Determinants of Changes in Mobility and Travel Patterns in Developing Countries

Case Study of Chennai, India

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This study analyzes changes in sociodemographic, activity, land use, and mobility patterns and their effects on travel dimensions in the context of a developing country. More specifically, increase in vehicle ownership (both two-wheelers and cars) and changes in mode choice over time are observed and analyzed with the use of household data from Chennai, India. Three sources of dynamics are analyzed: exogenous variable dynamics, sensitivity changes over time, and the influence of lagged and persistent effects. The key drivers of growth in travel demand include the increase in vehicle ownership, the number of workers, and the increase in female drivers. The influence of social and technological factors on vehicle ownership and mode choice such as peer pressure and mobile phone ownership are also significant. In addition, the effect of land use, accessibility, and activity has been investigated. Results show significant evidence of differences in travel decisions across different user segments (on the basis of driving knowledge and vehicle–worker ratio) and over time. The proposed disaggregate models provide a reasonably good description (goodness of fit is 47% to 64%) of the observed changes in travel patterns. The findings and results assume importance in the context of increasing congestion, declining public transportation share, and the imminent need for enhancing urban transportation system capacity in cities of developing countries.

Rapid economic growth, urbanization, and motorization are leading to substantial deterioration of urban transportation systems in many developing countries in Asia (*1*). Because of resource constraints and the limited ability to increase system capacity, the mismatch between demand and supply is increasing further (*2*). As a result, many cities are facing problems of increased congestion, suburbanization, and deterioration in safety and air quality (*3*).

Because of the rapid nature of these changes, complex land use and transport interactions, and the specific characteristics and mobility needs in developing countries, solutions developed elsewhere may be inadequate in addressing these problems (*4*). Therefore, insights on the changing mobility and travel patterns in developing countries and their determinants are essential. This paper analyzes the factors influencing changes in mobility and travel patterns in Chennai, India.

Interest in understanding the changing mobility and travel patterns also stems from policy and planning applications, including (*a*) evaluating long-term land use and transportation plans to support mobility needs and economic growth and (*b*) prioritizing investment decisions in transportation infrastructure. In making these large-scale investments, planners in developing countries are forced to rely on growth rates, prioritization heuristics, or "gut feel," partly because of the lack of sufficient data (*5*). Furthermore, during such transition periods assumptions such as independence, stationarity in parameters, and the absence of dynamic effects may not hold.

In view of these motivating considerations, this study pursues the following objectives:

- To examine the ongoing changes in sociodemographic, land use, and activity characteristics in Chennai City and their impact on travel patterns during the past 5 years and
- To analyze key determinants of dynamics in vehicle ownership and mode choice decisions at the household level during the past 5 years.

To achieve these objectives household data were collected using a retrospective survey with a nearly 0.7% sample in Chennai City. The increase in two-wheeler and car ownership is modeled using ordinal response models; the mode choice changes are investigated by developing multinomial logit models of current and past mode choice decisions.

Through these objectives, this study aims to augment the body of knowledge on rapid transportation changes occurring in developing countries. Unlike many studies based on cross-sectional data, this study seeks to analyze sources of dynamics in mode choice and vehicle ownership decisions in the medium term (5-year period). Specifically, three sources of dynamics are considered: exogenous variable dynamics, sensitivity changes over time, and the influence of lagged and persistent effects. Further the influence of factors such as peer pressure and technological factors, land use, accessibility, and activity characteristics on current changes is also examined.

The rest of this paper is organized as follows. A brief review of the relevant literature is presented, followed by a description of the context of the study and the associated data and sample characteris-

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Transportation Research Record: Journal of the Transportation Research Board, No. 2038, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 42–52.
DOI: 10.3141/2038-06

tics. Ordered response models of changes in car ownership and two-wheeler ownership are presented next. In the following section factors influencing the changes in mode choice decisions for work trips are discussed. Finally, concluding remarks and directions for further research are presented.

BACKGROUND AND LITERATURE REVIEW

Background

This study is based on data from Chennai, a major metropolis in India with a population of more than 7.5 million. The city is currently witnessing rapid demographic (population growth of 10% in the past decade), economic, and motorization growth [vehicle growth > 50% during past 5 years (*6*)]. The growing mobility needs, vehicle ownership levels, and declining public transportation use are contributing to increased congestion and air quality problems. Therefore, the following review focuses on two related dimensions: vehicle ownership growth and mode choice decisions.

Vehicle Ownership Models

Many studies and models have been developed to predict vehicle ownership frequency and vehicle-type choice decisions. Vehicle ownership decisions are influenced by household size, income, residential location, population density, vehicle prices, and supply-side factors of auto makers (*7, 8*). Zonal variables, such as the quality of the pedestrian environment, accessibility of employment and retail facilities from the household, and attitudinal factors, have also been found significant (*9*). Tuan and Shimizu (*10*) reported that motorcycle ownership depends on the increase in the number of workers or students, motorcycle price, income, and previous transactions.

Vehicle transactions (disposal, purchase, replacement) over time have also been studied in the literature (*11*). Ramjerdi et al. (*12*) found that household size, number of license holders, age, income, number of cars owned, and age of car are significant determinants of vehicle type and transactions. Fewer studies on vehicle ownership based on longitudinal data are reported in the literature. Along this line, Meurs (*13*) has developed a panel data model of car ownership and mobility that captures the endogeneity between the two dimensions and controls for unobserved heterogeneity. Dargay and Vythoulkas (*14*) proposed a "pseudopanel" approach (using independent cross sections over time) to estimate a dynamic model of vehicle ownership, based on data from annual family expenditure surveys in the United Kingdom. The determinants of car ownership investigated include income, the costs of car ownership and use, public transport fares, and the sociodemographic characteristics of the households.

