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A Nested Logit Model of Travel Mode to Work and Auto Ownership[1]

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INTRODUCTION

Estimating the demand for urban passenger travel is useful in transport planning. An appropriately specified model may be used not only to predict the demand for various travel models but also to examine the effect of policy changes on the welfare of individuals. Such policies may include changing the public transport fare structure, changing the tax on petrol, adding more buses to the existing fleet, or making a certain travel mode accessible to more people. When the choice of mode to work and auto ownership is jointly modeled, the effect of, say, an increase in bus fares on the demand for various travel modes, as well as the effect on the demand for car ownership, can be predicted.

This paper estimates a probabilistic joint choice model of travel mode to work and auto ownership. The probabilistic models consider the probability that an individual makes a certain choice (e.g., the choice of mode to work) as a function of attributes of the choice and socioeconomic characteristics of the individual. Such models are behavioral, based on disaggregated data, and policy oriented in that they are sensitive to changes in policy variables.

An important advantage of the probabilistic models is that under certain assumptions, they can be derived from a theory of stochastic utility maximization. Further the decision set may include several modes and allows for joint decisions such as buying a car and going to work in a bus. If the joint nature of a decision is ignored it may bias coefficient estimates in addition to decreasing their efficiency. Decisions such as whether to make a trip or the time of day to make the trip can also be handled although they are usually difficult to model and data are often unavailable.

[1]This paper is a refinement of the author's Ph.D. thesis at Yale University. He is grateful to his advisors John Quigley and T. N. Srinivasan for guidance. Support for data collection was provided by the International Labour Office, Geneva. Office space and research assistance during the data collection period were kindly provided by the Applied Economics Research Centre, Karachi University. The author thanks Valerie Kozel who suggested many of the refinements in this paper and Eric Swanson with whom he has had many useful discussions. He is also grateful to a reference for pointing out an important error and making useful suggestions.

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While the probabilistic models are typically laid out within a framework which allows for elaborate joint decisions, few studies estimate the joint decisions. Studies of the latter sort include Adler's and Ben-Akiva's [1] study on shopping trips and Lerman's [6] study on choice of residential location, type of housing, automobile ownership, and mode to work. More recently Train [12] estimates a joint choice model of auto ownership and mode to work based on a sample of households in the San Francisco area. Using Train's approach, this paper estimates a joint choice model of auto ownership and mode to work based on household survey data from Karachi.

There are several reasons for choosing to model this set of joint decisions. The trip to work is a large percentage of total trips made by the household and the primary use of public transport is for work trips. It is made to a fixed destination at a relatively fixed time of day and demand for the trip is inelastic. This allows one to ignore the effect of a price change on the decision to go to an alternate location or not make the trip at all.

One would expect that the decision to buy a car or motorcycle is determined simultaneously with the decision to choose a particular mode to work. If so, and the simultaneity is ignored, coefficient estimates are biased. By correctly modeling the joint decision it is possible to see the effect, for example, of an increase in petrol price not only on demand for a mode to work, but also on demand for car ownership.

Fitting the model to household data from Karachi is interesting because Karachi has a rich variety of modes. Further, it is relevant because all fares in Karachi and the petrol prices are regulated by the government so that policy instruments are readily available. It is instructive to compare travel behavior in a city in a developed country (San Francisco) with Karachi. Are values of time and price and time elasticities different between these cities? This paper extends Train's paper in that it explicitly shows how one could use such a model to make welfare comparisons under different policies.

THE NESTED LOGIT MODEL

The nested logit model is a generalized version of the multinomial logit model.[2] An outline of the model as it applies to the problem at hand is given below.

The consumer is assumed to face a joint decision of choice of auto ownership indexed $c = 1, \ldots C$ and mode to work indexed $n = 1, \ldots N_c$.[3] The consumer derives utility U_{cn} which is a function of the attributes of the alternative cn. The attributes may be variables related to the consumer, such as family size and household income; auto ownership, such as maintenance

[2]See Domencich and McFadden [4] and McFadden [10].

[3]The set N_c will vary according to c since it is assumed that a person cannot decide not to own a car but to go to work in one.

and depreciation; the choice of mode to work such as commuting time; or interaction variables, such as cost of the mode divided by the individual's wage rate. The consumer then chooses the alternative that gives the highest utility. All consumers are assumed to have the same stochastic utility function.

