Role of Bicycle Sharing System Infrastructure on Usage: Evidence from Montreal

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Overview

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Introduction

- Bicycle-Sharing Systems (BSS)
  - a service in which bicycles are made available for shared use to individuals on a short term basis
  - more than 500,000 public bicycles around the world and more than 500 cities have installed or planning to install a bicycle-sharing system

Wuhan, China
90,000 bicycles
1318 stations

Paris, France
20,600 bicycles
1451 stations

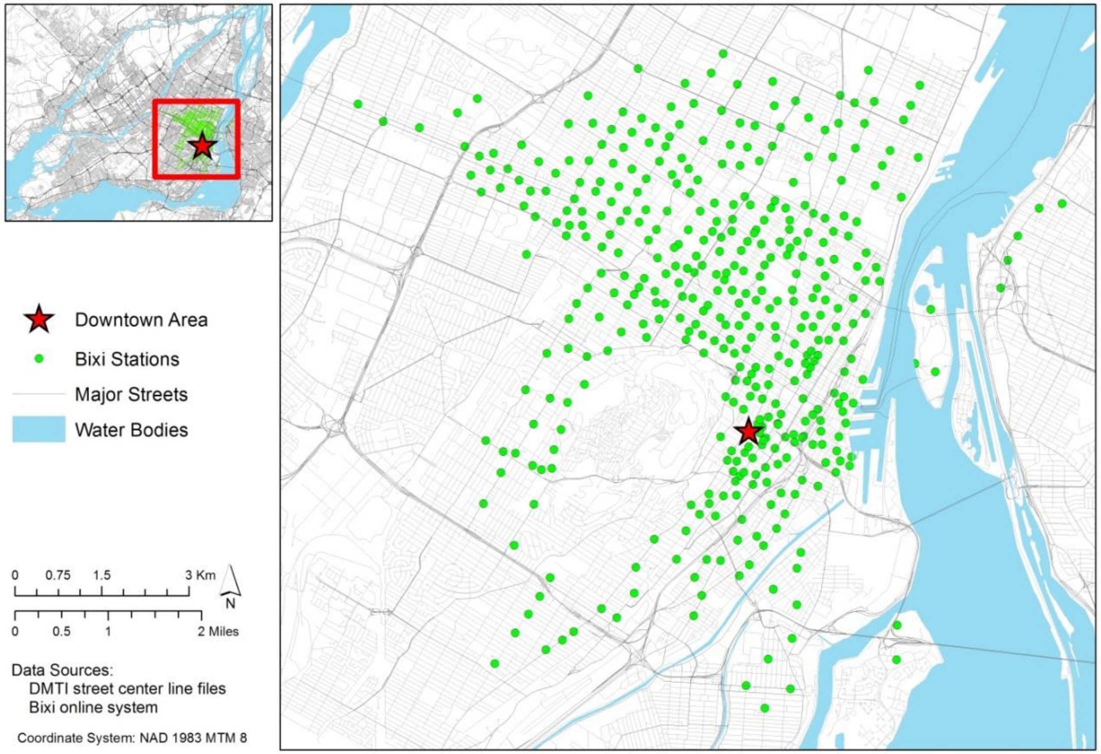
New York, US
6,000 bicycles
332 stations

Introduction

- Benefits
  - Flexible mobility
  - Physical activity benefits
  - Support for multimodal transport connections
  - Does not have the costs and responsibilities associated with owning a bicycle for short trips
  - No need to secure bicycles
  - The decision to make a trip by bicycle can be made in a short time frame

Introduction

- ***BIXI*** (**BI**cycle and ta**XI**) installed in 2009
- Began with 3000 bicycles and 300 stations
- In 2012, 410 stations, more than 4000 bicycles
- More than 3.4 million trips in the 2010 season



Earlier Studies

- Relatively very few studies on BSS

- Feasibility analysis
  - proposing different BSS for different cities
    - for example see Gregerson et al., (2010)

- User behavior studies
  - survey data rather than actual bicycle flows
    - BIXI studies:
      - Bachand-Marleau et al. (2011, 2012), Fuller et al., (2011).

