The Dynamics of Automobile Ownership Under Rapid Growth:
The Santiago de Chile Case

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ABSTRACT
Little quantitative research has focused on how factors influencing travel behavior change in rapidly developing and motorizing cities. We examine the particular case of household motor vehicle ownership, focusing on potential variations in preferences revealed through vehicle choice models estimated for Santiago de Chile in 1991 and 2001, and including zonal-level measures of relative location, metro proximity, residential density, and land use mix. The results indicate that preferences have changed from 1991 to 2001, suggesting that as incomes rise and vehicle ownership becomes increasingly affordable, demographic and land-use and other contextual variables change in their apparent influence. The results vary across land use and locational variables; most notably the relationship between vehicle ownership and land use mix appears to weaken over time, while the distance to CBD effect strengthens, and the residential density effect varies in the apparent direction of change, depending on the vehicle ownership category. An effect of proximity to Metro apparently emerges by 2001 for the household decision to own 3 or more vehicles. This research shows that although income and motorization rates rapidly increased in Santiago, certain elements of the built environment influence household vehicle ownership, and these influences change over time. Future research should focus on various potential market segments, such as suburban versus urban, and aim to control for self-selection regarding the land use and locational characteristics.

INTRODUCTION
The growth in motor vehicle fleets arguably poses as the single most important factor influencing developing countries' mobility and accessibility. Most persons want the convenience, status, and comfort of private motorized travel, but in aggregate these desires translate into well-documented problems. The potent force of global motorization raises numerous interesting questions. Does a foreseeable ceiling exist for motorization (vehicles per capita) in cities of the developing world? Will resource constraints or the accumulation of externalities attenuate motorisation? Do the dynamics of vehicle ownership structurally change cities? Do the dynamics of urban growth change vehicle ownership preferences and trends?

In this paper, we set out to shed some light on the last of these questions, examining the case of Santiago de Chile, during the 1990s. International comparative evidence shows a strong relationship between income and motorization (e.g.,*1*). In much of the developing world, the vast majority of the population is still at income levels well below the minimal vehicle ownership threshold. This situation is changing, however, both as incomes rise, and vehicle prices fall, spurred in part by entrance into the international motor vehicle production market of companies from countries like China and India (e.g., the Nano) as well as international trade of used vehicles (e.g., *2*).

Within a country or city, the same income-ownership relationship exists, but at this finer resolution the influences of local policies and other more nuanced factors appear. In Chile, for example, household vehicle ownership data from household travel surveys suggest that those cities that are "free trade zones" (import-tariff-free) – Punta Arenas, Iquique, Arica – have the lowest share of zero-car households in the country (*3*). Other local policies, not originally aimed at affecting vehicle ownership per se, also play a role. For example, Mexico City's "*Hoy No Circula*" program, a restriction on driving by certain vehicles (based on license plate numbers) during high pollution days, created the perverse impact of promoting the purchase of an additional second hand vehicle (apparently imported from other parts of the country) by many families – increasing the motorization rate (*4*). The government more recently adapted the ban to create an incentive for purchasing cleaner vehicles, an approach also adapted in the case of Santiago, which uses a similar restriction policy.

Evidence also suggests a relationship between household automobile ownership and relative transportation levels of service, and urban form and design. In fact, increasing motorization and its attendant impacts may actually further induce motorization (*5*). For example, motorization fuels spatial decentralization, which then further drives motorization. Further, while motorization exacerbates congestion, congestion may then create the perverse incentive of increasing automobile ownership and use. Since increasing congestion further encumbers main arteries and slows buses and other surface transit, there is increasing advantage to using a car because it enables substitution with a route that avoids traffic and/or a destination in a less congested direction (*5*). Zegras (*6*) finds, for the Santiago case in 2001, that household vehicle ownership can be partly explained by the household's relative location in the city, distance to metro stations, its relative accessibility levels between auto and bus modes, and various neighbourhood design characteristics, including density and land use mix.

Concerns about motorization relate not only to the overall magnitude – that is, a city's total motor vehicle fleet size – but also the rate of increase, as this rate may outpace relevant physical and institutional capabilities. Ultimately, motorization is a fundamental driving force behind increases in transportation greenhouse gas and local pollutant emissions, pressures for land conversion to urban uses, dependency on petroleum, and demands for infrastructure expansion. In the face of these daunting challenges, in this paper we take on a relatively modest topic, attempting to discern whether household vehicle ownership preferences have apparently changed over time, and if so, what particular influencing factors have changed the most. Specifically, we look at households in Santiago, in 1991 and 2001, estimating and comparing vehicle ownership models. The following section describes the modelling approach. The third section briefly introduces the empirical setting. The fourth section presents the modelling estimation and discusses the results. The final section concludes.

VEHICLE OWNERSHIP MODELING

Two basic approaches to household vehicle ownership exist, aggregate and disaggregate, as reviewed in detail by de Jong et al (*7*). Aggregate analyses model vehicle ownership at zonal, urban, or national levels, and can be used for inputs into travel forecasting models, and/or for intra-city, inter-city, or international comparative efforts, to derive, say, the income elasticity of demand for motor vehicles, and/or develop forecasts of future vehicle fleets. Such models generally use ordinary least squares (OLS) type regression models to predict vehicle fleet size.

Disaggregate models, on the other hand, typically use household-level data to examine more detailed behavioral relationships at the decision-maker level. Disaggregate models actually comprise a range of types, depending on purpose and data availability (again, see (*7*)). The most basic, static vehicle holding models aim to predict the number of cars owned by a household at a given time (i.e., cross-sectional) and can reveal relevant household characteristics, such as number of employed adults, and household locational attributes, such as distance to central business district and local land use mix (e.g., *6*). More refined static models focus on the vehicle type (e.g., "alternative fuel") and can contain a number of vehicle-specific attributes such as operating costs and top speed (e.g., *8*). These disaggregate approaches, catching a single glimpse in time, can be used to develop long run forecasts with fairly moderate data demands (*7*); however, they do not capture more fine-grained behavioral dynamics, such as the timing of decisions about new vehicle purchases, vehicle disposal, additional acquisitions, and so on (e.g., *9*). Dynamic disaggregate models aim to model such effects, explicitly over time, utilizing household panel (or pseudo-panel) data (e.g., *10*). Such modeling approaches can reveal changes due to lifestyles, cohort effects, vehicle prices, fuel prices, etc. and enable both short- and long-term forecasting; the challenges lie in their data requirements (*7*).

