Sustainable Urban Mobility: Deriving and Demonstrating an Operational Definition and Metric

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Outline

I. Sustainable Mobility: An Operational Definition
II. Sustainable Mobility: An Indicator
III. Accessibility: Meanings and Measures
IV. Empirical Demonstration: Santiago de Chile
V. Implications, Conclusions, Reflections

I.
Sustainable Mobility: Deriving An Operational Definition

"Sustainable" Mobility: What are we trying to sustain?

Accessibility

- To daily wants and needs (e.g., to stores, schools, friends, work, recreation, etc.).
- Accessibility measures have a long history in geography, transportation and urban planning studies
  - proposed as economic and social indicators since at least the 1960s (see, e.g., Wachs and Kumagai, 1973).

Accessibility & Sustainable Mobility

- Accessibility (or access) in several definitions of sustainable transportation
  - e.g., WBCSD, the OECD's EST, the Canadian Center for Sustainable Transportation, EU's "PROSPECTS" project.
- Can be directly linked to the sustainable ***development*** priorities of developing countries
  - E.g., Amartya Sen's "functionings" and "capabilities"

Sustainable Mobility: An Operational Definition

maintaining the capability to provide non-declining accessibility in time

Building on Capital Concepts

Natural Capital
Fuels, lands, air, climate systems, etc.

Human-made Capital
Infrastructures, vehicles, etc.

Financial Capital
Investments, payments

Social Capital
Organizations, Institutions, Associations, Agencies, etc.

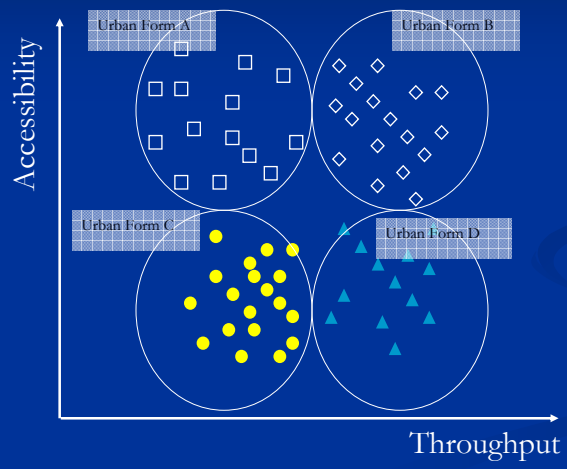
Increasing Accessibility
(to Jobs, School, Health care, Leisure, etc.)

Human Capital
Health, Skills, Knowledge, Relationships, etc.

Sustainable Mobility: Interpreting a Normative Measure

- A *more* sustainable mobility system provides more welfare (utility) per unit of throughput (capital drain)
  - Welfare: accessibility
  - Throughput: mobility

Sustainable Mobility "Trade Off" Space



From a SM perspective (*ceteris paribus*):
Urban Form (UF)
UF A > UF B,C,D
UF C > UF D
UF B > UF D

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How to Measure the "Throughput"?

- "Full Costs"?
- Ecological Footprint?
- Energy Use?
- Ultimately, the impacts are locally specific, should be locally derived, based on local inputs (i.e., participation)
- A weighted Passenger Distances Traveled can be used as a simple proxy

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III. Accessibility: Meanings and Measures

How to Measure Accessibility?

- *Infrastructure-Based:* e.g., levels of service
  - A throughput-biased metric
- *Location-Based*: e.g., gravity measures
  - Not inherently behaviorally based
- *Person-Based*: e.g., "Space-time prisms"
  - Reflect spatial & temporal constraints for individual

Utility-Based Accessibility

- Can reflect individual preferences
  - Consistent with Sen's "human freedoms" perspective
  - Based on the individual's *actual* choice set
- Directly linked to traditional measures of consumer surplus
- Based in microeconomic theory
- Derived from discrete choice models
  - With a long tradition of application in transportation system analyses

Utility-Based Accessibility: the Logit Model

Rests on basic assumption that people select alternative that provides highest utility.

