The Built Environment and Motor Vehicle Ownership & Use: Evidence from Santiago de Chile

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ABSTRACT
This paper examines the role that the built environment – both micro-scale “neighborhood” design characteristics and meso-scale relative location – play in influencing motor vehicle ownership and use in a rapidly motorizing, developing city context: Santiago de Chile. The paper first answers the question, what role, if any, do factors such as dwelling unit density, land use mix, street design, and proximity to public transportation stations play in determining household motor vehicle ownership? The question is answered by specification and estimation of a multinomial logit model of vehicle choice. The paper then turns to a second-stage question: what role does the built environment play on household automobile use? This question will be answered by specification and estimation of an ordinary least squares regression model, predicting the amount of total household automobile use (measured by distances traveled on a given day). The two models are explicitly linked via the use of the “selectivity bias correction factor.” The implications of the findings for planning and design are discussed.

INTRODUCTION
After more than 50 years of research and analyses, questions about the quantifiable influence of the built environment on travel behavior remain and active research in the area continues. Numerous reviews of this research exist as does at least one attempt, by Ewing and Cervero, to generalize the results in the form of elasticities of vehicle trips and vehicle distances traveled (*1*). Generalizing this research, despite Ewing and Cervero’s ambitious effort, remains a challenge, due to: variations in the scale of analysis – that is, isolating meso-level relative location effects versus micro-level, “neighborhood” effects; different types of built environment measures used (population density, dwelling unit density, entropy measures of land use mixes, etc.); variations in areal scales of measurement (and potential effects related to the Modifiable Areal Unit Problem, see *2*); differences in travel behavior data used (spatially aggregated versus disaggregate individual/household); differences in analytical approaches and control variables employed; and, differences in the ultimate outcomes measured (trip frequencies, mode choices, distances traveled, etc.).

The great part of this research base focuses on the industrialized world. Yet – with massive increases in motorization and urbanization – cities in the so-called developing world may stand to gain the most from efforts to modify urban development patterns to change travel behavior. Developing country-specific research in this area, however, remains limited. In this context, this paper presents models of household automobile ownership and automobile distances traveled for a rapidly developing city, Santiago de Chile. The focus on vehicle distances traveled (i.e., VKT or VMT), as opposed to trip frequencies, substitution rates, or mode choices, is important since automobile travel distance is often identified as an important indicator of transportation performance (e.g., *3*,*4*).

Many relevant research precedents exist. Beesley and Kain (*5*), for example, using aggregate data from 45 U.S. cities in 1960, developed a regression model to predict automobile ownership as a function of median household income and gross city-wide population density. In 1980, Cheslow and Neels (*6*) provide one of the first studies to explicitly recognize and attempt to quantify “neighborhood scale” (p. 77) effects (measured at the traffic analysis zone) together with meso-level effects (distance to CBD), using zonally aggregated data. They find significant effects of local-level densities as well as distance to CBD on automobile distances traveled. Miller and Ibrahim (*7*), using zonally-aggregate data from Toronto, Canada, find distance from CBD to be the most important variable explaining VKT per worker. Holtzclaw et al (*8*) use aggregate data from three U.S. cities to claim an apparent universal influence of residential density (measured by households per acre) on vehicle ownership and use. The latter three analyses do not include household income effects.

Using disaggregate-level data to measure <u>vehicle ownership</u>, Cambridge Systematics find significant effects of population density in an ordered logit model of household vehicle availability for Philadelphia (*9*) and find significant effects of dwelling unit densities in a multinomial logit model of vehicle availability in San Francisco (*10*). Hess and Ong (*11*) find a significant effect of land use mix on household auto ownership in Portland Oregon. Kitamura et al (*12*) find some evidence of residential density influencing autos per household member in Southern California. Using the 1990 U.S. Nationwide Personal Transportation Survey, and city-wide measures of urban form and structure, Bento et al (*13*) find increased sprawl (developed as a Gini-coefficient, ranking census tracts by distance from CBD) to increase vehicle ownership trends, but confounding effects of density and land area. In terms of vehicle use, Cervero and Kockelman (*14*), find that local built environment measures (including street network characteristics, building type, land use mix, and block type) exhibit significant effects on non-work VKT, but to exert no measurable influence on total household VKT.

In estimating household vehicle use, at least one econometric correction needs to be made, to account for the fact that the households for whom vehicle use is measured may have specific reasons for using their vehicle intensively. These unobserved characteristics can bias estimates. Train (*15*) and Mannering (*16*) offer the first examples of using the necessary econometric correction for predicting household motor vehicle use, but do not include variables specifically related to the built environment. Kitamura et al (*12*) use a similar modeling approach, including some measures of local built environment and meso-level relative accessibility. Bento et al (*13*) also employ the correction, linking ownership and use models at the city-wide level using the NPTS data. This paper builds on the established research base to estimate – for the Santiago case – linked models of automobile ownership and use, utilizing meso-level measures of relative location and micro-level measures of urban design and disaggregate individual/household data from a 2001 household travel survey.

