The impact of urban highways and subways on a city's structural density: evidence from a large investment in transport infrastructure

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Motivation

Sprawled cities are characterized by:

- Low population density
- Long travel distances that are often car reliant
- Congestion
- High levels of greenhouse emissions
- Increased costs of public service provision
- High opportunity cost for people living outside the city center

International organizations encourage policies that help manage urban sprawl and promote socially desirable levels of population density (OECD 2018).

Motivation

Urban transport infrastructure is a critical aspect that defines the geospatial topology of a city.

Understanding the role that highways and rail investment have on the structure of a city can guide policymakers in the design of well-functioning cities and in this way, foster economic development.

Research question

This study explores the effects of urban transport infrastructure on a city's spatial structure. In particular, this investigation identifies the degree to which urban highways and subways have an impact on a city's built area.

Literature review

Effects of highways on intracity outcomes:

- Decentralization of population (Redding and Turner 2015; Baum-Snow 2007; Baum-Snow, Brandt, et al. 2017; Garcia-López, Holl, and Viladecans-Marsal 2015),
- Decentralization of manufacturing industry (Baum-Snow, Brandt, et al. 2017).
- Population growth in the vicinity of the infrastructure (Baum-Snow 2007)
- Employment growth (Duranton and Turner 2012)
- Driving in the city (Duranton and Turner 2012), amongst others.

Literature review

Effects of subways and railways on aggregate outcomes:

- Decentralization of population (Gonzalez-Navarro and Turner 2018).
- Increase employment outcomes (Mayer and Trevien 2017).
- Increases property prices (Baum-Snow and Kahn 2000; Gibbons and Machin 2005; Baum-Snow and Kahn 2000; Bowes and Ihlanfeldt 2001).

Literature review

- Most of these studies have focused on aggregate city outcomes rather than changes in its internal composition.
- Studies that consider highways mostly use interstate or intercity highways and sometimes in their urban segment.
    - We consider urban highways that are built entirely within the city to improve its accessibility and are not a segment of an intercity highway.

Contribution

- This paper contributes to the literature by considering the construction of two simultaneous infrastructure, urban highways, and subways on the internal composition of the city.
- To the best of our knowledge, this is the first study that focuses on the impact of urban highways and subway expansions on the structural density of a city.

Considerations

- In the 2000s, the Chilean Government invested in urban highways, subway lines, and bus corridors.
- Results of this presentation consider only infrastructure inaugurated between 2000 and 2009.

Santiago's Transport Infrastructure

Table 1: Opening date of Santiago's urban highways

Highway	**Type of Highway**	**Inaguration**
Autopista Vespucio Norte	Upgrade	04/Jan/06
Vespucio Sur Express	Upgrade	27/Apr/06
Autopista Central	Upgrade	08/May/06
Costanera Norte	New	04/Oct/07
Autopista Nororiente	New	06/Feb/08
Túnel San Cristóbal	New	03/Jul/08

Source: Ministerio de Obras Públicas

Santiago's Transport Infrastructure

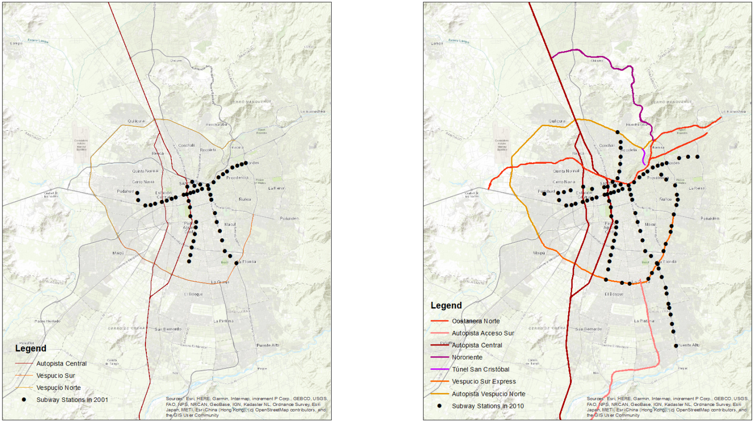
Table 2: Opening date of Santiago's Subway expansions

Subway Line	Number of Stations	Inaguration
Line 5	2	31/Mar/04
Line 2	2	08/Sep/04
Line 2	2	22/Dec/04
Line 2	2	25/Nov/05
Line 5	1	30/Nov/05
Line 4	9	30/Nov/05
Line 4	8	30/Nov/05
Line 4	5	02/Mar/06
Line 4A	6	16/Aug/06
Line 2	3	21/Dec/06
Line 4	1	05/Nov/09

Source: Ministerio de Obras Públicas

Santiago's Transport Infrastructure

Figure 1: Santiago's Transport Infrastructure Evolution (2000 - 2010)



(a) Before **(b)** After

Data

- Area built: Chile's Internal Revenue Service (Servicio de Impuestos Internos) for 1995, 2000, 2005 and 2009.
- The spatial unit of analysis are the ones defined by Chile's transport planning authority (the so-called "Estraus" zone).
- Socioeconomic Covariates: Chile's Census 2002.
- Geocoded map and timing of subway line openings.