$$U_{jn} = V(z_{jn}, s_n, \beta) + \varepsilon_{jn}$$

$$P_n(i) = \frac{e^{\mu V_{in}}}{\sum_{j=1}^{j} e^{\mu V_{jn}}}$$

Utility-Based Accessibility: The "Logsum" and Nested Logit

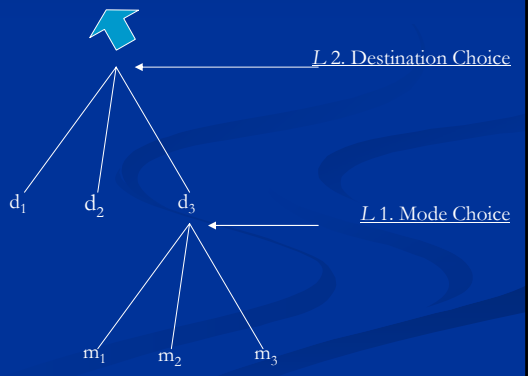
$$P_n(dm) = P_n(m|d)P_n(d)$$

"Logsum" at "the root" represents composite benefit ("Expected Maximum Utility") of the entire choice process

$$E(\max_{i \in C_n} U_{in}) = \frac{1}{\mu} \ln \sum_{i \in C_n} e^{\mu V_{in}}$$

$$P_n(d) = \frac{e^{(V_d + V'_d)\mu^d}}{\sum_{d \in D_n} e^{(V_d + V'_d)\mu^d}}$$

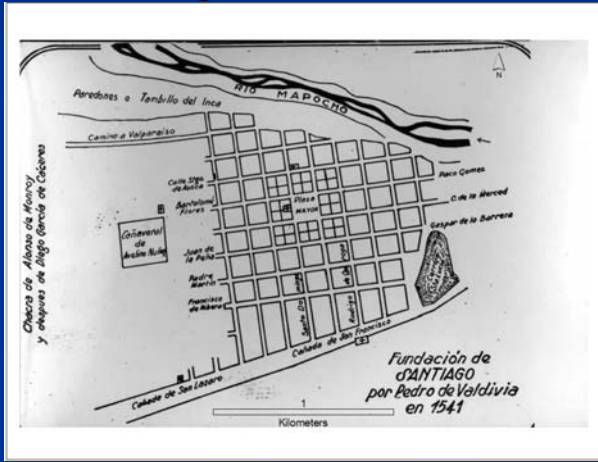
$$P_n(m \mid d) = \frac{e^{(V_m + V_{dm})\mu^m}}{\sum_{m \in M_{nd}} e^{(V_m + V_{dm})\mu^m}}$$



Logsum Accessibility Measures

- Several Relevant Precedents
  - Niemeier, 1997; Limanond and Niemeier, 2003
  - Hausman et al., 1995;
  - Hunt, 2003
  - Srour et al, 2002
  - Martínez and Araya (2000)
- None yet explicitly linked to the idea of sustainable mobility