Not all attributes of the utility function are observed. Unobserved variables have some probability distribution conditioned on the values of the observed variables. If the observer knows the form of the utility function and the probability distribution of the unobserved variables, he can make a probabilistic statement of the expected choice, namely

$$Pr_{cn} = \text{Prob}[U_{cn} \geq U_{bm} \text{ for } bm \neq cn] \tag{1}$$

where Pr_{cn} denotes the probability of choosing cn.

The joint probability above may be estimated by specifying a functional form for U_{cn} and by using the identity

$$Pr_{cn} = Pr_{n|c} \cdot Pr_c \tag{2}$$

where Pr_{cn} is the joint probability that the individual chooses mode n to work and the household choses the auto ownership category c, $Pr_{n|c}$ is the conditional probability of the worker choosing mode n given auto ownership c, and Pr_c is the marginal probability of the household choosing auto ownership category c.

The utility function U_{cn} can be decomposed into three components as shown below

$$U_{cn} = \beta' x_n + \alpha' y_c + \lambda_{cn} \tag{3}$$

where x_n is a vector of observed attributes which vary with mode attributes of the work trip[4] (e.g., in-transit time), y_c is a vector of observed attributes which vary only with auto ownership (e.g., depreciation cost), and β' and α' are vectors that may be estimated using maximum likelihood methods by specifying a structure for the stochastic error term λ_{cn}.

If the λ_{cn} are identically and independently distributed having a Weibull distribution, then Pr_{cn} is multinomial logit. However, McFadden [10] has shown that if the λ_{cn} have a particular generalized extreme value distribution, then the conditional and marginal probabilities described above are

[4]We have assumed that the nonstochastic component of the utility function is linear in parameters. In addition, whereas the general model allows for x_n to vary with both mode ownership and mode to work attributes, in this model x_{cn} equals x_n since the variables such as in-transit time by bus are independent of whether the household owns a car.

given by

$$Pr_{n|c} = \frac{e^{\beta' x_n/(1-\sigma)}}{e^{I_c}} \tag{4}$$

and

$$Pr_c = \frac{e^{\alpha' y_c + (1-\sigma) I_c}}{\sum_{b=1}^{C} e^{\alpha' y_b + (1-\sigma) I_b}} \tag{5}$$

where

$$I_c = \log \sum_{n=1}^{N_c} e^{\beta' x_n/(1-\sigma)}. \tag{6}$$

A more intuitive interpretation of inclusive value in this model is that it is the aggregate utility (summed over all available modes) from the trip to work in each of the auto ownership categories. It is the "utility" from each of the available public modes and walking, plus the "utility" from taking the car to work. Both (4) and (5) are in the logit form and hence easy to estimate. If the coefficient of I_c in (5) is estimated to be 1 (i.e., $\sigma = 0$) then the joint model is multinomial logit. However, in general, the joint model is not restricted to be multinomial logit. It is an advantage when one suspects that the assumption of the independence of error terms in the multinomial logit model is violated. In this case σ gives an estimate of the degree of dependence between the error terms. In addition, the two-step procedure results in computational savings since there are fewer alternatives and fewer parameters to be estimated at each stage. The gain comes at the expense of some loss in efficiency.

It is worth noting that the model is consistent with stochastic utility maximization only for $0 \leq \sigma \leq 1$ with one extreme $\sigma = 0$ giving us the multinomial logit case and the other extreme $\sigma = 1$ implying that the two decisions are in fact independent—that the mode to work decision is independent of the auto ownership decision.

The best way to proceed is to first estimate (4), obtain $\beta'/(1 - \sigma)$, and calculate I_c. Using these estimates of I_c, estimate (5) to obtain α' and $(1 - \sigma)$ and test for the coefficient of I_c being different from 1. If it is not different from 1 then we are in the multinomial logit world ($\sigma = 0$). If it is between 0 and 1 we have a nested logit model which is consistent with stochastic utility maximization. Other values of the coefficient lead us to reject the joint choice model.