Earlier Studies

- Few quantitative studies on bicycle-sharing systems employing actual bicycle usage data
  - Nair et al. (2013) - Velib' bicycle-sharing system in Paris, France.
  - Buck and Buehler (2012), Daddio (2012) - Capital Bicycle-sharing system in Washington.
  - Krykewycz et al. (2010) estimated demand for a proposed BSS for Philadelphia using observed bicycle flow rates in European cities.
  - Rixey (2013) - three different cities in the US.
  - Wang et al. (2012) – twin cities, Minnesota , US.

Earlier Studies

- Problems:
  - Aggregated bike flows (Monthly or yearly)
    - Neglect variations in the short terms
    - Cannot provide the operators the bicycle demand profiles including excess and shortage information
- Hampshire et al. (2013) – Barcelona and Seville – Hourly rates, at SCD level
- Gebhert and Noland (2013) - Capital Bicycle-sharing system in Washington – Hourly rates and Station level, but only exploring weather impact on flows and usage
- Faghih-Imani et al. 2014 recently used hourly data and concluded that bicycle infrastructure (number of stations and capacity) have a substantial influence on BSS usage

Motivation

- Growing installation of BSS
  - What are the contributing factors on usage?
    - Bicycle infrastructure
    - Land use and urban form attributes
    - Temporal characteristics

- However, these studies ignore the potential impact of the decision to install BSS infrastructure
  - The current infrastructure (No. of stations and capacity) are not randomly assigned

Motivation

- Impact of the decision to install BSS infrastructure (number of stations and capacity) on usage
  - the BSS infrastructure installed is based on expected bicycle usage patterns
  - the BSS usage models consider the bicycle flows as the dependent variable and BSS infrastructure as an independent variable
  - the measured dependent variable is closely tied to one of the independent variables BSS infrastructure
  - a classic violation of the most basic assumption in econometric modeling
    - the dependent variable is not correlated with the exogenous variables

Objective

- Capturing the potential impact of the decision to install BSS infrastructure:
  - consider the bicycle infrastructure installation itself as a dependent variable - simultaneously along with usage patterns
  - consider the impact of common unobserved variables influencing infrastructure installation and usage patterns
  - → a joint modelling process
- Gives rise to the classic endogeneity problem
- In this study, we examine self-selection in the context of BSSs

Data

- From the BIXI website
  - Bicycles/docks availability at each station for every minute
  - Station capacity and location
  - Records from April to August 2012

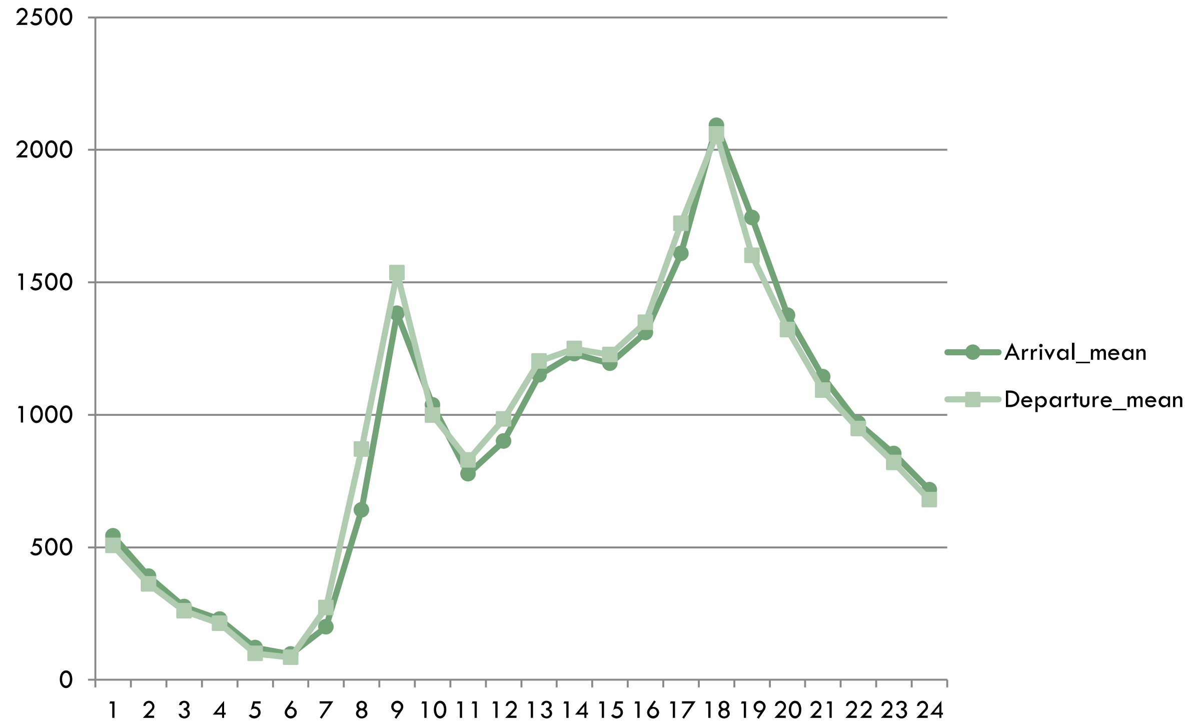
- The minute by minute arrival or departure rates
- Aggregate to 5min level for consideration of rebalancing operation
  - A heuristic mechanism to capture removal/refill operations