IV.
The Empirical Case: Santiago Case de Chile

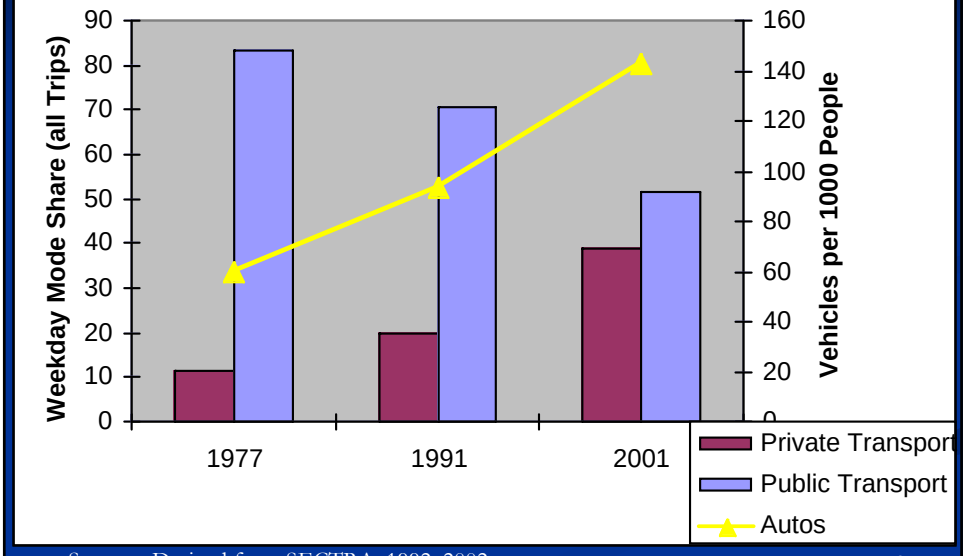


Greater Santiago: A Middle Income Metropolis

Income Category	Number of Households	% of Total Households	Average HH Income (US$2001)
High Income	85,226	5.6%	50,300
Medium Income	822,964	54.4%	11,250
Low Income	605,747	40.0%	3,070
All	1,513,937	100.0%	10,200

Source: Derived from SECTRA, 2002

The Emerging Middle Class



Sources: Derived from SECTRA, 1992; 2002

A Note on Data Sources

- Activity points (geo-coded at street address) based on 2001 property tax cadastre and Municipal business license records (Source: SECTRA)
- Open spaces (sports, plazas, cemeteries, agricultural land, etc.) based on 1998 survey by environmental authorities and zoning regulations (Source: MINVU)
- Census block map (Source: MINVU)
- Road Network (1999) and Metro Network and Stations (Source: SECTRA)

A Note on Data Sources

Household travel survey (2001)

- 15,000 households (1% sample)
  - 12,000 during "normal season"
  - 3,000 during summer
  - Geo-coded at census block centroid
- 38 Municipalities; 780 Traffic Analysis Zones (TAZs)
- All Trips in public space, by all individuals in HH
- Trip origins and destinations geocoded at nearest street corner

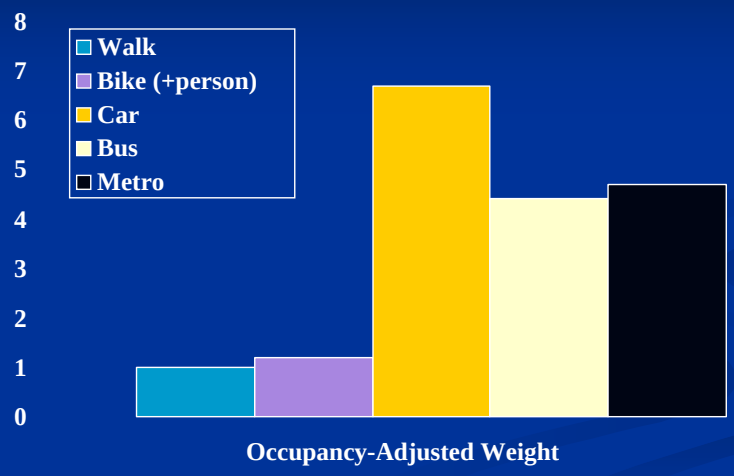
Trip Purpose Subset

- Discretionary (non-work, non-school) trips
  - "Leisure": Social and Recreational Travel
- For modeling convenience
- Arguably, greater room for planning influence
- Historically under-studied
- Highly suitable data
- Not-insignificant share of total mobility throughput
  - 2nd largest single share (15%) of PKT
  - We would expect it to grow with income

