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1. Introduction

In recent years, there has been a concerted attempt by economists as well as urban planners towards understanding travel behavior of individuals in major metropolitan areas. This is partly due to the increasing awareness on the part of social scientists and various metropolitan authorities of the impact of the transportation system on the economy and thus, of the necessity of careful planning and policy making. Most of the early works, however, were mainly empirical and, as such, embodied no formal development of any a priori logical hypothesis about individual travel behavior.[1] In the last decade or so, contributions by Baumol and Quandt (1966), Lisco (1967), Quarmby (1967), Quandt (1968), McGillivray (1970), Ben-Akiva (1972) and others have provided useful insights about the many dimensions involved in urban mode choice situations. The most significant among these new approaches is perhaps the contribution being made by McFadden and his collaborators at the Institute of Transportation and Traffic Engineering in Berkeley, California.[2] McFadden's main contribution has been in bridging the gap between models of individual choice (which is the basic ingredient of a disaggregate approach) and those of population behavior. By postulating that individuals' preferences differ from one another in some specified stochastic manner, McFadden and his associates succeed in translating their theory of population choice into econometrically testable propositions. We shall review their method in section 3 of this paper.

The results that studies of this type have come up with include the following:

(a) the relative monetary costs for different modes are not the primary determinants of the choice of mode;

(b) excess travel time (i.e., in excess of in-vehicle time) is important in the choice, and individuals do not attach the same weights to the various travel time components.

(c) mode choice process is not homogeneous across the dimensions of trip purpose (see de Donnea (1972) and Watson (1974)).

More recently, Gillen (1977) using 1964 Toronto data finds that the traditional approach by failing to distinguish between parking cost and the remainder of the money cost of a trip has yielded biased predictions. Obviously, the correct specification of cost and travel time variables has important policy implications in the transportation planning context. The author feels that this question has been inadequately discussed, especially across the different dimensions of trip purposes. The present paper tests for the appropriate specifications of both the cost and the travel time variables for four different trip purposes (work, shopping, leisure and study) using the 1974 survey data collected by the Montreal Urban Community Transit Commission. This is done by using a binary logit model (auto vs. metro) of the type used by McFadden (1974) and Gillen (1977).

The plan of the paper is as follows. We attempt an alternative description of an individual's choice of travel mode in section 2. In section 3, we discuss how the model discussed in section 2 can be modified such that one can make valid inferences regarding population choice, which is essentially McFadden's approach. Section 4 discusses the empirical findings using the 1974 Montreal data. Section 5 offers some concluding remarks and discusses the scope of possible extensions.

2. A Model of Individual Choice of Travel Mode

First we observe that transportation services are not desired for their own sake, i.e., the demand for these services is derived from the demand for other more basic wants that individuals would like to fulfill. In this particular context, we postulate that these more basic wants are non-transport goods and leisure. We may also want to think of them as relevant characteristics that the commuter has preferences over. Here we use the term "characteristic" in the sense of Lancaster.[3] Thus the commuter's problem is to choose some mode for which the collection of characteristics is such, that utility is at the maximum level possible, given the constraints on the allocation of budget and the available time.

2.1 The Basic Model

A commuter's preferences over the characteristics can be summarized by a utility function,

$$U(G,L) \tag{1}$$

where G denotes the level of consumption per period of a non-transport composite commodity and L denotes the amount of leisure per period consumed by the individual. G and L are measured in suitably chosen physical as well as temporal units such that they are agreed upon by all concerned. Further, U has all the required properties of a well behaved utility function (namely, quasi-concave and at least twice continuously differentiable).

The appropriate constraints are:

$$pG + q_j d + r_j d \leq \omega H + M , \tag{2}$$

and

$$d_j(h_j^v + h_j^\ell + h_j^w) + L + H \leq T \text{ ,} \qquad (3)$$

where the notation is as follows:

- j : index for the various modes available ($j = 1, 2, \ldots$)
- p : price of a unit of G
- q_j : money cost of a trip per mile on mode j
- r_j : parking cost for a trip on mode j (where applicable) per mile
- d : number of miles travelled
- ω : wage rate per unit of time worked
- H : number of work units per period
- M : non-wage income per period
- h_j^v : in-vehicle travel time per mile on mode j
- h_j^ℓ : walking time for a trip on mode j (where applicable), per mile
- h_j^w : waiting time for a trip on mode j (where applicable), per mile
- T : number of units of time available per period

Note that constraints (2) and (3) delineate the precise manner of evolution of the quantities of the two characteristics by a given mode j. In Lancaster's words, conditions (2) and (3) also describe the underlying consumption technology for the commuter. Further note that these relationships between a given mode j and its associated characteristics are defined in the characteristics-space. Therefore, we can obtain a direct solution of the commuter's problem.[4]

From (3), we obtain

$$H \leq (T - L - [h_j^v + h_j^\ell + h_j^w]d) \tag{4}$$

Substituting (4) in (2), we have

$$pG + q_j d + r_j d \leq \omega[T - L - (h_j^v + h_j^\ell + h_j^w)d] + M \tag{5}$$

Setting up the Lagrangean, we have

$$\underset{\{G,L,\lambda\}}{\text{Max}} \; F = U(G,L) + \lambda[\omega(T - L - [h_j^v + h_j^\ell + h_j^w]d) + M - pG - q_j d - r_j d] \tag{6}$$

The necessary conditions for the existence of a maximum are given by the following Kuhn-Tucker conditions:

$$U_g - p \leq 0 \quad \text{and} \quad G \geq 0 \tag{7}$$

$$U_L - \lambda\omega \leq 0 \quad \text{and} \quad L \geq 0 \tag{8}$$

and the inequality (5) such that $\lambda \geq 0$.

