not possible for most Dutch citizens. Consequently, the gains to wealth originating from appreciation of land values are largely constricted in the Netherlands. Only the very wealthy can own a home on an individual lot. One must balance such restriction of freedom in private land ownership against the situation that might have evolved over the years had there been no such restrictions. Basically, what is involved is the trade-off of one kind of freedom for another kind of freedom. The loss of freedom of land ownership for the majority has probably meant a more stable economic and social system for the nation as a whole—hence higher national output and total personal income, a higher standard of living for the majority, and freedom from economic want.

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The Effects of Urban Structure on Automobile Ownership and Journey to Work Mode Choices

John F. Kain and Gary R. Fauth, Department of City and Regional Planning, Harvard University, Cambridge, Massachusetts

This study documents an investigation of the effects on automobile ownership and use of intermetropolitan differences in transit and highway service levels and overall urban development patterns. Specifically, we present models of the determinants of automobile ownership and mode choice for 163 488 white, single-worker households from the largest 125 standard metropolitan statistical areas in 1970. Indexes of highway capacity, transit service levels, and overall residential density for each area as well as each household's socioeconomic characteristics, workplace location, and residence choice, are used to explain the number of automobiles owned by each household, and, given that, each household's work trip mode (automobile driver; automobile, bus, or rail passenger; or walking). The models offer a framework for considering the effect of alternative urban development scenarios on automobile ownership and use, and for comparing alternative development and infrastructure policy options. Because the models were estimated using households from different areas, they are particularly appropriate for investigating changes in spatial structure.

Forecasts of automobile ownership and use are crucial inputs to the transportation planning process. Attempts to model these decisions based on disaggregate probabilistic techniques have recently received much interest. Typically, these studies focus on a particular metropolitan area, take each individual's workplace and residence zone as fixed, and characterize the ownership or use decision as dependent on various socioeconomic factors and the costs of alternative modes of travel.

This study has a similar approach in its disaggregate probabilistic framework and in its selection of variables that influence the ownership and use decisions. The analysis, however, addresses a range of questions that studies of a single metropolitan area are not designed to answer, such as how the overall arrangement of land uses (the density, location, and juxtaposition of workplaces and residences, in combination with the transit and highway systems serving them) affect the level of automobile ownership and mode choices of urban households.

Statistical studies of a single metropolitan area cannot capture or quantify the effects of the overall spatial structure and transportation systems on automobile ownership and travel behavior. However, these aggregate effects are required to evaluate the effects of major transportation investments or of extensive changes in land use patterns. A household whose sole or primary wage earner works in Manhattan must choose from a different set of housing and mobility choices than an otherwise identical household whose primary wage earner is employed in the suburban New York area, in the Phoenix central business district (CBD), or at a suburban workplace in Phoenix.

MODEL OVERVIEW

The analyses presented in this report consider the determinants of two interrelated decisions: (a) the number of automobiles each household owns and (b) the modes of travel employed members of the household use to commute to work. The statistical model employs a three-stage method of estimation that analyzes automobile ownership and modal choice decisions of urban households within a recursive model structure. The procedure first estimates the expected probabilities of owning zero, one, or more than one automobile based on the socioeconomic demographic characteristics of the sample households. Similarly, we obtain estimates of the expected probability that households in each automobile ownership class use each mode, again based solely on socioeconomic demographic characteristics.

The second stage of the analysis incorporates the estimated expected probabilities of owning zero, one, or more than one automobile (obtained from the first-stage national probability model) into a multivariate linear probability model of automobile ownership. The six equations of the automobile ownership model consider (a) whether the employed household member works in the CBD, (b) the location and other characteristics of the household's residence, (c) a series of variables that quantify the principal aspects of urban spatial structure of the 125 metropolitan areas included in the study, and (d) several measures of the extent and quality of the competing transportation modes available in each standard metropolitan statistical area (SMSA). Estimates of independent effects of each type of variable are obtained by using a multivariate linear probability model. The automobile ownership and modal choice equations presented in this report are estimated by ordinary least squares (OLS).

The third stage is similar to the second except that the dependent variables are the probabilities that the employed household member commutes to work as an automobile driver; an automobile, a bus, or a rail passenger; or by walking. The conceptual framework requires a separate modal choice equation for each of three levels of automobile ownership, for each of three workplace locations, and for each of five modes. Stratification of the mode choice equations by both workplace and automobile ownership reflects the recursive or conditional nature of the model. Each equation evaluates the independent effects of the several household characteristics, of residence location, of the overall measure of urban spatial structure, and of the measures of urban transportation supply on the household's modal choice, given its workplace and automobile ownership. Equations 1 through 4 provide a compact description of the three-stage model used in this study.

Stage 1

$$\hat{A}_i^n = H_i \tag{1}$$

$$\hat{M}_i^m = (H_i, A_i^n) \tag{2}$$

where

$\hat{A}_i^n$ = expected probability of owning n automobiles,
$\hat{M}_i^n$ = expected probability of using mode m,
H_i = a vector of household characteristics consisting of race of head, number of employed workers, family size, age of head, and household income, and
i = sample households.

Stage 2

$$A_{ij}^n = (\hat{A}_i^n, R_i, W_i, U_j, T_j) \tag{3}$$

where

A_{ij}^n = the probability of owning n automobiles,
R_i = vector of dummy variables depicting residence occupied by the ith household,
W_i = vector of dummy variables describing workplace location of the ith household,
U_j = vector of variables intended to describe the overall urban structure of each of the 125 sample metropolitan areas, and
T_j = vector of variables describing the characteristics of the competing transport modes in the 125 metropolitan areas.