Published research on disaggregate vehicle ownership modeling in the developing world remains somewhat limited. Wu et al. (*11*) model auto ownership in Xi'an, China based on a 1997 survey, developing and operationalizing the concept of "symbolic utility," or psychological satisfaction, in the ownership model. The results support the role of "symbolic utility" in influencing vehicle ownership, although income dominates; they also indicate a significant role of bus stop accessibility and neighborhood parking availability in the decision not to own a car. Dissanayake and Morikawa (*12*) model automobile and motorcycle ownership in a nested logit model of vehicle ownership, mode choice, and trip chaining in Bangkok using 1995-96 data. Srinivasan et al. (*13*) model the change in vehicle ownership, as reported retrospectively by respondents to a 2004-2005 household survey in Chennai, India. Using an ordered probit model, they find, among other factors, that parking space proximity, home ownership, peer pressure, and social connectivity are positively associated with an increase in car ownership while grocery store proximity is negatively associated with an increase in car ownership. Li et al (*14*) model the household choice to own a vehicle or not in Chengdu and Beijing, China, using logit on data for 2005 and 2006, respectively. They find population density to be negatively associated with auto ownership in both cities and, in contrast to studies in the West, that the likelihood of vehicle ownership declines with greater distance from the CBD. As discussed in the introduction, Zegras (*6*), using a multinomial logit model finds a number of transport level of service, relative location, and built environment variables to be related to vehicle ownership using a multinomial logit model on 2001 data for Santiago. We use that same dataset for the 2001 model applied below.

Modeling Approach

Based on analysis of four different datasets, Bhat and Pulugurta (*15*) find that the unordered (i.e. MNL) model outperforms an ordered response model (according to several measures of fit), leading them to conclude that the unordered response choice (i.e., MNL) mechanism is a better representation of the household auto ownership decision (consistent with global utility maximization). In the traditional MNL model, a decision-maker, faced with multiple alternatives, chooses that which provides the greatest utility, with utility itself viewed as a random variable. Assuming a logistically distributed error term (ε_n), we can estimate the probability of choosing alternative *i* as (*16*):

$$P_n(i) = \Pr(U_{in} \geq U_{jn}) \quad (1),$$

$$= \frac{e^{\mu V_{in}}}{e^{\mu V_{in}} + e^{\mu V_{jn}}}$$

where:
$P_n(i)$ is the probability of decision-maker *n* choosing option *i*;
U_{in} represents the random utility of option *i* to decision-maker *n*;
U_{jn} represents the random utility of option *j* to decision-maker *n*;
V_{in} represents the systematic utility of option *i* to decision-maker *n*;
V_{jn} represents the systematic utility of option *j* to decision-maker *n*; and,
μ is a positive scale parameter arbitrarily assumed to be one.

In this formulation, $U_{in} = V_{in} + \varepsilon_{in}$ and $U_{jn} = V_{jn} + \varepsilon_{jn}$, with ε_{in} and ε_{jn} representing the random disturbances.

Our interest is in examining the stability of vehicle ownership decision-making over time: we want to compare models from two different time periods, 1991 and 2001. Doing so requires ensuring that any observed differences from model estimation do not actually derive from variances in the underlying data, that is accounting for potential differences in the magnitudes of the random error component variability. Such an approach allows distinguishing between differences in model parameter estimates that arise from different error variances and those that arise from real differences in the model parameters (*17*). Specifically, as discussed for Equation (1), the scale parameter, μ, cannot be identified and is arbitrarily assumed to be one, an assumption with no effect on the utility order within a particular dataset. Between datasets, however, the values of the scale parameters may differ significantly, implying variability *across* the datasets. Although μ cannot be identified in a single data source, the ratio of the μ's from different datasets can be estimated, relative to an arbitrary reference.

As such, when comparing parameters from models in different times, one must account for the possible differences in error component variances. Following Severin et al. (*17*), consider β_{91} and β_{01} to represent, respectively, vectors of parameters for choices in datasets from 1991 and 2001, and μ_{91} and μ_{01} to represent the respective scale parameters. If the differences in parameter estimates arise from variance scale ratios not equal to one, as opposed to actual differences in the β's, then $\beta_{91} = \beta_{01}$ and $\mu_{91}/\mu_{01} \neq 1$. In other words, if estimation produces different model parameters over two periods, one might infer that the effects of common observed factors (e.g., income) have changed over time, when the difference actually comes from the variance scale ratio (μ_{01}/μ_{91}). These differences can be tested via different model estimations, specifically: (1) estimating separate models for each dataset (allowing different parameters for each) and, then, (2) estimating a single model with the combined dataset, restricting the parameter values (β's) to be identical but allowing for different variance scale ratio parameters (μ's) for each dataset. The preferred model – either (1), the "unrestricted" model or (2) the "restricted" model – can be determined by applying a likelihood ratio test. This approach is known as the stability of preferences test.

EMPIRICAL CASE: SANTIAGO DE CHILE

Santiago is the capital of one of Latin America's most consistently growing economies. The country has sustained strong economic growth since its return to democracy in 1990, and entered into the OECD as of 2010. Santiago concentrates a large share (greater than 40%) of the nation's population, jobs, and wealth. Since our analysis focuses on the vehicle ownership changes between 1991 and 2001 the following description primarily concerns basic city dynamics in that period.

In the 10 years between the 1991 and 2001 household travel surveys, the greater metropolitan area experienced a mean annual growth in average household income of 6.5%, from US$ 4,700 to US$ 9,000 (in US$2001) (This comparison should be viewed with caution; the 1991 survey reported income in categories; we derived an average based on the midpoint of each income category for the relevant household and ignoring the six percent of households in 1991 reporting no income and converted the 1991 income categories to 2001 using the Chilean CPI; both values were then converted to US$ on prevailing average exchange rates from 2001). By 2001, a burgeoning middle class was evident (see Figure 1).

Nonetheless, while by 2001 over 50% of the households earned, on average, between US$6,000 and $13,000 per year, a large share still earned less than $4,000 per year. In fact, 15% of the households earned, on average, less than the minimum monthly wage (equivalent to approximately $2,400 per year). Considering the rising cost of living that accompanied economic growth, these households averaged just enough income for subsistence (the average household size in this income stratum is 2.95; the per capita subsistence cost is $36 per month). On the other extreme, lies the wealthy – a small share of city households in 2001 already enjoyed average incomes on par with the industrialized world; with 5% of the households earning on average roughly the same income as the median US household in 2003. Santiago's residential geography has historically been characterized by socioeconomic spatial segregation, a pattern moderating somewhat in recent years (*18*).