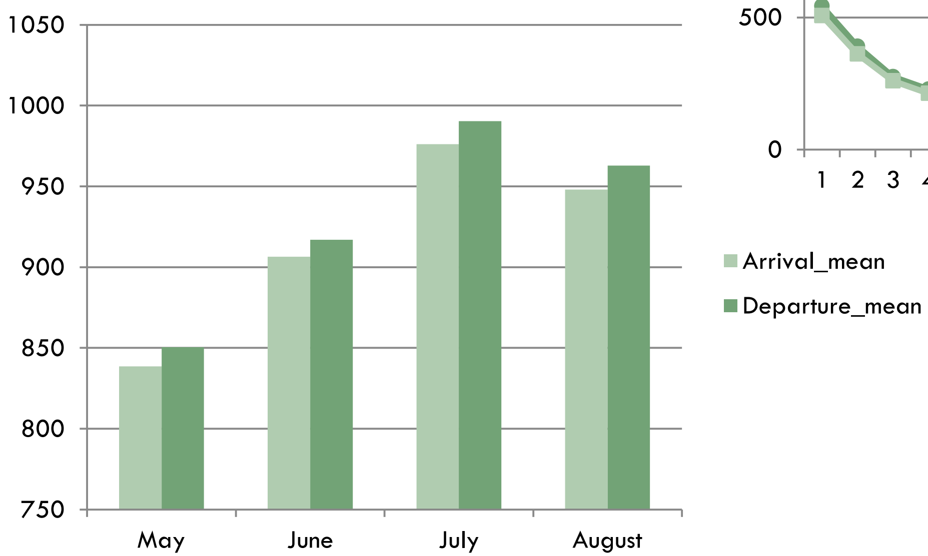
Data

- Consideration of rebalancing operation
  - a rebalancing operation has occurred if the 5-minute arrival/departure rate is greater than the 99th percentile arrival/departure for that station
  - when such a trigger is identified, the actual bicycle flow for this 5-minute period is obtained by averaging the bicycle flow rates of the two earlier 5-minute periods and the remainder of the flow is allocated to the rebalancing operation
    - Example: for station1 these are arrivals for every 5minutes
    - Arrivals: …, 2, 0, 3, 5, 2, 20, 4, 2, …
    - 99 percentile rate is 12, rebalancing is identified → true arrivals: (3+5)/2=4, the refill flows: 20-4=16 bikes
- Obtain "true" arrival or departure rates
- Aggregate to an hourly level rates

Data

- hourly arrival and departure rates for every station
- May, June, July and August 2012