Stage 3

$$M_{ij}^m = (\hat{M}_i^m, R_i, W_i, U_j, T_j) \tag{4}$$

where M_{ij}^n = the probability of using mode m.

NATIONAL PROBABILITY MODELS

The national probability model used to estimate the proportion of white, single-worker households owning no automobiles is displayed in Table 1. Identically structured models were used to estimate the proportion of one- and multi-automobile households. The family size and age of household head dimensions represent differences in automobile ownership preferences. Economic theory and a large number of previous studies also indicate that household income has a large independent effect on automobile ownership and modal choice.

Careful examination of the three national probability models reveals that all three variables have an important independent influence on the probability of owning a specific number of automobiles. For each family size and age of head category, the probability of owning at least one automobile increases with income. When income and family size are held constant, the proportion of households owning at least one automobile tends to be greatest for those households whose heads are younger than 35 years of age and lowest for those whose heads are older than 65 years of age.

In the first stage of the modal choice analysis we estimate the proportion of workers choosing a particular mode. The sample used to make the estimates is only 151 059 households rather than the 163 488 used in the

Table 1. National probability model: proportion of households owning no automobiles by family size, age of head, and income.

		Income ($000s/year)									
Family Size	Age of Head	0	0 to 2	2 to 4	4 to 6	6 to 8	8 to 10	10 to 12	12 to 15	15 to 25	25+
1	Under 35	0.35	0.39	0.33	0.27	0.21	0.18	0.11	0.14	0.15	0.12
	35 to 65	0.43	0.48	0.47	0.40	0.32	0.25	0.20	0.15	0.14	0.13
	65+	0.50	0.63	0.56	0.49	0.46	0.35	0.36	0.26	0.26	0.31
2	Under 35	0.27	0.25	0.18	0.17	0.11	0.08	0.06	0.04	0.02	0.03
	35 to 65	0.22	0.26	0.26	0.22	0.15	0.10	0.06	0.04	0.03	0.03
	65+	0.37	0.43	0.29	0.25	0.21	0.17	0.14	0.11	0.08	0.06
3	Under 35	0.25	0.24	0.18	0.12	0.07	0.04	0.03	0.02	0.02	0.05
	35 to 65	0.15	0.20	0.24	0.19	0.13	0.08	0.05	0.03	0.02	0.01
	65+	0.39	0.37	0.29	0.28	0.21	0.19	0.15	0.10	0.06	0.06
4	Under 35	0.20	0.15	0.18	0.12	0.06	0.02	0.02	0.01	0.01	0.02
	35 to 65	0.11	0.16	0.23	0.17	0.10	0.05	0.03	0.02	0.01	0.01
	65+	—	0.44	0.18	0.27	0.21	0.17	0.17	0.11	0.10	0.00
5+	Under 35	0.26	0.16	0.20	0.16	0.08	0.04	0.02	0.01	0.01	0.01
	35 to 65	0.20	0.19	0.24	0.18	0.10	0.05	0.03	0.01	0.01	0.00
	65+	—	0.45	0.41	0.21	0.22	0.15	0.05	0.00	0.03	0.08

calculations of automobile ownership probabilities. The discrepancy between the two samples is caused by households that have a member of the labor force who was unemployed, worked at home, or did not report the mode used to commute to work.

Fifteen national probability models were used to predict the proportion of zero-, one-, and more than one-automobile households driving an automobile to work; commuting to work as automobile, rail, or bus passengers; or walking to work. By far the most striking feature of the national probability models for modal choice is the importance of automobile ownership stratification. Households that have no automobiles are the principal users of the bus, rail, and walking modes. In contrast, one-automobile households, for the most part, use one of the automobile modes. The automobile driver mode is almost universally chosen by households that have at least two automobiles available.

There are subtle but important systematic variations within automobile ownership categories, which are correlated with income, age of head, and household size classifications. For example, the proportion of those walking to work from households that have no automobiles tends to decline as their incomes increase. Automobileless households tend to make more use of the two transit modes (bus and rail) as their incomes rise.

Labor force members from households whose heads are aged 65 or older are less likely to commute to work by automobile and are more likely to use some form of public transit. Between the two transit modes, they are more likely to use bus than otherwise similar households whose heads are younger. These findings may be the result of a tendency for households whose heads are older to be in older and more dense neighborhoods, which have especially good bus service. Family size also influences modal choice: When one automobile is available, larger households tend to make a smaller proportion of automobile driver trips and a larger proportion of automobile passenger trips.

The national probability model results are interesting in their own right. The determination of how household characteristics are related to automobile ownership and use for SMSAs as a whole is an important first step in understanding how intermetropolitan variations in land use and transportation supply affect automobile ownership and modal choice decisions. In addition, national probability models provide estimation efficiencies in two ways:

1. The prediction, when used as an independent variable, replaces 149 dummy variables that would be required to represent an equally complex interaction structure; such a problem would be expensive to solve through computation.
2. The remaining explanatory variables are discrete categorical variables: households are classified by workplace, residence type, and SMSA location.

In a single pass of the household microdata tape, we can sort households by class to produce actual and predicted values of the appropriate dependent variable. SMSA-specific variables can be tested by fitting regression lines using the cells of the classification scheme as observations, weighted by the number of households contained in each cell.