EMPIRICAL CASE: SANTIAGO DE CHILE

Santiago, despite rapid economic growth over the past two decades, continues to exhibit motorization rates that, relative to the industrialized word, lean much closer to the dense Asian cities than Europe or North America. Somewhat surprisingly, perhaps, this comparatively low motorization rate seems to hold relative to Santiago's "peer" cities as well (*17*). In the latter case, it is not clear whether the apparently lower motorization comes from vehicle costs (due to, perhaps, stricter vehicle emission standards and/or restrictions on used vehicle imports), income distribution and relative purchasing power across all households (e.g., *18*), Santiago's built urban environment, and/or other factors (including inevitable data quality differences across different cities).

Santiago's economic growth, together with changing demographics and land use patterns have contributed to notable changes in basic travel behavior and related influencing factors, based on analyses of data from the 1991 and 2001 origin-destination surveys (*19*). Auto mode share increased at a rapid pace between 1991 and 2001, virtually identical in rate to motorization (6.8% and 7% per year growth rates, respectively). This brought a concomitant decline in public transport mode share, although in total by only half the rate of auto use increase; this result indicates that auto use is increasing total mobility – eating away at public transport mode share, but also inducing new travel, on average. Total trips by both bus and Metro continue to increase, but at a rate slower than population growth. In 2001, Santiago still enjoyed remarkably ubiquitous bus service, while for the Metro coverage was obviously more limited; not an insignificant fact, given the fact that for most periods of the day walking is the primary means of Metro access and egress (*20*). The survey data reveal, somewhat surprisingly, a consistent increase in the share of walking trips. Some of this increase may derive from survey methodology differences, but could also result from other social and behavioral changes (e.g., increased comfort in public spaces), some of which might even be attributable to changes in built environment. The data also reveal a clear increase in discretionary travel; while the trip rate for school and work remained nearly the same, the total trip rate increased, as we would expect given income growth. Some of the changes between the two survey years may also be attributable to improved survey methodology.

Direct Research Precedents

For the case of Santiago, several relevant analyses into the influence of built environment on travel behavior exist. As previously summarized (*21*), aggregate, Municipal-level regression analyses using the 1991 survey data revealed little evidence of population density on Municipal mode share or walking trips, although the municipal-wide density measure is a gross built environment proxy. In an earlier analysis of the 1991 travel survey data, I followed the Boarnet & Crane (*22*) approach to assess the influence of three gross measures of urban form on travel behavior in Santiago (*21*). Specifically, controlling for socioeconomic and demographic factors and trip cost variables at the scale of the traffic analysis zone, I looked at the influence of population density, relative share of commercial and service land uses, and relative share of vacant land on an individual's propensity to make home-based, non-work, non-school (HB NWNS) walking trips. The model results suggested that an increased share of commercial and service uses in the zone of trip origin increases the likelihood of making HB NWNS walk trips, while vacant land intensity decreased the probability. Somewhat surprisingly, population density in the zone of origin had no significant effect. Overall the models had little explanatory power, suggesting possible mis-specification and/or poor measures of land use.

Finally, and most recently, Donoso et al (*23*) carried out an analysis of the potential role for land use to influence travel behavior with the express purpose of reducing greenhouse gas (GHG) emissions in Santiago. The study utilized the 2001 travel survey as well as the 2001 land use cadastre in developing an integrated suite of models to simulate transportation and land use market equilibriums and to identify "optimum" land use patterns (with the goal of minimizing GHG emissions). The model focused primarily on meso-level, relative location effects. The analysis suggested several useful extensions, including: extending the analysis to account for off-peak travel and weekend travel; assessing more thoroughly the degree to which *micro*-level urban design might influence travel behavior; developing a vehicle ownership model that also reflects sensitivities to land use variations; among others.

Data Sources

Travel Data
Travel data for this analysis come from the 2001 household origin-destination (OD) survey carried out for national transportation planning authorities (SECTRA). The survey was based on a randomly generated sample of fifteen thousand households: 12,000 surveyed during the "normal season" and 3,000 during the summer time (in total, 1% of Greater Santiago's households). The urban area included 38 *comunas* (municipalities) and was broken down into 779 traffic analysis zone (TAZ), ranging in size from 17 to 19,000 hectares, with an average of 250 hectares. The survey included all trips in the public space taken by all household members (regardless of age), for 13 trip purposes, by 28 different travel modes (e.g., auto driver) or combination of modes (e.g., auto passenger-Metro). The survey contains information on individual educational level, job status, household income (actual reported or estimated), etc. The household information is geo-coded at the center of the census block (nearly 50,000 blocks, average size 1.5 hectares), while the trip origin and destination information is geo-coded at the nearest street corner (or, sometimes, census block). The time of trip departure and arrival is also included. Additional detail on the survey techniques and results can be found in Ampt and Ortúzar (*24*).