It is apparent from (5) that if the model is estimated without the term I_c, the coefficient α' may be biased depending on the correlation of I_c with Y_c. In addition, standard errors on the estimated coefficients α' will be larger. Thus if one is interested in modeling the decision to buy a car, but neglects to take into account the additional utility that an individual may obtain from taking the car to work, coefficient estimates may be biased and have larger standard errors.

THE SURVEY

Four hundred households throughout Karachi were interviewed for the purpose of this study. Of these, 330 were households where at least one household member made a trip to work. A description of the sampling methodology is given below.

To ensure enough variation in mode choice, it was important to have sufficient observations within various income categories. Accordingly, the city was divided up into certain similar areas depending on the area's median household income, as reported in a study previously carried out by a UNDP mission to the Master Plan Office [7]. In addition to income, the groups were similar with respect to literacy levels, water and sewerage connections, and percentage of brick or concrete (*pucca*) houses. The Master Plan income figures were used only as a basis for sampling—the subsequent analysis uses income levels reported by the survey.

It was also considered important to have sufficient observations on households that live near the city center as well as those that live at a distance. Therefore these income areas were further split into three distance categories—zero to 3 miles, 3 to 5 miles, and 5 or more miles from the center of the city. Some areas were then discarded for various reasons such as for being red-light districts or for having moved significantly from their income groups since the UNDP study. Two areas were randomly selected from the list of areas in each cell. Since random sampling within these relatively large areas was not feasible, a sample of about 50 households within each of the areas was chosen by the author after inspection to ensure that the block of houses selected was not atypical for the area. Interviewers were then sent out to interview at least 13 households in each of the 30 areas selected.

The richness of the data comes from information not only on the trips made by each individual of the household on the day prior to the interview, but also on demographic characteristics of the household, income, hours worked, expenditure by various categories, assets, availability of public modes, present and purchase price for owned modes, and maintenance expenditures on these modes. The questions on trips made included origin and destination, purpose, mode used, in-transit and waiting time, distance

covered, number of persons in mode, cost (if public mode), and trip frequency.

MODAL SPLIT ANALYSIS

The N choices for the mode to work for a consumer include car, taxi, rickshaw (three-wheeled motorcycles which carry two passengers in addition to the driver), minibus (14-passenger wagons), walking, and bus. Not all modes are available to all consumers. A car is considered available either if the consumer rode to work in one or if the household owns a car. Other public modes are considered available either if the consumer used it to get to work or if he answered yes to the question "is the mode readily available in your area?" The frequencies of the available and chosen alternatives are given in Table 1.

The dependent variable for the modal split analysis is the probability of the consumer choosing a mode conditional on the availability of the mode. The multinomial logit model was estimated using maximum likelihood methods. A description of the independent variables along with their means is given in Table 2.

To calculate values for time and cost, a regression of reported time or cost by mode on reported distance was run using income and area dummies. The resulting coefficients were then used to predict values for time and cost both for the modes not chosen as well as for the chosen model. The hourly wage rate was calculated by taking the reported pretax monthly wage income and dividing by the hours worked per week times the 4.28 weeks per month. Income taxes are not an important component of total income for most individuals, and it is doubtful whether using post-tax wage rates if they were available would change the results significantly. A cross tabulation of household income category by household expenditure category shows that almost all households lay either along the diagonal or below it leading one to have some faith in the reported income figures. The estimation results are

TABLE 1
Modal Split Analysis of Frequencies of Alternatives

	Frequency	Percent of cases	Frequency chosen	Percent chosen
Car	104	33.23	90	86.54
Taxi	208	66.45	8	3.85
Rick	237	75.72	14	5.91
Mini	218	69.65	36	16.51
Walk	313	100.0	44	14.06
Bus	245	78.27	121	49.39

TABLE 2
Modal Split Analysis

Description of Variables

OVTT	Out of vehicle travel time in minutes—it includes waiting time and walk time.
IVTT	Time (in minutes) spent in-vehicle for all modes except walk.
IVTT(mode)	Alternative specific IVTT; equals IVTT for alternative (mode); else zero.
COSTWA	Monetary cost in rupees divided by wage in rupees/minute.
DHEAD	Equals one if alternative is car and person is head of household; else zero.
D(mode)	Alternative specific dummy; equals one for alternative (mode); else zero.