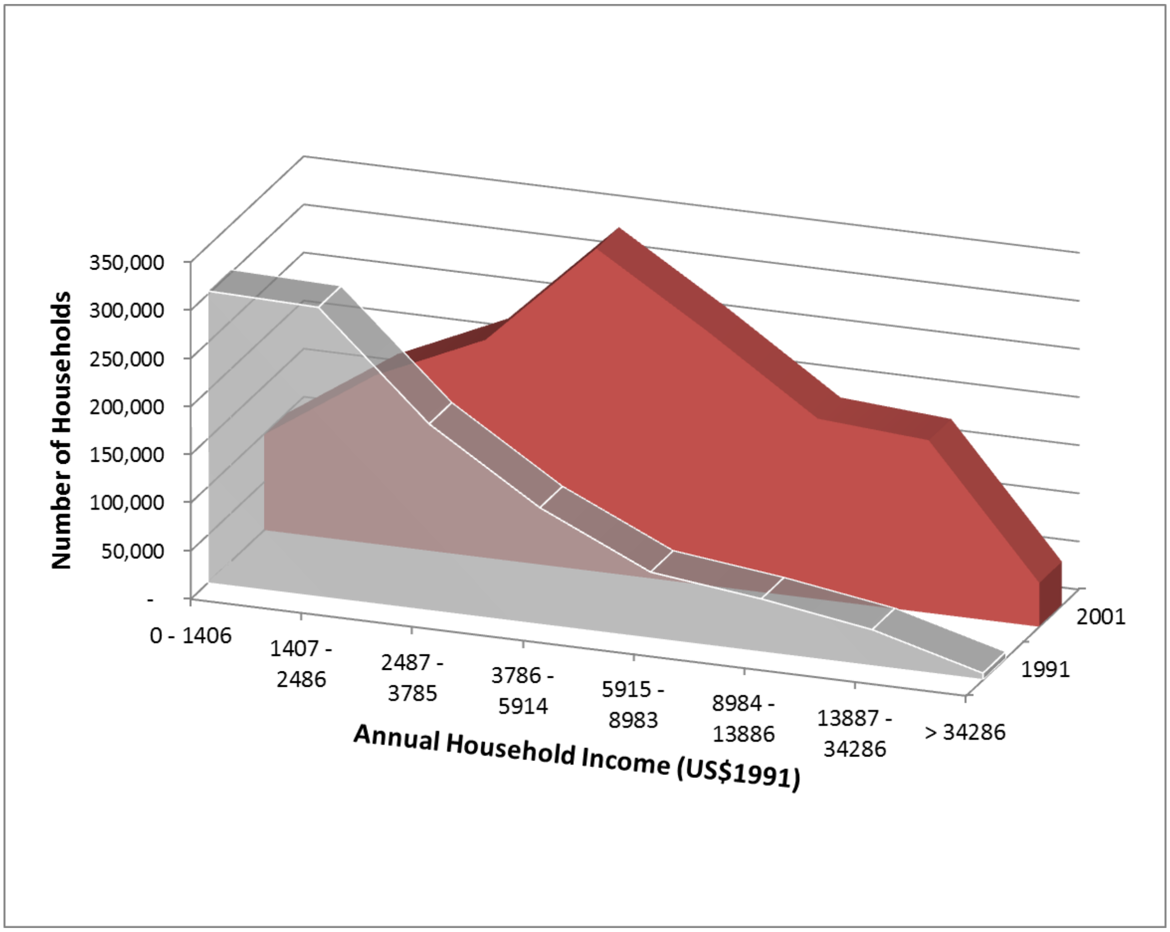

FIGURE 1 The Emergence of a "Middle Class City"?
Notes: Derived from household travel surveys provided to authors by SECTRA. The 1991 Origin Destination Survey reported household income by range. The 2001 survey values were deflated to 1991 pesos using the Chilean Consumer Price Index and converted to US$ at the 1991 average observed exchange rate.

Land Use and Transportation Characteristics: 1991 to 2001

In terms of physical structure, Santiago began experiencing accelerated urban expansion in the early 1980s, when the city-wide population density began declining more rapidly than in any other period of the previous 50 years, influenced by factors like road-building, low density suburban subdivisions, distant public housing projects, and industrial relocations (*19*). By the mid-1990s a new CBD emerged, 4.5 kilometers east of the traditional CBD, giving the city an emerging duo-centric business core, linked by a major commercial thoroughfare. Suburban office parks and increasing office development and shopping malls on the fringe were already apparent by 2001.

Residential dwelling characteristics largely match spatial income distribution patterns, with low income areas associated with high dwelling unit densities. The primary exception comes from the high densities of large apartment buildings in the traditional and eastern CBDs and apartments continuing to sprout up in the wealthier east. Land use mixes largely follow a radial pattern of the primary commercial arterials, with large swaths of areas with low land use mix across the city. The historical grid pattern street still predominates, until one gets fairly distant from the center of the city, most notably in the far Eastern foothill suburbs. Zegras (*18*) provides more detailed analysis of Santiago's urban structure, form and design. Urban growth in Greater Santiago is regulated by an inter-municipality land use plan; an update to the 1960 plan was approved in 1994; the 1994 was subsequently modified in 1997 to add 19,000 urbanizable hectares (approximately 35% of the metro area's urban area at the time) in the north of the metro area (*19*).

As would be expected, the city's changing socio-economic characteristics and physical form have impacted travel behavior in the city. The motorization rate (vehicles per 1000 persons) increased by over 4% per year over the period 1991-2001 (although in 2001 it still stood at only 20% of the US level and just 30% of Western European levels), while private motorized mode share increased even more rapidly (almost 7% per year) and public transport mode share declined (by 3% per year) (*6*). In 2001, Santiago still enjoyed remarkably ubiquitous bus service, while the Metro coverage was obviously more limited; not an insignificant fact, since for most periods of the day walking provides the primary means of Metro access and egress (*20*).

In the past 40 years, the Santiago bus system has changed dramatically. In the 1970s and 1980s service provision and fares were completely deregulated. The early 1990s brought the gradual re-introduction of regulation for road-based public transportation, producing incremental improvements in the quality of the bus system via the route concessions tendered in 1992, 1994, and 1998. The results included: reduced overall number of vehicles (from a high of approximately 14,000 in 1992 to 9,000 in 2000) (Figure 2), stabilized fares (see Figure 3), and improved service quality (*21*). Nonetheless, the system remained loosely regulated, marked by atomized ownership structure, competition in the streets for passengers, fairly unsafe operations, congestion and air pollution, and an important degree of collusion among the companies (*19*). Moreover, fares on the system were not integrated, neither between buses nor between buses and the Metro, making transfers expensive. By 1999, the bus system carried 4.7 million passengers per day (*22*) and operated without any direct government subsidy. Most recently, and perhaps most famously (and/or notoriously), in 2007 Santiago launched a massive and single-stroke reform of its public transportation system, known as *Transantiago*. As this reform occurred after the time period of interest to us, we do not detail it here. Interested readers should consult Muñoz and Gschwender (*23*).