Assuming that, at the optimum, all G, L and λ are strictly positive, we can rewrite the above necessary conditions as follows.

$$U_g = \lambda p \tag{9}$$

$$U_L = \lambda\omega \tag{10}$$

$$\omega[T - L - (h_j^v + h_j^\ell + h_j^w)d] + M = pG + q_j d + r_j d \tag{11}$$

From (9) and (10), we observe that

$$\frac{U_g}{U_L} = \frac{p}{\omega} \;, \tag{12}$$

i.e., the equilibrium marginal rate of substitution between goods and leisure equals the ratio of per unit price of the non-transport goods and the wage rate. This is a familiar result in standard microeconomic theory.

Notice that the optimal solution to problem (6), say, denoted by (G^*, L^*, λ^*), can only be obtained from the equilibrium conditions (9), (10) and (11) in implicit function forms, and not in an explicit manner. For the latter, one normally has to assume specific forms of the utility function. The model is easily amenable to various comparative static exercises.[5]

3. From Individual to Population Behavior

The utility function, U, defined over the space of characteristics (G and L) in the individual choice model in section 2 above can be taken to be the deterministic part of the true utility function relevant to population choice behavior. The "true" utility function can be written as

$$V = U(x) + \varepsilon(x) \tag{13}$$

U(x) now denotes the maximized value of U(G,L), i.e., the solution to problem (6), and is thus the indirect utility function. Hence the vector x denotes the various monetary and time cost variables that are appropriate arguments of the indirect utility function corresponding to the problem (6). $\varepsilon(x)$ is a stochastic term describing the unobserved variations in the characteristics among individuals in a given sample. The probability that a randomly sampled individual will choose an alternative i from a set of j alternatives, equals

$$P_i = \text{Prob}[U(x_i) + \varepsilon(x_i) > U(x_j) + \varepsilon(x_j), \quad \forall j, j \neq i]$$

or

$$P_i = \text{Prob}[U(x_i) - U(x_j) > \varepsilon(x_j) - \varepsilon(x_i), \quad \forall j, j \neq i] \tag{14}$$

Let $F(s_1,\ldots,s_j)$ denote the cumulative joint distribution function of $(\varepsilon(x_1),\ldots,\varepsilon(x_j))$ and let f_i denote the i-th derivative of F. Then

$$P_i = \int_{-\infty}^{+\infty} f_i([s + U(x_i) - U(x_1)],\ldots,[s + U(x_i) - U(x_j)])ds$$

Following McFadden (1974), if we assume that $\varepsilon(x_j)$ follow the Weibull distribution, namely,

$$\text{Prob}[\varepsilon(x_1) < \varepsilon] = e^{-e^{-\varepsilon}} \tag{15}$$

the probability of choice of alternative 1 is

$$P_1 = \frac{e^{U(x_1)}}{\sum_{j=1}^{J} e^{U(x_j)}} . \tag{16}$$

Further, the relative odds of choice follow

$$\log\ (P_i/P_j) = U(x_i) - U(x_j) \tag{17}$$

This is known as the Logit model. In our empirical work, we shall adopt the version of this model as detailed by Press and Nerlove (1973). The model estimates the relationships, for a <u>single dichotomous dependent variable</u> (e.g., Auto-Metro journey-to-work mode choice).

$$P_k = F(\psi(x_k)) \tag{18}$$

where P_k denotes, say, the probability that the chosen travel mode is <u>auto</u> (as opposed to <u>metro</u>) for the k-th set of characteristics (i.e., for the k-th observation), and $\psi(x_k)$ is linear in x_k (i.e., $\psi = x_k' \beta$, β being a vector of constants), i.e.,

$$P_k = F(x_k^{'} \beta) . \tag{19}$$

Note that P_j is non-decreasing in $(x_k^{'} \beta)$, but may be decreasing in some k depending upon the algebraic sign of relevant coefficient. Press and Nerlove further interpret $F(x_k^{'} \beta)$ as the standardized cumulative logistic distribution function; so that

$$P_k = \frac{1}{1 + e^{-x_k^{'} \beta}} \tag{20}$$

In other words,

$$x_k^{'} \beta = \log \left(\frac{P_k}{1 - P_k} \right) \tag{21}$$

The model described by (27) is estimated by maximum likelihood procedure. The appropriate likelihood function is

$$\mathcal{L}(y_1, \ldots, y_n | x_1, \ldots, x_n) = \prod_{k=1}^{n} [F(x_k^{'} \beta)]^{y_k} [1 - F(x_k^{'} \beta)]^{1-y_k} , \tag{22}$$

where y is the single dochotomous dependent variable. The model, therefore, estimates (26) by maximizing (29) where F is standard logistic. Press and Nerlove argue that since log $\mathcal{L}$ is globally concave, the above procedure provides an absolute maximum.

Press and Nerlove further demonstrate the superiority of this method of estimation over all other available methods, especially when the sample size is not too large. All the empirical results reported in this paper are obtained using the above described procedure.

4. Empirical Results

In this section, we analyze the Auto vs. Metro mode choice for one-way trips for the following purposes:

(a) work,

(b) shopping,

(c) leisure,

(d) study.