Unlike in developed countries, relatively fewer insights are available on vehicle ownership trends and growth in developing countries. As a result, factors affecting two-wheeler ownership are less well understood compared with cars. Furthermore, the influence of social factors, such as peer pressure, activity patterns (in-home and out-of-home activities), and the mobility and connectivity afforded by information and communication technologies on vehicle ownership decisions, has not received attention. Many studies noted above consider vehicle ownership under nearly saturated vehicle ownership conditions (at least one car per household). For instance, Meurs (*13*) reported that decisions concerning the first car in the household are difficult to influence because most households possess one car. Second car ownership, however, may be more sensitive to changes in the observed contributing factors. In the context of developing countries, the issue translates into one of new car ownership and additional two-wheeler ownership, because of increasing affordability, mobility needs, and economic growth.

Mode Choice

Mode choice is influenced by various factors including the level-of-service attributes (travel time, cost, waiting time, reliability), subjective factors, land use and accessibility, and individual and household characteristics (*15*).

Compared with cross-sectional mode choice analysis, the literature on dynamic and longitudinal mode choice models is relatively sparse. Although cross-sectional models can partially capture the effect of changes in exogenous variables, they are not able to capture a variety of richer behavioral features including lagged effects, persistent correlations, change in responsiveness over time, asymmetry, hysteresis, and shock effects (*16*). In contrast, longitudinal data offer higher statistical efficiency, more accurate predictions, and the ability to capture changes and examine behavioral dynamics. Furthermore, the use of cross-sectional mode choice can lead to inaccurate forecasts and erroneous policy recommendations. Despite being theoretically richer compared with cross-sectional models, fewer dynamic mode choice models have been reported in the literature owing to the increased complexity in analysis and higher costs. The related longitudinal–dynamic mode choice studies are reviewed below.

Clarke et al. (*17*), in an important earlier study, proposed a conceptual model with three overlapping levels at which dynamics interact with travel behavior: microdynamics (relating to within-day-activity travel), macrodynamic modifiers, and macrodynamic processes (dealing with processes such as birth, aging, and death). Golob et al. (*18*) analyzed the patterns of change in the use of various modes of transport in the Netherlands based on three waves of panel data using generalized linear models. The key explanatory variables included age, gender, employment status, household size, driving experience, and vehicle ownership. Golob (*19*) in another study, also analyzed dynamic relationships between car ownership, travel time per week by car, travel time by public transit, and travel time by nonmotorized modes based on panel data at two points in time and found that vehicle ownership and travel times by car and public transit modes were endogenous.

Kitamura (*16*) provided a synthesis of theoretical foundations of behavioral dynamics observable with panel data and identified two main sources of dynamics: macroscopic changes and microscopic changes. Macroscopic changes included changes taking place at the system level such as continuing urbanization, highway and transit improvements, and changes in transportation, energy, and air quality policies. Microscopic changes included changes at the level of the household and individual attributes such as income, household composition, employment, and license holdings. These changes are expected to lead to residential relocation, car acquisition or disposal, and changes in daily travel patterns.

Most studies noted above were conceptual and theoretical in nature, but empirical insights and understanding of key factors influencing medium- and long-term changes in mode choice decisions are currently inadequate. For instance, the relative influence of exogenous changes (income increase), segment transitions (single-worker to

two-worker household), changes in sensitivity, and captivity to different modes over time are not well understood.

In summary, the data, models, and insights on the dynamics in travel decisions in developing countries are relatively sparse and are currently inadequate to support policy making. Understanding the changes occurring in travel behavior and mobility needs over time is important for improved transportation planning and evaluation, congestion management, and transit operations.

CHANGES IN SOCIODEMOGRAPHIC, ACTIVITY, LAND USE, AND MOBILITY PATTERNS IN CHENNAI

Data Collection and Survey Description

This study reports the findings from the Chennai Household Travel Survey conducted between December 2004 and May 2005. The city of Chennai has an area of 1,167 km^2 and a population of 7.5 million. The study sample was selected at random from 12 zones in Chennai City that are representative of the city (*6*). Data were obtained using face-to-face interviews because of their lower respondent burden and higher response rate. Data reported here are from nearly 1,200 households in the Chennai area and represent a (0.7%) random sample of the population in the selected zones.

The survey was specifically designed with the aim of understanding the changes in sociodemographic characteristics, land use and activity patterns, and mobility-related variables and their influence on changes in travel patterns in Chennai during the past 5 years. Data on vehicle ownership and mode choice 5 years ago were also obtained retrospectively. The data were obtained on the following categories of attributes and summarized subsequently in this section: personal and household characteristics, travel attributes, activity characteristics, and land use and accessibility characteristics.

Personal and Household Characteristics

Personal and household characteristics include age, gender, driving experience (number of years), household size, number of full-time workers, number of female workers, monthly household income, household type (joint family, nuclear, other), and presence of children (<5 years, 6–17 years).

Travel Attributes

Travel attributes include vehicle ownership (two-wheelers and four-wheelers), current work-based trip frequency (including trips from work to locations other than home), mode of travel to work (now and 5 years ago), and number of drivers.

Activity Characteristics

Activity characteristics include out-of-home trip frequencies for social, shopping, recreational, maintenance (personal business), and eat-out activities; duration spent on different in-home activities; and availability of information and communication technology (ICT) devices (mobile phone, Internet), which may influence travel or activity patterns.

Land Use and Accessibility Characteristics

Land use and accessibility characteristics include the availability of parking near home and work; accessibility to bus stop and railway station near home and near workplace; availability of activity centers such as grocery stores/markets, amenities (bank/post office), and recreational facilities near home; type of residence and home ownership status; and residential location (classified as urban, periurban, and suburban locations).