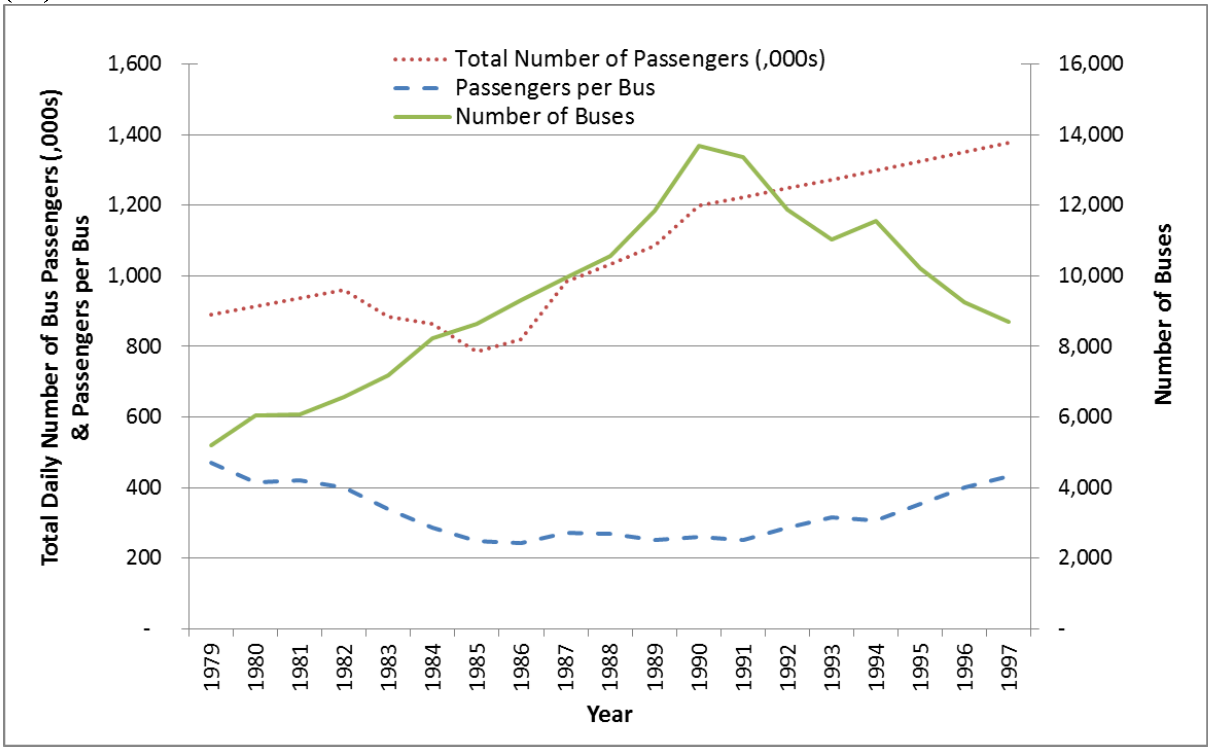

FIGURE 2 Bus Ridership and Fleet Growth During 1980s and 1990s

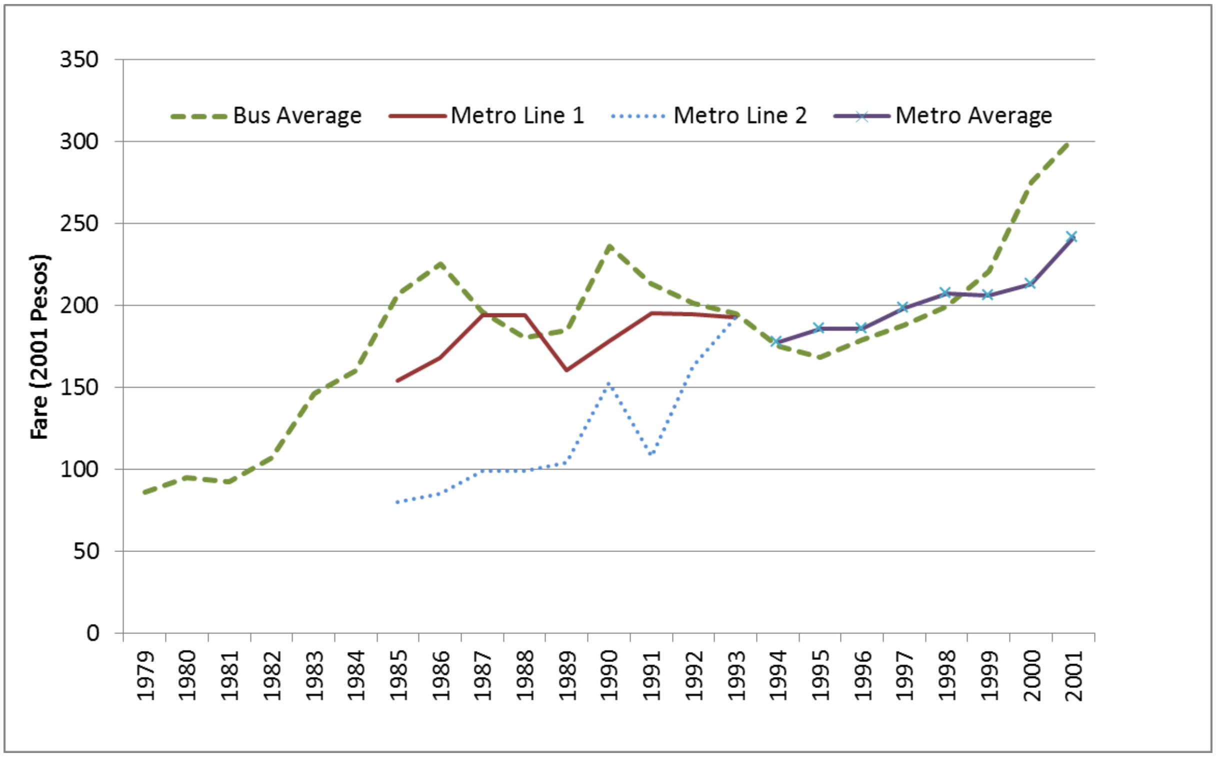

FIGURE 3 Evolution of Bus and Metro Fares in Greater Santiago: 1980s and 1990s (*21*).