The data used for the empirical work reported here have been provided by the Montreal Urban Community Transit Commission (MUCTC) and they consist of a sub-sample of the 1974 Origin-Destination Survey (MUCTC, 1974). Because of the large size of the original sample surveyed by the MUCTC, the resource constraints necessitated a somewhat arbitrary choice of zones of origin as well as destination. Out of a possible 66 zones, we chose zones numbered (6, 9, 13, 18, 19, and 36) as the origins and those numbered (10, 21, 22, and 23) as the destination zones. The idea behind this choice was that the sectors of origin were mainly residential, and that destination zones were mainly non-residential. This gives us a sample of 2827 individual observations. For the chosen zones of origin, out of 2827 trips, about 62% of all trips were for either work or study. Likewise, the destination zones included in the sample indicate that only about 20% of all trips ending in these sectors were for return to residences.

The sample (2827) included trips for the following purposes and using the following modes:

Purposes

1. Work (48.2% of all observations)
2. Return to Residence (20.1% of all observations)
3. Study (13.1% of all observations)
4. Shopping (6.9% of all observations)
5. Leisure (4.1% of all observations)
6. Other (7.7% of all observations)

Modes

1. MUCTC (Either Metro only, or MUCTC Bus only, or both - 43.3%)
2. Car (36.9%)
3. Train (4.5%)
4. Foot (4.0%)
5. Taxi (0.8%)
6. School Bus (0.6%)
7. Other Bus (0.2%)

Further the survey included observations such that there were no cars in the household, and/or the person surveyed was less than 16 years old (which is the legal driving age). Thus, after eliminating observations where

(i) the age of the person is less than 16,

(ii) there are no cars in the household,

(iii) the trip purpose is either return to residence, or other, and

(iv) the chosen mode is other than Metro alone (this would allow Metro and MUCTC Bus, but not MUCTC Bus alone) or, Car alone,[6]

we were left with 1173 observations. Trips for returning to residence were dropped because of insufficient information. The survey does not provide information regarding whether the trip in question is returning home from work, study, shopping or whatever. We also dropped taxi and train largely because of resource constraints. In order to end up with a reasonable sample size for these modes, we would require a much larger data set, and further we have to obtain information on costs and time variables from sources other than the MUCTC.

More detailed discussion of the demographic and other characteristics of the sample is presented in the appendix.

4.1 Auto-Metro Mode Choice and the Journey to Work

We have 845 observations on work trips. This is to our knowledge one of the largest data sets that anyone has worked with. Different models are employed in order to test alternative hypotheses on the underlying trip behavior. In each instance, we estimate the probability of choosing auto over metro as a function of several explanatory variables. The estimation procedure has been described in section 3. The variables used for the work trip analysis are:[7]

AGE - Age of the trip maker. Broken down into four classes (16-29, 30-44, 45-64, 65 and above). Since we have a large number of observations in the (16-29)-group (40%) and virtually none in the (65+)-group, we expect the coefficient for this variable to be positive (i.e., an increase in AGE to raise the probability of choosing the auto over metro.

SEX - Dummy variable, set to 1 if male and 2 if female. From casual observations as well as from other studies, it would seem that this coefficient is likely to be negative.

TIME - Time of day when the trip was undertaken. Dummy variable set to 1 if peak-period and 2 if otherwise.[8] For work trips, this coefficient is likely to be positive.

AUTOSPP - Number of cars per person in the household. This is expected to have a strong positive influence on the choice of auto as the chosen mode.

WTM - Auto-metro difference in waiting time for a given trip (in minutes). Since we assume that there is no waiting time for auto, this is simply the waiting time for metro. The coefficient is expected to be positive.

WALKTM - Auto-metro difference in walking time per mile[9] (in minutes). Again walking time is assumed to be zero for the auto alternative. The coefficient is likely to be positive.

RTT - Ratio of in-vehicle travel times for a given trip (auto over metro). This is expected to have a negative effect on the choice of auto.

ROTT - Ratio of overall travel timesfor a given trip (including waiting and walking times). Again, a negative coefficient is expected.

RCOST - Ratio of all money costs (including parking fees) for a given trip (auto over metro).[10]

RCOSTLP - Ratio of cost (less parking fee) for a given trip (auto over metro).

WPARKC - Parking cost variable for work trips. This is the ratio of the parking fee for a given trip over the money cost of the trip by metro (i.e., RCOSTLP + WPARKC = RCOST).

All cost variables are expected to have negative effects on the probability of choosing auto as the travel mode. These a priori hypotheses on the expected direction of all transport system coefficients (i.e., WTM, WALKTM, RTT, ROTT, RCOST, RCOSTLP, WPARKC) are entirely consistent with the theoretical discussion (section 2). The discussion of the individual characteristics (i.e., AGE, SEX, TIME and AUTOSPP) and their possible effects on mode choice are more ad hoc in nature. The theoretical model is not specified enough to generate any specific hypotheses. The hypotheses stated in these contexts are those that appear reasonable, and in most instances accord with the existing results in the literature.

4.1.1 Discussion of Econometric Results

Four models were fitted to test the following three hypotheses.