Data

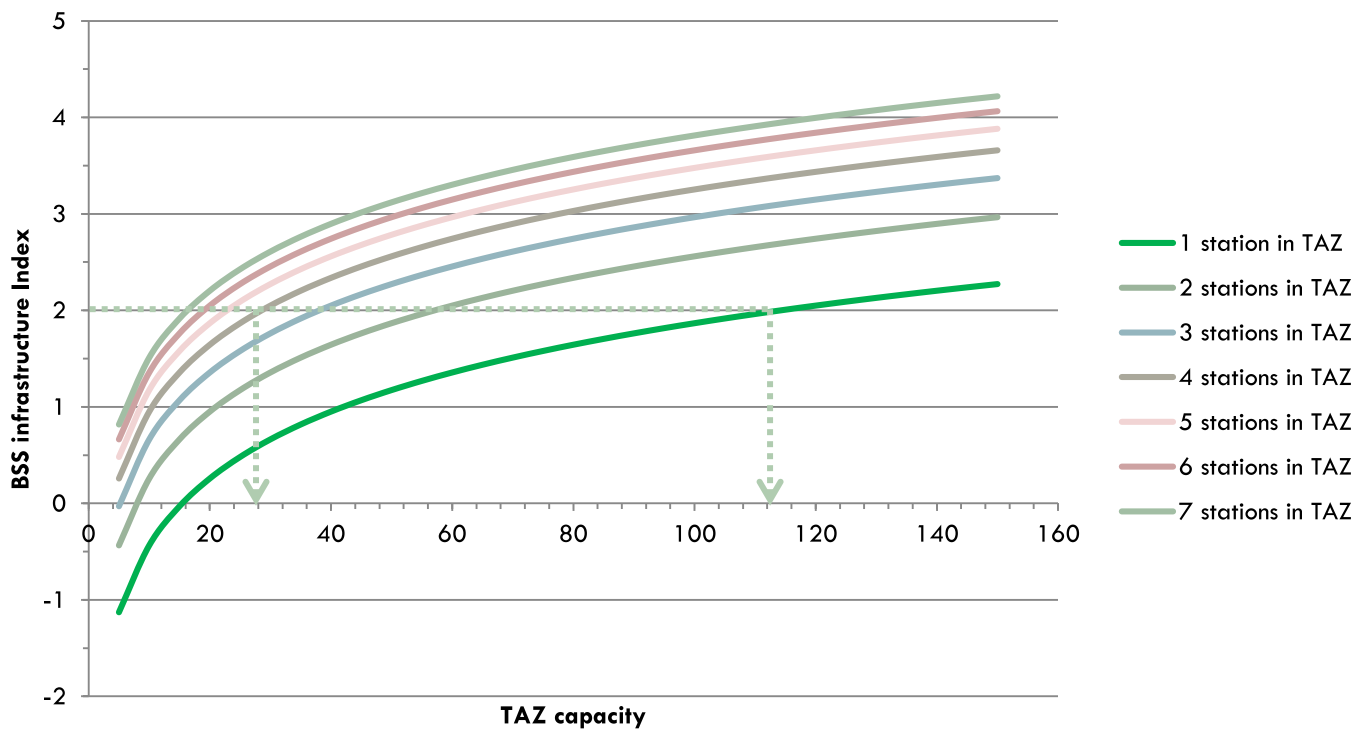
- TAZ level flows: adding arrival and departure flows of all the stations in one TAZ
- 5 time periods: AM (6-10), Midday (10-16), PM(16-20), Evening (20-24), and Night (24-6)
- Randomly select seven consecutive days for every TAZ
- The final sample: 8225 records (5 time periods * 7 days * 235 TAZs) of arrivals and departures at TAZ level

- What should represent BSS infrastructure? Number of Stations or Capacity of Stations?