Santiago's original two lines of Metro (urban heavy rail) were completed at the end of the 1970s, totaling approximately 27 kilometers and 37 stations. A third Line (known as Line 5) was brought into service in 1998 (see Figure 4) adding 13 kilometers and 15 stations. By 2001 the system carried an average 725,000 passengers per work day (*20*). In 1991 Metro lines 1 and 2 had two separate fares, and a transfer from line 2 to line 1 required an additional fee (Figure 3). In 1994, an integrated, differential fare for both lines replaced the separate fee system, which likely improved customer experience.

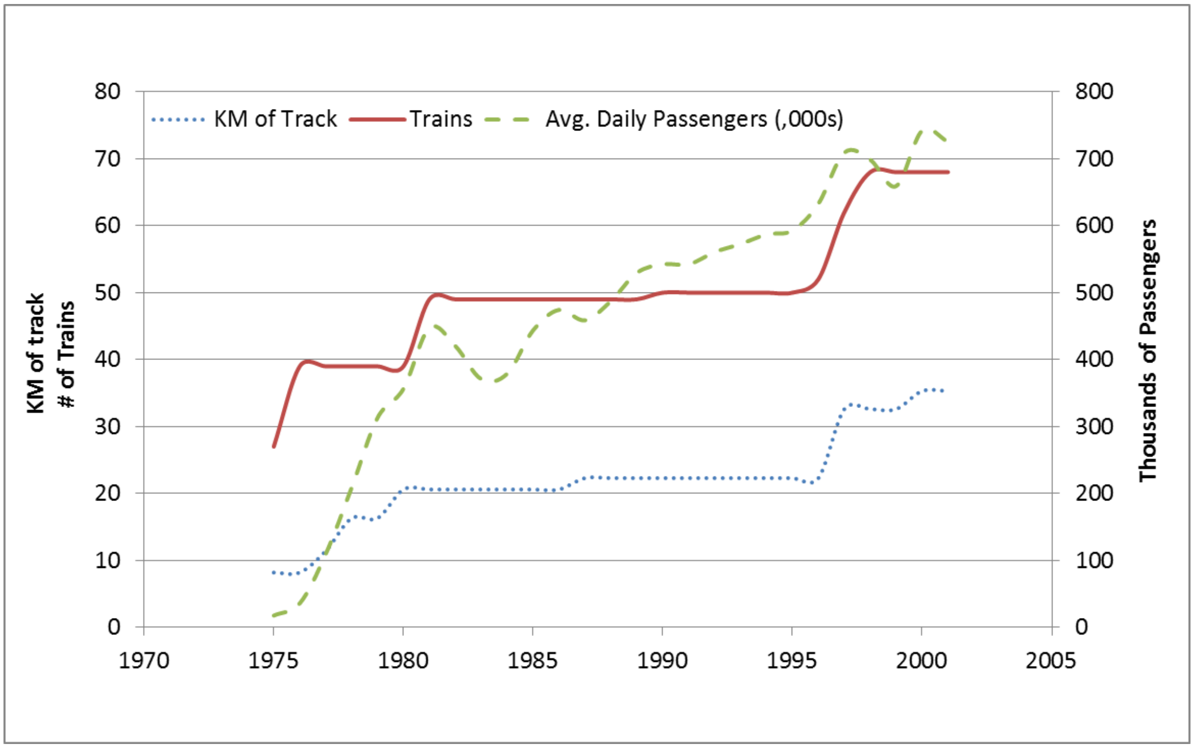

FIGURE 4 Metro Ridership and Infrastructure Growth in Time: 1970s to 1990s (*20*).

Despite a history of relative demand management-focused transportation planning, by the early 1990s, large-scale roadway upgrades began and by the late 1990s plans were in place for Chile's highway concessions program to bring large investments to highway upgrades and expansions in the city. Nonetheless, by 2001 none of the concessioned highways had yet entered operations. By one estimate, Santiago in 2001 had a slightly smaller share of its urban area dedicated to highways as Chicago in 1956 (2.1% versus 2.8%), when that city was just at the beginning of the massive highway investments that would come via the USA Federal highway investment program (*18*).

HOUSEHOLD MOTOR VEHICLE CHOICE IN SANTIAGO: 1991 VERSUS 2001

Data Sources

Data for this analysis come from the 1991 and 2001 household origin and destination (OD) surveys carried out for the national transportation authorities (SECTRA). The surveys benefit from consistency in implementation approach, team, and authority (*24*,*25*) and benefit from the long tradition of transportation engineering excellence in Chile. The 1991 survey was based on a randomly generated sample of approximately 32,000 homes surveyed in April, May and June (in total, 3% of Greater Santiago's households). The urban area included 34 *comunas* (municipalities) distributed over 420 km^2 (see Figure 4). The region was divided into 409 OD survey zones, ranging in size from 18 to 27,000 hectares, with an average of 478 hectares. The 2001 survey was based on a smaller sample of 15,000 households, of which 12,000 were surveyed during the normal work/school season and 3,000 during summer time (in total, 1% of household in the Santiago Metropolitan area). The urban area had also expanded to include 38 *comunas* distributed over 2,000 km^2, and further divided into 778 OD zones, ranging in size from 17 to 19,000 hectares with an average of 250 hectares.

Both surveys contained information on family size, reported income, and number of vehicles per household, as well as each family member's job status. In 1991 income was expressed in income categories; in 2001 the survey recorded reported monthly income. To minimize the differences between each data set, all 2001 incomes were deflated to 1991 values, using the official consumer price index for Chile, and assigned a corresponding income bracket from the 1991 survey. The household survey information was geo-coded to the OD zone level for the 1991 data, and to the center of each census block for the 2001 data. For this analysis, only OD zone level characteristics were considered, for consistency. Lastly, both surveys included expansion factors that related the characteristics of the sample population to Greater Santiago's actual population characteristics. These expansion factors were used to determine the number of dwelling units per OD zone in the dwelling unit density calculation.

Land Use Variables and Accessibility Proxies

A consolidated form of the 1991 and 2001 national tax records data is available on SECTRA's website (*26*). It aggregates all land-use to the travel model (*ESTRAUS*) zones and into 5 general categories (e.g., residential, commercial, educational), providing the m^2 of constructed area for each registered activity. This information was used to characterize land uses within the OD zones by joining the *ESTRAUS* zones to each year's corresponding OD zones.

Local land use mix was measured through a diversity index, following Rajamani et al. (*27*). The diversity index, DI, is calculated as:

$$DI = 1 - \left[\frac{\left|\frac{r}{T} - \frac{1}{5}\right| + \left|\frac{c}{T} - \frac{1}{5}\right| + \left|\frac{e}{T} - \frac{1}{5}\right| + \left|\frac{s}{T} + \frac{1}{5}\right| + \left|\frac{i}{T} - \frac{1}{5}\right|}{\frac{8}{5}} \right] \quad (2),$$

where:

r = square meters of residential floor space;
c = square meters of commercial floor space;
e = square meters of education floor space;
s = square meters of services floor space;
i = square meters of industrial floor space; and,
T = r + c + e + s + i.