(a) First, we test whether the disaggregated travel time variables {WTM, WALKTM, RTT} explain mode choice better than a single aggregate, ROTT. THis can be tested either in the context of a model where the corresponding money cost variables are expressed as an aggregate, RCOST, or, in the context of a model where we believe that the commuter's behavior is better described by a separate parking cost (WPARKC) as well as the ratio of cost less parking variable (RCOSTLP), as has recently been argued by Gillen (1977). From models 1 and 3, likelihood ratio test reveals that the disaggregated time variables have no additional explanatory power over ROTT[11] in the context of disaggregate cost variables. Comparing models 2 and 4, it is seen that, in the context of an aggregate cost variable (RCOST), the disaggregated travel time variables lack any additional explanatory pwoer over a single aggregate time variable.

(b) Next, we test whether the disaggregated cost variables (RCOSTLP and WPARKC) explain travel behavior better than an aggregate RCOST variable. Again this test can be carried out in the context of disaggregate and aggregate time variables. Comparing models 1 and 2, it is seen that in the context of disaggregate travel time variables, the separate cost variables do not perform better than the single aggregate, RCOST. The same conclusion follows from models 3 and 4 in the context of an aggregate time variable.

(c) Finally, we test whether, the disaggregate time and disaggregate cost variable, together, explain mode choice better than the appropriate aggregates. This is done by comparing models 1 and 4. The answer is negative.

On balance, then it would seem that model 4 best describes journey-to-work mode choice. The conclusions that follow from model 4 are:

(i) Other things equal, men are more likely to drive to work than women;

(ii) Somewhat surprisingly, neither the age of the person, nor the timing of the trip had a significant influence on the choice of mode;

(iii) Auto-ownership and the ratio of over-all travel times were highly significant determinants of mode choice; and

(iv) Ratio of money costs for the two modes is not a significant determinant of mode choice. This is contrary to the findings by, among others, Gillen (1977) and McFadden (1974).

Also note that all four models indicate the rejection of the hypothesis of independence of the dependent variable from the explanatory variables at the .005 confidence level.[12]

4.2 Shopping Trip Mode Choice (sample size 106)

The variables used for analyzing shopping trip behavior are basically the same as in the work trip analysis. The only changes are changes in the parking fee, and consequently, also in the ratio of cost variable (RCOST).[13] The major conclusions are:

(a) Comparing models 1 and 2, it is seen that in the presence of disaggregate travel time variables (WTM, WALKTM and RTT), the disaggregate cost variables (RCOSTLP and SPARKC) do not explain mode choice better than does a single overall cost variable (RCOST). Comparing models 3 and 4, we see that minus twice the difference in the logs of maximized likelihood functions (= 1.546), which is approximately distributed as χ^2 with 1 d.f., is not significant even at the 10% level. Thus, the separate parking cost variable does not explain mode choice better than an all inclusive cost variable.

(b) Comparing models 1 and 3, it is seen that in the context of separate cost variables (SPARKC and RCOSTLP), the disaggregate travel time variables (WTM, WALKTM and RTT) explain mode choice better than an overall travel time variable (ROTT). This is significant at the 2.5% level. The χ^2-value required for significance at 1% level is 9.210 (2 d.f.), while the number obtained is 7.492. The same result obtains when the cost variables are expressed as a single aggregate. The χ^2-value is 9.064

Table 1

Journey to Work Mode Choice - Model 1

	Independent Variable	Parameter Estimate	Asymptotic t-ratio	Significance Level
(1)	Pure Auto Preference Effect (CONSTANT)	2.85	3.13	1%
(2)	AGE	.05	1.15	-
(3)	SEX	-.72	8.43	1%
(4)	TIME	.10	.97	-
(5)	AUTOSPP	1.15	5.52	1%
(6)	WTM	-.004	.18	-
(7)	WALKTM	.14	1.46	10%
(8)	RTT	-1.58	6.61	1%
(9)	RCOSTLP	-.24	1.02	-
(10)	WPARKC	-.07	.64	-

$-2 \log \lambda = +257.90$

No. of iterations needed for convergence = 6

log likelihood = −456.762

Table 2

Journey to Work Mode Choice - Model 2

	Independent Variable	Parameter Estimate	Asymptotic t-ratio	Significance Level
(1)	Pure Auto Preference Effect (CONSTANT)	2.95	3.29	1%
(2)	AGE	.05	1.16	-
(3)	SEX	-.72	8.46	1%
(4)	TIME	.10	.95	-
(5)	AUTOSPP	1.15	5.54	1%
(6)	WTM	-.009	.43	-
(7)	WALKTM	.16	1.70	5%
(8)	RTT	-1.49	8.46	1%
(9)	RCOST	-.12	1.59	10%

$-2 \log \lambda = +256.60$

No. of iterations needed for convergence = 6

log likelihood = -456.915

Table 3

Journey to Work Mode Choice - Model 3

	Independent Variable	Parameter Estimate	Asymptotic t-ratio	Significance Level
(1)	Pure Auto Preference Effect (CONSTANT)	2.53	3.88	1%
(2)	AGE	.05	.96	-
(3)	SEX	-.72	8.46	1%
(4)	TIME	.10	.96	-
(5)	AUTOSPP	1.10	5.32	1%
(6)	ROTT	-3.37	7.20	1%
(7)	RCOSTLP	-.11	.89	-
(8)	WPARKC	.01	.11	-

$-2 \log \lambda = 258.58$

No. of iterations needed for convergence = 13

log likelihood = -456.420

Table 4

Journey to Work Mode Choice - Model 4

	Independent Variable	Parameter Estimate	Asymptotic t-ratio	Significance Level
(1)	Pure Auto Preference Effect (CONSTANT)	2.77	5.68	1%
(2)	AGE	.05	.95	-
(3)	SEX	-.73	8.48	1%
(4)	TIME	.10	.96	-
(5)	AUTOSPP	1.11	5.34	1%
(6)	ROTT	-3.18	10.31	1%
(7)	RCOST	-.04	1.04	-

$- 2 \log \lambda = +258.28$

No. of iterations needed for convergence = 11

log likelihood = -456.575

which is only slightly below that required for significance at 1% level. Thus, the separate time variables (rather than one aggregate variable), although not significant at the 1% level, are definitely significant at the 2.5% level.