Regression runs on grouped data, using a much smaller number of independent variables, produce large efficiencies in fitting the multivariate linear probability models of automobile ownership and mode choice at the cost of a somewhat restrictive model specification. Specifically, we cannot incorporate interaction effects among individual household variables and the remaining variables included in the models. Obviously we consider the price worth paying.

Second Stage Model

The multivariate linear probability models of automobile ownership in this section were estimated using a sample of 124 050 households. The sample excludes approximately 25 percent of the households that were represented in the national probability models because data describing transit and highway systems were incomplete. Table 2 gives estimates of the probability of a household owning zero, one, or two or more automobiles as a function of (a) an expected probability computed from the national probability model; (b) the workplace location of the household's employed member; (c) certain characteristics of the household's residence; (d) the level of highway and transit service prevailing in the SMSA where the household resides;

Table 2. Regression results for automobile ownership categories.

	Automobile Probability if CBD Workplace (n = 12 820)			Automobile Probability if Other Area Workplace (n = 113 749)		
Item	0	1	2 or more	0	1	2 or more
Constant	$+0.26^{a}$	-0.13^{a}	$+0.13^{a}$	$+0.19^{a}$	-0.08^{a}	$+0.16^{a}$
Expected probability	$+1.16^{a}$	$+0.69^{a}$	$+0.77^{a}$	$+0.60^{a}$	$+0.89^{a}$	$+0.80^{a}$
Residence type						
Built 1960 to 1970						
1 to 4 units	-0.07^{a}	$+0.26^{a}$	-0.21^{a}	-0.01^{a}	$+0.17^{a}$	-0.15^{a}
5 to 19 units	-0.07^{a}	$+0.25^{a}$	-0.21^{a}	-0.02^{a}	$+0.20^{a}$	-0.18^{a}
20+ units	$+0.06^{a}$	$+0.13^{a}$	-0.24^{a}	$+0.02^{a}$	$+0.17^{a}$	-0.18^{a}
Built 1940 to 1960						
Single family	-0.02^{a}	$+0.10^{a}$	-0.09^{a}	-0.01^{a}	$+0.07^{a}$	-0.16^{a}
1 to 4 units	$+0.01^{c}$	$+0.21^{a}$	-0.26^{a}	$+0.03^{a}$	$+0.19^{a}$	-0.22^{a}
5 to 19 units	$+0.09^{a}$	$+0.09^{a}$	-0.24^{a}	$+0.06^{a}$	$+0.17^{a}$	-0.22^{a}
20+ units	$+0.16^{a}$	+0.01	-0.23^{a}	$+0.14^{a}$	$+0.10^{a}$	-0.22^{a}
Built before 1940						
Single family	-0.00	$+0.15^{a}$	-0.17^{a}	$+0.02^{a}$	$+0.13^{a}$	-0.13^{a}
1 to 4 units	$+0.07^{a}$	$+0.13^{a}$	-0.25^{a}	$+0.11^{a}$	$+0.14^{a}$	-0.24^{a}
5 to 19 units	$+0.25^{a}$	-0.11^{a}	-0.22^{a}	$+0.25^{a}$	-0.01^{a}	-0.22^{a}
20+ units	$+0.25^{a}$	-0.11^{a}	-0.21^{a}	$+0.34^{a}$	-0.10^{a}	-0.21^{a}
Mobile home	-0.10^{a}	$+0.22^{a}$	-0.16^{a}	-0.02^{a}	$+0.16^{a}$	-0.13^{a}
Single family (%)	-0.41^{a}	$+0.25^{a}$	$+0.15^{a}$	-0.28^{a}	$+0.09^{a}$	$+0.19^{a}$
Rapid rail available	$+0.04^{a}$	$+0.07^{a}$	-0.09^{a}	$+0.03^{a}$	$+0.01^{a}$	-0.04^{a}
Highway route miles/mile^2	-0.18^{a}	0.09	+0.18	-0.14^{a}	-0.05^{a}	$+0.20^{a}$
Bus vehicle miles/central city population	-0.02	$+0.05^{a}$	-0.03^{a}	-0.03^{a}	-0.03^{a}	$+0.00^{a}$
R^2	0.79	0.32	0.73	0.80	0.56	0.85

Notes: The above was done in U.S. customary units; therefore, no SI units are given.
Superscripts indicate statistical significance levels (a = 0.01, b = 0.05, c = 0.10).

and (e) the average density of the county or county group where the household resides.

As is evident from Table 2, our model specification requires six equations for workers employed in the CBD and three for workers employed outside of the CBD. The decision to estimate separate equations for CBD and non-CBD workplaces reflects our conviction that workplace and residence choices are important influences in household decisions to own a certain number of automobiles and to use a certain mode to commute to work. The CBD versus non-CBD distinction reflects large differences in the extent and quality of transit services serving the workplaces located in these areas. In subsequent analyses we plan to explore the roles of workplace location and differential transportation access to the workplace in more detail, as well as disaggregate other workplace locations into central city outside the CBD and the suburban ring of each SMSA.

All six automobile ownership probability models explain a large part of the variance in their dependent variables (Table 3); ranging from 32 percent for the equation that explains the probability of CBD workers owning one automobile to 85 percent for the equation that explains the proportion of non-CBD workers owning at least two automobiles. All but a small fraction of the individual regression coefficients are significant at the 1 percent level and have signs that are consistent with our a priori expectations. Stratification by workplace does not add substantially to the explanatory power, but individual coefficients are significantly different across workplaces. Moreover, given the recursive structure of the overall model and the importance of the stratification to the mode choice equations, the stratification for automobile ownership equations is useful and important.

Table 3. Analysis of variance of the overall multivariate linear models of automobile ownership.