This measure attempts to capture the relative mix of uses in a given zone: a value of 0 implies that the zone is single use, while a value of 1 indicates that the land is perfectly divided among all five uses. Theoretically, the mix of uses generates different transportation demands for the zone's residents; we would expect, all else equal, that higher land use mix would be associated with lower household vehicle ownership.

Lacking comparable transportation levels of service measures for the two years studied, we test relatively crude measures of accessibility: the household OD zone centroid's distance to the traditional CBD (in meters); and if the household OD zone centroid is within 500 meters of a metro station.

Although the city expanded outward considerably over the 1991-2001 period, and the 2001 household survey covers this broader expansion area, especially to the rapidly suburbanizing North. We restrict our analysis to a common geography, in order to isolate changes within the same area; we discuss the implications of this restriction below.

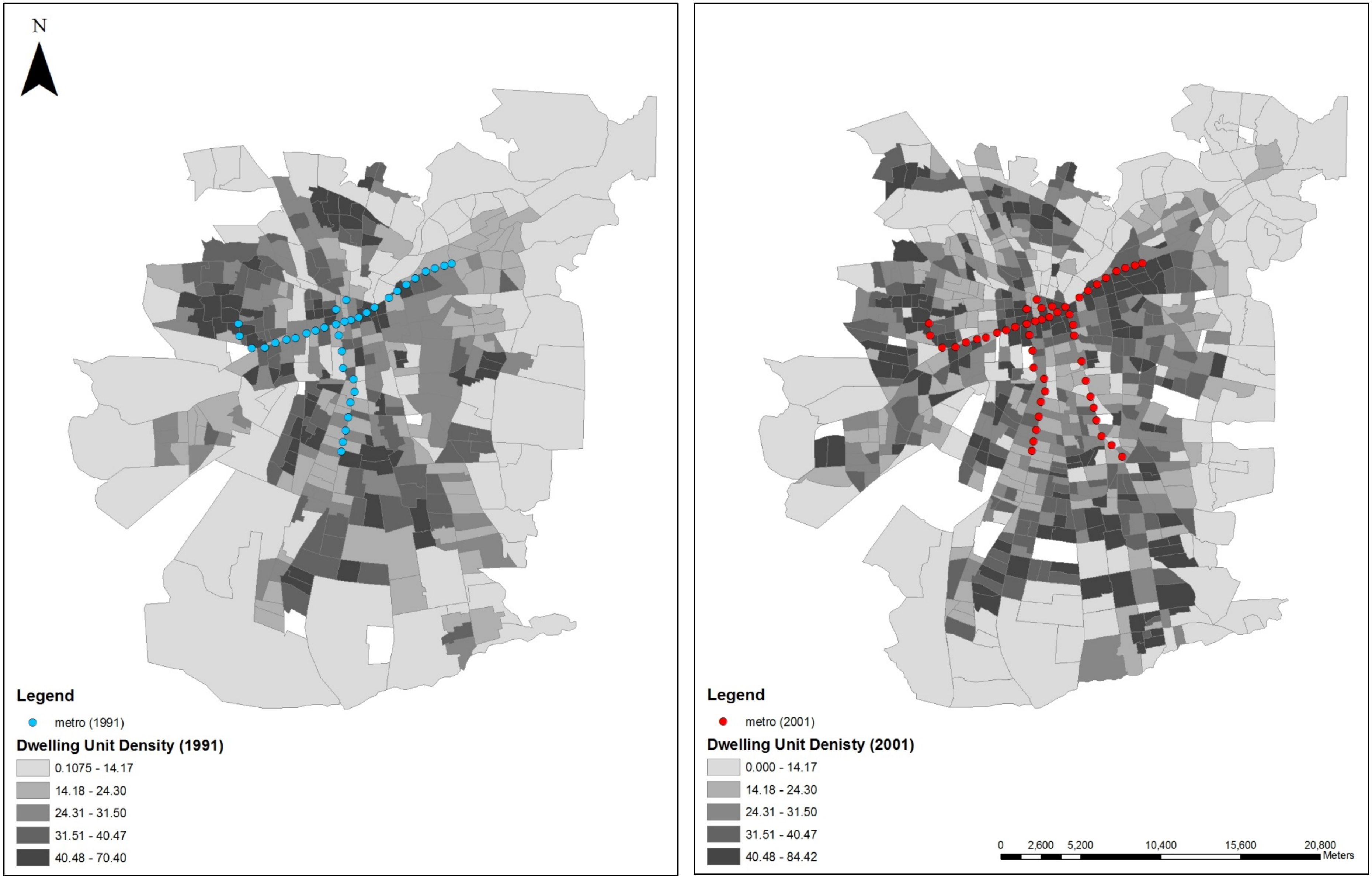

FIGURE 4 Modeled Areas in 1991 (left) and 2001 (right): OD Zones, Densities, and Metro Stations.

Data Summary

Table 1 presents the variables used in the models and their descriptive statistics. The data reveal the increase in household incomes and the larger concentration of households in the middle income groups (seen also in Figure 1). Consistent with this, the share of zero-car households decreased by 5%; the largest increase was in one-car households. Labor participation increased modestly as 0 worker and 1-worker households declined (consistent with increased women in the workforce), while 2 and 3 worker households increased. The number of children per household decreased slightly, with more households having one child in 2001 and fewer having three children.

TABLE 1 Variables, Definitions, and Descriptive Statistics

Variable	Description	1991 Mean or proportion	2001 Mean or proportion
#Autos	Autos per Household	0.48	0.54
	Household has 0 vehicles	63.10%	58.56%
	Household has 1 vehicles	28.20%	31.40%
	Household has 2 vehicles	6.90%	7.86%
	Household has 3+ vehicles	1.80%	2.18%
Household Monthly Income Category (1991 Pesos)	1 (0 to 41,000)	23.67%	6.76%
	2 ($41,001 to 72,500)	25.18%	12.09%
	3 (72,501 to 110,400)	16.94%	15.28%
	4 (110,401 to 172,500)	10.98%	21.46%
	5 (172,501 to 262,000)	6.50%	17.83%
	6 (262,001 to 405,000)	5.58%	12.19%
	7 (405,000 to 1,000,000)	3.90%	11.30%
	8 (> 1,000,000)	0.59%	3.08%
	9 (No Response)	6.67%	n/a
# Work	No. Workers	1.37	1.52
	0 Wkr HH	14.60%	11.10%
	1 Wkr HH	46.50%	40.54%
	2 Wkr HH	26.30%	33.48%
	3+ Wkr HH	12.60%	14.87%
# Child	No. Children	1.61	1.5
	0 Child HH	23.10%	24.23%
	1 Child HH	23.10%	27.12%
	2 Child HH	29.80%	28.84%
	3 Child HH	17.60%	13.84%
	4+ Child HH	6.40%	5.97%
Dist to CBD	OD Zone centroid meters to Plaza de Armas	9248.7	10044.5
.5 Metro	OD Zone Centroid w/in .5km Metro	13.00%	13.74%
DI	Diversity Index	0.24	0.20
Res Dens	DU per hectare	28.9	33.95

Note: 1991 data have 31,267 households and 409 zones; 2001 data have 15,537 households and 778 zones.

