Travel and Activity Participation as Influenced by Car Availability and Use

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1. Research Objectives and Data

1.1 Research Objective

The objective of the research described in this paper is to determine how the use of specific modes of travel affects the relationships between out-of-home activity duration and the travel required for such activities. We proceed by constructing a model that interrelates classes of out-of-home activities and the travel required to participate in these activities, all as a function of population sociodemographic characteristics and the modes of travel used by the population.

1.2 The Survey

The 1994 UK Activity/Travel Survey was designed and carried out expressly for the project "Dependence on the Motor Car as a Mode of Transport", funded by the RAC Foundation for Motoring and the Environment. The aim of the survey was to provide a detailed picture of the patterns of car ownership and use among different social groups, and to explore how those patterns are related to residential, lifestyle, attitudinal and perceptual factors. The survey consisted of six interrelated components addressing different aspects of car ownership. These elements were:

For each household:

- A questionnaire collecting information on household demographics, resources, income expenditure patterns, locational behavior, accessibility to local facilities, accessibility to public transportation, etc.

For each household member over the age of five:

- A personal questionnaire collecting information on personal demographics, individual responsibilities within the household, general travel and driving experiences, perceived degree of dependence on different modes, etc.

- An attitudinal questionnaire collecting information regarding individuals' attitudes towards general transportation and environmental issues, both in the short and longer term.

- A seven day activity/travel diary in which respondents were asked to record details of all of their out-of-home activities and the associated means of travel.

For each vehicle available to the household:

- A "current" vehicle questionnaire collecting information on vehicle ownership, funding, make, model, engine capacity and annual operating costs.

- A "past" vehicle questionnaire, collecting similar information on any vehicles disposed of by the household during the previous year.

Sampling of survey households took account of both geographic and demographic factors. The sample was drawn from three geographic regions in England: urban/suburban locations in the Birmingham conurbation, ex-urban free-standing towns in Hertfordshire, and rural towns in Hereford, Worcester and Shropshire. Within each region, a combination of census data and information provided by local public transportation operators was used to select a number of specific survey locations which encompassed a range of different urban, suburban and rural land use and settlement patterns and significant variation in transit provision. Within each survey location, households were sampled using a quota-controlled procedure based on car ownership, household structure and residence tenure. The quotas were designed to deliberately over-sample car owning households (since the behavior of these households was the prime focus of the study), but to produce a sample that was otherwise representative of the population as a whole. Although car-owning households were over-sampled, it is important to point out that the sample was not restricted only to car-owning households, since that would have severely limited the scope for analysis of the relationship between car ownership and use and other aspects of lifestyle.

The main survey fieldwork was carried out during November and early December 1994. Households were contacted in-person at home, and those households that indicated that all members would be prepared to participate were recruited to the sample. During the initial contact visit, the interviewer administered the household-level and vehicle-level questionnaires and explained to a nominated contact person within the household how to complete the various self-completion person-level questionnaires, including the 7-day activity/travel diaries. (In order to reduce the burden on younger respondents, simplified versions of the person-level questionnaires were given to those aged under seventeen.) The placement of the 7-day diaries was organized to ensure that roughly equal numbers of respondents started their diaries on each day of the week. This was done to help reduce the risk of confounding of genuine "day of week" effects with artifactual effects due to the diary sequence day. During the diary period, interviewers kept in touch with respondents so as to be able to offer support and encouragement and to arrange a second visit to collect the completed questionnaires.

1.3 The Data

A total of 305 households were surveyed, containing a total of 561 adults and 111 children aged over 5 (plus a further 77 children aged five or less). The sampling approach succeeded in capturing very considerable variation in household demographic and locational characteristics, not only between regions but also between different locations within the same region. The presence of such variation is vital in explaining car ownership and use behavior.

With the exception of car ownership, the demographic characteristics of the sample are very close to the national averages, as reflected in the 1991 UK Census. As is to be expected given the over-sampling of car-owning households, license holding in the sample is somewhat higher than in the general population, especially among females, with a sample average of 0.74 licenses/female adult compared to the national average of 0.55. Despite the higher levels of car ownership and license holding, however, the overall pattern of mobility, as reflected in mode shares over the entire seven day diary period, is similar to that recorded in the most recent UK National Travel Survey (1991/93).

A more complete description of the survey data can be found in the project final report (Transport Studies Unit 1995).

The model which is the focus of this paper concentrates primarily on the amount of time traveling to/from and participating in various activities, as reported in the seven-day diaries. To make the analysis tractable, we must first classify all out-of-home activities into a small number of categories. Based on previous research, we choose three types:

1. subsistence activities, defined as work and school,
2. maintenance activities, defined as weekly / grocery shopping, pick up and drop off passengers, personal business and “other” activities, and
3. discretionary activities, defined as other types of shopping, eating out, and visit / social / sport.

There are consequently six endogenous variables in this analysis. The descriptive statistics for the endogenous variables are given in Table 1. The sample size was 289, representing all adult activity diary respondents with non-missing exogenous variables.

In addition, there are ten exogenous variables, and one segmentation variable. All of these exogenous variables are dummy variables, the frequencies for which are given in Table 2. The segmentation variable represents a four-way classification of mode dependency, as described in Table 3.

Table 1: The Endogenous Variables (N = 287)

Endogenous Variable	Acronym	mean	median	std. dev.
work/school activity duration (hours/week)	subs. dur.	22.40	20.25	20.00
work/school journey time (minutes/week)	subs. trav.	101.30	55	162.57
maintenance activity duration (hours/week)	maint. dur.	4.91	2.75	5.89
maintenance journey time (minutes/week)	maint. trav.	73.06	38	106.69
discretionary activity duration (hours/week)	discr. dur.	12.66	10.5	10.81
discretionary journey time (minutes/week)	discr. trav.	97.29	70	95.23

Table 2: The Endogenous Sociodemographic Dummy Variables (N = 287)

Variable	Frequencies	
	"0" state	"1" state
Gender (1 = male)	160	127
Low income	224	63
High income	185	102
Children present	144	143
Married person	101	186
Homemaker	248	39
Retired person	235	52
Employed part time	248	39
High profession	211	76
Renter	207	80

Table 3: The Segmentation Variables (N = 287)

Segment	Mode Dependency	n
1	Exclusively car	114
2	Car + walking or bicycling only	100
3	Car + public transport	31
4	Exclusively mode(s) other than car	42

The segmentation is based on responses to the multi-part question "How frequently do you use EACH of the following means of transport." The modes presented to the respondents were: (1) drive a car/van/motorbike, (2) passenger in a car/van, (3) walk all the way, (4) bus, (5) train/tube, (6) coach, (7) taxi, (8) bicycle, (9) plane, and (10) special bus service. The seven response categories for each mode varied from "about 5+ days per week" to "not this year or never."