Econometric Model

We use a difference-in-difference strategy described in equation (1) that models the effect of proximity to different infrastructure on density. Treated areas are those located within 3 kilometers of an urban highway or a subway station.

$$\Delta(\ln(SMB))_s = \beta_1 * Dist._i^{NUHW} + \beta_2 * Dist._i^{UGUHW} + \beta_3 * Dist._i^{SW} + \theta X_{i0} + \epsilon_{it} \tag{1}$$

The dependent variable is the change in natural logarithm of squared meters built of zone s, between the years 2000 and 2009 (not distinguishing by type).

Econometric Model

We use a difference-in-difference strategy as described in equation (1). Treated areas are those located within 3 kilometers of an urban highway or a subway station.

$$\Delta(\ln(SMB))_s = \beta_1 * Dist._i^{NUHW} + \beta_2 * Dist._i^{UGUHW} + \beta_3 * Dist._i^{SW} + \theta X_{i0} + \epsilon_{it}$$

Equation (1) consideres the effect of the distance from the centroid of the zone i to the new urban highways (β_1), to the upgraded urban highway (β_2), and to the nearest subway station (β_3).

Econometric Model

We use a difference-in-difference strategy as described in equation (1). Treated areas are those located within 3 kilometers of an urban highway or a subway station.

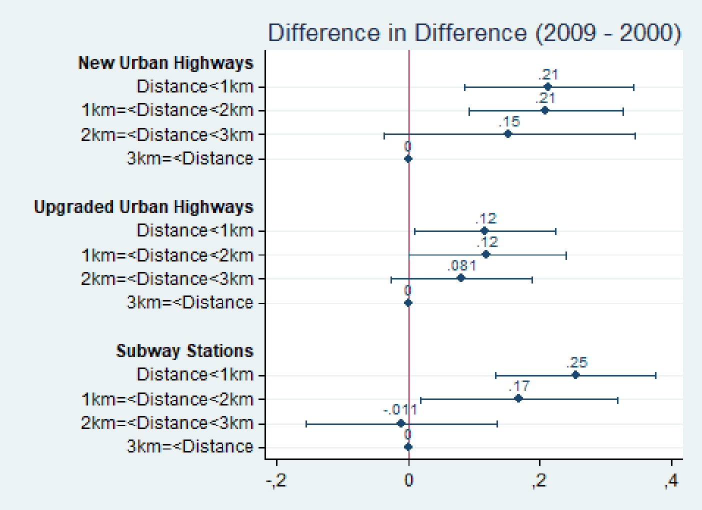
$$\Delta(\ln(SMB))_s = \beta_1 * Dist._i^{NUHW} + \beta_2 * Dist._i^{UGUHW} + \beta_3 * Dist._i^{SW} + \theta X_{i0} + \epsilon_{it}$$

- Location and socioeconomic covariates are included in X_{i0} for the base year.
- In all the regressions, we report clustered standard errors at a zone level.

This specification controls for unobserved-but-fixed omitted variables (confounding factors).

Main Results

Figure 2: Difference in differences results (2000-2009)

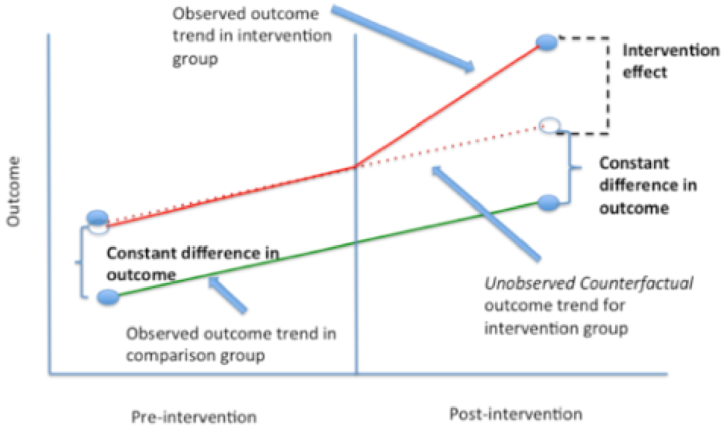


Testing Parallel Trends

A difference-in-difference strategy requires that the "counterfactual **trend** of treatment and control groups be the same" (Angrist and Pischke 2008) to estimate causal effects.