(c) Finally, comparing models 1 and 4, it is seen that the disaggregate travel time variables together with disaggregate cost variables explain mode choice better than the aggregate variables. We accept this hypothesis at the 5% level. (The χ^2 value is 9.038 with 3 d.f.)

Both models 2 and 4 describe shopping trip behavior quite well. By means of testing significance with t-ratios we can make the following conclusions:

(i) Age and the timing of the trip (TIME), again fail to explain shopping choice of mode.

(ii) We accept the hypothesis that men are more likely to choose auto over metro at 1% level.

(iii) Auto ownership, though significant, is less important than it was for work trips.

(iv) Somewhat surprisingly walking time has a strong perverse effect on mode choice (significant at 1% level). Noticing that this is walking time per mile, as WALKTM increases (=8/DISTANCE), the distance travelled decreases. Thus we have the quite plausible result that as distance travelled drops, the probability of choosing metro over auto increases.

(v) The aggregate ratio of cost is also significant (at 1% in model 2, 5% in model 4).

The only comparable study of shopping behavior is that of McFadden (1973). His results are quite similar to ours especially in connection with the AUTOSPP, RTT and RCOST variables. He does not analyze separate parking cost variable.

4.3 Leisure Trip Mode Choice (Sample Size 65)

Due to a rather small sample (65), the results on leisure trips may be somewhat less reliable than others reported in this paper.[14] Nevertheless, for all the models tested in this case, we reject the hypothesis of independence between the dependent variable (i.e., the probability of choosing auto over metro) and the alternative sets of explanatory variables at the .005 confidence level. The variables used are similar to those used before, except that the timing of the trip variable (TIME) had to be dropped because all the leisure trips in sample were undertaken during the non-peak period.[15] The parking variable is computed the same way as that for shopping trips, and thus they are identical. However, we denote it by LPARKC. The major results are as follows:

(a) Regardless of how we treat the travel time variables (i.e., disaggregate vs. aggregate), we reject the hypothesis that {RCOSTLP, LPARKC}-variables explain leisure trip mode choice better than an aggregate cost variable (RCOST) at the 10% level. This is seen by comparing Tables 9 and 10 for disaggregate travel time variables, and Tables 11 and 12 for the aggregate travel time variable.

(b) Regardless of the treatment of the cost variables (disaggregate vs. aggregate), we reject the hypothesis that the disaggregate

Table 5

Shopping Trip Mode Choice - Model 1

	Independent Variable	Parameter Estimate	Asymptotic t-ratio	Significance Level
(1)	Pure Auto Preference Effect (CONSTANT)	11.48	3.96	1%
(2)	AGE	-.08	.56	-
(3)	SEX	-.98	3.23	1%
(4)	TIME	-.48	1.18	-
(5)	AUTOSPP	1.36	2.02	5%
(6)	WTM	-.01	.13	-
(7)	WALKTM	-.59	2.45	1%
(8)	RTT	-1.33	1.58	10%
(9)	RCOSTLP	-1.09	1.22	-
(10)	SPARKC	-1.00	2.10	5%

$- 2 \log \lambda = 51.37$

Number of iterations - 13

log likelihood = -46.859

Table 6

Shopping Trip Mode Choice - Model 2

	Independent Variable	Parameter Estimate	Asymptotic t-ratio	Significance Level
(1)	Pure Auto Preference Effect (CONSTANT)	11.48	3.97	1%
(2)	AGE	-.08	.55	-
(3)	SEX	-.98	3.24	1%
(4)	TIME	-.47	1.20	-
(5)	AUTOSPP	1.35	2.04	5%
(6)	WTM	-.01	.16	-
(7)	WALKTM	-.58	2.58	1%
(8)	RTT	-1.28	2.12	5%
(9)	RCOST	-1.03	3.05	1%

$- 2 \log \lambda = 51.40$

No. of iterations = 13

log likelihood = -46.846

Table 7

Shopping Trip Mode Choice - Model 3

	Independent Variable	Parameter Estimate	Asymptotic t-ratio	Significance Level
(1)	Pure Auto Preference Effect (CONSTANT)	5.80	3.43	1%
(2)	AGE	-.004	.03	-
(3)	SEX	-.92	3.07	1%
(4)	TIME	-.30	.79	-
(5)	AUTOSPP	1.34	2.17	5%
(6)	ROTT	-1.43	1.11	-
(7)	RCOSTLP	.26	.59	-
(8)	SPARKC	-.74	1.77	5%

$- 2 \log \lambda = 43.88$

No. of iterations = 11

log likelihood = -50.605

Table 8

Shopping Trip Mode Choice - Model 4

	Independent Variable	Parameter Estimate	Asymptotic t-ratio	Significance Level
(1)	Pure Auto Preference Effect (CONSTANT)	4.85	3.24	1%
(2)	AGE	-.04	.30	-
(3)	SEX	-.91	3.08	1%
(4)	TIME	-.37	.97	-
(5)	AUTOSPP	1.37	2.28	5%
(6)	ROTT	-2.61	2.97	1%
(7)	RCOST	-.26	2.23	5%

$-2 \log \lambda = 42.34$

No. of iterations - 12

log likelihood = -51.378

travel time variables, {WTM, WALKTM, RTT}, explain leisure trip mode choice better than an aggregate travel time variable, ROTT at the 10% level. This is seen from Tables 9 and 11 for disaggregate cost variables, and from 10 and 12 for an aggregate cost variable.