Anyone indicating use of a mode at least two days per week were classified as being dependent upon that mode.

2. Methodology

2.1 The Structural Equation Model

The standard structural equations model (without latent variables) is given by

$$\mathbf{y} = \mathrm{B}\mathbf{y} + \Gamma\mathbf{x} + \zeta \qquad (1)$$

where **y** is an (m by 1) column vector of endogenous variables, and **x** is an (n by 1) column vector of exogenous variables. In the present application m = 6 and n = 10. The structural parameters are the elements of the matrices:

$\underset{(m\times m)}{\mathrm{B}}$ = matrix of causal links among the m = 6 endogenous variables,

and

$\underset{(m\times \mathbf{n})}{\Gamma}$ = matrix of direct causal (regression) effects from the n = 10 exogenous variables to the m endogenous variables.

The error-term parameters are the elements of the variance-covariance matrix:

$\underset{(m\times m)}{\Psi} = E(\zeta\zeta')$ = symmetric variance-covariance matrix of the unique, or unexplained, parts of the endogenous vars.

For identification of system (1), B must be chosen such that **(I -** B**)** is non-singular, where **I** denotes the identity matrix of dimension m.

The total effects of the endogenous variables on each other are given by

$$\mathrm{H} = (\mathbf{I} - \mathrm{B})^{-1} - \mathbf{I}\,. \qquad (2)$$

And the total effects of the exogenous variables on the endogenous variables in a structural equations model of this type are given by

$$\mathrm{T} = (\mathbf{I} - \mathrm{B})^{-1}\,\Gamma, \qquad (3)$$

which are the parameters of the reduced-form equations.

In multi-group structural equations modeling, used here, all matrices are partitioned along a third, grouping or segmentation, variable, which in the present case is of order three, representing the four mode dependency segments described in Table 3. The default form of the model postulates that all structural

parameters in the B and Γ matrices are equal across the three segments. The equality restrictions are released where warranted by significant improvements in model goodness-of-fit. Multi-group modeling is a particularly powerful technique for finding statistically significant interactions between individual segmentation groups and structural parameters. An overview of structural equation modeling is provided by Bollen (1989).

2.2 Specification

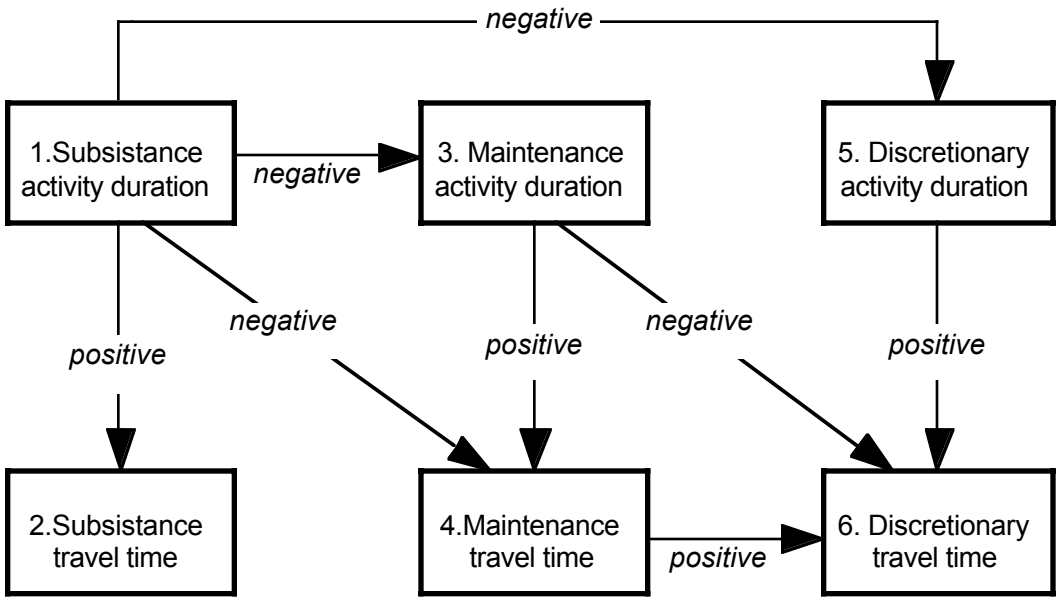
The postulated structure among the endogenous variables is shown in the flow diagram of Figure 1. Each arrow (direct effect) in this diagram represents a postulated free parameter in the B matrix.

The three direct effects from each activity duration to the travel for that activity (the effects from y_1 to y_2; from y_3 to y_4; and from y_5 to y_6) quantify travel as a derived good; they are interpreted as the number of minutes of travel required for each hour of the out-of-home activity.

The two direct effects from subsistence activity duration to maintenance activity duration and to discretionary activity duration (y_1 to y_3; and y_1 to y_5) capture the expected (negative) relationships that workers have less time available for other activities. The expected (negative) effect from subsistence activity duration to maintenance journey time (y_1 to y_4) presumes that workers will spend less time traveling for a given amount of maintenance activity, by linking work and maintenance activity trips and possibly by choosing closer destinations for convenience. Similarly, the (negative) direct effect from maintenance activity time to discretionary travel (y_3 to y_6) captures a linkage of these two classes of activities. Finally, the expected (positive) effect from maintenance travel to discretionary travel captures a potential spatial clustering of maintenance and discretionary activity sites: if a person travels further to access maintenance activity sites, he or she is likely to also travel further to access discretionary activity sites, and conversely. Subsistence (mainly, work) activity sites are more likely to be distributed in a spatially more independent manner.

This specification is similar to that proposed by Golob and McNally (1995), who investigated interactions between household members by simultaneously modeling the activity participation and travel of male and female heads of households. The present model extends the Golob and McNally model by introducing mode dependency as a segmentation dimension. Sample sizes are two small to model more than one person with the present data.