Testing Parallel Trends

Figure 3: Example of Parallel Trends

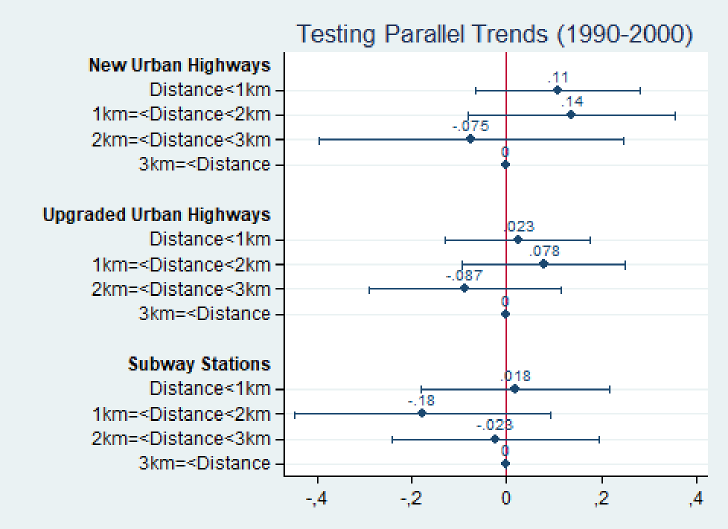


Testing Parallel Trends

When testing for these parallel trends, we observe that the difference between the treatment and control group before the inauguration is not statistically significant.

Testing Parallel Trends

Figure 4: Difference in differences results (2000-1990)



Conclusion

- New urban highways increase a city's structural density around 20% in a 2km bandwidth.
- Upgraded highways have a smaller effect on density, of around 13% in the 2km bandwidth.
- Subways increase density around the first km in 28%, and this effect declines with distance.
  - In the first kilometer, the point estimate value of subways is larger than for highways, though they are not statistically different from each other.

Reflection

While interstate highways in the USA caused suburbanization (Baum-Snow 2007), urban highways in Santiago caused structural densification. Compatibility of findings?

- Interstate highways vs (completely) urban highway.
- While most interstate highways in the USA were toll-free, the toll in Santiago's urban highways is \$.32/km.

Ongoing Work and Future Research

- Exploring microdata on built surface.
- Using changes in accessibility as the treatment variable. (Tsivanidis 2017; Ahlfeldt 2013; Gibbons and Machin 2005; Mayer and Trevien 2017).
- Estimating effect on area built for commercial and residential purposes.
- Studying the effects on property prices as an alternative (jumpy) dependent variable.
- Estimating heterogeneous effects with respect to transport infrastructure, local regulatory plans (restrictions on height and area built), socioeconomic variable, initial density, and distance to CBD.

Ongoing Work and Future Research

- Study the effect of transport infrastructure on the extensive and intensive margins of a city's built area.
- Planned Route Instrumental variable approach.
  - Because of the non-random treatment assignment, there is reverse causality in the location of the infrastructure and density outcomes. To account for this endogeneity issue, and estimate causal effects consistently, we are also working on an instrumental variable approach.

Thanks! Questions?[1]

[1] For any additional comments or question, please contact us!(aaherrera2@uc.cl)

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Results

Table 3: New UHW Difference in differences results (2000-2009)

	(1)	(2)	(3)	(4)	(5)	(6)
	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$	$\Delta(\ln(SMB))$
Distance $<$ 1km	-0,116**	-0,156**	-0,179***	-0,034	-0,039	0,213***
	(0,051)	(0,067)	(0,068)	(0,062)	(0,081)	(0,065)
1km $\leq$ Distance $<$ 2km	-0,046	-0,063	-0,062	0,012	0,006	0,208***
	(0,055)	(0,061)	(0,061)	(0,058)	(0,077)	(0,060)
2km $\leq$ Distance $<$ 3km	0,078	0,077	0,063	0,129	0,123	0,153
	(0,208)	(0,210)	(0,200)	(0,202)	(0,214)	(0,097)
Socioeconomic	No	Yes	Yes	Yes	Yes	Yes
Population Density	No	No	Yes	Yes	Yes	Yes
Area	No	No	No	Yes	Yes	Yes
CBD	No	No	No	No	Yes	Yes
Lagged dep. var. ($ln(SMB\_1995)$)	No	No	No	No	No	Yes
Observations	601	601	601	601	601	601
R^2	0,0203	0,0301	0,0801	0,1161	0,1161	0,6613