Land Uses and Measures of the Built Environment
The land use data come from year 2001 national tax records and business and land use permits (as reported to Municipal governments) and include information (e.g., type of use, floor space constructed) for roughly 1.3 million residences and 400,000 non-residential land uses, geo-coded at the street address level or sometimes the census block level. Land uses included 17 general categories (e.g., residential, manufacturing, public administration), for each registered activity, information included the constructed floor space and the relevant plot size. Additional measures, including street widths, intersection densities, block morphology, etc. were derived from digital block maps and street center-line maps. For this analysis, the data were aggregated to the TAZ, except for household relative location measures (distance to CBD and Metro stations), which was measured from the households census block centroid (additional details on built environment variable construction can be found in *17*).

Most of the built environment measures used are fairly straightforward. However, to measure local land use mix, a land use dissimilarity or diversity index is used, following Rajamani, et al. (*25*). The measure aims to capture the mix of uses relative to a perfect distribution of uses. In this case, the index includes six different land uses, measured by built floor space:

$$DI = 1 - \left[\frac{\left|\frac{r}{T} - \frac{1}{6}\right| + \left|\frac{c}{T} - \frac{1}{6}\right| + \left|\frac{h}{T} - \frac{1}{6}\right| + \left|\frac{o}{T} - \frac{1}{6}\right| + \left|\frac{p}{T} - \frac{1}{6}\right| + \left|\frac{s}{T} - \frac{1}{6}\right|}{\frac{5}{3}} \right] \quad (1),$$

where:
r = square meters of residential floor space
c = square meters of commercial floor space
h = square meters of health floor space
o = square meters of office floor space
p = square meters of public administration floor space
s = square meters of social services floor space and
T = r + c + h + o + p + s

A value of 0 for this index means that the land in the area has a single use and a value of 1 indicates perfect mixing among the six uses.

HOUSEHOLD MOTOR VEHICLE CHOICE IN SANTIAGO

Theory suggests that the choice to own an automobile would be influenced by where we live: both micro-level design factors and meso-level locational relativity. At the micro level, factors such as parking hassle, the relative utility of having a vehicle (i.e., convenience of alternative travel options) would influence auto ownership choice. What role, if any, do these influences have in rapidly motorizing Santiago?

Model Specification, Estimation, Results

To determine what influence the built environment has on motor vehicle ownership, I estimated a multinomial logit model (*26*) of motor vehicle choice by household. The alternatives available to a given household are zero, one, two, or three (or more) motor vehicles. An incremental model specification approach was taken. The basic model included only household socioeconomic and demographic characteristics, with transportation performance characteristics (zonal level accessibility; equation 2, below) then added, and, finally, meso- and micro-level built environment characteristics included. Only variables that were significant at greater than 95% and that increased the model goodness of fit (as measured by the likelihood ratio test) were retained in the final model specification.

Accessibility in the Motor Vehicle Choice Model

Theoretically the relative convenience of alternative travel options may well influence the utility an individual or household derives from vehicle ownership. All else equal, a household that can more easily access other desired destinations without using an automobile will have less use for one. Therefore, that household’s probability of auto ownership will be lower. Several different ways of measuring accessibility exist (see Geurs and van Wee (*27*) for a good recent review). For the motor vehicle ownership model, I use a traditional, Hanson-type gravity measure whereby accessibility represents a theoretical measure of a household’s potential access to all other relevant locations in the city:

$$A_i^m = \sum_{j \in L} w_j \, f_{ij} * 100 \quad (2),$$

where:

A_i^m is the accessibility measure for mode *m* in zone *i*,

L is the set of all zones,
w_j is zone *j*'s share of all *W*,
W is the total square meters (constructed floor area) of commercial and services, health, manufacturing, offices, social and community services, public administration, indoor sports facilities, and housing; and, the total square meters (land area) of parks and outdoor sports facilities,

f_{ij} is exp($-bTT_{ij}^m$),

TT_{ij}^m is the travel time for mode *m* from zone *i* to zone *j*, and

b is a parameter representing travel time sensitivity.