Figure 1: Flow diagram of Postulated Direct Effects Between the Endogenous Variables



2.3 Estimation Method

Structural equations systems of this type can be generally estimated using methods of moments (also known as variance analysis methods). The method proceeds by defining the sample variance-covariance matrix of the combined set of endogenous and exogenous variables, partitioned with the endogenous variables first:

$$\mathbf{S} = \begin{bmatrix} S_{yy} & S_{yx} \\ S'_{yx} & S_{xx} \end{bmatrix}, \tag{4}$$

where $\mathbf{S_{yy}}$ denotes the variance-covariance matrix of the endogenous variables, $\mathbf{S_{yx}}$ denotes the covariance matrix between the endogenous and exogenous variables, and $\mathbf{S_{xx}}$ denotes the variance-covariance matrix of the exogenous variables. In this model, there are 6 endogenous variables and 10 exogenous variables, so $\mathbf{S}$ is a (16 by 16) symmetric matrix.

It can be easily shown using matrix algebra that the corresponding variance-covariance matrix replicated by model system (1), denoted by

$$\Sigma = \begin{bmatrix} \Sigma_{yy} & \Sigma_{yx} \\ \Sigma'_{yx} & \Sigma_{xx} \end{bmatrix}, \tag{5}$$

is:

$$\Sigma_{yy} = (I - B)^{-1}(\Gamma S_{xx}\Gamma' + \Psi)\left((I - B)^{-1}\right)', \tag{6}$$

$$\Sigma_{yx} = (I - B)^{-1}\Gamma S_{xx}, \tag{7}$$

and $\Sigma_{xx} = S_{xx}$ is taken as given. The structural equation system is estimated using the variance-analysis normal-theory maximum likelihood method. The fitting function for structural equations maximum likelihood (ML) estimation is

$$F_{ML} = \text{Log}\left|\Sigma(\theta)\right| - \text{Log}|S| + \text{tr}\left[S\Sigma(\theta)\right] - (m + n), \tag{8}$$

where $\Sigma(\theta)$ represents Σ (equations 5-7) implied by the vector of model parameters, θ. This fitting function is (-2/n) times the log of the likelihood function that **S** is observed if $\Sigma(\theta)$ is the true multivariate normal variance-covariance matrix. Minimization of $\mathbf{F_{ML}}$ is equivalent to maximization of the likelihood function. Under the assumption of multivariate normality, $n\mathbf{F_{ML}}$ is chi-square distributed, providing a test of model rejection and criteria for testing hierarchical models. The maximum likelihood estimation method has been shown to be robust under common deviations from multivariate normal distributions (Boomsma, 1983).

In multi-group structural equation modeling, there is an observed and model-replicated variance-covariance matrix for each of the g = 1 to G groups, and the objective function becomes

$$F_{ML} = \sum_{g=1}^{G}\left(\frac{N_g}{N}\right) F_g\left(S_g, \Sigma_g(\theta_g)\right) \tag{9}$$

In the present model, G = 4 mode dependency segments.

3. Model Results

The four-segment model fits excellently. The model chi-square value is 280.11 with 266 degrees of freedom, representing a probability value of $p = 0.264$. Thus, the model *cannot* be rejected at the 95% confidence level (p being greater than .05). The postulated endogenous variable structure depicted in Figure 1 was generally upheld, with only a few significant differences across the mode dependency segments.

The R^2 values for the endogenous variables by segment are listed in Table 4. In general, the model explains well all endogenous variables with the exception of maintenance and discretionary activity durations. In addition, R^2 values are lower for all travel times, particularly maintenance and discretionary travel times, for persons solely dependent on the car. This indicates that personal and household characteristics here are less effective in explaining the wide variation in car travel patterns, compared to other modes.

Table 4: Percent Variances Accounted for (R^2) by Mode Dependency Segment

Endogenous Variable	Segment			
	car only	car + non-motorised	car+public transport	public transport
work/school activity duration (hours/week)	0.43	0.55	0.56	0.55
work/school journey time (minutes/week)	0.19	0.27	0.74	0.57
maintenance activity duration (hours/week)	0.02	0.19	0.16	0.03
maintenance journey time (minutes/week)	0.10	0.37	0.66	0.48
discretionary activity duration (hours/week)	0.20	0.08	0.15	0.07
discretionary journey time (minutes/week)	0.45	0.26	0.46	0.32

The estimated direct effects among the endogenous variables are listed in Table A.1 of Appendix A. The postulated causal structure between the endogenous variables depicted in Figure 1 was verified, but some differences were found in the structures for the different mode dependency segments. These are differences between the mode dependency segments that take into account the sociodemographic differences between the segments, because the effects of the exogenous variables are simultaneously estimated in the structural equation model.

Focusing on the derived demands for travel functions of out-of-home activities, the travel requirement for subsistence activities was identical for all four segments, being approximately 3.5 minutes of travel required for each hour of activity

duration. This translates into 28 minutes of travel for eight hours of activity. However, the travel required per unit time of maintenance activities was less for the car and the car plus non-motorised modes segments (segments 1 and 2), compared to the car plus public transport and the public transport segments (3 and 4).

The travel required per hour of out-of-home discretionary activities was also greater for those depending upon the car and public transport. But for discretionary activities, the travel burden is the same for those depending solely on public transport as it is for those depending on the car alone and the car plus non-motorised modes. The other differences between the segments involve the relations between subsistence activity duration and maintenance activity duration and travel time. All of these segmentation differences consummate in the total effects on required travel for maintenance and discretionary purposes. The total effects are calculated using Equation System 2.

