

# **The Influence of Land Use on Travel Behavior: Empirical Evidence from Santiago de Chile**

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## **ABSTRACT**

In an attempt to expand the research base on the land use-transport link in the developing world, this paper adopts a microeconomic model developed in the industrialized world context. The analysis focuses on the influence of three gross measures of urban form on travel behavior in Santiago de Chile. Controlling for socioeconomic and demographic factors, the analysis attempts to demonstrate 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 walking (HB NWNS) trips. Consistent with intuition, the model results suggest that the relative share of land devoted to commercial and service uses in the zone of trip origin increases the likelihood of making HB NWNS walk trips, while the relative share of vacant land decreases the probability. Somewhat surprisingly, population density in the zone of origin has no significant effect.

## Effects of Neighborhood-Scale Urban Form on Transportation

Premise: local-level urban form (Density, Diversity, Design – 3 D’s) influences travel behavior in three basic ways:

1. reducing the number of motorized trips;
2. increasing the share of non-motorized trips; and,
3. reducing distances of and increasing occupancy rates of motorized trips

## Measuring Local Urban Form –Difficulties & Approaches

- potential collinearity b/w variables related to densities, mix of uses, amenities
- defining “neighborhood” scale; finding “built form” data at that scale
- inevitable imperfections in measuring the built form variables
- data availability versus actual development patterns; the use of untested proxy variables; and, the use of variables that capture heterogeneity instead of the complementarity of land uses (Hess et al, 2001)
- Cervero & Kockelman (1997): factor analysis on 22 variables (representing 3Ds), eg: retail store density, retail intensity (*density*); sidewalks & street lights, block length, planted strips (*design*). Neighborhood scale (San Fran.)
- Krizek (2003): 3 “tenets” (analogous to 3Ds), variables incl: housing unit and person density, # employees in neighborhood, and street design. Data at 150-meter grid cell (Seattle, WA)

## **Land Use Transport Link: Evidence from the United States**

### Metro Scale: Metropolitan Form

- early 1980s: e.g., “wasteful commuting” (e.g., Hamilton, 1982); jobs/housing balance; “surplus” commuting time
- Density and energy (e.g., Newman and Kenworthy (1989)).

### Meso Scale:

- Pushkarev and Zupan (1977) on public transport.
- Small’s work (1980) suburban v/scity center travel behavior; residential location influence on auto ownership and use.

### Micro (Neighborhood) Scale

- Cervero (1989) mixed uses: intra-suburban comparison
- 1990s, “new urbanism” – the neighborhood; Cervero and Gorham (1995) transit and auto neighborhoods; Handy’s (1996) neighborhood classification; etc.
- By 2000, over 50 empirical analyses in N. America (Ewing & Cervero, (2001)

# **Land Use Transport Link: Evidence from the United States**

## Results?

- Mixed, conflicting.

## Criticisms

- methodological weaknesses, data availability/quality, and/or model specification
- theoretical shortcomings: lack of solid behavioral framework to clarify causes of variation and help generalize results.

## Research Advances: Based on Behavioral (consumer choice) Theory

- Boarnet and Crane (2001), Greenwald and Boarnet (2001): trip generation by mode types
- Cervero (2002), Rodríguez & Joo (2004), Zhang (2004): mode choice

## **Evidence from Developing World?**

- Kenworthy and Laube (1999) include some developing cities (Jakarta, Bangkok, Kuala Lumpur, Surabaya, Manila) in update to metropolitan-level comparisons
- Little (any?) work looking at intra-metropolitan (local-level) effects

## Model Specification (Follows Boarnet & Crane and Greenwald & Boarnet).

- Individuals choose the number of trips by each travel mode

$$\begin{array}{ll} \text{Maximize:} & U(a, w, b, x) \\ \text{subject to:} & y = x + ap_a + wp_w + bp_b \end{array}$$

Where:

- $U$  is a utility function of the benefits of using time for each purpose
  - $a$  is a vector of the number of auto trips for each purpose,
  - $w$  is a vector of the number of walk trips for each purpose,
  - $b$  is a vector of the number of bus trips for each purpose,
  - $x$  is a composite variable of the time spent on other activities,
  - $p_i$  is the respective vector of time for each trip type in each mode,  $i$ , and
  - $y$  is the total available time.
- Important assumption: individuals have Cobb-Douglas preferences.
    - Implies that individuals will allocate a fixed portion of their time to each activity (e.g.,  $a, w, b, x$ ), likely a limited representation of actual consumer behavior.