	Probability					
	No Automobile		One Automobile		Two or More Automobiles	
Item	n	%	n	%	n	%
Total sum of squares	3973		3164		5418	
Variation explained by stratification by workplace	244	6	67	2	55	1
Variation explained by regressions	2972	75	1576	50	4492	83
Variation unexplained	757	19	1521	48	921	16

Overall Model of Modal Choice

The multivariate linear probability model of mode choice consists of 45 equations estimated by OLS. The specifications of the modal choice equations are similar to those used to estimate the multivariate linear probability models of automobile ownership, except: (a) The expected probability of owning zero, one, or two or more automobiles used in the automobile ownership equations is replaced by the expected probability of using the appropriate travel mode; (b) the number of automobiles owned by the household is added to the model and is used to stratify the sample. Separate mode choice equations are calculated for each level of automobile ownership; and (c) the sample is stratified by workplace [CBD, central city (CC), and suburbs] instead of the two used for the automobile ownership analysis. Table 4 displays results of the six equations used to predict automobile driver and automobile passenger commutes for households that have more than one automobile available.

Table 5 gives summary statistics for the multivariate linear probability models of mode choice. The first row in the table gives the sum of the squared deviations from the overall sample mean proportion using each mode for the entire sample of 124 050 households. For each mode, the total sum of squares is the yardstick against which to measure the performance of our multivariate linear probability model. The R^2, or coefficient of determination, is the proportion of total variance explained by the model and measures how well we have done.

The importance of the sample stratification by workplace and automobile ownership levels is clear from

Table 4. Multivariate linear probability models of mode choice for automobile driver and automobile passenger trips for households owning two or more automobiles.

	Probability of Automobile Driver Commute			Probability of Automobile Passenger Commute		
	Workplace			Workplace		
Item	CBD (n = 3376)	CC (n = 16 907)	Other n = 20 331)	CBD (n = 3376)	CC (n = 16 907)	Other (n = 20 331)
Constant	+0.19	+1.03^a	+0.90^a	+0.01	-0.03^a	+0.01^a
Expected probability	+0.90^a	-0.08^a	+0.02	+0.82^a	+0.80^a	+0.84^a
Residence type						
Single family						
Built 1940 to 1960	+0.01	-0.01^a	-0.01^a	-0.02^a	+0.00^a	+0.00^a
Built before 1940	+0.01	-0.04^a	-0.05^a	-0.02^a	+0.01^a	+0.01^a
1 to 4 units						
Built 1960 to 1970	+0.07^a	-0.02^a	+0.01	-0.00	+0.00	+0.00
Built 1940 to 1960	+0.02	-0.03^a	-0.03^a	-0.02	+0.02^a	+0.01^a
Built before 1940	-0.03^c	-0.06^a	-0.04^a	-0.01	+0.02^a	+0.01^a
5 to 19 units						
Built 1960 to 1970	-0.05^c	-0.00	+0.00	+0.01	-0.00	-0.00^c
Built 1940 to 1960	+0.02	-0.08^a	-0.02^a	-0.06^a	-0.01^c	+0.00
Built before 1940	-0.25^a	-0.11^a	-0.09^a	-0.06^a	-0.02^a	+0.00
20+ units						
Built 1960 to 1970	-0.00	-0.03^a	-0.05^a	+0.01	-0.00	+0.02^a
Built 1940 to 1960	-0.04	-0.08^a	-0.02^a	-0.03	-0.00	-0.00
Built before 1940	-0.09^b	-0.34^a	-0.10^a	-0.06^a	+0.08^a	-0.01
Mobile homes	+0.00	-0.04^a	-0.01^c	-0.02	+0.01^a	+0.01^b
Rapid rail available	-0.44^a	-0.10^a	+0.01^a	-0.01	+0.01^a	-0.01^a
Bus vehicle miles/central city population	-0.08^a	-0.01^c	-0.01^a	+0.01^b	+0.01^a	-0.01^a
Highway route miles/mile^2	-0.15^a	-0.02	+0.10^a	-0.00	+0.04^a	-0.06^a
Proportion single family	-0.12^a	-0.02^a	+0.00	+0.02	+0.03^a	-0.00
R^2	0.50	0.22	0.06	0.02	0.04	0.05

Notes: The above was done in U.S. customary units; therefore, no SI units are given.
Superscripts indicate statistical significance levels (a = 0.01, b = 0.05, c = 0.10).

Table 5. Analysis of variance of the overall multivariate linear probability models of mode choice.

Item	Automobile Driver		Passenger						Walking	
			Auto-mobile		Bus		Rail			
	n	%	n	%	n	%	n	%	n	%
Total sum of squares	10 916		1241		2853		3022		1365	
Variation explained by stratification	8 544	78	225	18	1510	53	799	26	453	33
Variation explained by regressions	898	8	132	11	327	11	1567	52	178	13
Variation unexplained	1 474	14	884	71	1016	36	656	22	734	54

the second row in Table 5, which is the amount of variance explained by the stratification. The fifth row provides this information as a percentage of the overall sum of squares. In the case of automobile drivers, for example, the workplace and automobile ownership stratifications explain 78 percent of the total variance in the probability of commuting to work as an automobile driver. The percentage of variance explained by stratification is largest for the automobile driver mode and smallest for the automobile passenger mode.

The overall explanatory power of the multivariate linear probability model of mode choice is, however, given by the combined total of the variances explained by stratification and by the 45 regression equations. As the sixth row in Table 5 indicates, the share of total variance explained by the nine regression equations for each mode varies from a low of 8 percent for automobile driver trips to a high of 52 percent for rail passenger trips.