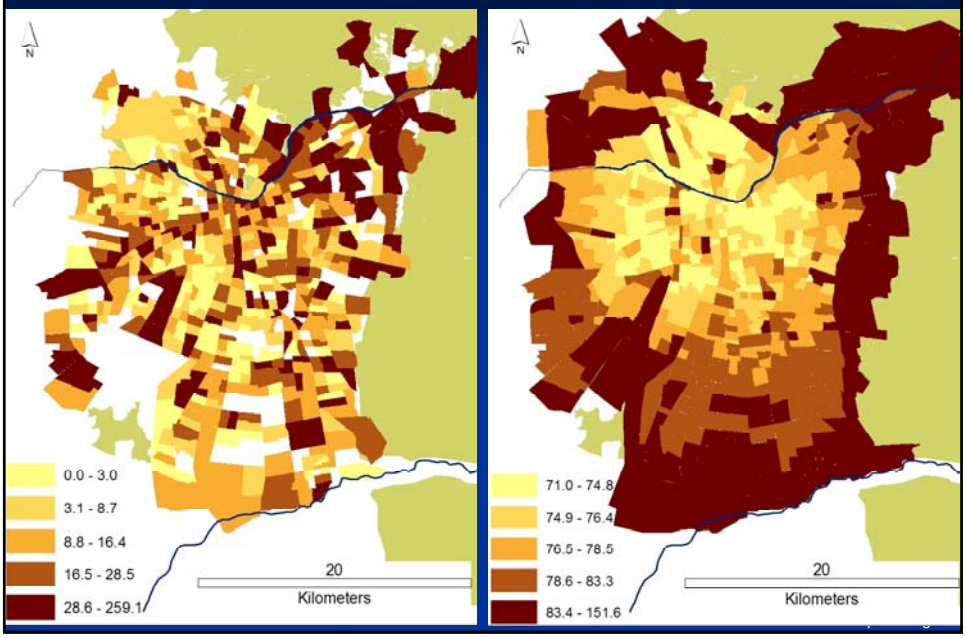
Mobility Throughput Measure

- OLS model of Weighted Passenger Kilometers Traveled (WPKT)
  - On day of survey
  - Distance derived from trip x,y coordinates and shortest path on road network
- PKT = *f* (HH Socio-demographics, Individual, Trip-Characteristics, Urban Form, Urban Design)