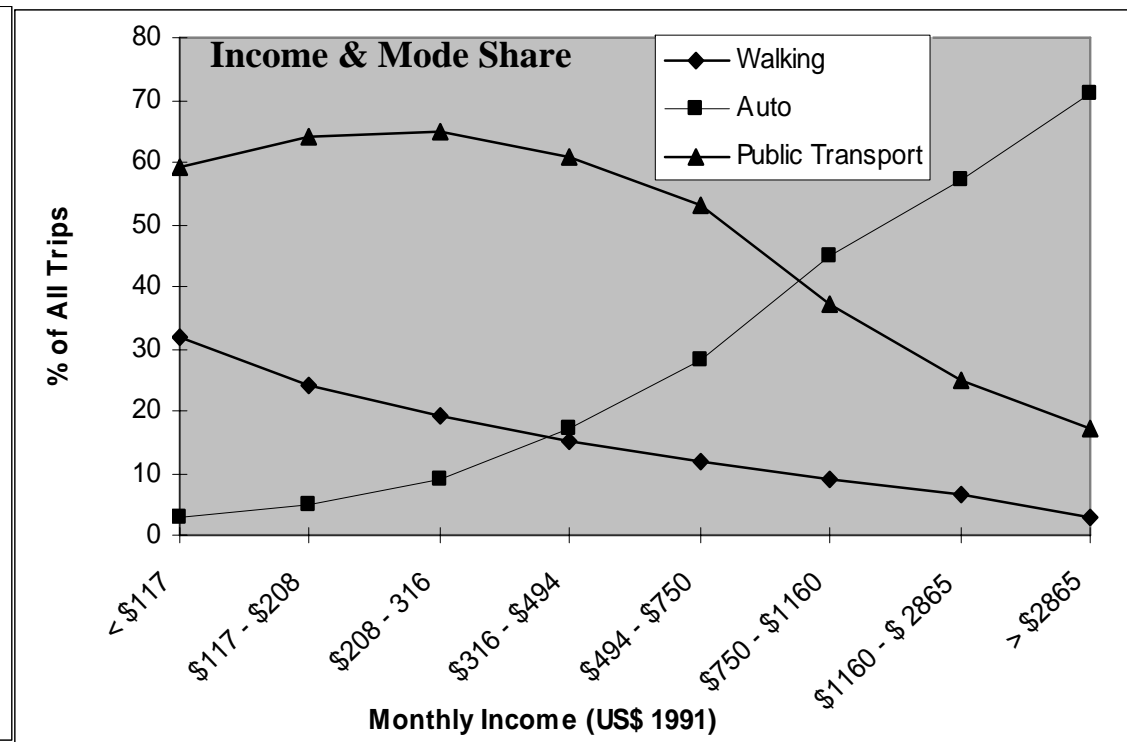
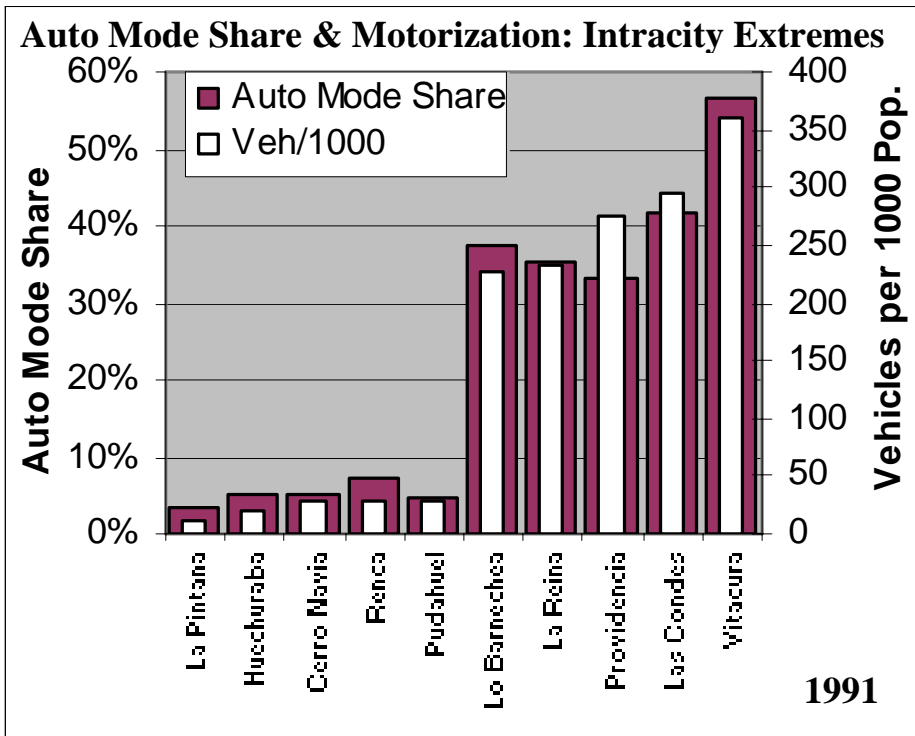
## General Modeling Approach (from Boarnet and Crane (2001))