For this case, only travel times for automobile and bus were estimated. Inter-zonal travel times come from an ESTRAUS model run (Santiago's travel forecasting model) provided by SECTRA for the year 2001, AM peak period. For bus, the travel time included in-vehicle time, access and egress time and wait time. In rigor, the b parameter should be empirically derived from a trip distribution model. In this case, a value of 0.4 was used (*28*). Within zone opportunities were not included in the accessibility metric due to the unavailability of relevant travel times. However, as several land use measures from the household's home zone were included in the model, these serve as proxies for local level accessibility.

Model Results

Table 1 presents the model results. The parameter estimates, in all cases but one (discussed further below), carry the expected signs and are highly statistically significant and the model displays a high goodness of fit as measured by the rho-square value. The parameter estimates (the "Beta" column for each vehicle choice) are not directly comparable within each choice bundle, but they are comparable across bundles. In other words, one cannot directly compare the influence of, for example, household income with dwelling unit density in the household probability of owning two vehicles by simply looking at the relevant "Betas." One can, however, use the "Beta" values to compare the influence of the relevant variable <u>across</u> vehicle choice decisions (as clarified in the discussion below). To compare the influence of the different variables <u>within</u> each choice set decision, Table 1 also presents a statistic analogous to the standardized coefficient value from a traditional ordinary least squares regression (following Levine (*29*)). The statistic is calculated by multiplying the variable's "Beta" value times the standard deviation of the variable within the choice set. This "relative importance" statistic indicates the relative contribution of the variable to the choice process since this contribution comes from the size of the "Beta" value and the variation of the relevant variable. The measure provides two advantages over the conventional multinomial logit elasticities: (1) it is constant over the range of the variable and (2) it includes information on the variation of the independent variable across the choice set (*29*).

Starting with basic household socio-economic characteristics, we see the expected effect of household income; the effect is positive and increasingly influential with the decision to own multiple vehicles (comparing across the "choice bundle" of number of motor vehicles to own). Looking at the relative importance of household income (columns labeled D in Table 1), this variable dwarfs all others. This confirms our expectation that as soon as income allows, at least one vehicle in a household is almost a certainty. The variable adults per household presents slightly strange results. The variable only entered significantly into the decision to own one or three or more vehicles and in both cases is the next most influential variable. However, in the one vehicle ownership case, the effect is negative, meaning all else equal, the probability of a household owning 1 vehicle (relative to zero), declines with an increased number of adults in the household. I cannot come up with an intuitive explanation for this result. On the other hand, the number of persons per household exhibits a roughly comparable, positive influence on the decision to own one or two vehicles, but is negative in the case of three or more vehicles. This latter result may reflect the fact that, *all else equal*, as the household size increases the attractiveness of owning many vehicles declines due to household budgetary constraints (i.e., more money is required to clothe, feed, etc. the household members, reducing possible vehicle expenditures).

TABLE 1 Multinomial Logit Model of Household Motor Vehicle Choice

Variables	0 Veh. (base)	1 Vehicle			2 Vehicle			3+ Vehicle		
		Beta	**T-test**	**D**	**Beta**	**T-test**	**D**	**Beta**	**T-test**	**D**
Household Characteristics										
HH Income		0.17	27.82	1.98	0.21	28.31	4.42	0.23	26.67	7.39
Adults per HH		-0.14	-5.78	-0.17			n.a.	0.70	9.70	1.05
# Persons in HH		0.06	3.61	0.09	0.06	3.18	0.10	-0.28	-4.57	-0.55
Transport Characteristics										
Auto:Bus Accessibility Ratio[a]		0.07	4.32	0.09	0.09	2.67	0.12	0.09	2.67	0.13
Meso- and Micro BE Characteristics										
Live in Apartment[b]		-0.42	-7.55	-0.17	-0.72	-6.55	-0.28	-1.27	-5.52	-0.41
Dwelling Unit Density[c]					-0.01	10.34	-0.61	-0.02	-7.78	-0.92
Diversity Index[d]					-3.71	-7.86	-0.38	-6.90	-7.33	-0.61
Distance to CBD (KM)					0.03	3.21	0.12	0.03	3.21	0.11
Constants		-2.01	-23.98		-3.27	-14.70		-4.82	-11.96	
Chosen Observations	8632	4662			1135			300		
% of Observations	59%	32%			8%			2%		

Notes: all variables included significant at > 95%; Sample Size: 14729; Null Log-Likelihood: -20418.7; Final Log-Likelihood: -11207.7; LR Test: 18422; Rho-Square: 0.451. When a cell in the table is blank, it means that variable was not included in the choice's relative utility function. When a parameter value is the same across choice sets (in the case of the ratio of auto to bus accessibility and distance to CBD for 2 and 3+ vehicle choices), a single parameter was estimated for the two choices (this proved to be the best model specification). D represents a measure of relative importance, similar to a standardized coefficient. See text description. (a) Entered as Ln(auto accessibility/bus accessibility, with accessibility calculated from equation 2; (b) dummy variable = 1, if household lives in an apartment; (c) # of dwelling units per hectare of constructed area; (d) as calculated by equation 1.