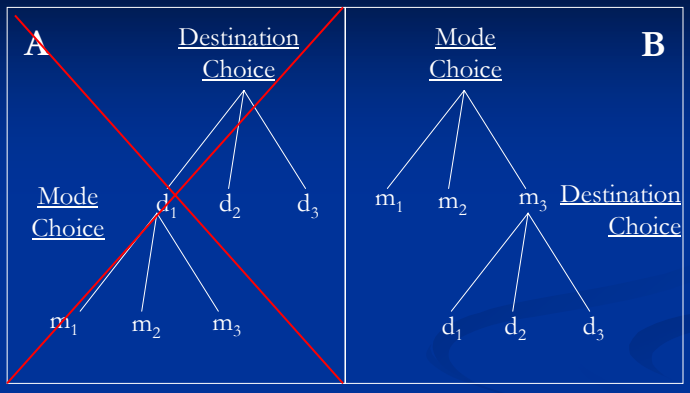
Weights for PKT Throughput



Actual & Predicted Social WPKT



Nested Logit Model Structure

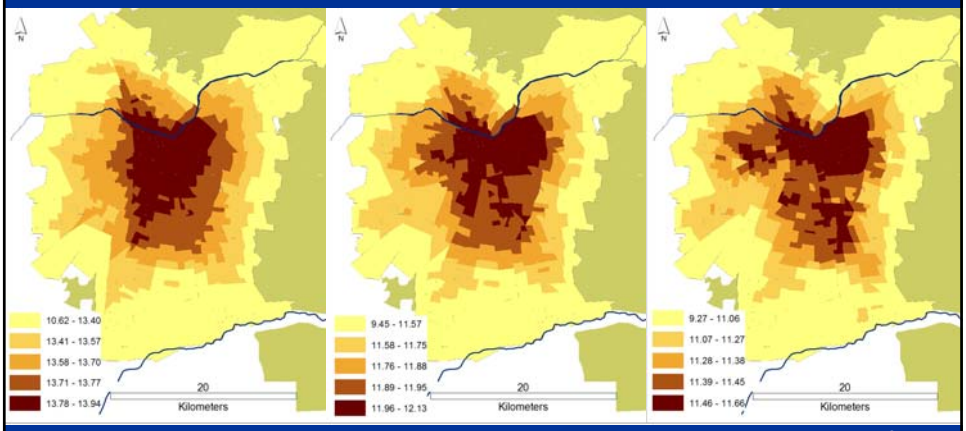


The traveler views all of the places that s/he can go by a particular mode, such as auto or bike, as more similar than the different potential leisure trip destinations

Social Accessibility Levels (Logsum)

Female Adult, Evaluated at Mean Relevant Characteristics for Income Category

High Income | Middle Income | Low Income



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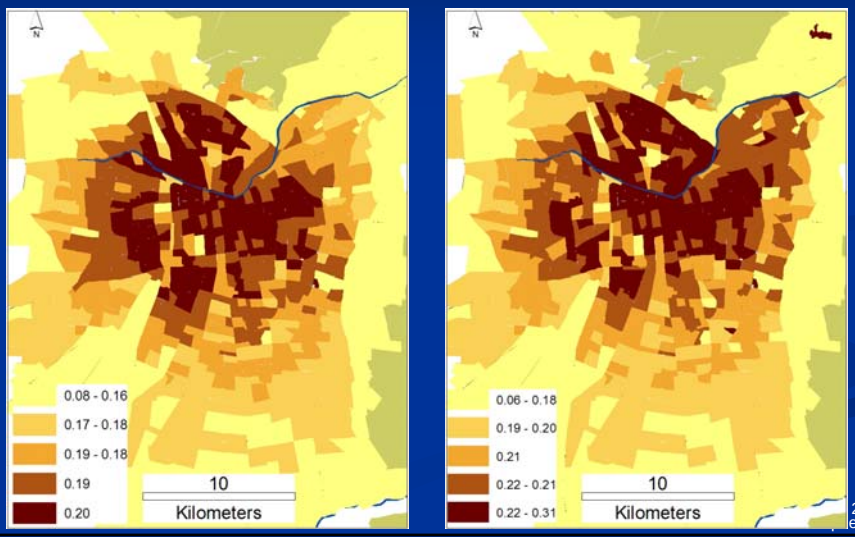
Accessibility:WPKT Sustainable Mobility Ratio

35-Yr. Old Middle Income Female

Social | Recreation



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Better Performing Zones?

- Looking at the 40% of zones with highest relative levels of sustainable mobility (social trips)
  - Lower plaza density
  - Higher concentration of commercial and services
  - Lower dwelling unit densities
  - Higher block porosity
  - Higher density of intersections per road-km
  - Lower share of dead ends per road-km

VII.
Implications & Conclusions

Sustainable Mobility: The Construct

- My proposed definition
  - Straightforward, but not necessarily obvious
  - Operational, albeit imperfectly in this case
  - A framework that should be intelligible to the transportation and land use planners/modelers
  - Implementable in an integrated transportation-land use modeling framework
  - Flexible; e.g., the weighted "throughput" metric

Empirical Results

- Should be interpreted tentatively
  - Need for more effective predictive models of WPKT
- The subset focus is an artificial and potentially mis-leading boundary
- For leisure trips, *Santiaguinos* display a modal dependency.
  - i.e., "I have a car, where am I going?" *Not*, "I am going to the park, how will I get there?"
- Built environment does play an apparent role

Research Directions

- Additional Trip Types (e.g., shopping)
- Integrated land use-transport modeling framework
  - constraints on trip ends
- Identification of neighborhood types that epitomize differences
- More refined throughput metric
- Accessibility in a more complete sense
  - Activity-based approach
- What about freight?
- Latin American/Developing City Comparative Assessments?