Changes in Sociodemographic Characteristics

The most significant sociodemographic changes include the increase in the number of workers per household and the corresponding increase in income (see Table 1). The average number of workers per household has increased from 1.17 to 1.45 (25% increase) during the past 5 years. The average number of male workers has increased from 1.19 to 1.35 per household, and the corresponding average number of female workers has increased from 0.24 to 0.33 per household.

This increase in the number of workers has significant implications for mobility needs and travel demand in Chennai City. With an estimated 1.74 million households, this increase (0.28 worker/household) translates into a substantial increase of nearly 0.4 million additional work trips during the past 5 years in the city. This large-scale increase in travel demand argues the need for more transportation system capacity, the use of high-occupancy modes (public transportation), and the identification of appropriate demand management measures for meeting these mobility needs in a sustainable manner.

The workforce is relatively young (65% of workers are younger than 45 years) and may be more inclined to travel. The average household size has declined marginally from about 4.4 to 4.3 in the same period. There is also a small change in the household type (nearly 2.9% increase in nuclear families from joint families), which may also contribute to increased trip making.

The average monthly household income in the sample has risen by nearly 31% from Rs. 13,376 to Rs. 17,536 (approximately $291 to $381) during the past 5 years. The sample income from this study compares reasonably well with the average income estimated for Chennai (*20*). The estimated income is Rs. 16,875 at 2005 levels assuming a discount rate of 5% per year. The increase in income has implications for vehicle ownership and mode choice as noted in the following sections. The other noteworthy demographic change that could influence travel behavior is the reduction in the number of households with children. Thus, despite a reduction in household size marginally from 4.4 to 4.3, there is a small increase in the number of nonworking adults (18+ years).

Mobility-Related Factors

The increase in workers and income has spurred the growth in personal vehicle ownership (which has grown from 0.78 vehicles/household to 1.45 vehicles/household in the sample). The latter number is reasonably consistent with the vehicle registration data for Chennai City (1.44 vehicles/household). In contrast to developed countries, the majority of the vehicles (3/4) owned are two-wheelers (motorbikes, scooters, mopeds). There has been a substantial increase in the number of two-wheelers (by 80% from 0.64 to 1.15/household) and cars (nearly doubled) in the sample during the past 5 years.

TABLE 1 Summary of Sociodemographic and Land Use Attributes in Sample (1,172 households)

	5 Years Earlier (1999)	Recent (2004)
a. No. of workers		
Percentage of households with 0 workers	16.2	11.9
Percentage of households with 1 worker	56.2	47.4
Percentage of households with 2 workers	22.1	28.0
Percentage of households with 3 or more workers	5.5	12.7
Average number of workers per household	1.17	1.45
Average number of male workers	1.19	1.35
Average number of female workers	0.24	0.33
b. Family structure		
Percentage households with nuclear family structure	29.49	32.56
Percentage households with joint family structure	66.26	63.40
Other	4.25	4.04
c. Age of the individual		
% workers in category 18–25 years		2.53
% workers in category 26–35 years		29.72
% workers in category 36–45 years		32.54
% workers in category 46–60 years		32.97
% workers in category >60 years		2.24
d. No. of children in 0–5 year age group		
% households with 0 children in this age group	78.3	81.2
% households with 1 child in this age group	18.1	15.8
% households with 2 or more children in this age group	3.6	3.0
e. No. of children 6–18 years of age		
% households with 0 children in this age group	41.47	48.81
% households with 1 child in this age group	28.67	28.67
% households with 2 or more children in this age group	29.86	22.53
f. Driving knowledge among workers		
Males (%)	72.69	85.75
Females (%)	17.96	27.18
g. Vehicle ownership changes (% of households)		
0	40.70	14.68
1	43.60	44.28
2+	15.7	41.04
h. Mode choice dynamics (% share among workers)		
Nonmotorized	13.72	10.4
Two-wheeler	42.09	46.86
Four-wheeler	8.88	12.2
Public transportation	31.99	26.71
IPT	3.32	3.83
i. Accessibility		
i. % households with bus stop within 500 m from home	87.33	87.65
ii. % households with railway station within 1 km from home	32.53	37.84
iii. % workers for whom there is a bus stop within 500 m from workplace	NA	92.40
iv. % workers for whom there is a railway station within 1 km from workplace	NA	51.72
j. Type of residence		
% households residing in individual house	74.12	70.22
% households residing in flats or apartments	24.97	29.09
% households residing in other dwelling types	0.92	0.69
k. Work distance change over 5 years		
% workers with a decrease in work distance	4.44	
% workers with same work distance	87.19	
% workers with moderate increase (2.1–6 km)	2	
% workers with increase (6.1 km or more)	6.37	
l. Residential location (in the sample)		
% households in the sample in urban area	40.96	
% households in the sample in periurban area	26.96	
% households in the sample in suburban area	32.08	

Land Use Characteristics and Changes

The sample consisted of 41% households in the urban area, 27% in the periurban area, and 32% in the suburban area (Table 1). The data provide some evidence of changes in land use and the possibility of suburban sprawl. There is nearly a 4% increase in households residing in apartments rather than in individual houses and a nearly 7% increase in home ownership (from 63% to 70%) during the past 5 years. The distance from home to work has increased for nearly 9% of workers (and by more than 6 km for about 6.4% of workers). This increase may be due partly to relocation to suburban areas, possibly owing to lower costs and lower pollution levels.

Most households and offices are well connected by buses (nearly 87% of households and 92% of workplaces in the sample are within 500 m of bus stops), but not as well by trains (access from home has increased from 32.5 to 37.8, whereas from work it is 51.72). Buses are estimated to carry nearly 3.5 million riders each day, and the suburban railway system is estimated to carry nearly 0.6 million riders per day (*21*). Thus, Chennai City has a multimodal public transportation network that provides a reasonable degree of connectivity and access to residences and workplaces.