Turning to the relative accessibility, we see a positive effect of the auto-to-bus accessibility ratio, an effect fairly comparable across the choice sets. The modal accessibility variables were tested independently also (i.e., auto accessibility, bus accessibility), however (the log of) the ratio of the two variables (representing relative attractiveness of auto) proved to be the best model specification. The effect of this variable does not differ across the choice of 2 or 3+ vehicles. When a household lives in a zone with poor bus accessibility relative to auto accessibility, the household's probability of auto ownership increases. Finally, looking at the built environment characteristics, we see that, with the exception of the effect of apartment living, the built environment exhibits no influence on the probability of a household owning at least one vehicle. As the choice becomes to own more than one vehicle, however, we discern a built environment influence, specifically dwelling unit density, the diversity index and the rough meso-level variable of distance to CBD. In zones with a high diversity index, the probability of owning two or three vehicles declines, with the effect increasing as the choice becomes owning more vehicles. The same can be said for dwelling unit density and apartment living. The influence of these variables on auto ownership may partly reflect reduced need for auto ownership (e.g., a high mix of local uses, represented by a high diversity index, means less need for automobiles). These variables may also represent some degree of auto ownership hassle and cost. In the case of apartment dwelling, for example, the issue of vehicle garaging plays a role. Dwelling unit density (in this case, measured as number of dwelling units per amount of total constructed space, in order to account for the fact that some zones may have a very large amount of undeveloped land, but with very dense developed areas) also reflects some amount of land scarcity for vehicle storage. Other built environment variables, including block morphology and intersection density (3- and 4-way) were tested, but showed no discernible influence. Household distance to the nearest Metro station was also included, but proved to be insignificant after including other meso-level characteristics.

Discussion

Overall, the model offers an interesting glimpse at the factors influencing the household vehicle ownership decision. As we might expect, household income dominates the choice process. Nonetheless, some role of the built environment (as well as relative transport levels of service) can be detected, particularly when the household choice is to own two or three or more motor vehicles. It is interesting to compare the results with similar types of models estimated in the United States. For example, Hess and Ong (*11*), using an ordered logit model of the household decision to own no automobiles in Portland Oregon, find a significant and positive effect of TAZ land use mix (entered as a dummy variable for “good” land use mix). Cambridge Systematics (*9*) reports significant effects of population density and a public transport-to-highway access ratio in an ordered logit model of household vehicle availability in Philadelphia. Using a multinomial logit model, Cambridge Systematics (*10*) estimated a vehicle availability model for San Francisco, also finding significant effects of a public transport-to-auto accessibility ratio for two or and three or more vehicles, significant effects of dwelling unit density for all three vehicle choice options, and nearly significant effects for a “vitality index,” again for the two and three vehicle choice decision. Kitamura et al (*12*), on the other hand, while finding some evidence of residential density influencing autos per household member, find no significant influence of regional accessibility measures (transit or auto; they do not, however implement a relative accessibility ratio), leading them to conclude that in a highly motorized region like Southern California accessibility may have marginal, if any, effects.

That the model estimated for Santiago produces results somewhat similar to several models for households in US cities is interesting in itself; despite motorization rates roughly 20% of US levels and much more rapid growth in the motor vehicle fleet, an effect of relative transportation levels of service and local land use characteristics can be detected. Any indications for policy related to land use planning and urban design influences need to be cautious and not overly optimistic, however. First, income still clearly dominates the ownership decision. Second, certain factors, such as the effect of apartment living, are not necessarily land planning policy variables, per se. This is particularly the case if we consider that this model does not account for potential self-selection: the fact that some households may choose their location (e.g., apartment and/or area with a high diversity of land uses) because of a preference for not wanting to own more than one automobile. At the same time, the model results do suggest that the built environment and relative accessibility should be incorporated into travel forecasting for Santiago; something which currently (to the best of my knowledge) does not happen in the city. Planning authorities currently utilize a household type approach (i.e., cross-classification) for forecasting auto ownership categories; no spatial variation in ownership is apparently accounted for. Such an approach could bias modeling results and policy analysis in ways even as simple as regulations regarding parking requirements for residential developments. The results presented here suggest more resolution in analysis could be valuable.

HOUSEHOLD VEHICLE USE

After household vehicle ownership is determined, how much automobile use will the vehicle-owning household undertake? Does the built environment have an influence on automobile use?