Means of Variables

	OVTT	IVTT	COSTWA	DHEAD
Car	0	18.30	27.36	0.644
Taxi	12.50	19.92	82.39	0
Rick	15.80	24.76	60.09	0
Mini	12.27	24.97	17.60	0
Walk	79.57	0	0	0
Bus	10.58	29.83	8.75	0

given in Table 3. Two models are presented. The first model considers IVTT to be a generic variable or implicitly assumes that a minute spent traveling in a car is as onerous as a minute spent in a bus. The second model with mode-specific IVTT allows the disutility of time to vary across modes.

Recall that the parameter estimates are coefficients of the linear utility function and so the coefficient of an attribute is simply the marginal utility of the attribute. The ratio of any pair of coefficients is the marginal rate of substitution between their respective attributes. Therefore the ratio of the coefficient of OVTT to that of IVTT of 2.8 implies that OVTT is about three times as onerous as IVTT. This result is similar to those reported in studies done in developed countries using multinomial logit techniques as well as other methods.

The cost-divided-by-wage (COSTWA) variable was used rather than cost to allow the value of time to vary directly with an individuals's wage. The variable is expressed in units of time and can be considered to represent the number of minutes a person has to work to earn the cost of his transportation. (The cost for a car includes gasoline and maintenance while the cost for public modes is the fare.) The marginal rate of substitution between IVTT and COSTWA is the value of time spent in the vehicle as a function of wage and is seen to be 3.8. While one could conceive of reasons why the value of time spent in a model might be greater than the wage rate, a value four times as great seems excessively high. However, most studies that

TABLE 3

A Modal Choice Model Conditional on Auto Availability

	Model with generic IVTT		Model with mode-Specific IVTT	
	Estimated coefficient	Asymptotic *t* statistic	Estimated coefficient	Asymptotic *t* statistic
OVTT	−0.1920	−6.323	−0.2017	−5.640
IVTT	−0.0698	−2.406	—	—
IVTTCAR	—	—	−0.0596	−0.7859
IVTTAXI	—	—	−0.0106	−0.2434
IVTTRICK	—	—	−0.0666	−1.651
IVTTMINI	—	—	−0.0957	−1.572
IVTTBUS	—	—	−0.0929	−2.147
COSTWA	−0.0184	−3.369	−0.0259	−3.346
DHEAD	2.455	3.325	2.541	3.657
DCAR	−2.285	−3.067	−2.639	−2.977
DTAXI	−2.673	−4.878	−3.623	−4.886
DRICK	−1.721	−3.801	−1.770	−2.969
DMINI	−2.146	−5.132	−1.756	−2.100
DBUS	−1.056	−2.287	−0.7492	−1.498
Likelihood ratio index	0.5832		0.5898	
Log likelihood at convergence	−182.4		−179.5	
Log likelihood at zero	−437.6		−437.6	
Degrees of freedom	1003		999	

Values of time as a percentage of wage	
IVTT (all modes)	379
Car	230
Taxi	41
Rickshaw	257
Mini	369
Bus	358
OVTT (includes walking)	1043 and 779

employ multinomial logit methods to estimate the value of time[5] find such unrealistically high ratios; in addition, these ratios differ widely from values obtained by earlier studies using other cruder techniques. Further work needs to be done to determine why modal split models estimated by multinomial logit techniques yield unrealistically high values of time.

The variable DHEAD was used as a way to decide who gets use of the car when there are competing demands on the car. The positive value of the

[5]See, for example, Train [12] Kozel [5], and Anas [2].

coefficient suggests that heads of household are more likely to get the car (or get greater utility from the use of the car). This result is also borne out by Train [12].

The models estimated in Table 3 assume that a minute spent walking is as onerous as a minute spent waiting for a mode. It is a plausible assumption that can be supported by other studies[6] and was necessary because walking time to the mode and waiting time for the mode could not be distinguished in the questionnaire.

