Quantitative Spatial Economics and Transportation

Urban Economics

Ignacio Sarmiento-Barbieri

Universidad de los Andes

October 23, 2024

Motivation

- This paper analyzes the construction of the world's largest Bus Rapid Transit (BRT) system: TransMilenio
- BRT provide an attractive alternative to subways in rapidly growing developing country cities since they are able to deliver similar reductions in commuting times at a fraction of the cost, and are much faster to build.
- **Why is this important?** To understand the implications of improving public transit on worker welfare, the GDP and the rents of the cities.

Urban Transit Infrastructure

Empirical Questions:

1. What are the **aggregate** effects of improving urban transit?
   - 2.5 billion people will move into cities by 2050, most in developing countries.
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.

Approach of This Paper

1. **New Commuter Market Access** approach from **general equilibrium theory** to measure effects of transit infrastructure within cities
   - **Individuals**: Access to Jobs.
   - **Firms**: Access to Workers
2. **Quantitative general equilibrium model of a city**:
   - **New Features**: Low/High-skill workers + Multiple transit modes
3. **Quantification + Counterfactuals**:
   - Quantitative welfare effects through value of time savings (VTTS) + reallocation and general equilibrium effects

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
2. **Distributional Effects**: High and low skilled benefit about the same
   - Higher public transit use of low-skilled offset by differences in commuting elasticities and GE effects
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

Background

Residence and Employment

- Bogotá is characterized by a high degree of residential segregation between the rich and poor.
- The high-skilled or the college-educated are much more likely to live in the North, with low-skilled workers located primarily in the city's South and periphery.
- While overall employment is concentrated along two bands to the west and north of the city center, high-skill intensive industries are located more towards the North.

Background

Commuting Prior and Posterior to TransMilenio

Commuting Prior to TransMilenio

- In 1995 the average trip to work in Bogotá took 55 minutes.
- The vast majority of these commutes was taken by bus (73%), followed by car (17%) and walking (9%).
- Public transportation in the city was highly inefficient.

Commuting Posterior to TransMilenio

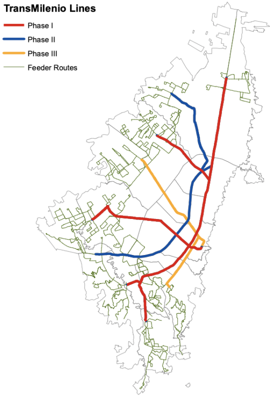
- Opened in 2000, TransMilenio is the world's most used BRT system with a daily volume of over 2.2mn trips.
- TransMilenio is more likely to be used for commutes to work rather than leisure trips, motivating the focus on access to jobs in this paper.

Background

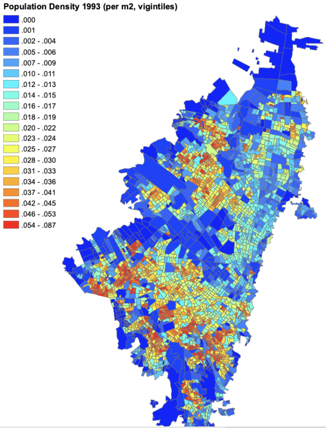
Commuting Prior and Posterior to TransMilenio

- TransMilenio was approved in March 1998. First phase added 42 km.
- Phases 2 and 3 added an additional 70 km in 2006 and 2011.

(a) TransMilenio Routes



(b) Population Density in 1993



A Quantitative Model of a City with Heterogeneous Skills

- Firms in different industries $s \in S$ produce using labor and commercial floorspace under perfect competition. Some locations are more productive than others.
- Each industry differs in its demand for skills: for example, hotels and restaurants demand more low-skilled workers while financial services require more high-skilled individuals. Since industries may be located in different places, wages for low- and high-skill workers will differ across the city.

A Quantitative Model of a City with Heterogeneous Skills

Workers
A worker ω in group g chooses a location i in which to live, a location j in which to work, and whether or not to own a car denoted by $a \in \{0, 1\}$.
Solving for the optimal demand for housing and consumption good yields the following expression for indirect utility:

$$U_{ijag}(\omega) = u_{iag} \left(\frac{w_{jg}\varepsilon_j(\omega)}{d_{ija}} - p_a a - r_{Ri}\bar{h} + \pi \right) r_{Ri}^{\beta-1} \nu_{ia}(\omega)$$

where $d_{ija} = e^{\kappa t_{ija}}$, and $\kappa > 0$ controls the size of these commute costs.