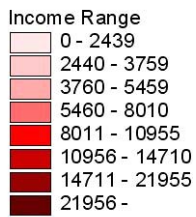
Model	Characteristics/Purpose	Shortcomings
<b>I</b> $a = f(L, y, S)$	Estimates trip behavior (a) based on land use (L), income (y) and socio-demographics (S).	Due to incomplete measurement of land use and design, differences in the time cost of travel might exist even with the land use variables included.
<b>II</b> $a = f(p, y, L, S)$	Aims to account for fact that price effects of travel might not be completely capture in land use variables (i.e., addresses shortcoming in model 1); <b>introduces trip cost related variables</b> (p) into model 1.	Trip cost related variables may still be endogenous to the individual traveler.
<b>III</b> 1: $p = f(L)$ 2: $a = f(p_e, y, S)$	Uses a 2-step procedure to account for the shortcoming in model 2 (endogeneity of trip costs); ultimately, includes (1) the effect of land use on trip prices and (2) the effect of predicted prices ( $p_e$ ) (from Step 1) on trip generation	Not explicitly showing land use variables in the model may complicate the interpretation (and hamper policy analysis).

# Model Application to a “Developing World” City

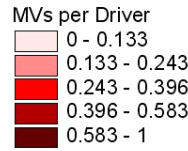
## Santiago de Chile

- 5.5 million people; metropolitan area of roughly 600 square kilometers.
- 1991 travel survey results:
  - 8.4 million trips per work day
  - Mode share of all trips: >50% public transport, 20% walk, 16% auto
  - Trip purposes: 36% work, 32% school, 32% other
  - Trip rate (trips per resident > 5 years old): 2.12 (range: 1.91-2.65)

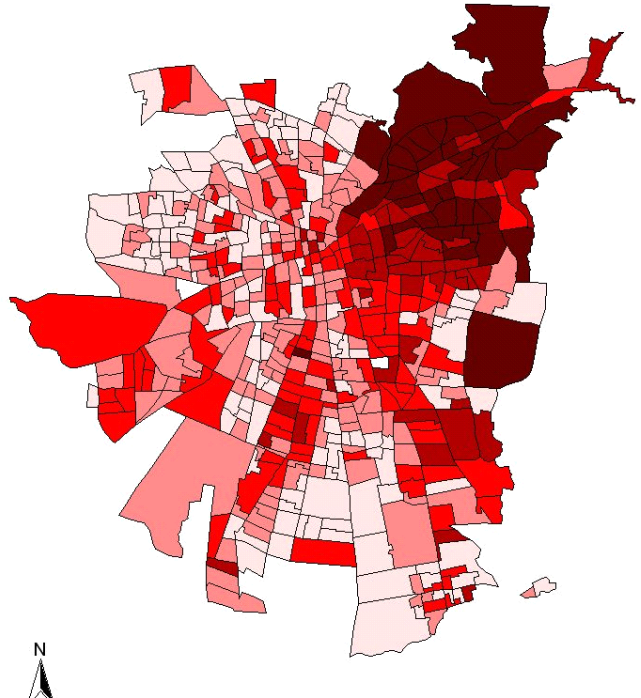
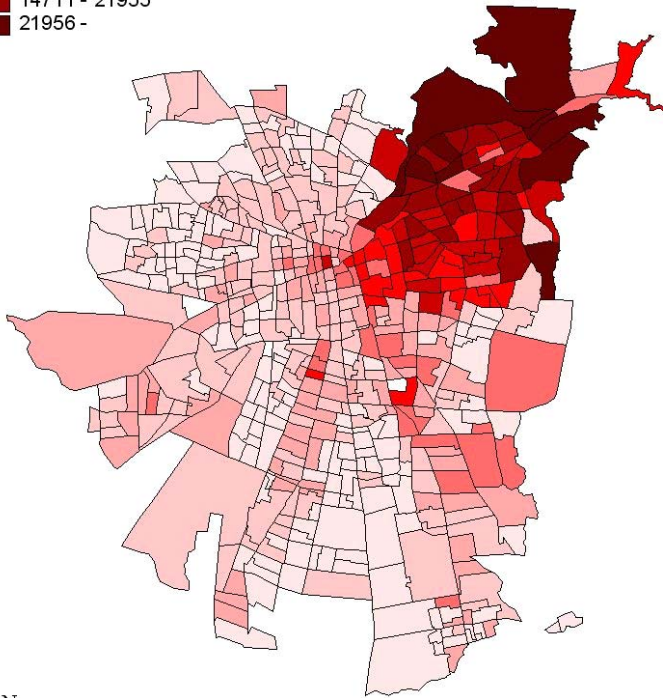