The hypothesis of the value of time being different in the various modes was tested in the second model of Table 3. As the reader can verify by means of a likelihood ratio test, the hypothesis that the value of time is equal in all modes was *not* rejected at the 5% level of significance. The results have been presented here because it is interesting to note that the values of time are ranked according to our expectations. Contrary to Train's model where the value of time spent in a car is much higher than that in a bus, in this model there is no significant difference and, in fact, the estimated coefficients point toward car travel time being less onerous than bus travel time. This is understandable because, unlike transit in San Francisco, buses in Karachi are very uncomfortable and extremely crowded. Kozel [5] also finds cars to be less onerous than transit modes in Bogota.

Two other hypotheses of interest (not shown in Table 3) are that income is not a significant variable in the decision to choose a mode to work and that people who locate away from the center of town have the same value of time as those near the Central Business District. At the 5% level of significance, the hypothesis that the coefficients of income are equal to zero was *not* rejected. The hypothesis that individuals who live more than 5 miles from the center of town have the same value of IVTT as those who live within 5 miles from the center was *rejected* at the 5% level. This supports Train's result that suburban dwellers have lower values of time as compared to urban dwellers. Although the inclusion of this result would improve the fit of the model slightly, it was decided to stay with the simpler formulation for simplicity and ease of comparison with other models. The hypothesis that these two groups of residents have the same value of OVTT was *not* rejected at the 5% level of significance (it was rejected at the 10% level).

The elasticities of demand for various travel modes with respect to time and cost are valuable to the planner who contemplates a change in these variables. In this paper, it was decided to simulate changes in variables to obtain arc elasticities rather than evaluate the point elasticities at the means of the independent variables. This is because point elasticities are very sensitive to where they are evaluated; arc elasticities are more relevant in

[6]See Bruzelius [3] for a survey.

TABLE 4
Modal Split Analysis of Simulated Demand Elasticities for Select Variables

	Car	Taxi	Rick	Mini	Walk	Bus
OVTT(mini)	0.01	0.02	0.05	−0.06	0.06	0.45
OVTT(bus)	0.03	0.05	0.16	0.35	0.14	−0.74
IVTT(mini)	0.01	0.02	0.04	−0.43	0.02	0.35
IVTT(bus)	0.03	0.06	0.17	0.45	0.06	−0.77
IVTT(car)	−0.04	*	*	0.01	*	0.02
COSTWA(mini)	*	*	0.01	−0.10	0.01	0.08
COSTWA(bus)	*	*	0.01	0.04	0.01	−0.06

*Less than 0.01.

this study of the effect on welfare of discrete changes in the attributes. The elasticities are given in Table 4.

All elasticities are based on a 10% change in the independent variables in the first model of Table 3. For example, to obtain the elasticity of waiting time for a bus [OVTT (bus)], the waiting time for each trip in the bus alternative was decreased by 10%. The new predicted probability shares were then compared with those of the original model. The difference in the probabilities was divided by 10 to yield the relevant arc elasticity for the individual. Next, these elasticities were weighted to reflect the number of such individuals in the population and then averaged across all trips. Note that, while the results presented here consider only the effect of a change in the attributes of one mode on the demand for various modes, this method can readily be extended to reflect simultaneous changes in a combination of variables as will be seen in the last section of the paper.

Since the value of OVTT was revealed to be very high, it is not surprising to find elasticities with respect to OVTT to be relatively high. Cross elasticities tend to be low except between bus and minibus which are close substitutes. The implication of the high OVTT elasticities and low cost elasticities is that higher gains are more likely to come as a result of decreasing waiting time for public modes (adding more buses or minibuses) than by making public transport cheaper. A welfare exercise which considers raising bus fares while simultaneously decreasing waiting time for a bus is described in the last section of the paper.

AUTO OWNERSHIP ANALYSIS

The model of the decision to own a car is estimated using binary logit. The two alternatives are to own a car or not own a car. Twenty-seven percent of our stratified sample owned a car. A description of the independent variables along with their means is given in Table 5.

TABLE 5
Auto Ownership Analysis

Description of Variables

AGGUTIL	Aggregate household utility in the trip to work—see Eq. (10) for a precise definition.
COSTINC	Annual depreciation and maintenance cost of a car divided by annual household income.
INCOME	Annual household income in thousands of rupees in the *own car* alternative; else zero.
NMEMBER	Number of members in the household in the *own car* alternative; else zero.
DCAR	Dummy; equals one in the *own car* alternative; else zero.