Thanks kindly to:

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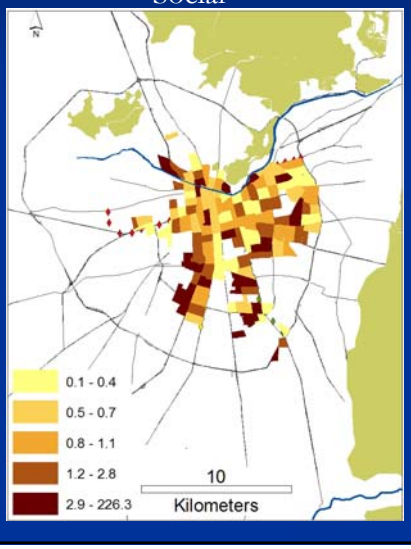
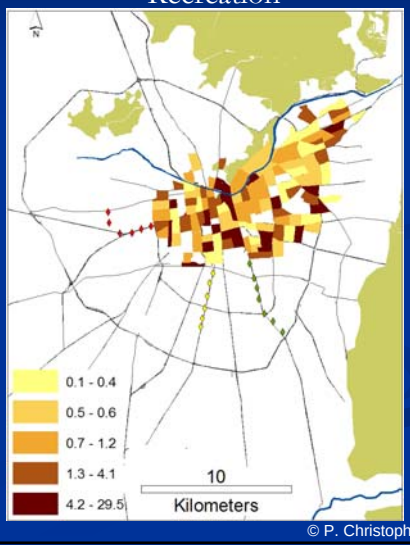
- MIT Presidential Fellowship
- US DOT/FHWA Eisenhower Fellowship
- Lincoln Institute of Land Policy Dissertation Fellowship

SM Ratio: Zones with 20% Highest Accessibility: Middle Income Female

Social



Recreation



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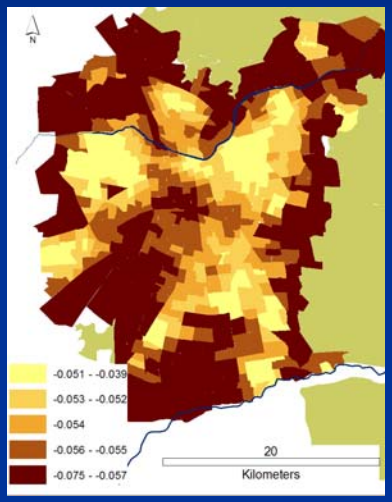
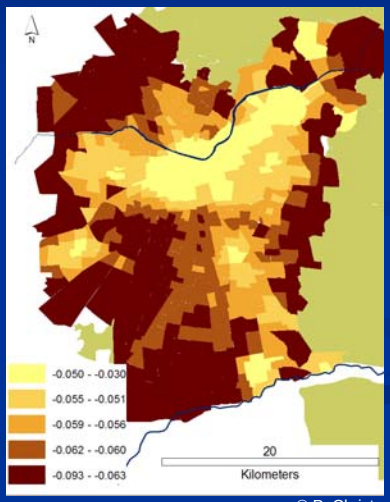
Average Relative Decline in Female Accessibility

Loss of Auto

Social



Recreational



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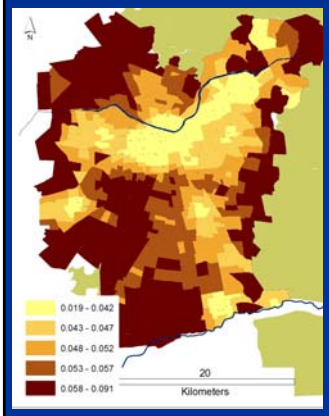
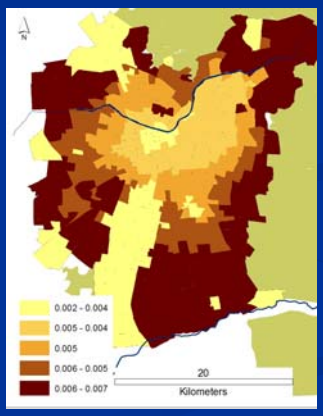
Relative Decline in Recreational Accessibility

