Evaluating the Impact of Urban Transit Infrastructure: Evidence from Bogotá’s TransMilenio

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Urban Transit Infrastructure

Empirical Questions:

1. What are the **aggregate** effects of improving urban transit?
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New Infrastructure → Save Time On Commute, Where to live
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- Save Time On Commute
- Where to live
- Where to work
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- Where to live
- Where to work
- House Prices, Wages
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2. How are the gains distributed across the low- and high-skilled?
   - Bogotá in 1995: low-skilled 25% more likely to commute using informal bus...
   - Which were 32% slower than cars
TransMilenio: World’s Most Used Bus Rapid Transit System

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Combine with detailed tract-level data to examine impact
Approach of This Paper

1. New Commuter Market Access approach from general equilibrium theory to measure effects of transit infrastructure within cities
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   - **Regression Framework**: Log-linear reduced form between CMA and outcomes

2. **Quantitative general equilibrium model** of a city:

   - **New Features**: Low/High-skill workers + Multiple transit modes

3. **Quantification+Counterfactuals**:

   - Quantify welfare effects through value of time savings (VTTS) + reallocation and general equilibrium effects
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Main Results

1. **Aggregate Effects**: Large gains, worth the cost
   - Welfare $\uparrow 1.63\%$, Output (net of costs) $\uparrow 1.44\%$
   - VTTS accounts for 60-80% of welfare gains, remainder by reallocation+GE effects
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3. **Key Policy Implication**: Large gains to integrated transit + land use policy
   - Average welfare gain 19% higher under more accommodative zoning policy
   - Revenue from Land Value Capture scheme covers 10-40% of const. costs
Roadmap

1. **Empirical Approach & Results**

2. **Quantification and Counterfactuals**
Simple Model to Guide Empirics

**Ingredients:**

- Many discrete locations indexed by \( i = 1, \ldots, N \) (e.g. blocks or census tracts)
- Locations differ in amenities, productivities, commute times, floorspace
- Individuals decide where to live and work
- Firms in each location decide how much labor+commercial floorspace to hire
- House prices and wages adjust to clear markets
Simple Model to Guide Empirics

Individuals: Choose between pairs of where to live $i$ and work $j$ that depends on:

- **Residential Location Characteristics:** Amenities, house prices in $i$
- **Workplace Location Characteristics:** Wages in $j$
- **Pairwise Commute Characteristics:** Cost of commuting from $i$ to $j$
Simple Model to Guide Empirics

**Supply of Residents:** Depends on amenities $u_i$, house prices $r_{Ri}$ and access to well-paid jobs $\phi_{Ri}$ (RCMA)

\[
L_{Ri} \propto \left( u_i r_{Ri}^{\beta-1} \right)^{\theta} \phi_{Ri}
\]
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**Computing CMA**: Unique values of RCMA and FCMA can be recovered from data $(L_{Fj}, L_{Ri})$ and parameterization of commute costs (e.g. commute times computed in ArcMap).
Distance-Based Treatment Effect: Close vs Far
Distance-Based Treatment Effect: Close vs Interm. vs Far
Residents: Change in InRCMA

Hot: Larger increase
Cool: Smaller increase
Firms: Change in lnFCMA

Hot: Larger increase
Cool: Smaller increase
Reduced Form Representation

Equilibrium can be written as:

\[
\Delta \ln Y_{R_i} = \beta_R \Delta \ln \Phi_{R_i} + e_{R_i} \\
\Delta \ln Y_{F_i} = \beta_F \Delta \ln \Phi_{F_i} + e_{F_i}
\]

where

- \( \Delta \ln Y_{R_i} = [\Delta \ln L_{R_i} \quad \Delta \ln r_{R_i}] \) and \( \Delta \ln Y_{F_i} = [\Delta \ln L_{F_i} \quad \Delta \ln r_{F_i}] \)' are changes in endogenous outcomes
- \( \beta_R, \beta_F \) are reduced form coefficients capturing direct+indirect effects of CMA on outcomes
- \( e_{R_i}, e_{F_i} \) are structural errors containing changes in amenities/productivities
<table>
<thead>
<tr>
<th>Dataset</th>
<th>Source</th>
<th>Year</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuting</td>
<td>DANE Mobility Survey</td>
<td>1995, 2005, 2011</td>
<td>Trip-diaries (trip and person characteristics)</td>
</tr>
<tr>
<td>Housing</td>
<td>Cadastral Department</td>
<td>2000-2013</td>
<td>Property value and characteristics, land use, land and floorspace area</td>
</tr>
</tbody>
</table>
| Employment (Firms) | General Census
                  | Business Registry (Chamber of Commerce)    | 1990, 2005, 2014 | Employment and industry (universe of estab.)                              |
| Employment (Workers) | DANE Household Surveys
                         | (ECH/GEIH)       | 2000-2014 | Employment and industry (formal estab.) Worker demographics and employment characteristics |
| Commute Times    | City Maps                                  | -                | Times by mode computed in ArcMap                                           |
Establishing Causal Impact of BRT