Data were also obtained on the availability of shopping facilities (which may influence shopping trips), amenities (bank, post office, etc.), and other trip attractors (such as hotels, cinema, religious places) near home. The data revealed significant mixed land use with good access to activity centers near home. The fraction of households with easy access to such activity locations has also increased over time. For instance, 87% of respondents now report the presence of a market within 500 m, compared with 72% 5 years ago. Similarly, the increase in proportion of households in proximity to banks and post offices is 15% and 7%, respectively. Accessibility (proportion of households residing within 1 km of the facilities) has increased to entertainment centers (cinema, parks, etc.), eateries and hotels, clinics and hospitals, and religious places by about 4%, 8%, 8%, and 6%, respectively. The mixed land use and availability of activity centers near residences may reduce the growth in motorized vehicle demand or the distance traveled for nonwork trips. For shopping and maintenance activities in the neighborhood, nearly 60% to 80% of trips are performed using nonmotorized modes. However, the share of two-wheeler trips appears to be significant (32%–48%) for discretionary activities such as recreational, social, religious, and eat-out activities, even for locations that are close to the residence (within 1 km).

Activity Patterns and Changes

Activity characteristics and associated changes were considered at three levels: (*a*) frequency of trips for performing various activities and change in frequency over 5 years; (*b*) duration of various in-home activities, which may affect out-of-home trips; and (*c*) changes in the availability of ICT devices, which may do any or all of the following: increase mobility and connectivity and lead to trip substitution.

The level of participation in out-of-home activities has increased for almost all activities, highlighting the role of nonwork activities in increasing travel demand, possibly during evening peak and off-peak periods. The increase in frequency was noteworthy for shopping (5.19% increase in three plus trips/week) and social activities (3.5% increase for three or more activities and 1.8% increase for one to two activities per week) (Table 2). A smaller increase was observed in the case of maintenance (2% increase in the 5 or more

TABLE 2 Summary of Facilities Accessible near Home, Modes Used, and Activity Characteristics

	% Households Where Facility is Accessible		Mode Share % to Access These Facilities When Accessible			
Facility	5 Years Ago (1999–2000)	Now (2004–2005)	Walk	Bicycle	Two-Wheeler	Other Modes
Within 0.5 km from home						
Market	72.26	87.07				
Grocery	85.02	94.78	2.62	74.91	19.77	2.71
Bank	53.77	69.78	13.61	46.16	36.95	3.28
Post office	66.52	74.23	26.92	35.71	34.29	3.08
Within 1 km from home						
Cinema	50.17	54.37	11.21	52.75	31.63	4.40
Hotel	66.78	75.26	15.71	43.10	38.97	2.22
Clinic	82.71	90.92	3.51	50.46	43.62	2.40
Religious place	88.61	95.55	2.63	68	47.92	1.45

	% Households with 3+ Times Per Week		Mean Frequency Per Week	
Activity Type	1999	2004	1999	2004
Shopping	28.84	34.03	1.94	2.11
Social	22.01	25.48	1.72	1.88
Recreational	12.55	12.56	1.15	1.19
Maintenance	10.24	12.26	0.97	1.11
Eat out	10.76	12.73	1.18	1.31

days/week category) and eat-out activities (about 2% increase in the 3 or more days/week category).

The duration of various in-home activities is also examined because it can affect the time available for and timing of out-of-home activities. An average worker spent nearly 31.8 min, 20.3 min, 8.2 min, and 8.1 min, respectively, on various in-home activities including entertainment activities, household chores, official work at home, and communication (over phone, etc.). These data suggest that the influence of in-home activities on travel and activity patterns may be relatively small in developing countries, but that remains to be corroborated with more disaggregate analysis.

The availability of ICT devices in the sample has increased considerably during the past 5 years. Cell phone availability (68% from 13%) has increased fivefold, and Internet availability at home has more than doubled (25% from 12%). These changes are of interest in view of their potential to generate trips (through more connectivity), modify trips (coordination of trip chaining and ride sharing), and substitute trips (telework arrangements, etc.).

MODELS OF CHANGES IN NUMBER OF TWO-WHEELERS AND CARS

This section analyzes the change in the number of two-wheelers and cars during the past 5 years. Because of the ordinal and integer valued nature of the dependent variables, ordered probit models are used. Because of fewer observations, some frequency levels of the dependent variable were consolidated for analysis (e.g., decrease by one or more vehicles, increase by two or more cars and three or more two-wheelers); results are shown in Table 3. To test for endogeneity across the two dimensions, the expected increase and the probability of increase of various levels for the other variable (increase in two-wheelers) were included as an explanatory variable for a given variable (increase in car) and vice versa. Neither endogeneity effect was found to be significant.

Sociodemographic Factors

The factors investigated included income and increase in income, increase in the number of male and female workers, average age of workers in the household, and presence of children below 5 years of age and school-age children (6–17 years).

The increase in the number of two-wheelers is affected (significant at 10% level) by income. However, the increase in car ownership is affected both by the income 5 years ago and the increase in income during the past 5 years. The effect of lagged income (1.7e-5) was marginally more than the effect of increase (1.3e-5). In other words, for the same increase in income, households that were already in a higher income group are more likely to purchase cars than households that had a lower income previously. Further, households with credit cards were more likely to purchase cars, but no effect was found for two-wheelers. Thus, the increase in the number of cars may be attributable partially to the greater availability of loans and easy financing options during the past 5 years.