The share of total sample variance explained by the nine mode choice regression equations as a whole should not be confused with the explained variance of coefficient of determination (R^2) for the 45 individual regression equations presented in Table 6. The explanatory power of individual equations varies widely from 2 percent for the probability of automobile passenger trips by CBD workers who have at least two automobiles available, to 78 percent for the probability that CC workers will commute by rail if they do not own an automobile.

The statistics summarized in Table 6 cannot be compared directly to those in Table 5 because different means are used to calculate the variances. The sums of squares presented in Table 5 are all computed using the overall sample means, but the coefficients of determination in Table 6 refer to the variances of each of the nine workplace-automobile ownership samples, which are computed using the means of each of the nine samples. The individual regression equations explain the total variance that remains after stratification. This statistic, which is given in the fourth row in Table 5, is only 14 percent of the original sample variances in the case of automobile drivers, but 71 percent of a much smaller total variance in the case of automobile passengers. One interesting observation is that the proportion of total variance explained by our entire multivariate linear probability model, including both the stratification and the nine regressions for each mode, increases with the aggregate size of the total sum of squares.

As Table 6 illustrates, the fit of the individual mode choice equations varies widely. The lowest R^2, 0.02, applies to the probability of multiple-automobile, CBD workers commuting to work as automobile passengers and the highest, 0.78, applies to the probability of CC workers who do not own automobiles commuting to work by rail. The final row in the table provides a summary measure of how well the equations for each mode as a group explain whatever variance remained after stratification. According to this summary statistic, the nine regressions for the rail passenger mode had the most overall success: In combination they explained 70 percent of the variance in the probability of using rail transit that remained after stratification by workplace location and automobile ownership. The nine automobile passenger equations were least successful using this criterion; they explained only 13 percent of the total sample variance that remained after stratification. The overall success of the rail passenger equations is not particularly surprising and is undoubtedly due to the explanatory power of the rail transit dummy, which distinguishes SMSAs that have extensive rapid transit systems.

Table 6. Percent of variance explained by individual multivariate linear probability models of mode choice.

Number of Automobiles and Workplace	Automobile Driver	Passenger			Walking
		Automobile	Bus	Rail	
0					
CBD	8	18	44	67	31
CC	24	31	20	78	20
Suburb	17	7	11	48	13
1					
CBD	57	9	20	77	15
CC	47	5	20	65	25
Suburb	10	4	14	28	15
2+					
CBD	50	2	13	67	8
CC	22	4	10	43	16
Suburb	6	5	3	22	9
Weighted average	38	13	24	70	20

PREDICTIONS

To demonstrate the potential use of the model as a tool for policy analysis, we made a few sample predictions of household automobile ownership and modal choice decisions for a typical household in Boston and in Phoenix. The two cities have widely different urban spatial structures and transportation systems: Boston is an older, denser, automobile-oriented city and has a well-developed public transportation system; Phoenix is a newer, more sprawling, automobile-oriented metropolitan area. Our predictions illustrate how a household's residence and workplace orientation within the two metropolitan areas affect decisions about automobile ownership and mode choice, as well as the way these decisions are influenced by differences in overall spatial structure and the general character of the transportation systems. At least one use of our model for policy analysis is to examine how alternative forms of urban development affect automobile ownership and transportation use. The model is capable, moreover, of assessing the independent effects of changes in the spatial distributions of residences and jobs within each metropolitan area, as well as changes in SMSA development patterns and transport infrastructure.

Table 7. Predicted probabilities of owning zero or more than two automobiles by workplace and type of residence.

Number of Automobiles	Residence Type	Workplace: CBD Boston	CBD Phoenix	Non-CBD Boston	Non-CBD Phoenix
0	Single family built 1960 to 1970	0.09	0.02	0.06	0.00
	20+ units built before 1940	0.34	0.27	0.40	0.34
2+	Single family built 1960 to 1970	0.50	0.64	0.64	0.71
	20+ units built before 1940	0.29	0.42	0.43	0.50

Table 7 gives the expected probabilities for a typical white, single-worker Boston or Phoenix household, whose worker is employed inside or outside the CBD. The age of the head of household is 35 to 64 years and the annual income is in the $10 000 to $12 000 range. In evaluating these data, note that single-family units built between 1960 and 1970 accounted for 29 percent of Phoenix's houses in 1970; structures of more than 20 units built before 1940 were only a negligible portion at that time. Similarly, single-family units built between 1960 and 1970 were 13 percent of the sample Boston households in 1970, and structures of more than 20 units built before 1940 constitute 3 percent of Boston's houses in 1970.

Table 7 reveals important differences in the probabilities that comparable Boston and Phoenix households would own zero or two or more automobiles. Estimates indicate that a Boston worker employed in the CBD and residing in a new single-family home would have a 0.50 probability of owning two or more automobiles; the same probability for a comparable Phoenix worker would be 0.64. A Boston worker employed outside the CBD and living in a new single-family home would have the same probability of owning two or more automobiles as an otherwise identical Phoenix resident employed in the CBD. This same Boston worker would, however, have a considerably lower probability of owning two or more automobiles than a comparable Phoenix worker who is employed outside the CBD.