A Quantitative Model of a City with Heterogeneous Skills

Having chosen where to live i and whether or not to own a car a, individuals draw a vector of match-productivities with firms in locations across the city. Tsivanidis assumes this is drawn from a Frechet distribution

Properties of the Frechet distribution imply that the probability a worker of type g who has made choice (i, a) decides to work in j is given by:

$$\pi_{j|iag} = \frac{\left(\frac{w_{jg}}{d_{ija}}\right)^{\theta_g}}{\sum_s \left(\frac{w_{sg}}{d_{isa}}\right)^{\theta_g}} = \frac{\left(\frac{w_{jg}}{d_{ija}}\right)^{\theta_g}}{\Phi_{Riag}}$$

Residential Location and Car Ownership Decisions. The supply of type-g individuals to location i and car ownership a is:

$$L_{Riag} = \lambda_{U,g} \left(u_{iag} \left(\bar{y}_{iag} - p_a a - r_{Ri} \bar{h} \right) r_{Ri}^{\beta-1} \right) \eta_g$$

A Quantitative Model of a City with Heterogeneous Skills

Firm Commuter Market Access and Labor Supply. Using the commuting probabilities, the supply of workers to any location is found by summing over the number of residents who commute there:

$$L_{Fg} = \sum_{i,a} \pi_{j|iag} L_{Riag}$$

A Quantitative Model of a City with Heterogeneous Skills

Firms

There are $s \in \{1, \ldots, S\}$ industries which produce varieties differentiated by location in the city under perfect competition. Firms produce using a Cobb-Douglas technology over labor and commercial floorspace.

$$Y_{js} = A_{js} N_{js}^{\alpha_s} H_{Fjs}^{1-\alpha_s}$$

where

$$N_{js} = \left(\sum_{g} \alpha_s L_{Fjgs}^{\frac{1}{1-\sigma}} \right)^{\frac{\sigma}{1-\sigma}}$$

Factor Demand Solving the firm's cost minimization problem, the demand for labor and commercial floorspace is

$$L_{Fjgs} = \left(\frac{w_{jg}}{\alpha_{sg} W_{ja}} \right)^{-\sigma} N_{js}$$

A Quantitative Model of a City with Heterogeneous Skills

Market Clearing

There is a fixed amount of floorspace H_i in any location, a fraction ϑ_i of which is allocated to residential use and $1 - \vartheta_i$ to commercial use. For any allocation, market clearing for residential floorspace requires that the supply of residential floorspace $H_{Ri} = \vartheta_i H_i$ equals demand:

$$r_{Ri} = (1-\beta)\frac{E_i}{H_{Ri} - \beta \bar{h} L_{Ri}}$$

Likewise, the supply of commercial floorspace $H_{Fj} = (1 - \vartheta_i)H_j$ must equal that demanded by firms:

$$r_{Fj} = \frac{\sum_s (1-\alpha_s)\left(W_{js}^{\alpha_s} r_{Fj}^{1-\alpha_s} / A_{js}\right)^{1-\zeta} X}{H_{Fj}}$$

A Quantitative Model of a City with Heterogeneous Skills

Worker Welfare

Tsivanidis equates the overall welfare of group-g residents with the expected utility prior to drawing their idiosyncratic preferences in the first stage, given by:

$$\bar{U}_g = \gamma_{\eta,g} \left[\sum_{i,a} \left(u_{iag} \left(\bar{y}_{iag} - p_a a - r_{Ri} \bar{h} \right) r_{Ri}^{\beta - 1} \eta_g \right)^{1/\eta_g} \right]$$

To build intuition for the channels through which changes in the transit network affect welfare, Tsivanidis totally differentiates the expression for average utility (the change in utility in response to a small change in commute costs).

Empirical Analysis

Using The Model To Guide Empirical Work

The equilibrium reduces to the following system:

$$L_{Ri} = \lambda_U \left(u_i \Phi_{Ri}^{1/\theta} r_{Ri}^{\beta-1} \right)^{\eta}$$

$$r_{Ri} = \frac{1-\beta}{H_{Ri}} \Phi_{Ri}^{1/\theta} L_{Ri}$$

$$\tilde{L}_{Fi} = w_i^{\theta-1} \tilde{\Phi}_{Fj}$$

$$\tilde{L}_{Fi} = \frac{1}{\alpha} w_i^{\alpha(1-\sigma)-1} A_i^{\sigma-1} r_F^{(1-\sigma)(1-\alpha)} P^{\sigma-1} E$$

$$r_{Fi} = \left(A_i^{\sigma-1} w_i^{-\alpha(\sigma-1)} P^{\sigma-1} E \left(\frac{1}{(1-\alpha) H_{Fi}} \right)^{\frac{1}{1+(\sigma-1)(1-\alpha)}} \right)$$

Reduced Form Representation

Equilibrium can be written as:

$$\Delta \ln Y_{Ri} = \beta_R \Delta \ln \Phi_{Ri} + e_{Ri}$$

$$\Delta \ln Y_{Fi} = \beta_F \Delta \ln \Phi_{Fi} + e_{Fi}$$

where

- $\Delta \ln Y_{Ri} = [\Delta \ln L_{Ri} \quad \Delta \ln r_{Ri}]$ and $\Delta \ln Y_{Fi} = [\Delta \ln L_{Fi} \quad \Delta \ln r_{Fi}]'$ are changes in endogenous outcomes.
- β_R, β_F are reduced form coefficients capturing direct + indirect effects of CMA on outcomes.
- e_{Ri}, e_{Fi} are structural errors containing changes in amenities/productivities.