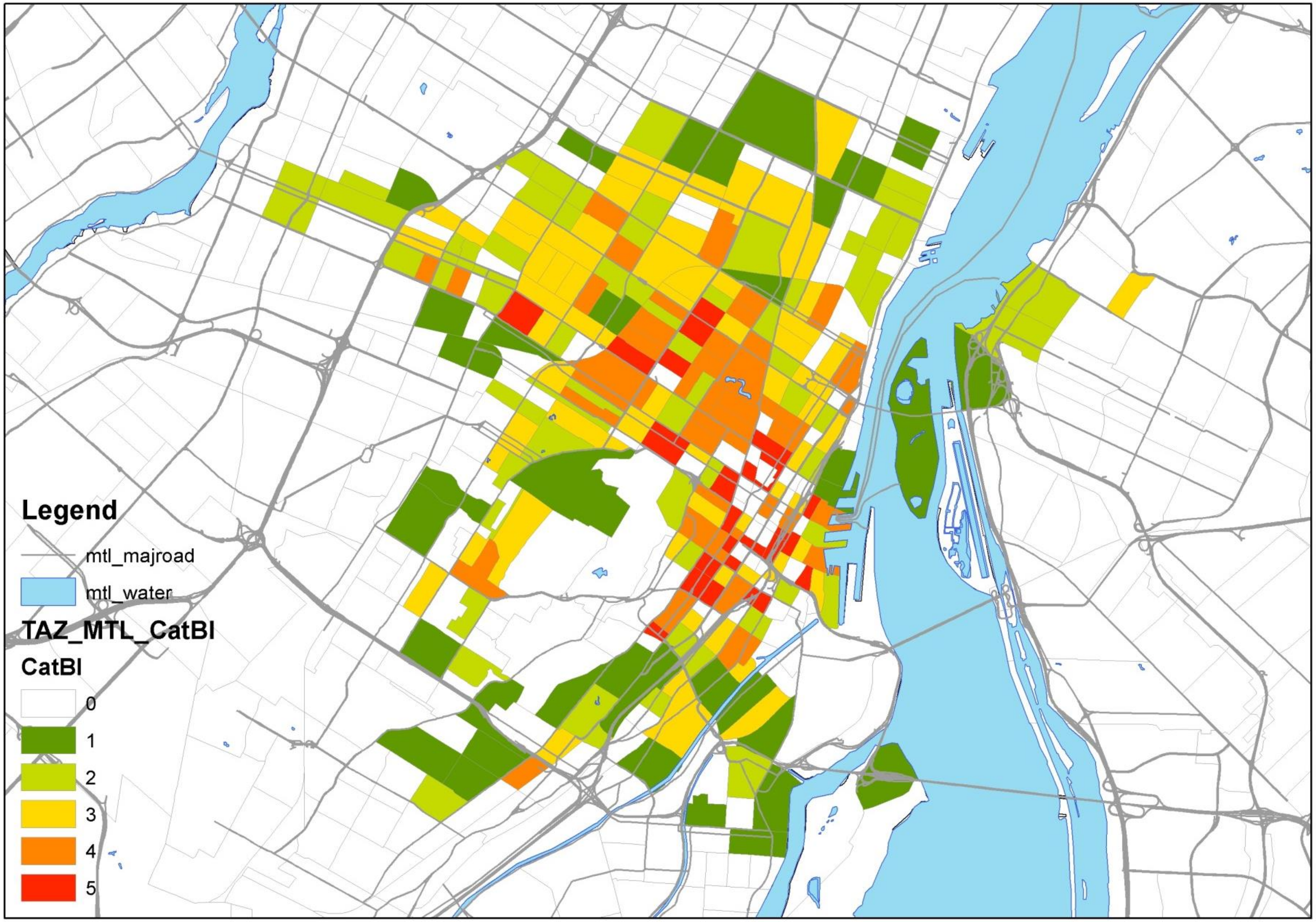
Data

- BSS infrastructure (BSSI) variable

$$BSSI = Ln\left(\frac{Number\ of\ Stations\ in\ TAZ}{Average\ Number\ of\ Stations\ in\ TAZ} \times \frac{TAZ\ Capacity}{Average\ TAZ\ Capacity} \times \frac{1}{TAZ\ area}\right)$$