Comparison between the estimates for residents of new single-family and old multifamily units, also shown in Table 7, illustrates how residential choices of urban households have a major influence on automobile ownership levels. Differences in structure type and its age have a large effect on automobile ownership levels in both SMSAs. For example, the probability of a typical Boston CBD worker owning two or more automobiles is 0.50 if she or he chooses a new single-family unit, but only 0.29 if the same worker lives in a structure with 20 or more units built before 1940. For Phoenix, the comparable probabilities are 0.64 and 0.42.

These calculations clearly demonstrate that for the household's workplace location, the type of housing chosen, the level of transit and highway service available to workplace and residence, and overall SMSA density all have large impacts on the levels of automobile ownership. We now consider how these factors affect the journey to work mode choice of the employed member of these households. Our estimates were obtained by first solving the appropriate modal share equations for the predicted probability that a representative Boston or Phoenix household working in one of three workplaces and living in one of two types of residences would use each mode if it owned zero, one, or two or more automobiles. These conditional probabilities of using each mode for each level of automobile ownership are then multiplied by the probability that the representative household would own zero, one, or two or more automobiles, obtained from Table 7. The resulting values are then summed to provide the mode choice probabilities displayed in Table 8.

The predicted probabilities of using alternative modes for the journey to work are remarkably consistent with our a priori expectations. The overall model predicts that 84 percent of Phoenix CBD workers who reside in new single-family units would commute to work as automobile drivers and that an additional 10 percent would be automobile passengers. Only 6 percent would use buses to reach work, and none would walk. The predicted probabilities based on Boston values of the explanatory variables are sharply different. Only 33 percent of Boston CBD workers who live in new single-family structures would commute to work as automobile drivers; another 6 percent would be automobile passengers. In contrast, 12 percent of such households would reach work as bus commuters and an additional 48 percent would arrive by rail.

The differences between the modal share estimated for Boston and Phoenix suburban workers are relatively modest. The model predicts that 85 percent of Boston's suburban workers that have the characteristics assumed for these comparisons would commute to work as automobile drivers, but 89 percent of the Phoenix suburban workers who possess the same characteristics would drive automobiles to work. Three percent of the sample Boston suburban workers would commute by rail and 2 percent would commute by bus. In Phoenix, 1 percent of comparable suburban workers would commute to work by mass transit.

Within each SMSA and workplace, differences in residence type also have the expected effects. For example, 76 percent of Boston's CC workers of the kind assumed for the analysis who live in new single-family units commute to work as automobile drivers. Only 34 percent of Boston CC workers who live in old multifamily structures, however, drive to work. The comparable

Table 8. Predicted probabilities of using alternative modes to work.

Residence Type	Travel Mode	Workplace: CBD Boston	CBD Phoenix	CC Boston	CC Phoenix	Other Boston	Other Phoenix
Single family built 1960 to 1970	Automobile driver	0.334	0.844	0.761	0.906	0.852	0.894
	Automobile passenger	0.059	0.096	0.050	0.024	0.045	0.055
	Bus passenger	0.121	0.060	0.054	0.039	0.019	0.014
	Rail passenger	0.483	—	0.104	—	0.034	—
	Walk	0.000	0.000	0.009	0.000	0.002	0.001
20+ units built before 1940	Automobile driver	0.128	0.531	0.343	0.464	0.533	0.600
	Automobile passenger	0.018	0.050	0.092	0.073	0.051	0.079
	Bus passenger	0.240	0.242	0.234	0.214	0.134	0.152
	Rail passenger	0.530	—	0.162	—	0.114	—
	Walk	0.037	0.082	0.158	0.094	0.061	0.038

numbers for Phoenix workers are 91 percent of those CC workers residing in new single-family units and 46 percent of those in structures of more than 20 units built before 1940.

FUTURE MODEL DEVELOPMENT

A recursive model structure subsumes a number of important conceptual and theoretical questions. The household's choices of workplace location, residence location, automobile ownership, and mode to work might be made simultaneously; therefore, both the structure of the model and the estimation methods used should reflect this. We plan to develop models that analyze the interrelationships between residential choices and automobile ownership as well as models, like those considered here, that relate automobile ownership and modal choice.

Although our models capture the gross effects of transportation supply and urban form variables, their lack of precision is equally evident. They show the considerable importance of transit and highway service levels and variations in urban spatial structure in determining automobile ownership levels and the modal choices of urban households, but they also raise questions about the interrelationships between land use and transportation. We expect to consider these issues in the next phase of our research.

We also plan to extend the models described in this report, or improved versions of them, to households having no members in the labor force, multiple-worker households, and black households. The decision to estimate separate models for these households is based on the hypothesis that the land use and transportation variables have a different effect on the automobile ownership and mode choice decisions of households having different numbers of labor force members. We chose single-worker households for the first stage of the analysis (rather than households without a member in the labor force) because we wished to study both automobile ownership and the mode used to commute to work. We also anticipated that workplace location would have an important influence on both automobile ownership and modal choice, and decided to deal first with the choices of single-worker households before modeling the far more complex choices of multiple worker households. Finally, black single-worker households were excluded because previous research has shown that housing market discrimination and segregation have large impacts on the workplace location, residence location, and travel behavior of black households. These are issues of great research and policy significance; we therefore deferred the analysis of these questions to a time when we can accord them the careful attention they deserve.

Discussion

Anthony James Catanese, School of Architecture and Urban Planning, University of Wisconsin, Milwaukee

This analysis of national data from 1970 is a welcome addition to our base of empirical knowledge on urban structure and land use as related to the journey to work and modal choice. It develops precise national models of modal choice and automobile ownership.