Empirical Analysis

Target: Empirically assess the effect of TransMilenio on land and labor markets outcomes through improved CMA. Taking the first two entries of the reduced form system delivers the baseline specification:

$$\Delta \ln Y_{Rit} = \beta \Delta \ln \Phi_{Rit} + \alpha_l + \gamma' X_{it} + \varepsilon_{Rit}$$

Resident Commuter Market Access Φ_{Rit}.

Typically this regression will be estimated in long-differences over a pre- and post-period.

Empirical Analysis

Challenges to Identification There are two key challenges to estimating the specification:

- Changes in market access contain population and employment in both periods. Local productivity and amenity shocks that drive movements in residence and employment will therefore be mechanically correlated with the error.

  $$\Rightarrow$$

  Address this by instrumenting for changes in CMA (Commuter Market Access) holding population and employment fixed at their initial values.

- Growth in CMA may be correlated with the error if routes targeted neighborhoods with differential trends in productivities or amenities.

  $$\Rightarrow$$

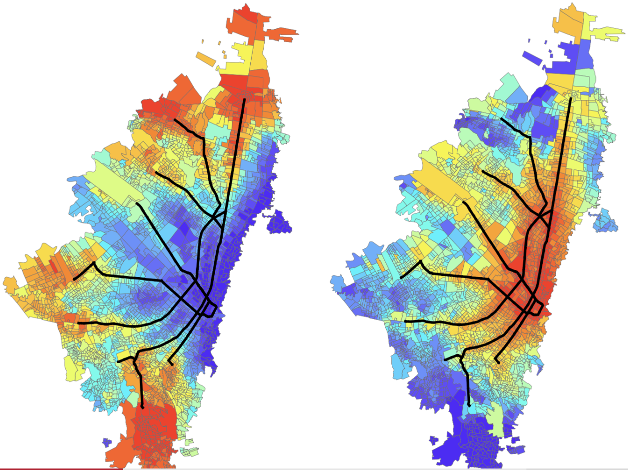
  The instrument for the change in CMA is then defined as the difference between this predicted CMA under TransMilenio and its value in the initial period without the system.

Background

Distribution of changes in commuter access across the city induced by the construction of the first two phases of the system.

Figure 1: Change in Commuter Market Access from TransMilenio

(a) Resident CMA (b) Firm CMA



Structural Estimation

Parameter Estimation

The procedure to estimate the parameters of the model can be summarized as follows:

- **Step 1.** Calibrate and estimate a subset of parameters without solving the full model.
- **Step 2.** Solve for wages using parameters from step 1.
- **Step 3.** Estimate remaining elasticities via GMM using moments similar to reduced form analysis.
- **Step 4.** With all parameters in hand, invert the model to recover unobservables.

Structural Estimation

Quantifying the Effect of TransMilenio

Cost vs Benefits: How did the output gains from TransMilenio compare with the costs of the system?

Table 1: Panel A: Costs & Benefits

	Closed City		**Open City**	
	No Spillovers	Spillovers	No Spillovers	Spillovers
NPV Increase GDP (mm)	57,359	72,052	190,282	286,812
Capital Costs (mm)	1,137	1,137	1,137	1,137
NPV Operating Costs (mm)	5,963	5,963	5,963	5,963
NPV Total Costs (mm)	7,101	7,101	7,101	7,101
NPV Net Increase GDP (mm)	50,258	64,952	183,181	279,711
% Net Increase GDP	2.73	3.53	9.96	15.21

Note: All numbers are in millions of 2016 USD. NPV is calculated over a 50-year time horizon with a 5% discount rate. Row (1) reports the increase in NPV GDP from phases 1 and 2 of the TransMilenio network from the baseline equilibrium in 2012. Row (2) reports the capital costs of constructing the system, averaging 12.23mm per km over 93km of lines. Row (3) reports the NPV of operating costs, while Row (4) reports the NPV of total costs. Row (5) reports the difference between Row (1) and Row (4). Row (6) shows the percentage of net increase in GDP.

Structural Estimation

Quantifying the Effect of TransMilenio

Comparison with VTTS Approach: The typical approach to evaluate the gains from commuting infrastructure is based on the Value of Travel Time Savings (VTTS) approach. In this framework, the benefits from new infrastructure are given by the marginal value of time times the amount of time saved. Welfare gains under VTTS are driven solely by mode choice: the low-skilled gain more than the high-skilled in row (1).

Table 2: Table 15: Comparison with Value of Time Savings Calculation

	Welfare Low	Welfare High
VTTS	4.203	3.396

Note: The first row reports the percentage change in each variable due to TransMilenio from a Value of Time Savings approach as described in the appendix. The second row reports the values from my model with the same θ, η, and perfect substitutes in production, in partial equilibrium where commute times change but all prices and location decisions are fixed. The third row does the same in the baseline model. The fourth row reports the values from my model with full general equilibrium adjustment. Partial equilibrium results computed in the same way as in Table 13, but with spillovers set to their estimated values.