(c) Finally, from models 1 and 4 (i.e., Tables 9 and 13), we conclude to reject the hypothesis that the disaggregate travel time variables together with the disaggregate cost variables explain leisure trip mode choice better than the corresponding aggregates at the 10% level.

This discussion then suggests that model 4 (Table 12) is perhaps the more representative description of leisure trip mode choice. Model 4 has the following implications:

(i) Contrary to the work and shopping trips, SEX is not a determinant of leisure trip mode choice.

(ii) Auto-ownership is still a significant determinant of mode choice.

(iii) We accept the hypothesis that the ratio of aggregate travel time (ROTT) is an important determinant of leisure trip mode choice at 1% level.

(iv) The ratio of aggregate cost, surprisingly, has the opposite sign, but it is barely significant at the 10% level.

Table 9

Auto-Metro Leisure Trip Mode Choice - Model 1

	Independent Variable	Parameter Estimate	Asymptotic t-ratio	Significance Level
(1)	Pure Auto Preference Effect (CONSTANT)	-4.02	.88	-
(2)	AGE	.04	.14	-
(3)	SEX	.36	.83	-
(4)	AUTOSPP	3.59	2.26	5%
(5)	WTM	.19	1.32	10%
(6)	WALKTM	.58	.85	-
(7)	RTT	-1.98	.82	-
(8)	RCOSTLP	-.62	.35	-
(9)	LPARKC	.62	.68	-

$-2 \log \lambda = 24.31$

No. of iterations = 10

log likelihood = -21.708

Table 10

Auto-Metro Leisure Trip Mode Choice - Model 2

	Independent Variable	Parameter Estimate	Asymptotic t-ratio	Significance Level
(1)	Pure Auto Preference Effect (CONSTANT)	-4.91	1.08	-
(2)	AGE	.05	.18	-
(3)	SEX	.37	.86	-
(4)	AUTOSPP	3.61	2.28	5%
(5)	WTM	.22	1.66	10%
(6)	WALKTM	.71	1.05	-
(7)	RTT	-.86	.92	-
(8)	RCOST	.23	.42	-

$- 2 \log \lambda = 24.07$

No. of iterations = 10

log likelihood = -21.830

Table 11

Auto-Metro Leisure Trip Mode Choice - Model 3

	Independent Variable	Parameter Estimate	Asymptotic t-ratio	Significance Level
(1)	Pure Auto Preference Effect (CONSTANT)	-1.46	.73	-
(2)	AGE	.11	.42	-
(3)	SEX	.41	.98	-
(4)	AUTOSPP	3.56	2.31	5%
(5)	ROTT	-6.99	2.39	1%
(6)	RCOSTLP	-.49	.68	-
(7)	LPARKC	.96	1.46	-

$- 2 \log \lambda = 20.88$

No. of iterations = 14

log likelihood = -23.421

Table 12

Auto-Metro Leisure Trip Mode Choice - Model 4

	Independent Variable	Parameter Estimate	Asymptotic t-ratio	Significance Level
(1)	Pure Auto Preference Effect (CONSTANT)	-.34	.20	-
(2)	AGE	.19	.74	-
(3)	SEX	.32	.81	-
(4)	AUTOSPP	3.23	2.20	5%
(5)	ROTT	-4.31	3.00	1%
(6)	RCOST	.27	1.35	10%

$- 2 \log \lambda = 19.64$

No. of iterations = 12

log likelihood = -24.044

4.4 Study Trip Mode Choice (147 Observations)

In analyzing study trip mode choice, we have assumed that students are not required to pay the commercial parking rates while making a study trip. In the absence of data, it was postulated that students do not pay any parking fee at all.[16,17] TIME variable was also dropped since an overwhelming majority of the trips were undertaken during the peak period.

The absence of a parking cost variable reduces the number of models from 4 to 2. Comparing Tables 13 and 14, it is seen that the disaggregate travel time variables has no additional explanatory power over an aggregate travel time variable. Model 2 (Table 14) would thus appear to be a better description of study trip mode choice. The conclusions drawn from Table 14 are as follows:

(i) AGE, SEX and AUTOSPP are all highly significant determinants of study trip mode choice. Of all the trip purposes AGE is significant only for study trips.

(ii) Ratio of overall travel time is also a significant determinant (at 5% level, the required t-ratio at 1% level is 2.35) of mode choice.

(iii) Ratio of cost is not a significant variable (and also of the perverse sign).