In terms of land use characteristics and relative location, the average zonal distance to the CBD increased by about 800 meters – households are moving outward even within the same geographical area.

Despite the expansion of the metro network, the share of zones within 500 meters of a metro station increased by less than one percent. Finally, average zonal density increased by 5 dwelling units per hectare, likely reflecting the growth in apartment building construction, particularly in the inner-Eastern parts of the city (see Figure 4); while average zonal land use mix slightly declined.

Model Estimations

We model the household decision to own 0, 1, 2, or 3+ vehicles via a multinomial logit (MNL) model and applying the stability of preferences test as described above. We first estimate two unrestricted models that allow for different parameters for each data set (first two columns in Table 2, Model A and Model B). We then combine the two datasets and restrict the coefficients to be identical, but allowing for different scale parameters for each data set (Model C, Table 2). The log-likelihood ratio test suggests, that although the variance differs, modestly, across the two data sets (significance of the scale parameter in Model C), the unrestricted (separate) models represent a better model fit than the restricted. This result suggests that preferences for household vehicle ownership have changed over the 10-year period. Comparing the differences between the model coefficients from 1991 and 2001 offers some indication of which variables have changed the most vis-à-vis relationship with the household vehicle ownership decision. Technically, to be fully comparable, the 1991 parameter estimates should be divided by the scale parameter estimate (1.13).

In most cases, the parameters carry the predicted signs and are statistically significant. Moreover, similar patterns exist between the parameters estimated in 1991 and those for 2001, indicating relative consistency in the data and analytical approach. Beginning with basic socio-economic characteristics, we see that higher income brackets have a positive and significant effect, as hypothesized. Higher income brackets also progressively increase the likelihood of owning multiple cars, which again, follows intuition. Generally, income had a stronger effect in 1991 than 2001, most notably in the lower income brackets; interestingly, although income was always positive and significant for 1991, in 2001 the lower-income brackets have less significance. This may, in part, be due to unobservable differences in the lowest income categories associated with 2001, which are a much lower share of the population than in 1991 (due to having to use the 1991 income categories for consistency across the two years). Household demographics also play largely expected roles, albeit apparently changing, in vehicle ownership. In both 1991 and 2001, for each number of children, the likelihood of owning more cars increases (i.e., parameters tend to increase across vehicle ownership categories for a given number of kids); for each vehicle ownership category, the number of children increases the ownership likelihood, although this effect plateaus. The general tendency is that the strength of the children effect declined from 1991 to 2001. The relationship between number of workers per household and vehicle ownership is more difficult to generalize. One worker had a positive association with owning one vehicle, but a negative one with owning two or three vehicles in 1991. In 2001, one worker had a positive relationship with owning one vehicle, but an insignificant one vis-à-vis owning 2 or more vehicles, and a negative, insignificant relationship with owning 3 vehicles. In both 1991 and 2001, the 3-plus worker variable had a negative effect on owning 1 vehicle, but varying relationships with owning 2, or 3+ vehicles. For 2 vehicles, 3-plus workers had a positive and significant effect in 1991, but a negative, though equally significant effect in 2001. For the 3+ vehicle choice, the positive relationship in 1991 becomes insignificant by 2001. More nuanced understanding of these relationships is necessary, possibly bolstered by qualitative analysis of vehicle choice processes within different household types.

With respect to the land use variables, land use mix had a negative relationship with all vehicle ownership categories in 1991 but this largely became insignificant by 2001, a result worth further examination. Dwelling Unit Density had a negative and significant effect on vehicle ownership in 1991 and 2001 as was hypothesized. The density effect increased in magnitude for the first vehicle choice, decreased for the second, and remained virtually unchanged for the third. Again, further examination is warranted.

Regarding the accessibility proxies that were used in this analysis, distance to CBD consistently associates with a higher likelihood of vehicle ownership, a relationship that strengthens with the number of vehicles chosen. In other words, households further away from the city center have higher likelihood of owning more cars. The quadratic of distance to CBD is also significant, however, suggesting a subcentering effect – households very far from the CBD have a lower likelihood of vehicle ownership. We tested various measures attempting to segment the distance to CBD effect by income category, but the more straightforward model implemented here proved the best model fit. Finally, the Metro effect, or lack thereof, is somewhat surprising. In 1991, no significant relationship between Metro proximity and household vehicle ownership emerges; in 2001, a marginally significant negative effect is detected for the 2 vehicle choice and a modestly significant and negative effect (on the order of having one child) is detected for the 3+ vehicle choice.

Limitations and Further Research

Our analysis faces a number of limitations which suggests cautions in interpretations and areas for further research. Most notably, the land use relationships identified may be a product of residential self-selection – meaning that households may choose their locations based on vehicle ownership preferences, at least in part. This may be confounding, for example, the strong distance to CBD effect detected. Future research should control for self-selection in these models, via, for example, joint residential and vehicle ownership models, or instrumental variables for the land use characteristics. In addition, the estimation process showed that the models were somewhat sensitive to the changing geographies over the two time periods – the emergence of distant suburbs in 2001 which were excluded from this analysis. Further research might examine various market segmentation approaches, both by income as well as by demographic and other household characteristics. One other promising path of research would more effectively control for transportation levels of service variations, although doing so would require historical data that might not be readily available. Furthermore, what we detect and call variation in preferences between the two model years may, in fact, be due to non-linear effects that are not captured by the null hypothesis of changes in the model coefficients. Finally, more work is clearly needed to understand the policy and planning implications of these model results.