In other sociodemographic changes, the increase in the number of workers in the household is a significant determinant of an increase in the number of two-wheelers. However, this variable does not affect the increase in the number of cars directly, but may influence it through the income effect noted above. However, no significant differences were observed based on the increase in the number of male or female workers for either two-wheelers or cars. Households with predominantly younger workers (average age 45 years or younger) are more likely to purchase two-wheelers than those with older workers. In contrast, the average age of workers has no effect on car ownership increase. These findings suggest that new workers are contributing to the increase in two-wheelers, whereas increasing income is a key driver of car ownership growth. The presence of school-age children in the household is also positively correlated with four-wheeler increase, whereas it has no effect on the increase in two-wheelers.

Mobility-Related Factors

In both models, the lagged number of female and male drivers has a strong influence on vehicle ownership. The number of male drivers 5 years ago has a stronger effect (coefficient = 0.8) on the increase in two-wheelers than the number of female drivers 5 years ago (coefficient = 0.54). In contrast, the number of female drivers 5 years ago has a stronger (nearly twice at 0.24) effect on car ownership increase than the number of male drivers 5 years ago. On further analysis, it was found that a greater number of male drivers and workers were present in lower-income households, whereas more female drivers were present in higher-income households.

In contrast to this lagged effect, the increase in the number of male and female drivers contributes nearly equally to an increase in the number of two-wheelers. However, only the increase in female drivers contributes significantly to the increase in the number of cars, also consistent with the lagged effect noted above.

A larger number of two-wheelers 5 years ago reduces the propensity for acquiring two-wheelers, but has no effect on car ownership decisions. Similarly, the presence of four-wheelers (5 years ago) reduces the propensity to purchase additional vehicles, more so, for cars (coefficient = –1.36) than for two-wheelers (–0.42). These results imply that the propensity to purchase two-wheelers (cars) is the largest among households without two-wheelers (cars) previously. Given that many households already possess a two-wheeler and more than 70% of the households do not own a car, these trends imply that car ownership may grow faster than two-wheeler ownership in the future, leading to a significant change in the character and composition of traffic. These variables denote state-dependence effects in which the past state of the dependent variable influences current choices.

Finally, work distance also influences the increase in the number of vehicles. As the work distance increases, the propensity to purchase two-wheelers is greater, whereas the tendency to purchase four-wheelers decreases. This may be attributed to the higher fuel efficiency of two-wheelers over cars. Work experience and the number of work trips did not influence the change in the number of vehicles.

Activity, Land Use, and Other Factors

The increase in the number of vehicles is also influenced by activity, land use, and peer-pressure effects. Households with a greater frequency of maintenance activities are more likely to acquire two-wheelers, but not cars. Households with greater shopping frequencies are less likely to acquire two-wheelers, probably owing to the inconvenience of two-wheelers for carrying goods during shopping trips. In a related finding, households with grocery stores or markets nearby (within 500 m) are less likely to acquire cars than other households. Thus, the availability of shops or markets and mixed land use near the residence appears to reduce the growth in the number of vehicles. In contrast, access to public transportation (bus or train) did not

TABLE 3 Ordered Probit Model of Increase in Number of Cars and Two-Wheelers at Household Level During 5-Year Period

	Cars		Two-Wheelers	
Variable	Coefficient	*t*-Statistic	Coefficient	*t*-Statistic
Constant	2.35	10.28	1.95	17.71
Role of sociodemographic factors				
Income 5 years back	1.70e-5	4.34		
Increase in income	1.30e-5	2.96	4.16e-6	1.53
No. of schoolage children (6–17 yrs)	0.084	1.60		
Increase in number of workers			0.094	1.83
Age indicator (more than 45 yrs)			–0.26	–2.19
Role of mobility-related factors				
No. of two-wheelers in household 5 years ago			–1.24	–20.38
No. of four-wheelers 5 years ago	–1.36	–11.39	–0.42	–4.44
No. of male drivers 5 years ago	0.12	2.04	0.80	15.94
No. of female drivers 5 years ago	0.24	2.01	0.54	4.94
Increase in male drivers			0.50	9.50
Increase in female drivers	0.27	2.67	0.53	6.46
Average work distance per worker	–0.02	–3.04	0.01	2.17
Car parking space available at home or nearby	0.28	2.63		
Role of activity and land use characteristics				
Proximity of activity centers (market/grocery) near home	–0.30	–3.43		
Average duration (in min/day) on household chores	–0.001	–2.06		
Home ownership indicator	0.38	3.70		
Shopping activity frequency			–0.068	–3.40
Maintenance activity frequency			0.11	3.90
Other factors				
Credit card-holding indicator	0.36	3.38		
Peer pressure two-wheeler ownership in neighborhood (more than 7 out of 10 households)	–0.33	–3.13		
Peer pressure two-wheeler ownership among friends, colleagues, etc. (more than 7 out of 10 persons own two-wheeler)			0.24	2.73
Peer pressure car ownership in neighborhood (more than 5 out of 10 households)	0.56	4.01		
Peer pressure car ownership among friends, colleagues, etc. (more than 5 out of 10 persons own cars)	0.68	3.76	–0.74	–4.56
Social connectivity indicator (= 1, if no. of cell phones/nonworkers > 0.4, 0 otherwise)	0.42	4.07	0.25	3.23
Threshold 1	3.82	37.41	2.86	41.24
Threshold 2	5.40	39.14	4.52	60.53
Threshold 3	NA	NA	5.59	47.77
	Convergence	Initial	Convergence	Initial
Log likelihood	–511.72	–1,435.0	–921.48	–2,418.8
No. of observations	1,172		1,172	
R^2	0.64		0.62	

significantly affect the increase in the number of vehicles. The average duration spent in-home on household chores was negatively correlated with an increase in cars, but not two-wheelers.

Among other land use variables, home ownership was significant for both models. Home owners were more likely to purchase cars. In a similar finding, recent home owners (those who had purchased a home in the past 5 years) were more likely to purchase two-wheelers. The result is significant in the context of growing home ownership, particularly in the suburban areas, and the resulting increase in commute distance. This finding is also consistent with the influence of increasing work distance on the increase in two-wheeler ownership noted earlier. Further, it is plausible that home ownership and vehicle ownership may represent economic and social status symbols in developing countries.