Model Specification

To assess the influence of the built environment on household motor vehicle use, I estimated an ordinary least squares regression, predicting total automobile use per auto-owning household. The dependent variable in this case was derived based on all auto-driver trips undertaken by the household on the day of the survey. The trip distance was derived from the geo-coded trip origin and destination and the shortest path on the road network. Trips with no derivable distance (due to lack of a geo-coded origin and/or destination) were assigned a dummy variable which was used as one of the dependent variables, with the expectation that the presence of such trips in the household would exert a downward influence on total auto distances traveled. Whether the auto trip was "external" to the study area was also coded and included as an independent variable, but it had no significant explanatory power.

As mentioned in the introduction, specifying and estimating such a model requires an important econometric correction to be theoretically consistent. Dubin and McFadden (*30*) lay out the relevant theoretical framework, in the context of a household's choice for electric appliance ownership (a discrete choice) and electricity consumption (a continuous choice). The basic bias in such a model system comes from the fact that the ordinary least squares regression to estimate vehicle use is actually conditional on the vehicle choice (the discrete choice). This bias, known as selection bias, can be easily understood in the following way. The model used to estimate vehicle use can be estimated only for households who choose to own a car; those households may have specific (unobserved) reasons for using their vehicle intensively. Thus, we are estimating the vehicle use model on a sample that may be biased towards high usage households. Technically speaking, the error term in the least squares regression may be correlated with variables that influence the vehicle choice probability, thereby violating a basic assumption of least squares regression (i.e., the expected value of the error term to be zero). This "selectivity bias" can be corrected in the ordinary least squares regression of vehicle use by incorporating for each household a selection bias correction factor that is directly derived from the vehicle ownership model (estimated above). Dubin and McFadden show the approach to be consistent with utility maximization; Train (15) offers a clear and comprehensive exposition and example application as does Mannering (*16*). The selectivity bias correction factor takes the basic form of a ratio of the relevant multinomial logit choice probabilities (*16*), $(1/K)\sum_{k\neq i}^{K}[P_k \ln P_k /(1-P_k)+\ln P_i]$, where K is the total number of alternatives and P_k is the predicted probability of choice k. This correction factor enters as an independent variable in the vehicle usage (continuous choice, ordinary least squares) model.

Estimation and Results

Similar to the vehicle choice model, an incremental approach was employed, starting with household socio-economic and demographic characteristics, and then adding measures of the built environment. Ultimately, several built environment variables, representing meso- and micro-scale influences proved to be significant explanatory variables (Table 2). Overall, the model has fairly good explanatory power (R-square of 0.27), particularly considering the disaggregate nature of the data and the fact that only a single day's automobile use is predicted. Similar vehicle use models, estimated on data for cities in the U.S. have displayed R-squared values in the range of 0.04 to 0.17 (e.g., *12*, *13*, *14*).

Focusing on the standardized coefficients, we can see that the strongest explanatory variable is the total number of trips a household makes. This result suggests possible endogeneity bias; households with a propensity for mobility may travel further distances. The next most influential variable is the number of vehicles within a household; this is controlling for possible selectivity bias in the sample, by applying the selectivity bias correction factor (which is significant), as discussed above.

TABLE 2 OLS Estimate of Household Total Automobile Use

Category	**Variable**	**Beta**	**Standard. Beta**	**Std. Error**	**T-Stat**	**Prob.**
Vehicles	Share of autos with catalysts in HH	3270	0.057	1225.71	2.67	0.0077
	Number Vehicles	9130	0.253	1188.56	7.68	0.0000
	Avg. Vehicle Age	-255	-0.067	78.83	-3.24	0.0012
HHs	HH Income (thousands US$)	69.6	0.052	26.68	2.61	0.0091
	# Drivers License	1029	0.037	539.17	1.91	0.0564
Trips	# Trips	925	0.281	60.16	15.38	0.0000
	No Distance coded	-1529	-0.089	266.68	-5.73	0.0000
	Normal Saturday	-2670	-0.032	1053.64	-2.53	0.0113
	Normal Sunday	-6749	-0.086	904.56	-7.46	0.0000
	Summer Sunday	-7346	-0.047	1753.67	-4.19	0.0000
Urban Form	Dist to CBD	0.59	0.109	0.125	4.74	0.0000
	Dist to Metro	0.61	0.074	0.196	3.11	0.0019
	Foothills	3100	0.035	1531.21	2.02	0.0430
Urban Design	4-Way Int. per KM	-1569	-0.048	490.60	-3.20	0.0014
	3-Way Int. per KM	479	0.035	210.20	2.28	0.0226
	Plaza Density	-16810	-0.022	7676.21	-2.19	0.0286
	Selectivity Bias Correction	5603	0.056	2081.5	2.69	0.0071
	Constant	-2108		2462.29	-0.86	0.39