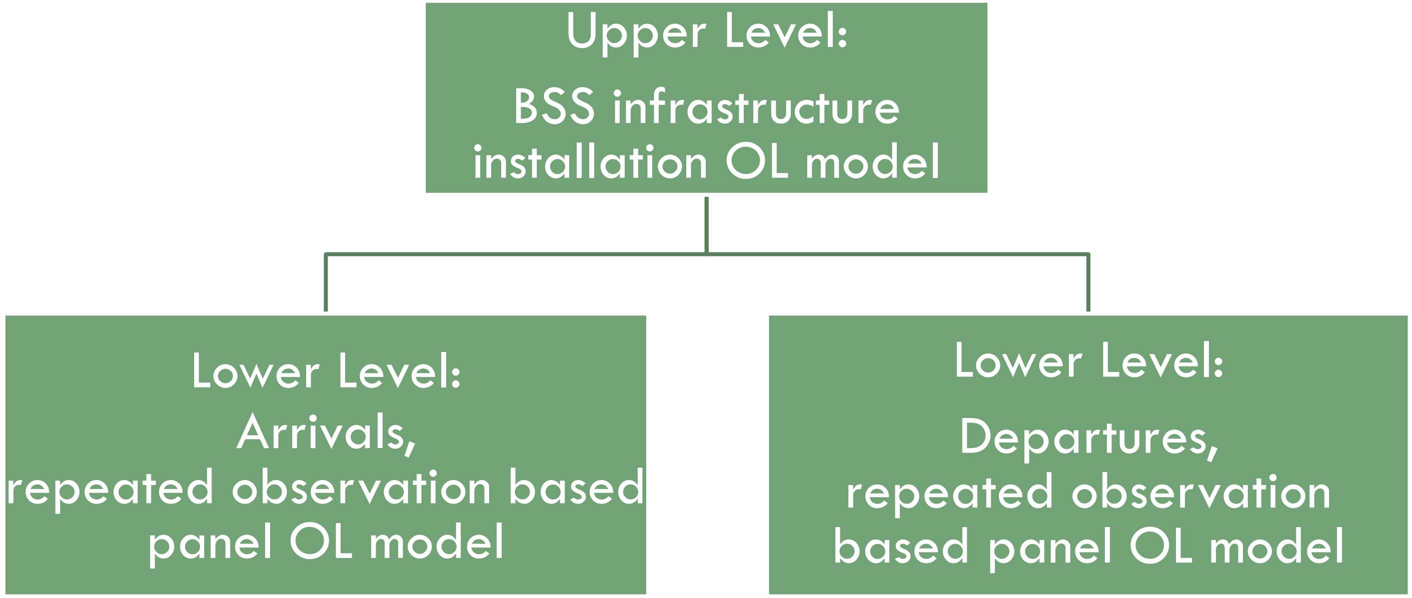


BSS infrastructure (BSSI) variable



Methodology

- Econometric framework: a 3 dimensional panel ordered formulation



- BSS infrastructure installation: a one-time decision process
- Arrivals and Departures: repeated observations

Methodology

(1) BSS installation $u^*_q = (\beta' + \gamma'_q)x_q + \eta_q x_q + \varepsilon_q\ ,\ u_q = j \text{ if } \psi_{j-1} < u_{qt} < \psi_j$

(2) Arrivals $y^*_{qt} = (\alpha' + \delta'_q)f_{qt} \pm \eta_q x_q \pm \nu_q f_{qt} + \xi_{qt}\ ,\ y_{qt} = k \text{ if } \omega_{k-1} < y^*_{qt} < \omega_k$

(3) Departures $z^*_{qt} = (\tau' + \lambda'_q)f_{qt} \pm \eta_q x_q \pm \nu_q f_{qt} + \zeta_{qt}\ ,\ z_{qt} = l \text{ if } \omega_{l-1} < z^*_{qt} < \omega_l$

Where:

- q is an index to represent TAZ
- t is an index to represent Time
- x and f represent independent elements in models
- β, α, τ represent corresponding vector of mean effects of the elements
- γ, δ, λ represent vector of unobserved factors moderating the influence of attributes in corresponding vector
- η captures unobserved factors that simultaneously impact BSS installation and arrivals/departures
- ν captures unobserved factors that simultaneously impact arrivals and departures for a TAZ
- ε, ξ, ζ are idiosyncratic random error terms assumed to be identically and independently standard gumbel distributed across TAZs