TABLE 2 Motor Vehicle Ownership Model Results

	1-vehicle			*2-vehicle*			*3-vehicle*		
Attribute	**Model A, 1991**	**Model B, 2001**	**Model C, Combined and Scaled**	**Model A, 1991**	**Model B, 2001**	**Model C, Combined and Scaled**	**Model A, 1991**	**Model B, 2001**	**Model C, Combined and Scaled**
Income 2	0.418	0.0174	0.358	0.679	-0.501	0.553	0.725	1.12	0.733
	(9.16)	(0.13)	(9.09)	(4.42)	(-1.21)	(4.31)	(2.45)	(1.03)	(2.89)
Income 3	1.09	0.698	0.969	1.31	-0.267	1.1	1.11	0.763	1.05
	(23.33)	(5.86)	(21.74)	(8.65)	(-0.7)	(8.54)	(3.70)	(0.69)	(4.06)
Income 4	1.72	1.28	1.51	2.18	0.929	1.89	1.79	1.12	1.57
	(33.81)	(11.25)	(29.36)	(14.58)	(2.83)	(14.52)	(5.94)	(1.06)	(6.05)
Income 5	2.35	2.05	2.11	3.24	2.19	2.88	2.68	2.28	2.37
	(38.22)	(17.79)	(35.16)	(21.46)	(6.87)	(21.16)	(8.86)	(2.21)	(9.15)
Income 6	3.2	2.75	2.8	4.72	3.49	4.13	4.09	3.5	3.56
	(40.03)	(22.74)	(40.14)	(30.82)	(11.02)	(28.90)	(14.12)	(3.43)	(14.09)
Income 7	3.91	3.67	3.64	6.29	5.24	5.79	6.09	6.02	5.7
	(19.80)	(27.71)	(42.28)	(32.97)	(16.51)	(36.97)	(20.17)	(5.96)	(22.26)
Income 8	3.35	4.15	3.92	6.69	6.76	7.03	7.52	8.05	7.69
	(7.33)	(15.18)	(17.75)	(14.94)	(17.24)	(28.09)	(14.87)	(7.77)	(23.56)
Income 9	1.7		1.51	22.69		2.91	3.23		2.92
	(27.57)		(24.03)	(22.69)		(21.19)	(11.70)		(11.76)
1 Child HH	0.271	0.0754	0.178	0.72	0.307	0.516	0.689	0.558	0.578
	(6.35)	(1.27)	(5.65)	(8.30)	(2.67)	(8.13)	(4.06)	(2.49)	(4.67)
2 Child HH	0.44	0.347	0.36	1.08	0.581	0.802	1.26	0.802	0.981
	(10.86)	(5.90)	(11.73)	(13.26)	(5.19)	(13.26)	(8.18)	(3.72)	(8.54)
3 Child HH	0.37	0.348	0.316	1.02	0.642	0.788	1.55	0.976	1.23
	(8.01)	(4.88)	(8.93)	(11.24)	(4.99)	(11.58)	(9.62)	(4.21)	(10.09)
4+ Child HH	0.232	0.2	0.192	0.874	0.73	0.713	1.33	1.03	1.09
	(3.54)	(2.04)	(3.86)	(7.02)	(4.42)	(7.85)	(6.40)	(3.79)	(7.25)
1 Worker HH	0.135	0.404	0.178	-0.272	0.0832	-0.195	-0.323	0.00319	-0.246
	(4.46)	(8.82)	(7.61)	(-4.45)	(0.94)	(-4.26)	(-2.65)	(0.02)	(-2.7)
3+ Worker HH	-0.0409	-0.639	-0.214	0.48	-0.724	0.0774	1.03	-0.0262	0.631

	(-0.86)	(-9.96)	(-5.95)	(6.77)	(-7.38)	(1.47)	(9.33)	(-0.17)	(7.73)
Diversity Index	-0.421	-0.215	-0.332	-2.54	-0.518	-1.42	-2.23	-0.415	-1.34
	(-2.07)	(-1.33)	(-2.82)	(-6.4)	(-1.71)	(-6.33)	(-3.19)	(-0.77)	(-3.4)
Distance to CBD	6.10E-02	9.04E-02	5.51E-02	6.84E-02	2.33E-01	1.12E-01	0.0642	0.334	0.119
	(3.69)	(4.42)	(4.86)	(2.05)	(5.81)	(4.91)	(1.06)	(4.27)	(2.83)
Distance to CBD^2	-3.80E-03	-4.09E-03	-3.20E-03	-5.94E-03	-1.05E-02	-6.79E-03	-6.88E-03	-1.51E-02	-7.91E-03
	(-5.36)	(-4.86)	(-6.59)	(-3.95)	(-6.13)	(-6.67)	(-2.47)	(-4.49)	(-4.17)
< 500 m to Metro Station	-0.0313	-0.0835	-0.0102	0.115	-0.209	0.0234	0.0631	-0.458	-0.0562
	(-0.67)	(-1.21)	(-0.28)	(1.37)	(-1.68)	(0.37)	(0.43)	(-1.85)	(-0.49)
Res Density	-0.00406	-0.00675	-0.00464	-0.0278	-0.0195	-0.0227	-0.0404	-0.0338	-0.0352
	(-3.61)	(-5.38)	(-5.94)	(-11.93)	(-7.87)	(-14.05)	(-9.35)	(-6.96)	(-11.67)
Scale			1.13						
			(4.74)*						
Log-Likelihood	-22742.48	-11228.4	-34132.821						

Model C - Chi-Square Test: -2(-34132.821-(-22742.48-11228.40)); Chi-Squared with 18 d.f. = 323.882; Critical Value = 28.90

Notes: 2nd row within each variable represents the robust T-Statistic; ASCs are not included in the interest of space; This table includes original coefficients; to compare the values between 1991 and 2001 the 1991 coefficients would need to be adjusted by the scale factor coefficient 1.13

CONCLUSIONS

We examined whether household vehicle ownership preferences have changed over a 10-year period in a rapidly developing city that has undergone important transportation system, urban development, and income changes. Our results demonstrate that preferences influencing vehicle choice models have, in fact, changed. The results suggest some interesting variations in relative influences among socio-economic and demographic factors and land use and locational variables. Among lower income groups, the models show a decreasing tendency for vehicle ownership, possibly due to improvements in public transportation during the 1990s in Santiago. The improved overall quality of service may have been notable enough to allow the lowest income brackets to prefer to depend on transit for their mobility needs.

Among the land use variables, we see countervailing changes – on the one hand, the influence of land use mix, while still negatively correlated with vehicle ownership, declines over time. The opposite trend appears in the case of distance to CBD. The effective of residential density changes modestly, while a slight proximity to Metro effect appears to emerge for the three vehicle choice by 2001.

The results suggest that household preferences for vehicle ownership are dynamic over time and that they respond to the rapidly developing and evolving environments around them. Nonetheless, the research raises a number of questions and areas for further investigation, including the role of self-selection, more effective treatment of potential market segmentation, and assessment of policy and planning implications.

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