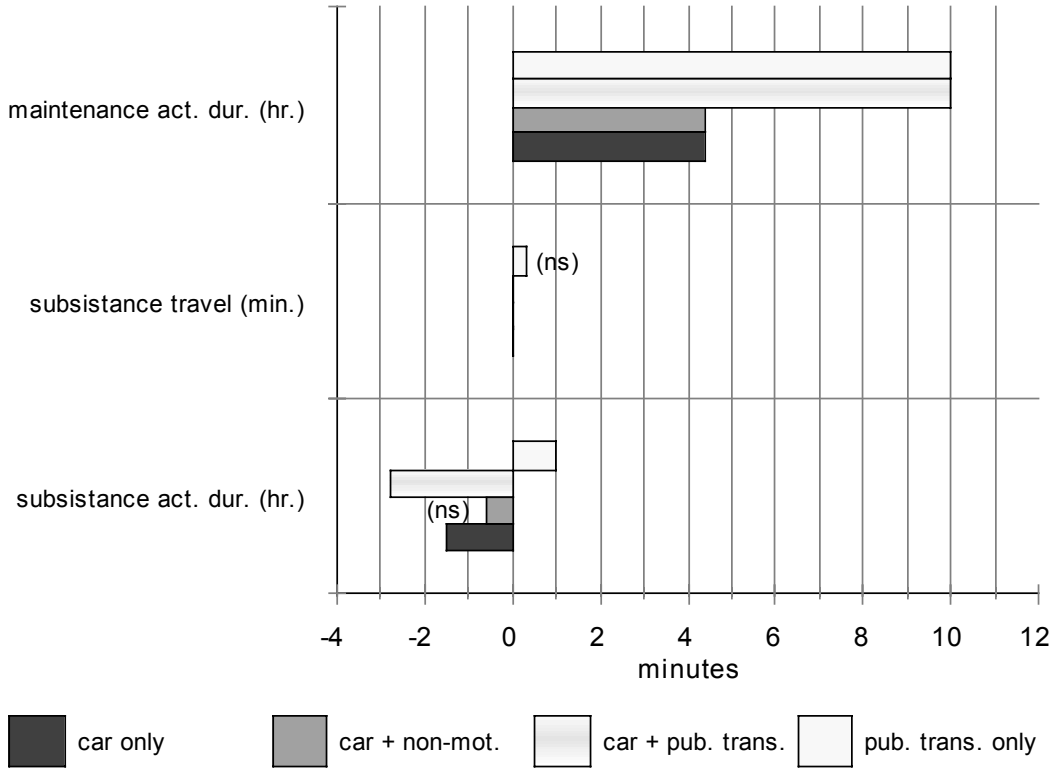
All non-zero total effects on travel time for maintenance activities are graphed in Figure 2. All but two of these total effects are statistically significant at the $p = .05$ level; the insignificant effects are marked as "(ns)" in Figure 2. These results quantify the strong relation between travel for maintenance purposes and the duration of out-of-home maintenance activities, representing travel as a derived demand for activities. Approximately ten minutes of travel is required per hour of maintenance activities for persons who rely on public transport modes, whether or not they also rely on the car; while only approximately half that amount of travel is required per hour of maintenance activities by those who rely on *the car* as their only motorised means of travel.

Subsistence activity duration also has significant negative effects on maintenance travel for the car only and the car plus public transport segments. For those solely dependent on the car, each hour of subsistence activities reduces maintenance travel by approximately 1.5 minutes, or by 12 minutes per eight-hour work day. This probably reflects both the substitution of activities within households and the ability to chain work trips and trips for subsistence purposes. However, conversely, each hour of subsistence activities increases maintenance travel times by about one minute for those solely dependent on public transport. This might be indicative of the difficulty of linking trips for work and subsistence purposes using public transport.

The total effects on travel time for discretionary activities are graphed in Figure 3. The effects that are *not* statistically significant at the $p = .05$ level are marked "(ns)" in this Figure. As for other types of travel, these results show that the principal cause of discretionary travel is the duration of out-of-home discretionary activities. Each hour of activity participation generates about four minutes of required travel for all persons except those who rely on the car plus public transport; for these people more than twice as much travel is required per hour of discretionary activity, *ceteris paribus*. (The standard errors of these estimates, in the range of

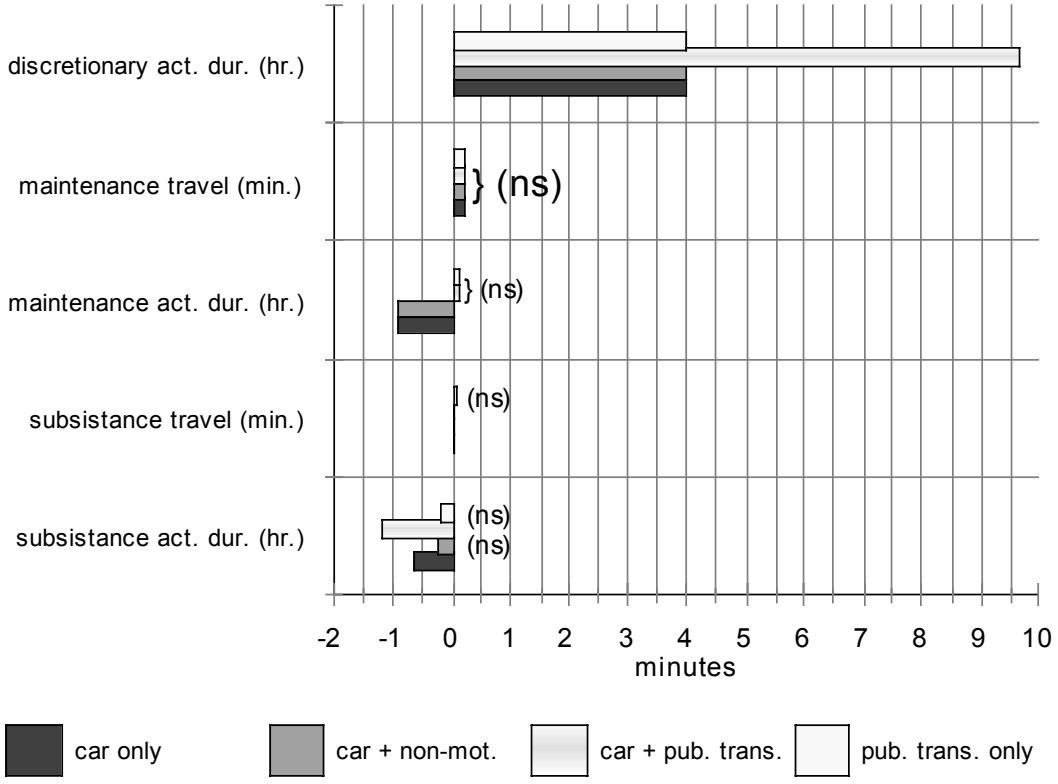
0.4, verify that this difference is statistically significant.) Perhaps persons relying on the combination of motorised modes are less able to chain trips, or they choose travel further distances, or they simply experience slower travel speeds.

Figure 2: Total Effects on Travel Time for Maintenance Activities



For those relying solely on the car, travel for discretionary purposes is also a function of the amount of time they spend on both subsistence and maintenance activities. This is mainly due to the strong negative direct effect from subsistence activity duration to discretionary activity duration (listed in Table A.1 of the Appendix). However, there are compensating effects for the public transport segment, so that the negative effect of subsistence on discretionary travel time is canceled out. It is possible that public transport dependents can more effectively link discretionary activities with work trips than can car dependents.