Table 13

Auto-Metro Study Trip Mode Choice - Model 1

	Independent Variable	Parameter Estimate	Asymptotic t-ratio	Significance Level
(1)	Pure Auto Preference Effect (CONSTANT)	.74	.26	-
(2)	AGE	.87	2.72	1%
(3)	SEX	-.68	2.90	1%
(4)	AUTOSPP	1.85	2.85	1%
(5)	WTM	-.06	.83	-
(6)	WALKTM	.08	.13	-
(7)	RTT	-1.47	2.25	5%
(8)	SRCOST	.07	.31	-

$- 2 \log \lambda = 55.65$

No. of iterations = 9

log likelihood = -69.860

Table 14

Auto-Metro Study Trip Mode Choice - Model 2

	Independent Variable	Parameter Estimate	Asymptotic t-ratio	Significance Level
(1)	Pure Auto Preference Effect (CONSTANT)	.07	.06	-
(2)	AGE	.84	2.63	1%
(3)	SEX	-.67	2.88	1%
(4)	AUTOSPP	1.79	2.78	1%
(5)	ROTT	-2.43	2.25	5%
(6)	RCOST	.08	.90	-

$-2 \log \lambda = 54.78$

No. of iterations = 10

log likelihood = -70.298

5. Summary and Conclusions

Using the MUCTC's 1974 origin-destination survey data, we have estimated the probability of choosing the automobile over metro as a linear function of a group of explanatory variables, where this linear function has a logistic distribution over the population. We have carried out the estimation for four different types of travel demand, namely, work, shopping, leisure and study. We have, by means of χ^2-tests, analyzed whether disaggregate travel time and disaggregate cost variables explain mode choice better than their corresponding aggregates. Our conclusions are as follows:

(a) Regardless of the treatment of the cost variables (i.e., disaggregate vis-a-vis aggregate), we reject at the 10% level the hypothesis that the disaggregate travel time variables, {WTM, WALKTM, RTT} explain mode choice better than an aggregate travel time variable, ROTT for work, leisure and study trips. However, for shopping trips, regardless of the treatment of the cost variables, we accept the hypothesis that the disaggregate travel time variables explain mode choice better than an overall travel time variable at the 2.5% level.

(b) Regardless of the treatment of the travel time variables (i.e., disaggregate vis-a-vis aggregate), we reject at the 10% level the hypothesis that a separate parking cost variable (and a cost less parking fee variable) explain mode choice better than an all inclusive cost variable for work, shopping and leisure trips.

(c) We reject at the 10% level the hypothesis that the disaggregate travel time variables together with the disaggregate cost variables explain mode choice better than the corresponding aggregates for work and leisure trips. For shopping trips, however, we accept this hypothesis at the 5% level.

To summarize the main conclusions that follow from the representative models, namely Table 4 (work trips), Table 6 (shopping trips), Table 12 (leisure trips), and Table 14 (study trips) we obtain the following:

(i) We reject at the 10% level the hypothesis that the age of the tripmaker is a significant determinant of mode choice for work, shopping and leisure trips. For study trips, however, it is highly significant.

(ii) We accept at the 1% level the hypothesis that men are more likely to choose auto over metro as the travel mode for work, shopping and study trips. For leisure trips, sex is not a significant variable even at the 10% level.

(iii) We reject at the 10% level the hypothesis that the time of the trip has a significant influence on mode choice for all trip purposes analyzed in the paper.

(iv) We accept the hypothesis that the number of automobiles available per person (per household) is a significant variable in mode choice at the 1% level for work and study trips, and at the 5% level for shopping and leisure trips.

(v) We accept that the ratio of overall travel times is a significant determinant of mode choice at the 1% level for work and leisure trips. For shopping trips, the ratio of in-vehicle travel times is significant at the 5% level.

(vi) We reject at the 10% level the hypothesis that the ratio of aggregate costs (RCOST) is a significant variable in explaining mode choice for work and study trips. For shopping trips, we accept the hypothesis at the 1% level.

These results point out that the determinants of mode choice can vary quite substantially with the purpose of the trip. Future research should therefore be directed towards a simultaneous explanation of all important trip purposes that a typical individual may want to undertake, and also towards the possibility of allowing for other modes that are valid alternatives in a given situation.

FOOTNOTES

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[1] References to early literature are found in Quarmby (1967).

[2] Some references are given McFadden (1974).

[3] For instance, see his <u>JPE</u>, 1966 paper (Lancaster, 1966).

[4] In Lancaster's case, the consumption technology was defined in the goods'-space, while his preferences were defined in the characteristics'-space. In such a situation, one faces the problem of having to transform the constraints into characteristics'-space (or, the objective function into goods'-space) before obtaining a solution.

[5] Since such results are very straightforward they are not presented in the text.

[6]There are some observations where both metro and car were used, or car and train. Thus we have retained metro alone or car alone.

[7]Ideally we want to include only the variables that are appropriate arguments of the indirect utility function (see section 3). Here the transport system variables can be argued to be those that come from the indirect utility function. The rest of the variables (age, sex, auto-ownership, etc.) are the characteristics of the individual tripmakers.

[8]According to the sample, the only peak-period is (5:53 a.m. - 9:07 a.m.). More than half of all trips undertaken occurred during this interval.

[9]Since walking time variable is 8 minutes for all trips in our sample, we decided to divide it by distance travelled. Otherwise, it is just another constant.

[10]This has been calculated as

$$\frac{\text{Parking Fee} + (0.07 \times \text{distance})}{0.31}$$

where \$0.07 is the per mile marginal cost of running an (average size) automobile in 1974. This includes the cost of gasoline, motor oil, cost of tires, maintenance and that part of market value of the car that depends on mileage (approximately 1¢ per mile, see the Canadian Red Book). \$0.31 is the MUCTC fare at the time of the survey.