**Average Annual Household Income**  
US\$ 1991



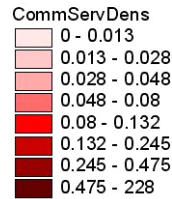
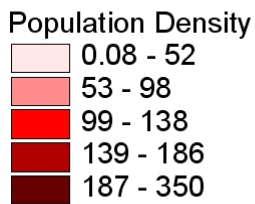
**Average Number of HH Motor Vehicles per Licensed Driver**  
1991



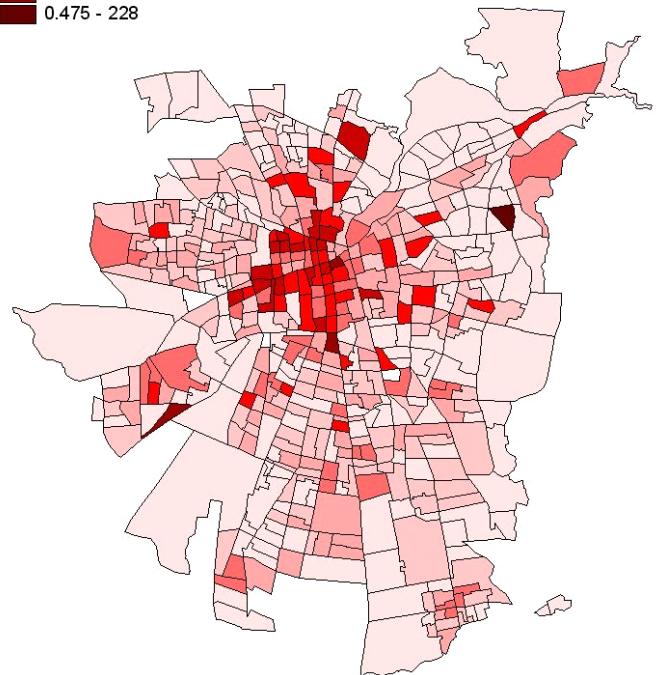
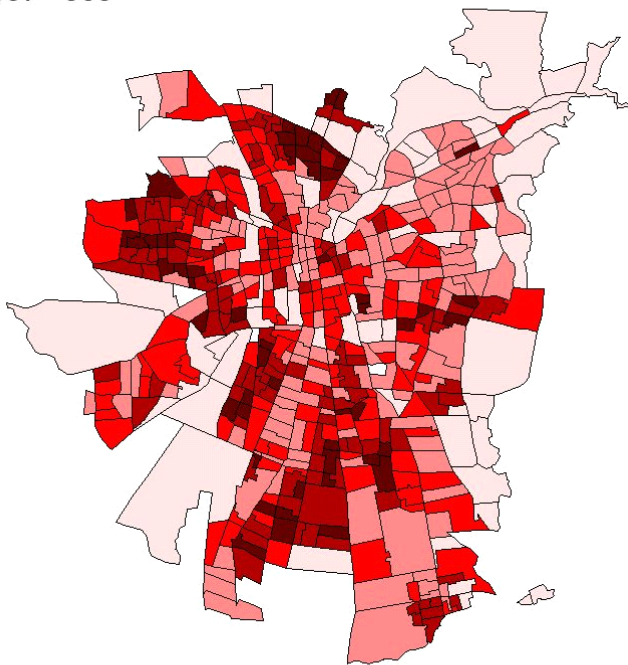
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**Population Density**  
Persons per Hectare  
1991