- **Challenge**: BRT routes chosen by government, may be correlated with other drivers of economic activity

- **Approach**:
  1. Predict TransMi routes using (i) historical tram and (ii) least cost construction routes
  2. Exploit opening across 3 phases to show no impacts until lines open
  3. Use changes in accessibility due to new lines >1.5km away

- **Additional Outcomes**: In paper, look at effect on commute distances, wages and gentrification
CMA Captures Differential Response Across Space
Residential Floorspace Prices vs RCMA
Res Pop vs RCMA

Change in Log Residential Population, residualized

Change in Log RCMA, residualized
Employment vs FCMA
Roadmap

1. Empirical Approach & Results

2. Quantification and Counterfactuals
Extended Model

To speak to distributional consequences, paper then develops model with multiple types of workers, firms and transit modes.
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Summary of Identification:

1. **Mode Choice Parameters**: Responsiveness of mode choices to differences in commute times

2. **Commuting Elasticity**: Responsiveness of change in commute flows to changes in commute times

3. **Agglomeration Externalities**: Responsiveness of change in productivities + amenities to exogenous shift in supply of residents and labor across city provided by ΔCMA instruments
### Aggregate Impacts of TransMilenio

#### Panel A: Aggregate Gains

- Output: 1.82%
- Average Welfare: 1.63%
- Rents: 1.91%

#### Panel B: Costs vs Benefits

- Capital Costs (mm): 1,137
- NPV Operating Costs (mm): 5,963
- NPV Total Costs (mm): 7,101
- NPV Net Increase Output (mm): 26,808
- Net Increase Output: 1.44%

Note: Table shows the (negative of the) value of the percentage change in each variable from removing phases 1 and 2 of the TransMilenio network from the 2012 equilibrium.
Welfare Decomposition

- **Theoretical Result**: In an efficient equilibrium, the first order welfare impact in the full GE model is simply the VTTS.

- **Empirical Question**: How important are reallocation + GE effects?
Welfare Decomposition

• **Theoretical Result**: In an efficient equilibrium, the first order welfare impact in the full GE model is simply the VTTS

• **Empirical Question**: How important are reallocation + GE effects?

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<th>Inequality</th>
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<tbody>
<tr>
<td>First Order Approximation (VTTS)</td>
<td>1.308</td>
<td>-0.172</td>
</tr>
<tr>
<td>General Equilibrium</td>
<td>1.628</td>
<td>0.085</td>
</tr>
</tbody>
</table>

• **Implication**: Reallocation + GE effects are important for large shocks + distributional consequences
Policy Counterfactuals 1: Network Components

1. **Geography Matters**: Low-skilled benefit most from lines connecting where they live with areas of dense employment

2. **Large Returns to Complementary Services**: “Feeder” network increases welfare more than any other line
Policy Counterfactuals 2: Land Value Capture

- In Bogotá, change in transit w/o complementary change in zoning laws
  - $\Rightarrow$ No significant response in housing supply to TM
- Land Value Capture:
  - "Development Rights Sale" - Gvt sells permits to build at higher densities near stations
  - Successful in Asian cities to (i) finance construction and (ii) increase housing supply
- 2 Policies: Allocate the same amount of new floorspace permits via
  1. Increase density by 30% within 500m of stations
  2. Increase density proportional to predicted change in CMA
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<th>Gvt. Rev Open City</th>
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<tr>
<td>Baseline</td>
<td>1.63%</td>
<td>0.09%</td>
<td></td>
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<tr>
<td>LVC-Distance</td>
<td>1.71%</td>
<td>0.03%</td>
<td>5.72%</td>
<td>17.82%</td>
</tr>
<tr>
<td>LVC-CMA</td>
<td>1.93%</td>
<td>0.01%</td>
<td>10.21%</td>
<td>41.07%</td>
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1. Average welfare gain 19% larger under LVC
2. Welfare + Revenue Gain greater under CMA-based scheme
3. Low-skilled benefit the most
Conclusion

• **My Contribution:**
  - Develop new empirical approach to measure effects of transit
  - Quantitative model to assess aggregate and distributional effects across groups
  - Combine rich microdata + construction of world’s largest BRT to assess causal impact

• **My Findings:**
  1. Investments in transit such as BRT have large aggregate net benefits to cities
  2. Low- and high-skilled benefit about the same ⇒ less precise policy tool to target the poor than implied by standard approach
  3. Complementary change in zoning policies ⇒ maximize returns from these investments