The findings are not surprising. They show that the wealthier, suburban residents tend to live in newer, single-family homes and to have much higher levels of automobile ownership and automobile commuting than several other groups. This was expected from previous research and a priori. That the trend is strong is clear from the sample data, which used white, single worker, four-person households whose heads were aged 35 to 64 and had incomes of $10 000 to $14 000. In short, the policy analysis example discussed in the conclusions was a rather typical suburban group, and the results were predictable.

If good research is meant to raise more questions than it answers, this research is very good. It demonstrates that such models, at a large level of aggregation, can predict automobile ownership and modal choice as related to residence and workplace. The policy questions implied, however, are far more interesting. The paper states that the next level of research will delve into the roles of workplace location and transit accessibility and level of service as contributing factors. I suspect these will be a strong set of factors for urban structure and land use patterns. Similarly, the research may go into other groups not presently included, such as multiworker households, single-person households, and minority households, where we expect some variation to occur.

The policy questions raised and implied are most interesting. If these are the trends, and they do have application in a given urban region, what costs and benefits are implied? What are the economic consequences of this pattern of automobile ownership and modal choice? What variations can be determined from these findings in cities that have undertaken massive transit programs to change such patterns? And finally, what are the long-term prediction strengths of the model that may be useful to planners attempting to project trends in land use?

The obvious question to ask is, What effect, if any, have the post-1970 gasoline embargo and higher prices had on these patterns? A recent Southeastern Wisconsin Regional Planning Commission study used a questionnaire to measure this and found essentially no effects, yet other researchers have found significant effects and behavioral changes.

This research points out trends and conditions. We should remember, however, that such findings may reflect major problems that need change. Such an empirical basis should bolster our imagination and intuition as we seek new solutions to transportation problems and innovative planning for urban structure.

Anthony R. Tomazinis, Transportation Studies Center, University of Pennsylvania, Philadelphia

The paper presents essentially two models—one on automobile ownership and another on modal choice for home to work trips. The population considered is restricted to only white families that have only one worker per household from the 125 larger standard metropolitan statistical areas (SMSA) of the country in 1970. The automobile ownership model is developed in two steps. In the first step the authors divide the households in their study into 150 groups by separating them into 10 income groups and 5 family size groups. Each of the 50 groups is further divided into 3 groups according to the age of the head of the household. For each of the 150 groups, the researchers establish the proportion of households owning no automobile, one automobile, or two or more automobiles.

The sample population includes 164 000 households. The proportions of households owning zero, one, or two or more automobiles are first called by the authors the national probability model. Later the proportions are assigned to each household in each group as the expected probability of owning zero, one, or two or more automobiles. In the second step the model assumes the expected probability of each group on the national scale and tries to improve this estimate by correlating the actual automobile ownership of each group in each SMSA with variables that express the housing characteristics of each household, and other variables that express the availability of mass transit and highways in each city. In order to improve the accuracy of the model, the correlations are made separately for household by workplace. The second step of the model has six regressions (three by automobile ownership level and two according to the workplace of the head of household) and 17 independent variables.

The modal choice model has a similar structure. In the first step the households are stratified into 450 cells. The initial 150 types were further divided into three groups according to automobile ownership level. For each of the 450 groups the proportion of automobile driver; automobile, bus, and train passenger; and walker commuting trips is estimated (2250 proportions) on a national scale for the household included in the study. The second step improves the national scale modal split rates by introducing characteristics of each city and subdividing the total into three groups according to the workplace of the worker. The step involves the estimation of 45 regression equations, of 17 independent variables each, for the five modes of travel, the three levels of automobile ownership, and the three types of workplaces. The 17 variables are, again, descriptive of types of housing occupied by the household and of the availability of mass transit, rapid transit, and highways.

Major Characteristics

Three major characteristics of the models deserve attention:

1. The striking amount of stratification of households required and the number of proportions that need to be specified at the first step;
2. The cross-sectional approach, based in this case on the 1970 census; and
3. The need in the second step to incorporate many variables that describe accurately and meaningfully the housing aspects of the households and the highway and transit availability in a SMSA.

Even though the authors focus on a small minority of the households in the urban areas, the model still specifies their stratification into 150 cells. In a universal approach, thousands of cells would have to be specified just to complete the first step. The models add the need to measure 450 proportions of ownership rates and 2250 proportions of commuting trips of the selected 150 household groups.

Cross sectional correlation models can work only with what is present and measurable at the time of data collection. They capture or match existing relations and may lead or mislead the researcher, depending on what they include or exclude. Recalling the numerous automobile ownership and modal split models that have reproduced reality at a given moment might be helpful for all of us. For this reason, I believe caution and reserve are required in reviewing the results.

Attention also needs to be paid to both the number and the format of the variables, whether dummy or real values. The culmination of data inputs takes place at this stage and the limitations of correlation analysis and of multiple sets of data must be kept in mind.

Strengths and Weaknesses

The automobile ownership model has several strong and weak points. Among its stronger points is the emphasis it places on the three sociodemographic variables (income, size of household, age of head of household), stressing the intrinsic significance that these household characteristics have on automobile ownership decisions. A second important point in its favor is the emphasis the model places on improving the estimates of nationwide proportions through the use of variables characterizing the types of housing situations and the relative availability of transit and highway facilities. The watershed is reached at this point because its further stratification according to the workplace is partly a strong point in terms of additional accuracy but a weak point in terms of additional stratification and restriction required.