To represent social and communication connectivity, the number of cell phones per worker was included as an explanatory variable (indicator = 1, if the ratio is > 0.4) in the model. This variable was found to be a key determinant of the increase in both two-wheelers and cars, more so for cars (the coefficient was twice as large) than two-wheelers. Ownership of mobile phones may also be a reflection of greater demand for communication and travel activities among some households.

The increase in the number of household vehicles also appears to be influenced by peer pressure. To capture peer pressure, two variables were included in the model: vehicle holding among neighbors (with more than seven two-wheelers or four cars in 10 households) and vehicle holding among colleagues and friends not in the neighborhood. If the car holding among peers, colleagues, and friends is significant (more than five of 10 people own a car), the propensity toward more two-wheelers decreases, but car ownership is likely to increase. A similar but slightly smaller effect is seen due to car ownership in the neighborhood, but only for the increase in cars. If the vehicle holding of two-wheelers in the neighborhood is substantial (more than seven of 10 households), the tendency to purchase a car is reduced. A high level of two-wheeler ownership among peers also appears to be positively correlated with two-wheeler increase. Although these effects may reflect peer pressure to a certain extent, they may also be indicative of the unobserved land use effects in the vicinity of the household and workplace.

ROLE OF EXOGENOUS CHANGES IN MODE CHOICE DECISIONS

This section focuses on mode choice decisions of full-time workers in the sample and the changes during the past 5 years. The mode choice alternatives considered include nonmotorized (NM) (walk/bicycle), two-wheeler (TW) (motor bikes, scooters, mopeds, etc.), cars (FW), public transportation (PT) (bus, train), and other (auto, share auto, company bus, etc.). For notational convenience, the "other" modes are referred to as IPT modes (intermediate public transport) hereafter. Because of the discrete and unordered nature of the alternatives, a multinomial logit model is used for its analysis in this study. Given the focus on systematic dynamic effects in this study, a simple model structure is preferred; however, in continuing work the role of unobserved effects will be modeled using more general error structures such as mixed logit models. Results are shown in Table 4. Owing to space considerations, the mode choice model for past choice is not shown; only the coefficients from that model for constants and travel time sensitivity are provided.

Sociodemographic Factors

To avoid confounding, the role of income is tested only for households with the same number of vehicles (vehicle effects were reported earlier). To test income effects, households were classified into four segments: low (<Rs. 7,000 per month), lower middle (Rs. 7,000–18,000 per month), upper middle (Rs. 18,001–Rs. 25,000 per month) and high income (>Rs. 25,000 per month). A greater propensity for nonmotorized modes is seen in households that either remain in the low-income group or have transitioned from the low- to the moderate-income segment. In contrast, workers who continue to remain in the moderate-income group are more likely to use a two-wheeler, four-wheeler, and IPT for work, suggesting the presence of lagged effects. Workers who have moved from the medium- to high-income groups are more likely to use personal vehicles now than even IPT. Note that these income effects reflect changes in use levels of personal vehicles, rather than vehicle availability (discussed in section on mobility-related variables). Experienced male workers (with 5+ years of work experience) are less likely to use public transportation than other modes. These findings suggest a greater valuation of comfort and convenience and greater affordability among experienced male workers.

Activity, Access, and Land Use Characteristics

Commuters making more trips to locations other than home from work are more likely to use two-wheeler, IPT, or nonmotorized modes for work than to use public transportation. That may be explained by the greater convenience of two-wheelers for trip chaining, parking, and maneuverability. Proximity to a railway station (within 1 km from home) increased the utility of the public transportation mode, but there was no influence of bus accessibility. Individuals who continue to reside in periurban and suburban areas (now and 5 years ago) were found to be more likely to use public transportation and nonmotorized modes than were urban residents. The increased tendency to use public transportation may be a reflection of a greater sensitivity to cost, whereas the increased tendency to use nonmotorized modes represents intrazone commute trips. An increase in work distance was not a significant factor.

Mobility-Related Variables

As expected, with an increase in the number of vehicles in the household, the tendency to use nonmotorized modes declines. In households that had no vehicles previously but have acquired a two-wheeler in the past 5 years, workers are more likely to use two-wheeler and public transport modes. Further, households with more four-wheelers even 5 years ago were less likely to use two-wheelers now, and vice versa, which represents state-dependence effects in mode choice decisions as well.

To study the influence of vehicle availability to workers on mode choice, households were classified into three segments. The first segment (S_1) represents households without vehicles, the second (S_2) denotes those with fewer vehicles than workers, and the third (S_3) with vehicle–worker ratio ≥ 1. In view of the changing sociodemographics in the number of both vehicles and workers, it is of interest to examine whether and how segment transitions affect mode choice. Although nearly 12%, 38%, and 16% of workers continue to remain in Segments 1, 2, and 3, respectively, 34% of workers experienced a segment transition. Nearly 6.9% and 6.4% of workers moved from Segment 1 to 2 (S_{12}) and 1 to 3 (S_{13}), respectively, whereas, 6.7% moved from Segment 2 to 3. Interestingly, nearly 12.9% of workers moved from Segment 3 (vehicles ≥ workers) to Segment 2 (vehicles < workers).