Figure 3: Total Effects on Travel Time for Discretionary Activities



The estimated total effects of the exogenous sociodemographic variables, given by matrix Equation 3, are listed for each segment in the Appendix, in Tables A.2 - A.5. The results listed there are largely as expected: Men participate more in subsistence activities and travel, while females participate more in maintenance activities and travel. Lower income households engage less in subsistence activities, but both lower and higher income households engage more in discretionary activities, compared to the (missing) base middle income group. Adults from households with children travel more for maintenance activities and engage less in discretionary activities and travel. Homemakers engage more in both maintenance and discretionary activities, and retired persons engage more in maintenance activities. Finally, persons who rent their homes travel less for discretionary purposes, probably because they are located closer to discretionary activity sites. These results are consistent with those of previous studies (*e.g.*, Pas, 1984; Townsend, 1987; van Wissen, 1989; and Stopher and Vadarevu, 1995).

3.1 Mode Dependency Differences in Sociodemographic Effects

We reformat these effects per exogenous variable by segment in Tables 10-18 in order to interpret the results in terms of mode dependency. The remainder of this memo focuses on the key differences exposed in Tables 10-18. In these Tables, the most important mode-dependency effects are highlighted using cell shading and outlining.

3.1.1 Gender

The mode-dependent differences in the effects of gender, shown in Table 5, are concentrated in participation in maintenance activities and travel for maintenance purposes. Women in who *depend on* both the car and non-motorised or public transport modes exhibit higher levels of maintenance activities and travel, *ceteris paribus*. This might be due use of the slower modes and associated lengthening of activity times for rest periods and to coincide with public transport schedules. However, these differences are imprecisely estimated, being statistically significant at only approximately the p = .10 level. Longer discretionary travel times are also exhibited for these same segments, but those differences are not statistically significant.

Table 5: Estimated Total Exogenous Effects of Gender by Mode Dependency Segment (*t*-statistics in italics)

Endogenous Variable	Effects of Gender (+ = female)			
	Car Only	Car + Non-mot.	Car + Public T.	Public T. Only
subsistence act. duration	-3.10 *-1.67*	-3.10 *-1.67*	-3.10 *-1.67*	-3.10 *-1.67*
subsistence travel	**-48.5** ***-2.88***	**-48.5** ***-2.88***	**-48.5** ***-2.88***	**-48.5** ***-2.88***
maintenance act. duration	0.00 *0.00*	0.40 *1.67*	0.40 *1.67*	0.00 *0.00*
maintenance travel	4.65 *1.51*	8.63 *1.61*	8.63 *1.61*	13.4 *2.77*
discretionary act. duration	0.28 *1.43*	0.28 *1.43*	0.28 *1.43*	0.28 *1.43*
discretionary travel	1.96 *1.53*	3.62 *1.49*	3.62 *1.49*	1.31 *1.19*

3.1.2 Household Income Effects

Travel times for maintenance activities are strongly related to mode dependency for persons from low-income households, as shown in Table 6. Travel time for maintenance purposes is longest when the person is solely dependent on the car, and it is shortest when the person is dependent on both the car and public transport, or when dependent on public transport alone. Either these persons choose to access further maintenance activity sites when using the car, or the separation of residence and activity sites in car-oriented environments forces them to travel further. Also, persons from low-income households spend more time in maintenance activities when they depend on non-motorised modes in addition to the car.

For high-income households (Table 7), mode dependency effects are concentrated on non-subsistence travel involving public transport. Maintenance travel time is longer for persons from high-income households who depend solely on public transport, *ceteris paribus*. In addition, travel times for discretionary trip purposes are higher for persons who depend on both the car and public transport. This effectively captures the travel time disadvantage of using public transport for non-commuting trips to destinations frequented by higher-income adults.

Table 6: Estimated Total Exogenous Effects of
Low Income Status by Mode Dependency Segment
(*t*-statistics in italics)

Endogenous Variable	Effects of Low Income Status			
	Car Only	Car + Non-mot.	Car + Public T.	Public T. Only
subsistence act. duration	**-9.83** ***-4.75***	**-9.83** ***-4.75***	**-9.83** ***-4.75***	**-9.83** ***-4.75***
subsistence travel	**-34.2** ***-4.15***	**-34.2** ***-4.15***	**-34.2** ***-4.15***	**-34.2** ***-4.15***
maintenance act. duration	0.00 *0.00*	**1.27** ***4.75***	0.00 *0.00*	0.00 *0.00*
maintenance travel	**14.8** ***2.84***	5.53 *1.24*	**-9.46** ***-1.99***	**-9.46** ***-1.99***
discretionary act. duration	**5.43** ***3.35***	**5.43** ***3.35***	**5.43** ***3.35***	**5.43** ***3.35***
discretionary travel	**24.0** ***3.49***	**20.2** ***2.96***	**19.6** ***2.90***	**19.6** ***2.90***

Table 7: Estimated Total Exogenous Effects of High Income Status by Mode Dependency Segment (*t*-statistics in italics)

Endogenous Variable	Effects of High Income Status			
	Car Only	Car + Non-mot.	Car + Public T.	Public T. Only
subsistence act. duration	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*
subsistence travel	**48.3** ***3.24***	**48.3** ***3.24***	**48.3** ***3.24***	**48.3** ***3.24***
maintenance act. duration	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*
maintenance travel	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	13.4 *3.24*
discretionary act. duration	**3.36** ***2.52***	**3.36** ***2.52***	**3.36** ***2.52***	**3.36** ***2.52***
discretionary travel	**13.2** ***2.43***	**13.2** ***2.43***	**32.4** ***2.50***	**15.6** ***2.84***

3.1.3 The Presence of Children

Adults exhibit longer travel times for maintenance activities when there are children in the household, and they participate less in discretionary activities and travel for discretionary purposes, as shown in Table 8. The only detectable differences between mode dependency segments is in terms of a reduction in travel time for discretionary purposes for persons depending on both the car and public transport. Public transport might effectively complement the car when satisfying family desires for discretionary activities.

3.1.4 Marital Status

Married persons who depend solely on the car display substantially less participation in out-of-home discretionary activities as well as substantially less travel in satisfaction of such activities (Table 9). Controlling for all other influences, married car-dependent adults spend more than six hours a week less in out-of-home discretionary activities than do married persons who do *not* depend solely on the car. Car-dependent married persons spend more of their free time at home, compared to married persons who depend on other modes.