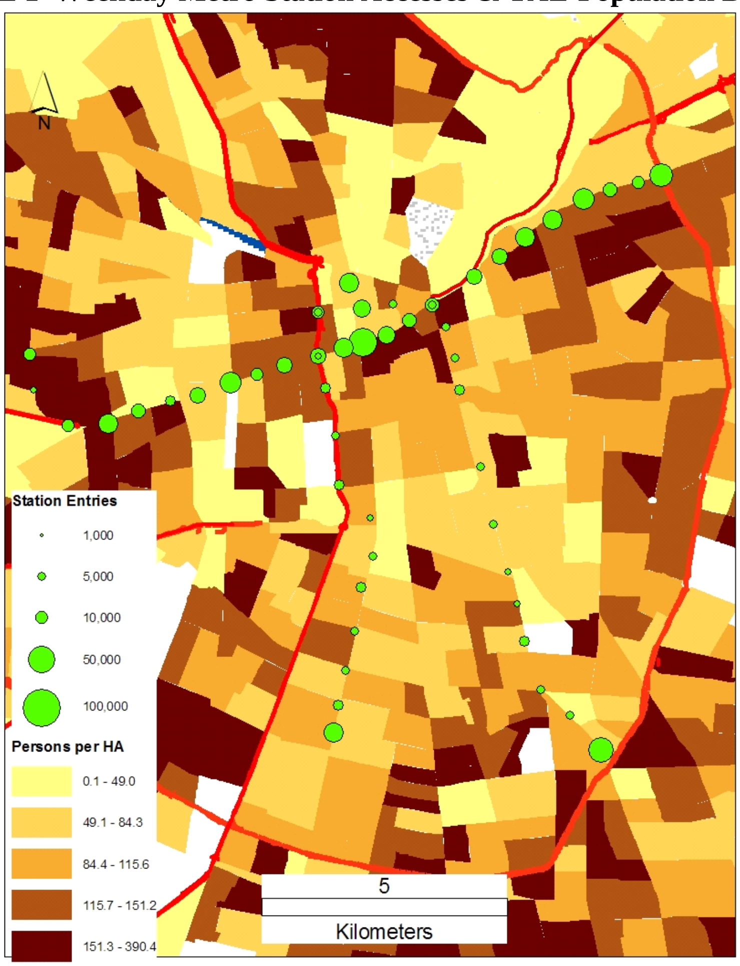
Notes: the dependent variable is total auto distance traveled (in meters) by household on the day of the survey; R-square: 0.27; F-statistic 94.9 (Prob. 0.0); N=4,279; standard errors are heteroscedasticity-consistent (using the White correction).

Other vehicle-related variables reveal expected signs. The proportion of vehicles in the household that is not subjected to Santiago's vehicle circulation restriction (*la restricción*, during which vehicles without catalytic converters are subjected to increased restrictions during pollution season), represented by the variable "share of autos with catalysts," increase vehicle travel. Second, the average age of the household's vehicle fleet exerts a downward bias – the older the vehicles in the home, the less they are used. Household income has a positive effect on vehicle use, as expected; while households tend to record lower auto distances on Saturdays and Sundays (including summer Sundays), relative to a normal work day.

Meso- and Micro-Scale Built Environment Characteristics

Looking at meso-level land use measures, we see a fairly strong distance to CBD effect (comparable in importance to income), lending some support to the structural idea of the compact city. For each kilometer increase in distance from the CBD, we would expect a household's daily auto use to increase by one-half a kilometer. We also see a significant influence of distance to the Metro. One way of looking at the influence of the Metro implied is to use the model to predict a household's auto use if all households lived at the mean distance to the nearest Metro station (for the sample, the mean household distance to the nearest Metro station is 4.2 kilometers). If all households that live within 1 kilometer of a Metro station (the average walking access distance for a Metro trip is 400 meters; 541 sampled auto-owning households lived within 1 kilometer of a Metro station) instead lived at the mean distance, these households would, on average, travel an additional 3.8 kilometers per day by car (this is the average difference between the predicted auto use at the mean distance and the actual auto use for the households). Further extrapolating (albeit tenuously), if we consider that roughly 190,000 households (580,000 persons) live within 1 kilometer of the Metro and we assume that 40% of these households have an automobile, then applying this average auto travel reduction due to Metro proximity means that the Metro accounts for approximately 105 million fewer auto kilometers per year, or about 1.6% of Santiago's annual auto use (assuming 365 days of effects, average intra-city vehicle use by *Santiaguinos* of 8,400 kilometers per year and fleet size of 770,000 private vehicles). As can be seen in Figure 1, there are important areas surrounding the existing Metro stations that have very low population densities, primarily on the two lines running south. Large parts of these areas are de-industrializing, such that regeneration with residential and commercial uses should be possible. This research suggests that those efforts might also produce VKT reductions.