Dependent Variable

- First-level Model, BSS infrastructure model
  - BSS infrastructure (BSSI) variable
  - 5 Categories

- Second-level Model, BSS flows models
  - TAZ bicycle arrival and departure rates
  - 4 Categories
    - Zero, Low rates (1-5), Medium (6-10), High (+10)

Independent Variables

- Weather:
  - hourly temperature, relative humidity, and hourly weather condition (rainy or not)

- Time:
  - time of day: morning (6AM-10AM), mid-day (10AM-3PM), PM (3PM-7PM) evening (7PM- 12AM)
  - day of the week: weekend or weekday
  - Friday and Saturday night: to account for young individual users

Independent Variables

- Land-use and built environment:
  - The length (or length/area) of bicycle facilities (including bicycle lanes, bicycle paths etc.), the length of streets and major roads in TAZ
  - Average distance of TAZ to CBD
  - Number of metro and bus stations and length of railroads and bus lines in TAZ
  - Points of interest:
    - Restaurants
    - Commercial enterprises
    - Universities
  - TAZ population and job density

Sample Characteristics

Continuous Variables	Min	Max	Mean
Number of BIXI stations in TAZ	1	6	1.74
Capacity of BIXI stations in TAZ	11	141	34.07
Station Capacity	7	65	19.53

Results

Models estimated

- We estimate two models
  - Model 1: 3 independent OL models
  - Model 2: 3POL model for BSSI, arrivals and departures

- Goodness of fit measures:
  - Mean Log likelihood
    - Model 1 -14725.2
    - Model 2 -11549.3
- Clearly the model that recognizes BSS infrastructure installation process performs better.

Results – Joint Model

- BSS Installation Model:
  - Bicycle Facility Density ↑
  - Metro stations in TAZ ↑
  - Downtown ↑
  - Number of Restaurants in TAZ ↑
  - TAZ Job Density ↑
  - TAZ Pop Density ↑

  - Highway Density ↓
  - Rails length ↓
  - Distance to CBD ↓

Results – Joint Model

- Both Arrival and Departure:
  - Weather:
    - Temperature ↑
    - Relative Humidity ↓
    - Rainy Weather ↓
  - Time:
    - PM ↑
    - Night ↓
    - Weekend ↓

Results – Joint Model

- Both Arrival and Departure:
  - Land-use and built environment:
    - Bicycle Facility Density ↑
    - Metro Station ↑
    - Number of Restaurants in TAZ ↑
    - BSS infrastructure ↑
    - Highway Density ↓
    - Distance to CBD ↓

Results – Joint Model

- Arrival and Departure Specific Variables:

Parameter	Arrival Rate		Departure Rate	
	Estimate	t-statistic	Estimate	t-statistic
University in TAZ * AM	0.6977	3.022	-0.7636	-3.277
University in TAZ * PM	-0.4355	-2.016	0.6948	2.784
TAZ Job Density * AM	0.9486	14.035	-0.3332	-4.882
TAZ Pop Density * AM	-9.5456	-9.003	9.628	7.93
TAZ Pop Density * PM	-	-	-6.5949	-4.527

Policy Exercise

Marginal Effects for TAZ Arrival and Departure Rates

3OL Model	Arrival Rate			
Scenario	Zero	Low	Medium	High
Number of Station +5, Capacity constant	-7.184	1.048	6.969	7.125
Capacity +25, Number of Stations constant	-7.144	1.362	6.729	5.993
Number of Station +3, Capacity +15	-11.640	2.557	10.167	9.498
Pop Density +25%	0.974	-0.162	-0.819	-1.071
Job Density +25%	0.012	0.055	-0.101	-0.126
Bicycle Facility Density +25%	-3.014	-0.156	2.367	6.443
3POL Model				
Scenario	Zero	Low	Medium	High
Number of Station +5, Capacity constant	-6.054	0.457	5.749	6.923
Capacity +25, Number of Stations constant	-5.882	0.694	5.752	4.715
Number of Station +3, Capacity +15	-9.788	1.727	7.581	8.590
Pop Density +25%	1.253	-0.233	-0.890	-1.200
Job Density +25%	-0.039	-0.108	-0.140	1.170
Bicycle Facility Density +25%	-4.753	-0.331	3.572	11.252