Workers remaining in either Segment 2 or Segment 3 were less likely to use public transportation and nonmotorized modes, which may be a reflection of the unobserved preference for greater mobility and convenience offered by a personal vehicle. Users who transitioned from Segment 1 to other segments were also less likely to use public transportation modes, but no effect was seen for nonmotorized modes. However, the disutility coefficient for public transportation modes for the transitioning group (S_{12} or S_{13}) was nearly half of the

TABLE 4 Effect of Dynamics in Sociodemographic, Activity, and Mobility Related Factors on Mode Choice Decisions

	Coefficient (*t*-stat)				
Role of Sociodemographic Changes	NM	TW	FW	PT	IPT
Increase in workers					
No. of male workers 5 years ago				−1.02 (−5.34)	
Effect of income					
Moved from low to lower middle income (with same number of two-wheelers and cars)	1.40 (3.64)				
Remain in low-income with same number of two-wheelers and four-wheelers	1.63 (4.99)				
Remain in moderate income category with no change in two-wheelers or cars		0.70 (1.90)	0.70 (1.90)		1.53 (2.97)
Moved from upper middle to high income with no change in two-wheelers or cars		1.84 (1.68)	1.84 (1.68)		
Role of land use, accessibility, activity changes					
Living in periurban area now and 5 years ago	0.5 (2.25)			0.5 (2.25)	
Living in suburban area now and 5 years ago	0.68 (3.40)			0.68 (3.40)	
No. of trips from work to location other than home	0.21 (1.81)	0.38 (4.49)			0.38 (4.49)
Railway station accessibility indicator (presence within 1 km from home now)				0.39 (2.40)	
Role of mobility-related variables lagged effects					
No. of two-wheelers 5 years ago			−0.34 (−1.95)		−0.34 −(−1.95)
No. of four-wheelers 5 years ago		−0.72 (−1.95)			
Transition in vehicle ownership status					
No. two-wheeler 5 years ago to one two-wheeler now	−0.73 (−2.28)		−0.81 (−1.69)	−0.73 (−2.28)	
Role of vehicle to worker ratio					
Households remaining in Segment 3 (vehicles ≥ workers)	−3.58 (−8.79)			−3.44 (−8.64)	
Households remaining in Segment 2 (vehicles < workers) now and 5 years ago	−1.10 (−3.21)			−2.02 (−5.19)	
Moved from Segment 1 to Segment 3 (S_{13}) (i.e., no vehicles to vehicles ≥ workers)				−1.72 (−4.21)	
Moved from Segment 1 to Segment 3 (S_{12}) (i.e., no vehicles to vehicles < workers)				−1.33 (−3.40)	
Moved from Segment 3 to Segment 2 (S_{32})	−3.53 (−4.42)			−3.29 (−6.61)	
Moved from Segment 2 to Segment 3 (S_{32})	−3.01 (−5.22)			−2.59 (−6.12)	
Increase in drivers					
Male without driving knowledge now	1.67 (4.03)	−0.89 (−2.52)	−0.89 (−2.52)		
Female without driving knowledge now					2.81 (8.59)
Recent male driver (driving now, but not 5 years ago)		1.14 (4.26)			
Sensitivity and captivity effects					
Cost now	−0.54 (−5.56)	−2.11 (−4.94)	−2.11 (−4.94)	−0.54 (−5.56)	−2.11 (−4.94)
Cost 5 years ago (on mode choice then)	−1.5 (−3.11)	−3.42 (−6.94)	−3.42 (−3.11)	−1.5 (−6.94)	−3.42 (−3.11)
Alternative specific constants now	1.43 (2.75)	Baseline	−0.21 (−0.39)	3.46 (7.06)	−0.11 (−0.23)
Alternative specific constants 5 years ago (on mode choice then)	2.73 (7.17)	Baseline	−1.46 (−5.92)	3.74 (10.79)	−1.93 (−7.34)
	Convergence	Initial			
Log likelihood (current mode choice)	−948	−1,804			
No. of observations	1,121				
R^2	47%				

corresponding disutility among Segments 2 and 3. Individuals transitioning from Segment 2 to 3 also exhibit a strong disinclination to use public transport and nonmotorized modes. More interesting, households that moved from the adequate-vehicles to the fewer-vehicles segment also showed a similar trend but with a slightly smaller disutility. This result suggests that despite the reduction in the number of vehicles relative to workers, the workers exhibit a lagged and persistent preference for comfort, convenience, and mobility offered by personal vehicles, which can contribute to the declining mode share of public transport and nonmotorized modes.

A significant proportion of female workers and a small fraction of male workers in the city do not possess driving skills. Understandably, their propensity to use personal vehicles is lower than other modes. Male workers in this category are more likely to use nonmotorized than public transportation and IPT; female workers are more likely to choose IPT over public transportation modes. Male workers who are driving now, but were not 5 years ago, are more likely to use two-wheelers, also consistent with their role in the increase in the number of two-wheelers noted previously in the section on models of changes in the number of two-wheelers and cars.

The policy implications of these findings are twofold. There appears to be some degree of endogeneity (such as comfort, convenience, mobility) that influences both vehicle ownership and mode choice decisions. As a result, the changes due to increase or decrease in vehicles relative to workers can result in an asymmetric shift away from public to private modes of travel (e.g., S_3 to S_2 and S_2 to S_3 both lead to a decrease in public transport share). The changes in mode choice behavior not only vary across segments based on vehicle–worker ratio, but are also influenced by segment transitions over time.

Changes in Sensitivity and Captivity Effects Over Time

To analyze whether captivity and sensitivity to travel time of different modes have changed over time, the coefficients of the alternative specific constant and cost were compared for current and past mode choice models. The sensitivity to nonmotorized and public transportation costs has decreased from –1.54 five years ago to –0.56 now. The sensitivity to costs for personal vehicles and IPT also appears to have decreased (–3.4 to –1.4). These results suggest that users are adapting to the increasing costs due to fuel price and other factors. As a result, a given increase in cost would induce a smaller propensity to shift away from personal modes than it would have 5 years ago. Thus, there is a greater reluctance to shift from personal means despite the increasing cost of operating personal vehicles. Further, if the travel time coefficients had remained unchanged during the past 5 years, these results also imply a greater value of time now than 5 years ago. Unfortunately, that could not be verified because only cost was included in the model owing to the strong correlation between cost and travel time.