Table 8: Estimated Total Exogenous Effects of
The Presence of Children in the Household by Mode Dependency Segment
(*t*-statistics in italics)

Endogenous Variable	Effects of Presence of Children			
	Car Only	Car + Non-mot.	Car + Public T.	Public T. Only
subsistence act. duration	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*
subsistence travel	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*
maintenance act. duration	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*
maintenance travel	**23.8** ***2.56***	**23.8** ***2.56***	**23.8** ***2.56***	**23.8** ***2.56***
discretionary act. duration	**-3.02** ***-2.43***	**-3.02** ***-2.43***	**-3.02** ***-2.43***	**-3.02** ***-2.43***
discretionary travel	**-23.4** ***-2.42***	**-23.4** ***-2.42***	**-40.6** ***-2.78***	**-23.4** ***-2.42***

Table 9: Estimated Total Exogenous Effects of
Marital Status by Mode Dependency Segment
(*t*-statistics in italics)

Endogenous Variable	Effects of Marital Status (+ = married)			
	Car Only	Car + Non-mot.	Car + Public T.	Public T. Only
subsistence act. duration	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*
subsistence travel	-26.6 *-1.82*	-26.6 *-1.82*	-26.6 *-1.82*	-26.6 *-1.82*
maintenance act. duration	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*
maintenance travel	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	-7.35 *-1.82*
discretionary act. duration	**-6.25** ***-3.24***	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*
discretionary travel	**-24.6** ***-3.08***	0.00 *0.00*	0.00 *0.00*	-1.33 *-0.17*

3.1.5 Occupation Effects

Homemakers (Table 10) travel more than non-homemakers for maintenance purposes, unless they are dependent solely on public transport. Moreover, maintenance activity participation and travel is highest for homemakers who depend on the car in conjunction with non-motorised modes or public transport. Possibly, non-car modes are used to access activity sites in city and village centers where travel and activity time is longer.

Table 10: Estimated Total Exogenous Effects of Homemaker Status by Mode Dependency Segment (*t*-statistics in italics)

Endogenous Variable	Effects of Homemaker Status			
	Car Only	Car + Non-mot.	Car + Public T.	Public T. Only
subsistence act. duration	**-24.0** ***-9.05***	**-24.0** ***-9.05***	**-24.0** ***-9.05***	**-24.0** ***-9.05***
subsistence travel	**-46.8** ***-2.08***	**-46.8** ***-2.08***	**-46.8** ***-2.08***	**-46.8** ***-2.08***
maintenance act. duration	0.00 *0.00*	**3.09** ***9.05***	**3.09** ***9.05***	0.00 *0.00*
maintenance travel	**36.0** ***3.29***	**76.4** ***7.21***	**66.7** ***5.21***	-12.9 *-1.09*
discretionary act. duration	**2.20** ***2.64***	**2.20** ***2.64***	**2.20** ***2.64***	**2.20** ***2.64***
discretionary travel	**15.2** ***3.52***	**17.2** ***3.51***	**28.0** ***3.12***	6.31 *1.60*

The effects of retirement status are listed in Table 11. Persons who are retired participate more in maintenance activities, and this is particularly true for those who depend on the car in conjunction with non-motorised or public transport modes. This influence of mode is similar to that found for homemakers (Table 10). In addition, retired persons solely dependent on public transport travel considerable more for discretionary activities. Similarly, persons who are employed part-time participate more in maintenance activities only if they depend on the car in conjunction with non-motorised or public transport modes, as shown in Table 12.

Table 11: Estimated Total Exogenous Effects of Retirement Status by Mode Dependency Segment (*t*-statistics in italics)

Endogenous Variable	Effects of Retirement Status			
	Car Only	Car + Non-mot.	Car + Public T.	Public T. Only
subsistence act. duration	**-21.6** ***-9.73***	**-21.6** ***-9.73***	**-21.6** ***-9.73***	**-21.6** ***-9.73***
subsistence travel	**-75.3** ***-6.42***	**-75.3** ***-6.42***	**-75.3** ***-6.42***	**-75.3** ***-6.42***
maintenance act. duration	**2.00** ***2.32***	**4.79** ***5.26***	**4.79** ***5.26***	**2.00** ***2.32***
maintenance travel	**41.2** ***3.89***	20.9 *1.93*	**80.3** ***5.49***	-0.85 *-0.07*
discretionary act. duration	-2.31 *-1.50*	-2.31 *-1.50*	-2.31 *-1.50*	-2.31 *-1.50*
discretionary travel	-5.03 *-0.75*	-13.5 *-1.86*	-15.9 *-1.02*	**87.4** ***13.5***

Table 12: Estimated Total Exogenous Effects of Part-time Employment by Mode Dependency Segment (*t*-statistics in italics)

Endogenous Variable	Effects of Part-time Employment Status			
	Car Only	Car + Non-mot.	Car + Public T.	Public T. Only
subsistence act. duration	**-6.07** ***-2.30***	**-6.07** ***-2.30***	**-6.07** ***-2.30***	**-6.07** ***-2.30***
subsistence travel	**-21.1** ***-2.22***	**-21.1** ***-2.22***	**-21.1** ***-2.22***	**-21.1** ***-2.22***
maintenance act. duration	0.00 *0.00*	**0.78** ***2.30***	**0.78** ***2.30***	0.00 *0.00*
maintenance travel	9.11 *1.93*	3.41 *1.12*	**16.9** ***2.16***	-5.84 *-1.59*
discretionary act. duration	0.56 *1.77*	0.56 *1.77*	0.56 *1.77*	0.56 *1.77*
discretionary travel	**3.85** ***1.97***	1.48 *1.15*	7.10 *1.89*	1.13 *1.03*

Finally, persons employed in higher-level professions are the antithesis of homemakers and persons who are retired or employed part-time, in that they participate less in maintenance activities if they depend on the car in conjunction with non-motorised or public transport modes. However, if persons in higher occupations are solely car-dependent, they spend less time traveling for maintenance purposes, and if they are solely dependent on public transport, they spend more time traveling for both maintenance and discretionary purposes, *ceteris paribus.*

Table 13: Estimated Total Exogenous Effects of High Professional Status by Mode Dependency Segment (*t*-statistics in italics)