Means of Variables

	AGGUTIL	COSTINC	INCOME	NMEMBER	DCAR
Own car	−0.1297	0.2058	42.34	6.392	1.000
Own no car	−2.749	0	0	0	0

In the joint choice model, the marginal probability of owning a car depends on, among other factors, the aggregate utility obtained by the household in its trip to work. This variable, which has been called "inclusive value"[7] and a "measure of work place accessibility,"[8] is what links the auto ownership decision with the choice of mode to work. In this model the aggregate utility measure is taken to be the inclusive value for the primary earner. The term is defined in (10). For the alternative *own no car*, it is constructed under the assumption that only the available public modes can be used for the trip to work. For the *own car* alternative, the accessibility measure assumes that in addition to the available public modes, a car is also available for primary earner's trip to work.

An alternative way of defining aggregate utility is to take the sum of individual inclusive values for all earners. A sufficient condition for this definition is that the car owned by the household can be taken to work by each of the earners and that the household utility function for the work trip is the sum of independent utility functions of each earner. This variable proved insignificant leading one to believe that it is unrealistic to expect either that every earner is able to take the car to work or that the household utility function is the sum of independent earner utility functions. The inclusion of the *primary* worker, however, proved significant suggesting that the primary worker is the person who has exclusive access to the car in the trip to work.

In the unconstrained estimation of Table 6, the coefficient of AGGUTIL lies between 0 and 1 which indicates that the decision to buy an auto and the choice of mode to work are indeed made simultaneously. Since the

[7]See McFadden [9].
[8]See Ben-Akiva and Lerman (1979).

TABLE 6
An Unrestricted Model of Auto Ownership

	Estimated coefficient	Asymptotic t statistic
AGGUTIL	0.3938	2.137
COSTINC	−17.02	−2.877
INCOME	0.0124	1.327
NMEMBER	−0.0159	−0.2274
DCAR	−0.5028	−0.3664
Likelihood ratio index		0.5083
Log likelihood at convergence		−75.66
Log likelihood at zero		−153.9
Degrees of freedom		222

coefficient is different from 1, it suggests that the joint choice model is not multinomial logit. The degree of dependence between the error terms of the first level of the model is 0.61. Since the coefficient of AGGUTIL is not zero and the variable is not expected to be exactly orthogonal to the other variables, estimation of the auto ownership decision without this variable should yield biased coefficients. When the auto ownership decision was estimated without the AGGUTIL variable, the model yielded different coefficients and a significantly worse fit. However, when the auto ownership model was reestimated with the coefficients of the other variables being constrained to those of the biased model, but AGGUTIL (and the dummy) being free to take on any value, a likelihood ratio test showed that the hypothesis that the coefficients of the biased model are not different from those of the unconstrained model could not be rejected at the 5% level. This implies that the loss in terms of bias would not have been large if the jointness of the decision were ignored.

The cost variable for the auto ownership decision (COSTINC) is assumed to be zero in the *own no car* alternative and equal to the average annual cost of owning a car in the *own car* category. It is divided by the annual household income to reflect the diminishing utility of income. Although the coefficient is negative and significant indicating that the variable is an important determinant in the decision to own a car, care must be taken in interpreting the coefficient. Since cost does not vary between individuals the coefficient actually reflects the reciprocal of income.

Income enters the model not only indirectly via its effect on COSTINC, but also directly as a proxy for certain unobserved variables such as social status. Its sign is found to be positive but not very significant. This is because its effect is predominantly captured by the COSTINC term described above.

A priori, the sign of the *number of members in the household* variable (NMEMBER) cannot be ascertained. One would expect it to be negative since, other things being equal, a larger household would have less money left over to own a car. On the other hand, a larger household would better utilize a car. In this model, the former effect barely outweighed the latter yielding a small and insignificant coefficient.

As in the last section, it was decided to simulate changes in variables to obtain the arc elasticity of car ownership with respect to income. The elasticity was found to be 1.4, which is not very different from those in other studies. In Kozel [5] the income elasticities lay between 1 and 1.3.

POLICY ANALYSIS AND CONCLUSIONS

Since the nested logit model has been derived from a theory of stochastic utility maximization where the model estimates coefficients of the nonstochastic components of a utility function, it would appear that a statement concerning the expected utility of a given situation can be made.

