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

Ahmadreza Faghih Imani
Naveen Eluru
Department of Civil Engineering, McGill University
Overview

- Introduction
- Objective
- Earlier Studies
- Data
- Methodology
- Results & Discussion
- Conclusion
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

<table>
<thead>
<tr>
<th>Location</th>
<th>Bicycles</th>
<th>Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wuhan, China</td>
<td>90,000</td>
<td>1318</td>
</tr>
<tr>
<td>Paris, France</td>
<td>20,600</td>
<td>1451</td>
</tr>
<tr>
<td>New York, US</td>
<td>6,000</td>
<td>332</td>
</tr>
</tbody>
</table>
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** (BIcycle and taXI) 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:
Few quantitative studies on bicycle-sharing systems employing actual bicycle usage data

- Nair et al. (2013) - Velib’ bicycle-sharing system in Paris, France.
- 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
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
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 station 1 these are arrivals for every 5 minutes.
  - 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?
BSS infrastructure (BSSI) variable

$$BSSI = \ln\left(\frac{\text{Number of Stations in TAZ}}{\text{Average Number of Stations in TAZ}} \times \frac{\text{TAZ Capacity}}{\text{Average TAZ Capacity}} \times \frac{1}{\text{TAZ area}}\right)$$
BSSS infrastructure (BSSI) variable
Methodology

- Econometric framework: a 3 dimensional panel ordered formulation

  Upper Level:
  BSS infrastructure installation OL model

  Lower Level:
  Arrivals, repeated observation based panel OL model

  Lower Level:
  Departures, repeated observation based panel OL model

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

(1) BSS installation  \[ u^*_q = (\beta + \gamma'_q)x_q + \eta_q x_q + \epsilon_q, \quad u_q = j \text{ if } \psi_{j-1} < u_q < \psi_j \]

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

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

Where:
• \( q \) is an index to represent TAZ
• \( t \) is an index to represent Time
• \( x \) and \( f \) represent independent elements in models
• \( \beta, \alpha, \tau \) represent corresponding vector of mean effects of the elements
• \( \gamma, \delta, \lambda \) represent vector of unobserved factors moderating the influence of attributes in corresponding vector
• \( \eta \) captures unobserved factors that simultaneously impact BSS installation and arrivals/departures
• \( \nu \) captures unobserved factors that simultaneously impact arrivals and departures for a TAZ
• \( \epsilon, \xi, \zeta \) 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

<table>
<thead>
<tr>
<th>Continuous Variables</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of BIXI stations in TAZ</td>
<td>1</td>
<td>6</td>
<td>1.74</td>
</tr>
<tr>
<td>Capacity of BIXI stations in TAZ</td>
<td>11</td>
<td>141</td>
<td>34.07</td>
</tr>
<tr>
<td>Station Capacity</td>
<td>7</td>
<td>65</td>
<td>19.53</td>
</tr>
</tbody>
</table>
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
Both Arrival and Departure:

- **Weather:**
  - Temperature $\uparrow$
  - Relative Humidity $\downarrow$
  - Rainy Weather $\downarrow$

- **Time:**
  - PM $\uparrow$
  - Night $\downarrow$
  - Weekend $\downarrow$
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:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Arrival Rate</th>
<th>Departure Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>t-statistic</td>
</tr>
<tr>
<td>University in TAZ * AM</td>
<td>0.6977</td>
<td>3.022</td>
</tr>
<tr>
<td>University in TAZ * PM</td>
<td>-0.4355</td>
<td>-2.016</td>
</tr>
<tr>
<td>TAZ Job Density * AM</td>
<td>0.9486</td>
<td>14.035</td>
</tr>
<tr>
<td>TAZ Pop Density * PM</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
## Policy Exercise

### Marginal Effects for TAZ Arrival and Departure Rates

<table>
<thead>
<tr>
<th>3POL Model</th>
<th>Arrival Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scenario</strong></td>
<td><strong>Zero</strong></td>
</tr>
<tr>
<td>Number of Station +5, Capacity constant</td>
<td>-7.184</td>
</tr>
<tr>
<td>Capacity +25, Number of Stations constant</td>
<td>-7.144</td>
</tr>
<tr>
<td>Number of Station +3, Capacity +15</td>
<td>-11.640</td>
</tr>
<tr>
<td>Pop Density +25%</td>
<td>0.974</td>
</tr>
<tr>
<td>Job Density +25%</td>
<td>0.012</td>
</tr>
<tr>
<td>Bicycle Facility Density +25%</td>
<td>-3.014</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3POL Model</th>
<th>Arrival Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scenario</strong></td>
<td><strong>Zero</strong></td>
</tr>
<tr>
<td>Number of Station +5, Capacity constant</td>
<td>-6.054</td>
</tr>
<tr>
<td>Capacity +25, Number of Stations constant</td>
<td>-5.882</td>
</tr>
<tr>
<td>Number of Station +3, Capacity +15</td>
<td>-9.788</td>
</tr>
<tr>
<td>Pop Density +25%</td>
<td>1.253</td>
</tr>
<tr>
<td>Job Density +25%</td>
<td>-0.039</td>
</tr>
<tr>
<td>Bicycle Facility Density +25%</td>
<td>-4.753</td>
</tr>
</tbody>
</table>
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

Thank You!

Questions?