Endogenous Variable	Effects of High Professional Status			
	Car Only	Car + Non-mot.	Car + Public T.	Public T. Only
subsistence act. duration	**10.3** ***5.08***	**10.3** ***5.08***	**10.3** ***5.08***	**10.34** ***5.08***
subsistence travel	**36.0** ***4.36***	**36.0** ***4.36***	**36.0** ***4.36***	**165.** ***20.0***
maintenance act. duration	0.00 *0.00*	**-1.33** ***-5.08***	**-1.33** ***-5.08***	0.00 *0.00*
maintenance travel	**-15.5** ***-2.90***	-5.81 *-1.24*	-5.81 *-1.24*	**45.7** ***9.24***
discretionary act. duration	**-0.95** ***-2.43***	**-0.95** ***-2.43***	**-0.95** ***-2.43***	**-0.95** ***-2.43***
discretionary travel	**-6.55** ***-3.06***	-2.51 *-1.29*	-2.51 *-1.29*	4.55 *1.90*

4. Conclusions

The model we developed here postulates that travel is derived from demand for out-of-home activities. We further postulate that there are causal linkages between the participation in, and travel for, three types of activities: subsistence (mainly work and work-related) activities, maintenance (shopping, personal business, serving passenger) activities, and discretionary activities. The model, which is applied simultaneously for four different segments defined on the basis of mode dependency, fits the data extremely well. The four segments are dependency: (1) solely on the car, (2) on the car and non-motorised modes, (3) on the car and public transport modes, and (4) solely on public transport modes. The results lead to several conclusions regarding how mode dependency affects relationships between activity and travel for different sociodemographic groups in the population.

Mode dependency is primarily related to participation in maintenance and discretionary activities and the travel required for such participation. Controlling for socioeconomic differences, persons in the four different mode dependency segments exhibited the *same* travel time requirement per hour of subsistence activity duration.

4.1 Mode Dependency Effects on Maintenance Activities and Travel

Those who rely on public transport for travel for maintenance activities experience approximately twice the travel time per hour of activity compared to those who rely on the car, *ceteris paribus*. That is, if we observe two persons with identical sociodemographic characteristics, the travel time of the one using public transport will be about twice that of the one using car for an identical duration of maintenance activities. Moreover, if both persons also work, the worker using the car will be able to reduce his travel time for maintenance purposes by linking trips, while the person using public transport will experience an increase in maintenance travel time because he or she is also working.

These overall results vary substantially by sociodemographic group. Maintenance travel times are significantly higher for persons from high-income households who depend solely on public transport, *ceteris paribus*. There are probably travel time disadvantages when using public transport for trips to shopping and personal business destinations frequented by higher-income adults. On the other side of the coin, maintenance activity travel times are longer for low-income persons who are solely dependent on the car, shorter for low-income persons who are dependent on both the car and public transport, or when dependent on public transport alone. Either these persons choose to access further maintenance activity sites when using the car, or the separation of residence and activity sites in car-oriented environments forces them to travel further. Also,

persons from low-income households spend more time in maintenance activities when they depend on non-motorised modes in addition to the car.

Homemakers who depend on the car in conjunction with non-motorised modes or public transport are more mobile in terms of maintenance activity participation and travel than when they are dependent solely on the car. The same is true for retired persons and to some extent for persons employed part time.

4.2 Mode Dependency Effects on Discretionary Activities and Travel

It is a different story for discretionary travel. For persons depending solely on the car, travel for discretionary purposes decreases in proportion to the amount of time they spend on both subsistence and maintenance activities. This is not true for persons depending solely on public transport segment; it appears that public transport users can more effectively link discretionary activities with work trips than can car dependents.

Dependence on both the car and public transport results in higher travel times for discretionary trip purposes for high-income persons, but shorter travel times for low-income persons *and* for adults in households with children. We surmise that this is due to the type of activity sites that are served by public transport as opposed to car.

Finally, married persons who depend solely on the car display substantially less participation in out-of-home discretionary activities as well as substantially less travel in satisfaction of such activities. Controlling for all other influences, married car-dependent adults spend more than six hours a week less in out-of-home discretionary activities than do married persons who do *not* depend solely on the car. Car-dependent married persons spend more of their free time at home, compared to married persons who depend on other modes. Car dependence means reduced discretionary mobility for certain sociodemographic groups.

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7. Appendix

Table A.1: Estimated Total Effects Between the Endogenous Variables for Each Segment numbered 1 through 4 (*t*-statistics in parentheses)

Influenced variable	*Influencing Variable*					
	work activity duration	work journey time	maint. activity duration	maint. journey time	discr. activity duration	discr. journey time
work activity duration						
work journey time	**all: 3.48 (8.54)**					
maint. activity duration	**1,4: 0.00 2,3: -.129 (-4.61)**					
maint. journey time	**1,3: -1.50 (-3.54) 2,4: 0.00**		**1,2: 4.36 (4.89) 3,4: 10.1 (7.36)**			
discr. activity duration	**all: -.092 (-2.76)**					
discr. journey time			**all: -1.71 (-2.30)**	**all: 0.181 (4.86)**	**1,2,4: 3.94 (9.70) 3: 9.64 (4.85)**	

Segment 1: car only Segment 2: car + non-motorised modes
Segment 3: car + public transport Segment 4: public transport only

Table A.2: Estimated Total Exogenous Effects
for Segment 1: Mode Dependency = Car Only
(*t*-statistics in italics)

Endogenous Variable	Exogenous Variable									
	gender female	low income	high income	with kids	married person	home-maker	retired person	part-time empl.	high prof.	renter
subsistence act. duration	-3.10 *-1.67*	**-9.83** ***-4.75***	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	**-24.0** ***-9.05***	**-21.6** ***-9.73***	**-6.07** ***-2.30***	**10.3** ***5.08***	0.00 *0.00*
subsistence travel	**-48.5** ***-2.88***	**-34.2** ***-4.15***	**48.3** ***3.24***	0.00 *0.00*	-26.6 *-1.82*	**-46.8** ***-2.08***	**-75.3** ***-6.42***	**-21.1** ***-2.22***	**36.0** ***4.36***	0.00 *0.00*
maintenance act. duration	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	**2.00** ***2.32***	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*
maintenance travel	4.65 *1.51*	**14.8** ***2.84***	0.00 *0.00*	**23.8** ***2.56***	0.00 *0.00*	36.0 *3.29*	**41.2** ***3.89***	9.11 *1.93*	**-15.5** ***-2.90***	0.00 *0.00*
discretionary act. duration	0.28 *1.43*	**5.43** ***3.35***	**3.36** ***2.52***	**-3.02** ***-2.43***	-6.25 *-3.24*	2.20 *2.64*	-2.31 *-1.50*	0.56 *1.77*	**-0.95** ***-2.43***	0.00 *0.00*
discretionary travel	1.96 *1.53*	**24.0** ***3.49***	**13.2** ***2.43***	**-23.4** ***-2.42***	**-24.6** ***-3.08***	**15.2** ***3.52***	-5.03 *-0.75*	**3.85** ***1.97***	**-6.55** ***-3.06***	**-27.3** ***-2.88***