**Commercial and Service Density**  
Square Meters per Hectare  
1991



# Model Application to Santiago Case

**Units of Analysis:** Individuals in HHs; HHs in Travel Analysis Zones

## **Dependent variable**

- # of walk trips for home-based non-work, non-school (HB NWNS) trips
  - i.e., all discretionary trips
  - HB NWNS trips: approximately 12% of all trips
  - Between 0 and 6 HB NWNS person trips in 1991

## **Independent Variables**

- *Socioeconomic*: Age, HH Income, Gender, Education, persons/HH, MV per Driver in HH
- *Land Use*: Population Density, Relative Intensity of Commercial/Service Uses, Relative Intensity of Vacant land
- *Transportation*: Trip Cost
  - Average *reported* zonal walk time for all HB NWNS trips
  - Allows all HB NWNS trip makers included (i.e., by walk or not)
  - *But*, not entirely consistent with theoretical model (the cost variable does not necessarily reflect individual's time cost);
  - Demonstrates empirical *tradeoff*: use all observations & assume people face same avg. cost v/s use these person-specific trip costs but risk selection bias (only those that make *at least* one HB NWNS walk trip).

## Description of Variables Used in Modeling and Basic Summary Statistics (1991)

Variable Name	Description	Mean or Freq.	Min.	Max.	Std. Dev.
AGE	Age of trip-maker*	40.75	5	87	17.4
PERSONS	Number of persons in household	4.3	1	17	1.8
EDUC	Dummy variable = 1 if trip maker has a college or technical education.	0.22			
FEMALE	Dummy variable = 1 if trip maker is female	0.67			
MVPERDRIVER	Number of motor vehicles (inc. autos, motorcycles, trucks) per licensed driver (including motorcycle licenses) in the household	0.262	0	6	0.44
INCOME	Average Annual HH Income (in US\$1991)**	4,567	702	51,423	6,457
COMSERV	Amount of land in each <i>trip origin</i> zone used for commercial and services divided by total land area in zone (per hectare).	0.0315	0.02	0.48	0.04
VACANT	Amount of vacant land in each <i>trip origin</i> zone divided by total land area in zone (per hectare).	0.0491	0	0.7	0.067
POPDENS	Population (1992) in each <i>trip origin</i> zone divided by total land area (per hectare).	123.43	3.33	351	52.3
WALKTRIPS	The number of HB NWNS Walk Trips per person	0.42	0	6	0.67
AVGWALKTIME	The average walk trip time (in minutes) in each zone for trips originating in that zone. Proxy for walk trip costs.	16.999	6.9	60	5.35

\*Only trips made by people over 5 years of age were counted in the survey; \*\*Income in the survey was indicated by a dummy variable for 8 income ranges (and, “did not report”). To simplify, the mid-point of each range was used as the relevant household income (in 1991, roughly 300 Pesos = US\$1.00).

## Results: Ordered Probit Results for Number of HB NWNS Walk Trips in Santiago

Independent Variable	Socio-Demographic/ Economic Only			Model 1			Model 2		
	Coeff.	z- Stat.	Prob.	Coef.	z-Stat.	Prob.	Coeff.	z-Stat.	Prob.
<i>Sociodemographics and Income</i>									
AGE	<b>-0.0037*</b>	-2.826	0.0047	<b>-0.00436*</b>	-3.336	0.0009	<b>-0.004*</b>	-3.303	0.000
PERSONS	-0.0071	-.559	0.5759	-0.002	-0.178	0.859	-0.002	-0.15	0.877
EDUC	<b>-0.268*</b>	-4.5	0.000	<b>-0.294*</b>	-4.904	0.000	<b>-0.299*</b>	-4.964	0.000
FEMALE	<b>0.377*</b>	7.87	0.000	<b>0.378*</b>	7.88	0.000	<b>0.378*</b>	7.87	0.000
							-		
INCOME	<b>-0.00002*</b>	-4.861	0.000	<b>-0.00002*</b>	-4.84	0.000	<b>0.00002*</b>	-4.876	0.000
MVPERDRIVER	<b>-0.328*</b>	-5.477	0.000	<b>-0.324*</b>	-5.383	0.000	<b>-0.328*</b>	-5.45	0.000
<i>Land Use Variables</i>									
COMSERVDENS				<b>2.394*</b>	4.73	0.000	<b>2.438*</b>	4.814	0.000
VACDENS				<b>-0.865*</b>	-2.518	0.0118	<b>-0.884*</b>	-2.567	0.0103
POPDENS				-0.0002	-0.468	0.64	-0.0002	-0.474	0.635
<i>Trip Time-cost</i>									
AVGWALKTIME							<b>-0.010*</b>	-2.28	0.0226
<i>N</i>	3400			3400			3400		
<i>log(L)</i>	-2772.17			-2757.89			-2755.23		
<i>LR Ind. Pseudo R<sup>2</sup></i>	0.04			0.0453			0.046		

Note: \*Indicates coefficients that are significant at the five percent level or greater.