McFadden [10] has derived an expression for the expectation of the utility function used in generalized extreme value models of which our nested logit model is a special case. The expression for our model is

$$\ln\Big[\left(e^{V_{11}/(1-\sigma)} + e^{V_{12}/(1-\sigma)} + \cdots + e^{V_{16}/(1-\sigma)}\right)^{1-\sigma} + \left(e^{V_{22}/(1-\sigma)} + \cdots + e^{V_{26}/(1-\sigma)}\right)^{1-\sigma}\Big] \tag{6}$$

where V_{ij}, the nonstochastic component of the utility function obtained by choosing mode ownership category i and choosing mode j to work, is given by

$$V_{ij} = \beta' x_{ij} + \alpha' y_i. \tag{7}$$

(Note: V_{21} does not exist since a person is not allowed to choose not to buy a car but to take a car to work.)

The expected utility from a situation is the most meaningful measure of welfare. To compare the welfare from two situations one has simply to evaluate the above expression at each situation and see which is greater. If desired, such an exercise could be repeated for various feasible changes in independent variables to arrive at a maximum expected utility.

Here this method is used to evaluate a policy whereby the OVTT for a bus is decreased by 10% while the bus fare is simultaneously increased by 20%. In Karachi, where the majority of buses are privately owned, it is quite possible that the increased bus fare would induce enough additional investment in buses so as to result in a 10% decrease in OVTT for a bus. Therefore such a scheme may be a feasible way to improve the overall utility of consumers without using scarce government funds.

TABLE 7

Daily Gain to Consumers Caused by Decreasing Waiting Time for a Bus by 10% and Increasing Fare by 20%

	Income group					
	I	II	III	IV	V	Total
Sample gain	2.91	12.05	16.60	13.40	12.01	56.97
Trips in sample	29	60	84	75	65	313
Gain/trip (Rs)	0.1003	0.2008	0.1976	0.1787	0.1848	0.1820
Total trips (000/day)	604	1618	293	253	132	2900
Total gain (RS000/day)	60.6	324.9	57.9	45.2	24.4	513.0

To perform this exercise, the individual inclusive values were evaluated at the current level of the variables and then again with the new fare and OVTT figures for the bus. The difference in expected utility for each individual was converted to rupees by using an application of Roy's identity.[9] The resulting sample gains for each of the five income groups are given in Table 7. A figure for total trips to work in 1971 was obtained from the Master Plan survey.[10] Under the assumption that trips are proportional to population and based on income distribution and population growth to 1979, estimates for the total number of trips to work in 1979 were obtained for each income group. The rupee benefit per trip for each income group was multiplied by the total trips made per day by each income group, to obtain the total rupee benefit to consumers. All income groups tended to gain more from the reduced OVTT than they lost from the increased fare. This is not surprising when one consider the high marginal rate of substitution between OVTT and cost revealed by the model.

Before the planner decides on this policy he will need to know its effect on the demand for various travel modes to examine macro constraints that may have been ignored in the above exercise. To do this a method similar to that of calculating elasticities for the modal choice decision was used. The model was simulated with changes in independent variables induced by the policy and the predicted probability sums were compared with those in the earlier model. This particular change in bus attributes was found to change the demand for cars, taxis, rickshaws, minibuses, walking, and buses by −0.8, −6.7, −7.2, −5.3, −2.1, and 3.1%, respectively. Demand for all modes except the bus decreased.

In summary, the joint choice model estimated here reveals that the decision to own a car is made simultaneously with the decision of which mode to take to work. However, this study shows that had this simultaneity been ignored, the loss in terms of bias in the estimated coefficients would

[9]See Small and Rosen [11].

[10]Master Plan Office [8].

not have been large. The main cause of concern is that the estimated model, like many other multinomial logit models of modal choice, finds unrealistically high values of time. Further work needs to be done to determine the cause of this phenomenon. Otherwise, however the model has many advantages over the conventional transport demand models. It can be estimated using a small household sample; it is behavioral and responsive to most important instruments available to a planner; it allows one to make welfare comparisons between various policy regimes; and it allows one to calculate the effect of a policy change or change in the attributes of various modes on the demand for each mode and car ownership.

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