The presence of vehicles leads to a larger reduction in the utility of public transport, nonmotorized, and IPT modes now than 5 years ago. Further, a comparison of constants that reflect the baseline segment (no vehicle), indicate that the intrinsic bias toward public transport and nonmotorized modes has declined even in the no-vehicle households, whereas the preference for IPT has increased. Commuters from households with only four-wheelers are much less inclined to use nonmotorized, public transportation, and IPT modes than households with only two-wheelers. Thus, although workers with vehicles are becoming more captive to personal vehicles, the tendency to shift away from public transport and nonmotorized modes is significant even in households without vehicles. With increasing vehicle ownership, these changes portend a larger decline in public transport modes, unless corrective measures are undertaken expeditiously.

The modeling results from this study highlight some of the key factors influencing the ongoing changes in mobility and travel patterns among households in Chennai City. Because of the limitations of sample size, nature of the data, and modeling assumptions in this study, caution must be exercised in generalizing these findings. In further work, the insights here need to be confirmed with other empirical data from other similar contexts. This work can be generalized by relaxing assumptions concerning independent and identically distributed error structure, examining nonwork mode choice and nonworker mode choices in developing countries, and performing more disaggregate analysis (passengers/drivers, walk versus bicycle, etc.).

MEETING THE GROWING DEMAND FOR TRAVEL IN DEVELOPING COUNTRIES: EMERGING NEEDS AND CHALLENGES

The data and models presented in the previous section highlight the substantial changes currently occurring in many developing countries. The drivers of these changes include economic transition, rapid growth in vehicle ownership and number of workers, and changes in land use and activity patterns. Travel demand and trip pattern changes are captured by modeling the increase in vehicle ownership (both two-wheelers and cars) and changes in mode choice over time. In addition to the socioeconomic and demographic changes noted above, land use and activity characteristics and peer pressure also influence vehicle ownership decisions. Results also show significant evidence of differences in travel decisions across different user segments (based on driving knowledge, vehicle–worker ratio, etc.). Evidence of dynamics in travel decisions is observed at various levels, including significance of lagged effects, responsiveness to changes in exogenous variables, and changes in sensitivity to explanatory variables and captivity to modes over time. The proposed disaggregate models provide a reasonably good description (goodness of fit is 47%–64%) of the observed changes in travel patterns in Chennai.

If current economic and activity trends continue, a dramatic increase in the number of motorized vehicle trips is likely to occur, leading to a significant mode shift away from public transport. Given the already inadequate transportation system capacity, the gap between demand and capacity will likely worsen further. Therefore, without urgent and proactive countermeasures, a substantial increase in congestion and emissions and a reduction in system efficiency and safety may ensue. To address the challenges posed by the mounting travel demand growth, a judicious mix of short-term and long-term strategies is needed, including instituting congestion mitigation and demand management strategies, integrating and enhancing the bus and train networks to function as a seamless multimodal system, and increasing system capacity in a sustainable manner.

Several interesting methodological, substantive, and practical issues and opportunities arise relating to travel demand modeling in this context. A few of these are articulated below in an attempt to encourage and stimulate future investigations along these lines. Given the ongoing changes, there is a need for an alternative demand modeling framework that captures essential features such as dynamics, uncertainty, and significant heterogeneity in travel-related dimensions, while recognizing the causal role of activities on trips. To

support such modeling efforts, data at a sufficient temporal and spatial resolution are needed on changes in activities, land use, and travel patterns.

Several important substantive issues concerning the spatial distribution of activities and trips remain to be understood (*4*). Current travel demand forecasting methods in use in Chennai are deficient in regard to spatial representation; insights into the determinants of changing land use travel patterns, effect of suburbanization on transit use, and potential for exploiting mixed land use to meet activity participation needs remain to be investigated. Land use models from a developed country may not be transferable directly because of lack of data, differences in context and behavior, underlying assumptions, the deterministic nature of some models such as Index and UPlan), and cost considerations (MEPLAN, DRAM). In addition, such models for developing countries must capture time dependence and complex interactions as well as significant uncertainties. The use of the cellular automaton/Markov model, which explicitly recognizes these features, appears to show promise for these applications (*22*).

Improvements in demand modeling applications are also needed to support more accurate project evaluation and prioritization. In that regard, key inputs urgently needed include (*a*) accurate estimates of mobility needs and travel demand, (*b*) causal models of their growth over time due to underlying changes in sociodemographic and activity patterns, and (*c*) accurate quantification of benefits and costs due to policy and program interventions.

In the absence of supporting demand management measures, it is unlikely that supply and capacity expansion alone can help meet the rapid and large-scale demand growth. Therefore, it is of interest to examine whether and to what extent congestion pricing strategies might be beneficial and feasible, given the relatively low value of time in developing countries compared with time in developed countries. The performance of alternative demand management measures, including the promotion of nonmotorized modes, use of company buses, use of teleworking arrangements given the growing employment in the information technology sector, and use of ride-sharing incentives is also not well understood.

ACKNOWLEDGMENTS

This research is supported in part by the interdisciplinary research project on congestion mitigation in urban areas of the Indian Institute of Technology, Madras (IIT Madras). This support is gratefully acknowledged. The authors also acknowledge the significant contribution of Jiten Poojara, P. N. Raghavender, Vankayala Praveen, S. Raghu Prasad, and Vishnu Charan Arcot, former undergraduate students at IIT Madras, for their assistance in conducting this survey.

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The Transportation in the Developing Countries Committee sponsored publication of this paper.