# Results

Socioeconomics variables: consistent with intuition and theory

Model 1: Including land use variables

- Socioeconomic variables unaffected
- Land use mixing (COMSERV): significant, positive
  - increase in land use mixing in the zone of HB NWNS trip origin increases individuals' likely number of walk trips.
- Relative amount of vacant land (VACANT): significant, negative
  - increase in relative amount of vacant land in zone of trip origin decreases individuals' likely number of walk trips.
- Population Density (POPDENS): *insignificant*
  - Surprising result: non-work (e.g., social) walk trips not influenced by the population density in neighborhood?

Model 2: Including trip cost proxy

- previously included variables do not change (significance or sign)
- walk trip cost (AVGWALKTIME): significant and negative
  - increase in avg. walk trip time zone of trip origin decreases number of walk trips that an individual is likely to make.

Model 3: 2-step model, to account for potential trip cost endogeneity

- Not fully estimated
  - 1<sup>st</sup> step: no explanatory power, no significant coefficients
  - Suggests that average walking time in the zones is not related to land use mix, as measured through included variables

# Implications

- Overall: some evidence of zonal-level urban form influence on travel behavior, but distant from offering practical results
- Model 1: relative concentration of commercial/service and vacant land have expected effects on walking behavior.
- Model 2: suggests that land use variables do not completely capture travel cost effects (measured by travel time), suggesting:
  - 1) incomplete measures of land use characteristics (likely, given the gross land use variables & large size of analysis zones) and/or
  - 2) additional insights might be gained by controlling travel costs endogenous to the individual. But, Model 3 could not be estimated.

## Relative to previous work

- Results differ from Boarnet & Crane's findings that when land use variables impact non-work *auto* trip generation, it is through influence on trip prices.
- However, model here uses *zonal*, not individual, average walk times; not comparable to Boarnet & Crane; not entirely consistent with theory.
- Interestingly, Greenwald and Boarnet, estimating similar models for non-work pedestrian trips in Portland, also do not estimate model 3,

## Shortcomings

1. A Matter of Scale: Average size of zones (TAZs) is 1 km<sup>2</sup>, with smaller inner-city zones and large suburban zones
2. Urban Form: extremely limited measures of the 3Ds.
3. Very low explanatory power (pseudo R-squareds). E.g., using means of independent variables & Model 2 results (coefficients on the independent variables and probability limit ranges for values of the dependent variable):
  - To go from 0 to 1 predicted HBNWNS walk trips, requires:
    - a person 70% < avg. age (41) and 90% < avg. income
    - in a zone with comm./service intensity 100% > avg.; vacant land intensity 90% < avg.; avg. walk time 90% < avg.
4. Potential factors influencing low explanatory power:
  - model mis-specification, e.g.: Cobb-Douglass preferences;
  - omitted variables, e.g.: traffic safety, real/perceived crime risk
  - potential data problems, e.g.:
    - land use variables: do not represent origins/destinations, per se; do not reflect overall land use balance; maybe measured inaccurately; averaged over large area (loss of local effects)
    - walk times possibly inaccurately reported in the survey
5. Model still assumes causality, ignoring, e.g.: HHs might partly choose their location based on desired travel patterns; auto ownership might partly depend on walk preference

# Future Research Suggestions

1. Better data on locational characteristics, e.g.:
  - more disaggregate, at a spatial unit small enough “to capture variations in the phenomenon of interest” (Hess et al, 2001)
  - more accurate & robust measures of actual urban form (3Ds)
  - Outlook: A new HH travel survey completed in Santiago for 2001; data will be available at block level, possible to link w/ detailed, contemporary, land use data
2. Further elaboration of these or similar behavioral choice models (e.g., mode choice models)
3. Comparative studies between “developed” and “developing” cities, among “developing” cities, to assess similarities in relationships.
4. Integrating these local-scale, land use sensitive trip generation (or mode choice) with regional travel forecasting and land use models to better inform policy making.
  - Including direct links to local/global emissions models
5. Situating this research topic within broader activity-based research agenda, accounting for phenomena such as trip-chaining and stay-at-home activity realization, which are closely linked to the built environment and advances in communication technologies.