can justify the use of I in place of the expenditure rate, I/ (T-W), where I is income earned in period T and W is the time spent working in that period. Their formulation lead to

$$Vj = Aj + \alpha Cj + \beta ITj + \Phi TjCj - \sigma Cj^2/I - \gamma Tj^2 I + U2(Qj) \quad (7)$$

Corresponding to the simpler version of Vj that they suggest will be

$$Vj = Aj + \alpha Cj + \beta TjI + \Phi TjCj + U2(Qj) \quad (8)$$

Estimation of the full model proved impossible because of the collinearity of the variables. We have assumed that walk and wait time connected with public transportation mode will be weighted by a factor of two compared to in vehicle time.Table 6.1 presents result of estimated coefficients for formulation shown by Eq(8).Note that all coefficients have significant t-statistics and correct signs.

Table 6.1 Estimated Coefficients

Variable *	Parameter Value	t-value
Constant for,2	-.6155	(-2.1)
Constant for,3	-.5260	(-1.9)
Total cost, 1	-.06356	(-4.9)
Time*Income, 1,2,3	-.2462E-3	(-11.8)
Time*Cost,1	.3488E-3	(2.4)
Dummy, car used during work,1	1.908	(8.1)
Dummy, destination inner city,1	-.5708	(-2.9)
Car competition, 1	-.4237	(-3.3)
Dummy, for intra-zonal trip,2	-1.391	(-2.3)
Dummy, for intra-zonal trip,3	1.533	(4.3)
Sample size: 1231		
Log likelihood:		
zero coefficients -1255.89		
with constants only -1110.94		
final value - 717.34		
p2 w.r.t. zero .4288		
p2 w.r.t. constants .3543		

The expected value of marginal utility of income for different income strata as shown in table 6.2 are in fact very close to that which follows from the simple model (.03351) and do not vary between income groups. One can conclude that there is in fact no income effect in mode choice based on data for Stockholm. The expected subjective values of time from this formulation are within reasonable range and close to the expected subjective value of time from the simple mode choice model (19.26 Kr/hr). The main advantage of formulation of Vj by eq (8) has been that it captures the effect of income in the subjective value of time which brings consequence on the evaluation of a transportation project as will be shown later.

Table 6.2 Marginal Utility of Income and Subjective Value of Time for Different Income Groups.

Income group	I (1)	C (2)	μj (3)	svt (4)
0<I<95	50.77	8.33	.03386	17.00
95<I<130	75.35	8.24	.03253	29.00
130<I	115.65	7.67	.03484	44.40

(1) Average disposable personal income of the stratum in 1000 SEK /year
(2) Average cost based on average cost of all different modes for a stratum and the corresponding mode share
(3) The expected marginal utility of income
(4) The expected subjective value of time in SEK/hour

In summary there is no reason to believe that income effect is present in mode choice. Consequently different measures of user benefit coincide and are given by eq (1). However application of the simple mode choice model versus model presented by eq (13) to evaluate a transport policy is expected to produce different results, mainly based on difference in the expected subjective value of time from these models.

7. EVALUATION OF USERS' BENEFIT FROM A CORDON TOLL POLICY FOR STOCKHOLM

Two alternative models as presented in table 5.1 and table 6.1 will be used for the evaluation of a cordon toll policy for Stockholm. Table 7.1 describes users' benefit for different socio-economic groups from a cordon toll policy in Stockholm for mode choice model 5.1 and 6.1.

Table 7.1 Users' Benefit for Different Socio-Economic Groups from a Cordon Toll Policy in Stockholm.

Group	Cases	benefit in Kr per round trip	worker per round trip	worker per year(1)
Mode Choice Model as described in table 5.1				
Low Income	420.	41.876	.100	22.434
Medium Income	481.	-77.782	-.162	-36.384
High Income	378.	-462.410	-1.223	-275.244
Female	583.	-69.796	-.120	-26.937
Male	696.	-428.520	-.616	-138.530
To Inner city	356.	-1329.075	-3.733	-840.005
Others	923.	830.759	.900	202.514
Mode Choice Model as described in table 6.2				
Low Income	420.	-6.570	-.016	-3.519
Medium Income	481.	51.072	.106	23.890
High Income	378.	328.112	.868	195.304
Female	583.	-24.501	-.042	-9.456
Male	696.	397.116	.571	128.378
To Inner city	356.	-1056.990	-2.969	-668.042
Others	923.	1429.604	1.549	348.495

In a previous study (Ramjerdi, 1988) a cordon toll policy for Stockholm was evaluated. Peak period demand was used in this study. Costs and network data of the different modes have been simulated for a situation where a toll policy is implemented. Toll fee of 20 SEK per passenger equivalent to 25 SEK per car was adopted in these studies. It is assumed that one works 5 days per week and 45 weeks per year For the calculation of the users' benefit we assume the marginal utility of income to be 0.03351.

The two models show different overall evaluation of a cordon toll policy based on users' benefit. The total benefit that follows from choice model 5.1 (for a sample of 1279 workers) is -498.316 Kr/day (assuming a worker makes one round trip for work purpose per day). The use of model 6.1 shows a benefit of 372.614 Kr/day.

Table 7.1 shows that the two models give different results for different socio- economic groups. Model 5.1 shows larger benefit (smaller disbenefit) for low income groups and for female workers. While model 6.2 shows larger benefit (smaller disbenefit) for high income groups and for male workers. The disbenefit for those commuting to the inner city is less with model 6.1 because of the higher subjective value of time for this group when model 5.1 is used for the calculation of users' benefit.

8. CONCLUSION

There are two main conclusions of this study. First the different measures of users' benefit coincide for travel to work in Stockholm based on the data analyzed.

The second conclusion of this study is that a mode choice model which captures the effect of income on the subjective value of time, produces users' benefit that can be very different from that produced by a simple (linear in time and cost) mode choice model, especially for different socio-economic groups affected by a transportation project.

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