FIGURE 1 Weekday Metro Station Accesses & TAZ-Population Densities



Source: Station accesses from *20*; zonal densities from *19*.

Finally, it is worth mentioning the apparent meso-level influence related to development in the Eastern foothills, which also is associated with an increase in automobile use. In this case the hypothesis is that the hills make other travel modes less convenient and the coefficient value supports this; however, the variable was only entered as a dummy for those zones in the foothills; as such, it may be capturing other unobserved effects associated with those parts of the city.

Few other micro-scale built environment factors associated with auto ownership had a significant influence on auto use in this model. The variables that do play an apparent role, albeit modest, are the number of 4-way intersections per kilometer (a proxy for grid street network intensity and thus neighborhood porosity), which was associated with reduced auto use, while the opposite was true for 3-way street intersections. All else equal, this suggests that the traditional street grid reduces auto use slightly. A dummy for whether or not the household resides in a condominium was tested, with the goal of capturing potential "gated community effects" – under the supposition that such communities, typically with only one way in/out and a growing phenomenon in Santiago (*31*) and elsewhere in Latin America, might increase auto use. No significant effect was detected.

CONCLUSIONS

This paper set out the goal of answering the question "What role might Santiago's built environment play on household automobile ownership and use?" Via estimation of a multinomial logit model of household vehicle choice, we saw – as might be expected in a city undergoing rapid economic growth and motorization – that at least one vehicle seems almost a certainty as soon as household income allows. As the household considers additional vehicles, however, meso- and micro-level land uses, as well as relative transport levels of service, apparently influence the decision. Increased local land use mixes, dwelling unit densities and proximity to the central business district decrease the probability of additional vehicle ownership, as does improved bus levels of service relative to the auto. In terms of transportation analysis, the lesson is clear: future transportation forecasting efforts should include built environment and transportation levels of service for projecting household auto ownership. If not, biased forecasts are likely. For the purposes of urban planning and design, the findings suggest potential means of influencing household's decisions to own *additional* (i.e., after the first vehicle) autos: including, increased dwelling unit densities and land use mixes and incentives to reduce urban expansion. Local built environment effects such as street patterns, block morphology, and intersection densities had no detectable effect on auto ownership decisions.

To gauge the cascading effects of vehicle ownership on household vehicle use, we turned to an ordinary least squares model predicting household automobile distances traveled on the day of the survey. The number of household vehicles (controlling for selectivity bias) shows the most important influence. Income, independently, also displays the expected effects. Interestingly, meso-level built environment factors, in the form of household distance to CBD and household proximity to Metro stations have a larger influence on vehicle use than household income. The evidence suggests that households living close to Metro stations do use their vehicles less (perhaps up to 4 kilometers per day less, on average); as the Metro infrastructure is already in place and large areas of relatively sparsely populated land exists near an important number of Metro Stations (see Figure 1), this result should provide more concrete support for transit-oriented development, including along areas of current Metro expansion. As for micro-scale urban design effects, a more gridded street network (proxied by 4-way intersections per km) apparently diminishes household motor vehicle use (with a degree of influence roughly comparable to household income); as does public space provision (proxied by plaza density). No apparent *direct* effect of dwelling unit density or land use mix was found (these effects are apparently only exerted through the vehicle ownership decision). This evidence also implies potential analytical improvements from incorporating local level built environment factors into travel forecasting efforts.

The largest shortcoming in this research relates to the issue of self-selection and endogeneity in the models. In other words, both the decision to own vehicles and the decision to use them likely influence households location decisions, so both of the models presented still suffer from bias. In the future, a model of household residential choice will be developed to correct for this problem. With that correction, more rigorous use of the models can be made, including forecasts of the cascading effects of land use changes on auto ownership *and* use, thereby allowing, for example the calculation of the *indirect* effects of local design (such as land use mix, which influences vehicle ownership) on motor vehicle use. Other research contributions could be made by exploring alternative areal units for analysis – to capture "neighborhood" effects that the TAZ's may arbitrarily mask. Broader challenges remain in this field of research. One relates to the type of data typically used – trip-based household travel surveys for a single day (often a typical work week day). Data in this form make it difficult to assess broader travel impacts, including weekly shopping habits, recreational travel, and trip-chaining propensity. Such impacts have not been the focus of much research, in part because the data simply do not exist.

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