Middle Income Female

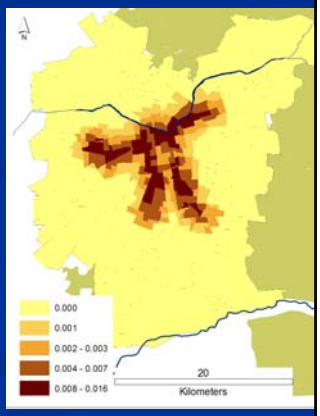
Loss of Auto



Loss of Bike



Loss of Metro



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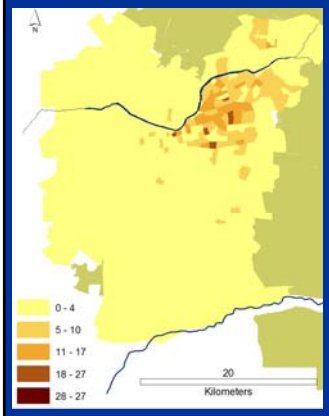
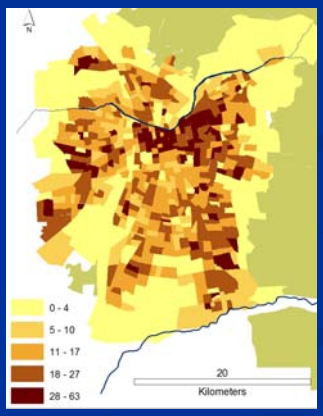
Population Distribution by Income Category (Households per Hectare)

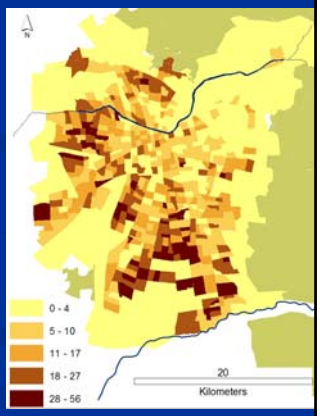
High Income



Middle Income



Low Income



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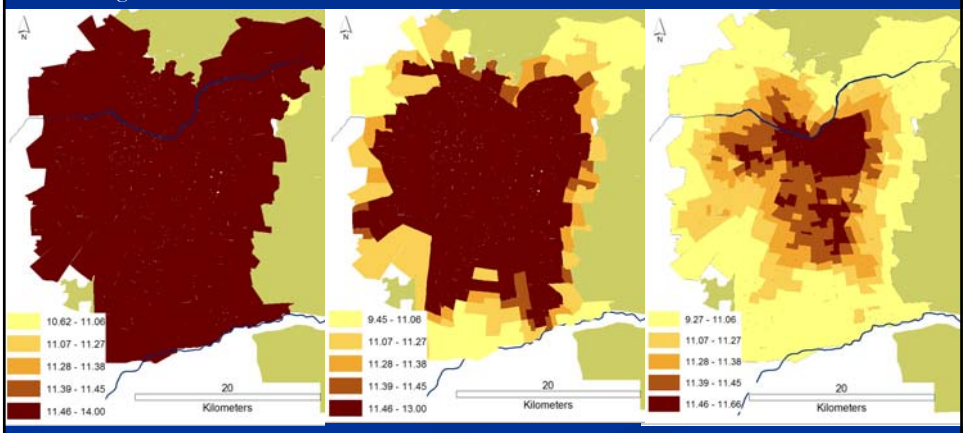
Social Accessibility Levels (Logsum)