Among the weak points that the model demonstrates, of particular signficance is the degree of household stratification that it prescribes. Every cell created in the first step of the model would need to be associated with urban pattern variables later on in step two of the model and then projected in case the model is to be used for projection purposes in a SMSA. Both steps are extremely risky; no guarantee exists of a relationship between the automobile ownership rates of all types of households and urban pattern variables. And projection 10, 20, or 30 years hence for that many household types in each small district of urban regions is just impossible. Also, there is the problem of the cross sectional data that the model utilizes. Such models can easily misread incidental, temporary occurences, as time-honored relationships. For instance, for most types of households in Philadelphia, the physical relationships stayed almost the same; even the sociodemographic characteristics stayed almost the same between 1960 and 1970. Yet the automobile ownership rate increased by almost 25 percent over these 10 years. The same has probably happened in Boston and in many other SMSAs. Clearly the trend of higher automobile ownership levels far exceeds changes in density, and in the provision of highways and transit. This point is also related to the observation that not all of the investigated relationships produced high correlations. In fact, in both steps of the model the one-automobile relationship produced the least satisfactory results. One-automobile households were found in larger numbers in all groups of households than any sociodemographic stratification or urban pattern variable would indicate. Such one-automobile households appear to be influenced more by a continuous trend towards a universal availability of one automobile for all urban households than by any ad hoc household characteristic. Perhaps one automobile per household should be considered the standard expected provision, from which deviations upwards and downwards should be identified, traced, and explained through the use of sociodemographic variables or urban pattern variables or other stratifications.

Another point of concern in the automobile ownership model is the finding that the real policy variables of the model have only marginal statistical importance. The most important variable is the expected probability variable of step one. The variables expressing bus and rapid transit availability are marginably important. Even the highway availability variable is minimized within the complex of 17 variables used by the model. Interestingly enough, the most important variable in many cases is the age of the household. Unfortunately, the age of the housing units is not a policy variable. In fact, it is only a substitute variable denoting, most probably, the manner in which apartment buildings and other housing units were designed before 1940. A final point in this connection is that the model, as it is presented in the paper, does not always present results consistent with a priori presumptions. For instance, the households in apartment buildings built before 1940 whose workers are employed in central business districts (CBDs) have a lower probability for not owning an automobile than does a similar household in the rest of the region—the opposite of what would normally be expected for Phoenix and Boston in 1970.

Turning to the modal split model for home to work trips, the main strong points of this model are two. First is the separation into two steps and the emphasis placed on the three sociodemographic variables (income, age, size of household) plus the automobile ownership variable. In emphasizing the intrinsic significance of these variables for modal split, the model again offers, as in the case of automobile ownership, a distinct contribution. The second strong point of the modal choice model is the additional stratification of the workplace. The circumstances in both the origin and the destination of the trip play the major role in the choice of travel mode. The level of stratification the model includes and the manner in which it incorporates urban pattern variables need improvement if the model is to add to the present array of modal split models. In addition, the model would need to reach much higher levels of simulation accuracy to compete effectively with other models in the field. Finally, the policy variables (except, possibly, the rail dummy variable) appear to carry only marginal importance in the correlations produced. Again the expected probability of step one is the dominant variable, followed in certain occasions by the old multiple apartment buildings variable.

COMMENTS AND REFLECTIONS

This paper has particular significance for both transportation and land use planners. It presents an innovative, intensive effort to develop new, predictive, and explanatory models for automobile ownership and modal choice. At the same time it explores in more depth the link between the transportation planner and the city planner. Although the title and some of the claims of the paper might be considered as somewhat unwarranted overstatements, the link between characteristics of the urban structure and the consumer patterns of urban residents is placed under central focus in the automobile ownership model. A similar link between urban structure and travel behavior centered on the most important component of urban travel, the home-to-work trip, is also attempted. What strikes me also as very important in these models is the two-step structure of the models and that the influence of the intrinsic characteristics of the household on automobile ownership and modal choice is emphasized first on a national scale, followed by the influence that some specific characteristics of each urban structure exert on automobile ownership and modal choice. Although in my view the models are not yet ready for widespread use, their contribution is clearly evident, especially with regard to the automobile ownership model. I hope that these and other researchers will continue the work in this field so that we may increase the hopes of establishing the frequently claimed but almost always elusive relationship between land use patterns and transportation.

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A Transit-Oriented City

Edward W. Walbridge, Department of Systems Engineering, University of Illinois, Chicago

Cities are designed to accommodate the automobile. A transit-oriented city is one that from inception is designed for public transportation modes rather than the automobile. In such a city, automobile use would be possible but unnecessary. The goal of a transit-oriented city is to make public transportation travel more attractive than driving so that automobiles will be little needed or used. One possible transit-oriented city is described. From this example we see that many of the advantages of current urban and suburban life-styles are attainable without automobiles. The building of a transit-oriented city as an experiment is suggested.

A transit-oriented city is designed to make automobiles little needed and little used; the movement of people is accomplished primarily by modes other than the automobile. Nonautomobile modes would include new and old types of mass transit, constant speed and accelerated moving sidewalks, bicycles, and walking. A transit-oriented city would be an altogether new city (or town or new town-in-town) to be built from the ground up. Travel by automobile would be possible and, in fact, would not be deliberately discouraged. However, the design goal would be to make public transportation faster, safer, cheaper, more pleasant, and more convenient than automobile transportation, so that residents would choose to make most in-city trips by public modes. Public transportation of such attractiveness can be achieved through the integration of land use and nonautomobile movement technologies.

When a conflict occurs in the design of a transit-oriented city between the needs of automobiles (such as close-in parking or direct nonstop routes) and the needs of nonautomobile modes, the latter are given priority.