Table A.3: Estimated Total Exogenous Effects
for Segment 2: Mode Dependency = Car Plus Non-motorised Modes
(*t*-statistics in italics)

Endogenous Variable	Exogenous Variable									
	gender female	low income	high income	with kids	married person	home-maker	retired person	part-time empl.	high prof.	renter
subsistence act. duration	-3.10 *-1.67*	**-9.83** ***-4.75***	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	**-24.0** ***-9.05***	**-21.6** ***-9.73***	**-6.07** ***-2.30***	**10.3** ***5.08***	0.00 *0.00*
subsistence travel	**-48.5** ***-2.88***	**-34.2** ***-4.15***	**48.3** ***3.24***	0.00 *0.00*	-26.6 *-1.82*	**-46.8** ***-2.08***	**-75.3** ***-6.42***	**-21.1** ***-2.22***	**36.0** ***4.36***	0.00 *0.00*
maintenance act. duration	0.40 *1.67*	**1.27** ***4.75***	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	**3.09** ***9.05***	**4.79** ***5.26***	**0.78** ***2.30***	**-1.33** ***-5.08***	0.00 *0.00*
maintenance travel	8.63 *1.61*	5.53 *1.24*	0.00 *0.00*	**23.8** ***2.56***	0.00 *0.00*	**76.4** ***7.21***	20.9 *1.93*	3.41 *1.12*	-5.81 *-1.24*	0.00 *0.00*
discretionary act. duration	0.28 *1.43*	**5.43** ***3.35***	**3.36** ***2.52***	**-3.02** ***-2.43***	0.00 *0.00*	**2.20** ***2.64***	-2.31 *-1.50*	0.56 *1.77*	**-0.95** ***-2.43***	0.00 *0.00*
discretionary travel	3.62 *1.49*	**20.2** ***2.96***	**13.2** ***2.43***	**-23.4** ***-2.42***	0.00 *0.00*	**17.2** ***3.51***	-13.5 *-1.86*	1.48 *1.15*	-2.51 *-1.29*	**-27.3** ***-2.88***

Table A.4: Estimated Total Exogenous Effects
for Segment 3: Mode Dependency = Car Plus Public Transport
(*t*-statistics in italics)

Endogenous Variable	Exogenous Variable									
	gender female	low income	high income	with kids	married person	home-maker	retired person	part-time empl.	high prof.	renter
subsistence act. duration	-3.10 *-1.67*	**-9.83** ***-4.75***	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	**-24.0** ***-9.05***	**-21.6** ***-9.73***	**-6.07** ***-2.30***	**10.3** ***5.08***	0.00 *0.00*
subsistence travel	**-48.5** ***-2.88***	**-34.2** ***-4.15***	**48.3** ***3.24***	0.00 *0.00*	-26.6 *-1.82*	**-46.8** ***-2.08***	**-75.3** ***-6.42***	**-21.1** ***-2.22***	**115.** ***14.07***	0.00 *0.00*
maintenance act. duration	0.40 *1.67*	**1.27** ***4.75***	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	**3.09** ***9.05***	**4.79** ***5.26***	**0.78** ***2.30***	**-1.33** ***-5.08***	0.00 *0.00*
maintenance travel	8.63 *1.61*	**27.4** ***3.81***	0.00 *0.00*	**23.8** ***2.56***	0.00 *0.00*	**66.7** ***5.21***	**80.3** ***5.49***	**16.9** ***2.16***	**-28.8** ***-3.97***	0.00 *0.00*
discretionary act. duration	0.28 *1.43*	**5.43** ***3.35***	**3.36** ***2.52***	**-3.02** ***-2.43***	0.00 *0.00*	**2.20** ***2.64***	-2.31 *-1.50*	0.56 *1.77*	**-0.95** ***-2.43***	0.00 *0.00*
discretionary travel	3.62 *1.49*	**55.1** ***3.46***	**32.4** ***2.50***	**-40.6** ***-2.78***	0.00 *0.00*	**28.0** ***3.12***	-15.9 *-1.02*	7.10 *1.89*	**-12.1** ***-2.78***	**-27.3** ***-2.88***

Table A.5: Estimated Total Exogenous Effects
for Segment 4: Mode Dependency = Public Transport (Non-car)
(*t*-statistics in italics)

Endogenous Variable	Exogenous Variable									
	gender female	low income	high income	with kids	married person	home-maker	retired person	part-time empl.	high prof.	renter
subsistence act. duration	-3.10 *-1.67*	**-9.83** ***-4.75***	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	**-24.0** ***-9.05***	**-21.6** ***-9.73***	**-6.07** ***-2.30***	**10.34** ***5.08***	0.00 *0.00*
subsistence travel	-48.5 *-2.88*	**-34.2** ***-4.15***	**48.3** ***3.24***	0.00 *0.00*	-26.6 *-1.82*	**-46.8** ***-2.08***	**-75.3** ***-6.42***	**-21.1** ***-2.22***	**165.** ***20.0***	0.00 *0.00*
maintenance act. duration	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*	**2.00** ***2.32***	0.00 *0.00*	0.00 *0.00*	0.00 *0.00*
maintenance travel	**13.4** ***2.77***	**-9.46** ***-1.99***	**13.4** ***3.24***	**23.8** ***2.56***	-7.35 *-1.82*	-12.9 *-1.09*	-0.85 *-0.07*	-5.84 *-1.59*	**45.7** ***9.24***	0.00 *0.00*
discretionary act. duration	0.28 *1.43*	**5.43** ***3.35***	**3.36** ***2.52***	**-3.02** ***-2.43***	0.00 *0.00*	**2.20** ***2.64***	-2.31 *-1.50*	0.56 *1.77*	**-0.95** ***-2.43***	0.00 *0.00*
discretionary travel	1.31 *1.19*	**19.6** ***2.90***	**15.6** ***2.84***	**-23.4** ***-2.42***	-1.33 *-0.17*	6.31 *1.60*	**87.4** ***13.5***	1.13 *1.03*	4.55 *1.90*	**-27.3** ***-2.88***