[11]Minus twice the difference in the maximized value of the log likelihood functions of the two models is approximately distributed as χ^2 with the degrees of freedom equal to the number of slopes set to zero. In

this case, d.f. = (3 - 1) = 2, while minus twice the difference in the maximized values of the log likelihood functions is a mere 0.684. For 2 d.f. the required χ^2-values are 10.597, 9.210 and 5.991 at .5%, 1% and 5% levels, respectively. All the χ^2-tests mentioned in the paper have been carried out in this manner.

[12]This is done by comparing the maximized value of the log likelihood function with no explanatory variables at all with the value obtained for each of the models, the degrees of freedom being the number of explanatory variables considered in the models.

[13]We have assumed that the parking fee for a shopping trip is half of the daily parking fee applied for work trips. We call the resulting variable, SPARKC. The ratio of cost variable, though different from that for work trips, is still denoted by RCOST.

[14]Notice that the maximum likelihood estimation procedure adopted here has been shown to be superior to its alternatives (e.g., the frequency methods) especially for small samples (see Press and Nerlove).

[15]See footnote 8 above.

[16]This would be appropriate even if there were some fixed levies as parking fees at schools, since the parking cost for a marginal trip would still be zero.

[17]The resulting cost variable, denoted SRCOST, is calculated as (.07 x distance)/.09, where .09 is the MUCTC student fare.

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APPENDIX

For study trips, the MUCTC student fares were effective for persons aged 17 and over. This implied a further reduction in the sample size from 1173 (as discussed in section 4 of the text) to 1168. In this appendix, we discuss how the mode chosen, age of the trip maker, sex of the trip maker and auto-ownership vary with the trip purpose.

A.1 Demographic and other characteristics of the sample

(a) Mode chosen and trip purpose

Table 1

Purpose / Mode (Row p.c.) (Col.p.c.) (Tot.p.c.)	Work	Study	Leisure	Shopping	Row Total
Auto	422 (73.2) (49.9) (36.1)	57 (9.8) (37.5) (4.9)	51 (8.8) (78.5) (4.4)	46 (7.9) (43.4) (3.9)	576 (49.3)
Metro	423 (71.5) (50.1) (36.2)	95 (16.0) (62.5) (8.1)	14 (2.4) (21.5) (1.2)	60 (10.1) (56.4) (5.1)	592 (50.7)
Column Total	845 (72.3)	152 (13.0)	65 (5.6)	106 (9.1)	1168 (100.0)

In the above table, the figures in brackets are the percentages.

(b) Age and trip purpose

Here the age is broken down into four classes:

1 : 16-29

2 : 30-44

3 : 45-64

4 : 65 and above

Table 2

Age (Row p.c.) (Col.p.c.) (Tot.p.c.) \ Purpose	Work	Study	Leisure	Shopping	Row Total
1 (16-29)	341 (64.1) (40.4) (29.2)	134 (25.2) (88.2) (11.5)	35 (6.6) (53.8) (3.0)	22 (4.1) (20.8) (1.9)	532 (45.5)
2 (30-44)	248 (78.7) (29.3) (21.2)	14 (4.4) (9.2) (1.2)	19 (6.0) (29.2) (1.63)	34 (10.8) (32.1) (2.9)	315 (27.0)
3 (45-64)	247 (82.6) (29.2) (21.1)	4 (1.3) (2.6) (0.3)	10 (3.3) (15.4) (0.9)	38 (12.7) (35.8) (3.3)	299 (25.6)
4 (65 and above)	9 (40.9) (1.1) (0.7)	0 (0) (0) (0)	1 (4.5) (1.5) (0.09)	12 (54.5) (11.3) (1.02)	22 (1.9)
Column Total	845 (72.3)	152 (13.0)	65 (5.6)	106 (9.1)	1168 (100.0)

(c) Sex and trip purpose

Table 3

Sex (Row p.c.) (Col.p.c.) (Tot.p.c.) \ Purpose	Work	Study	Leisure	Shopping	Row Total
Female	352 (67.2) (41.7) (30.1)	69 (13.2) (45.4) (5.9)	25 (4.8) (38.5) (2.1)	78 (14.9) (73.6) (6.7)	524 (44.9)
Male	493 (76.6) (58.3) (42.2)	83 (12.9) (54.6) (7.1)	40 (5.8) (61.5) (3.4)	28 (4.3) (26.4) (2.4)	644 (55.1)
Column Total	845 (72.3)	152 (13.0)	65 (5.6)	106 (9.1)	1168 (100.0)

(d) Auto-ownership and trip purpose

The number of cars variable is coded:

1 : if there is only one car per household

2 : if the number of cars is more than one.

Table 4

Number of Cars (Row p.c.) (Col.p.c.) (Tot.p.c.) \ Purpose	Work	Study	Leisure	Shopping	Row Total
1	655 (73.7) (77.5) (56.1)	100 (11.2) (65.8) (8.6)	55 (6.2) (84.6) (4.7)	79 (6.8) (74.5) (6.8)	889 (76.1)
2	190 (68.1) (22.5) (16.3)	52 (18.6) (34.2) (4.5)	10 (3.6) (15.4) (0.9)	27 (9.7) (25.5) (2.3)	279 (23.9)
Column Total	845 (72.3)	152 (13.0)	65 (5.6)	106 (9.1)	1168 (100.0)

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