Female Adult, Evaluated at Mean Relevant Characteristics for Income Category

High Income | Middle Income | Low Income



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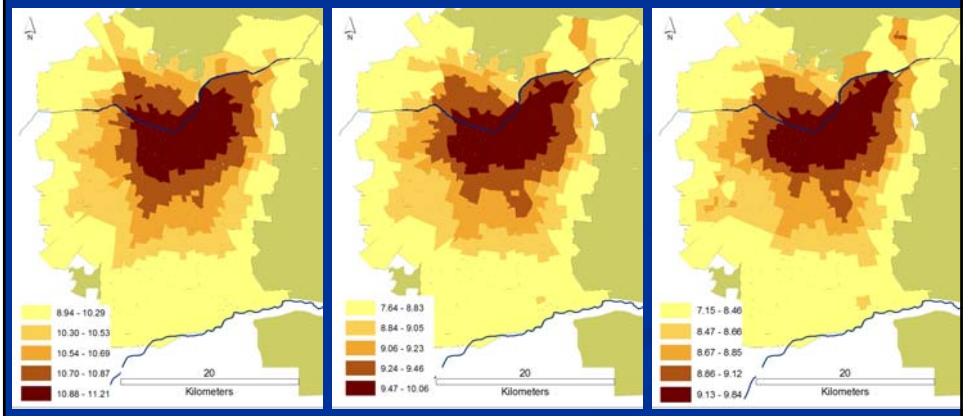
Recreational Accessibility Levels

Male Adult, Evaluated at Mean Relevant Characteristics for Income Category

High Income | Middle Income | Low Income



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Cate-gory	Variable	Beta	Std. Beta	T-Stat.
	Constant	-0.37		-0.15
HHs	HH Income	0.37	0.08	3.40
	Veh./Driver	9.55	0.09	4.95
Indiv-idual	Auto Avail.	45.73	0.32	17.58
	Bike Avail.	-3.01	-0.03	-2.46
	Age	0.22	0.07	6.93
Trip-Specific	Weekend	8.31	0.07	6.91
	PM	-5.5	-0.04	-4.13
	Night	-10.43	-0.06	-5.91
Urban Form	Dist. to CBD	0.78	0.06	5.50
	Foothills	14.94	0.06	4.55
Urban Design	Blk Equi. Rad.	0.05	0.05	3.37
	Div. Index	12.34	0.02	2.01

OLS Model WPKT Social Trips

Dependent variable:
Weighted PKT per trip

R-Squared = .21;
N=7546.

Heteroskedasticity-Consistent Standard Errors used to Determine Significance

Indeed, Model Form B Proves Correct

Social Trips Mode Choice (Upper Nest)

Name	Value	Robust Std err	Robust t-test
ASC-AD	1.716	0.127	13.558
ASC-AP	-0.271	0.105	-2.574
ASC-BK	0.797	0.129	6.192
ASC-BS	Fixed		
ASC-M	0.073	0.151	0.483
ASC-TX	-0.781	0.137	-5.705
ASC-WK	3.275	0.116	28.118
B_DIINDX_PT	0.018	0.003	5.712
B_DIINDX_WK	-0.011	0.004	-3.047
B_DUDENS_PT	0.018	0.002	7.899
B_FEMALE_AD	-1.071	0.113	-9.445
B_FEMALE_BK	-1.466	0.165	-8.908
B_HHINC_000s	0.041	0.004	9.144
B_LOGSUM	***0.691***	***0.042***	***16.477***
B_VEHPERDRIV	1.589	0.076	21.020

N=7410; Rho-Sq.=0.47

Recreation Trips Mode Choice (Upper Nest)

Name	Value	Robust Std err	Robust t-test
ASC-AD	0.869	0.121	7.182
ASC-AP	-0.720	0.081	-8.939
ASC-BK	0.054	0.112	0.482
ASC-BS	0.000		
ASC-M	1.289	0.152	8.467
ASC-TX	-1.856	0.139	-13.380
ASC-WK	2.984	0.100	29.704
B_FEMALE_AD	-0.815	0.146	-5.572
B_FEMALE_BK	-0.560	0.156	-3.590
B_HHINC_000s	0.037	0.004	8.857
B_LOGSUM	***0.646***	***0.044***	***14.565***
B_SUMMER	0.674	0.166	4.065
B_VEHPERDRIV	1.087	0.088	12.324

N=5339; Rho-Sq.=0.49