Policy Exercise - Findings

- Ignoring the installation decision results in over prediction of BSS infrastructure impact on usage

- Increase in the number of stations without increasing capacity in the TAZ has greater impact than increasing capacity by as much as an average station
  - reallocate very large stations as smaller stations with lower capacity in multiple locations to increase BIXI system usage

- Increasing bicycle facilities density (bike lane, etc.) has a significant positive impact on BSS usage

Conclusion

- Growing installation of BSS across the world
  - need more studies
- Determining accurately the contribution of various factors to BSS usage at TAZ level:
  - meteorological data
  - temporal characteristics
  - bicycle infrastructure
  - land use and urban form attributes

Conclusion

- Ignoring the installation decision lead to over prediction of BSS infrastructure impact on usage and reduce precision of estimation
  - use of more advanced econometric models
- Adding a BIXI station has a predominantly stronger impact on bicycle flows compared to increasing station capacity
  - adding additional stations
    - reallocating existing capacity from large stations to multiple small size stations
    - or adding new bicycle slots

  is more beneficial in terms of BSS usage compared to adding capacity to existing stations

References

- Bhat, C.R., and N. Eluru (2009), "A Copula-Based Approach to Accommodate Residential Self-Selection Effects in Travel Behavior Modeling," *Transportation Research Part B*, Vol. 43, No. 7, pp. 749-765
- Buck, D., Buehler, R., 2012. Bike lanes and other determinants of capital bikeshare trips. Paper presented at the 91st Transportation Research Board Annual Meeting 2012, Washington, DC.
- Daddio, D., 2012. Maximizing Bicycle Sharing: An Empirical Analysis of Capital Bikeshare Usage. University of North Carolina at Chapel Hill.
- Eluru, N., and C.R. Bhat (2007), "A Joint Econometric Analysis of Seat Belt Use and Crash-Related Injury Severity," *Accident Analysis and Prevention*, Vol. 39, No. 5, pp. 1037-1049
- Faghih-Imani A., N. Eluru, A. El-Geneidy, M. Rabbat and U. Haq, " How does land-use and urban form impact bicycle flows: Evidence from the bicycle-sharing system (BIXI) in Montreal," forthcoming Journal of Transport Geography

References

- Fuller, D., Gauvin, L., Kestens, Y., Daniel, M., Fournier, M., Morency, P., Drouin, L., 2011. Use of a New Public Bicycle Share Program in Montreal, Canada. American Journal of Preventive Medicine 41, 80-83.
- Krykewycz, G., Puchalsky, C., Rocks, J., Bonnette, B., Jaskiewicz, F., 2010. Defining a Primary Market and Estimating Demand for Major Bicycle-Sharing Program in Philadelphia, Pennsylvania. Transportation Research Record, 117-124.
- Nair, R., Miller-Hooks, E., Hampshire, R., Busic, A., 2013. Large-Scale Vehicle Sharing Systems: Analysis of Velib. International Journal of Sustainable Transportation 7, 85-106.
- PBSC 2013, PBSC Urban Solutions. http://www.publicbikesystem.com/what-we-achived/case-studies-info/?id=1.
- Rixey, R., 2013. Station-Level Forecasting of Bike Sharing Ridership: Station Network Effects in Three U.S. Systems. Paper presented at the 92nd Transportation Research Board Annual Meeting 2013, Washington, DC.
- Wang, X., Lindsey, G., Schoner, J., Harrison, A., 2012. Modeling bike share station activity: the effects of nearby businesses and jobs on trips to and from stations. Paper presented at the 92nd Transportation Research Board Annual Meeting 2012, Washington, DC.

Thank You!

- Questions?