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Results

Table 4: Upgraded UHW Difference in differences results (2000-2009)

	(1) $\Delta(\ln(SMB))$	(2) $\Delta(\ln(SMB))$	(3) $\Delta(\ln(SMB))$	(4) $\Delta(\ln(SMB))$	(5) $\Delta(\ln(SMB))$	(6) $\Delta(\ln(SMB))$
Distance $<$ 1km	-0,085	-0,002	-0,009	0,126*	0,121	0,117**
	(0,082)	(0,063)	(0,059)	(0,073)	(0,083)	(0,055)
1km $\leq$ Distance $<$ 2km	-0,053	0,015	0,012	0,090	0,085	0,119*
	(0,093)	(0,088)	(0,085)	(0,085)	(0,090)	(0,061)
2km $\leq$ Distance $<$ 3km	-0,083	-0,029	0,009	0,100	0,096	0,081
	(0,091)	(0,087)	(0,083)	(0,085)	(0,088)	(0,054)
Socioeconomic	No	Yes	Yes	Yes	Yes	Yes
Population Density	No	No	Yes	Yes	Yes	Yes
Area	No	No	No	Yes	Yes	Yes
CBD	No	No	No	No	Yes	Yes
Lagged dep. var. ($ln(SMB\_1995)$)	No	No	No	No	No	Yes
Observations	601	601	601	601	601	601
R^2	0,0203	0,0301	0,0801	0,1161	0,1161	0,6613

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Results

Table 5: Subway Difference in differences results (2000-2009)

	(1) $\Delta(\ln(SMB))$	(2) $\Delta(\ln(SMB))$	(3) $\Delta(\ln(SMB))$	(4) $\Delta(\ln(SMB))$	(5) $\Delta(\ln(SMB))$	(6) $\Delta(\ln(SMB))$
Distance $<$ 1km	-0,219***	-0,251***	-0,136**	0,060	0,056	0,254***
	(0,065)	(0,076)	(0,066)	(0,064)	(0,077)	(0,062)
1km $\leq$ Distance $<$ 2km	-0,174	-0,177	-0,030	0,136	0,132	0,168**
	(0,112)	(0,113)	(0,131)	(0,143)	(0,150)	(0,076)
2km $\leq$ Distance $<$ 3km	-0,204**	-0,205***	-0,072	0,051	0,048	-0,011
	(0,079)	(0,077)	(0,071)	(0,069)	(0,075)	(0,074)
Socioeconomic	No	Yes	Yes	Yes	Yes	Yes
Population Density	No	No	Yes	Yes	Yes	Yes
Area	No	No	No	Yes	Yes	Yes
CBD	No	No	No	No	Yes	Yes
Lagged dep. var. ($ln(SMB\_1995)$)	No	No	No	No	No	Yes
Observations	601	601	601	601	601	601
R^2	0,0203	0,0301	0,0801	0,1161	0,1161	0,6613

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Elements of theoretical models

Models like Ahlfeldt et al. (2015) relate residential and commercial floor space with commuting costs.
Tsivanidis (2017) extends the framework to include multiple groups of workers, industries and transit modes.

Elements of theoretical models

Key in Tsivanidis (2017): Workers first choose where to live and to own a car, and then they decide where to work.
Individuals maximize the following utility function[2]

$$\max_{C_i(\omega), H_{Ri}(\omega)} u_{iag} C_i(\omega)^{\beta} (H_{Ri}(\omega) - \bar{h})^{(1-\beta)} v_{ia}(\omega) \tag{2}$$

subject to

$$C_i(\omega) + r_{Ri} H_{Ri} + p_a a = \frac{w_{jg} \epsilon_j(\omega)}{d_{ija}} \tag{3}$$

Workers are heterogeneous in their match-productivity with firms where they work $\epsilon_j(\omega)$, they have wages w_{jg} for each type g, and have disutility from commuting that reduces their productivity at work $d_{ija} \geq 1$.

[2] Stone-Geary Preferences

Elements of theoretical models

Firms produce using a Cobb-Douglas technology over labor N_{js} and commercial floorspace H_{Fjs}

$$Y_{js} = A_{js} N_{js}^{\alpha_s} H_{Fjs}^{1-\alpha_s} \tag{4}$$

where

$$N_{js} = (\sum_g \alpha_{sg} \hat{L}_{Fjgs}^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}} \tag{5}$$

where the labor input is a CES aggregate over the effective labor across skill groups with elasticity of substitution σ, $\alpha_s = \sum_s \alpha_{sg}$ is the total labor share and A_{js} is the productivity of location j for forms in industry s. Industries differ in the intensity in which they use different types of workers α_{sg}

Elements of theoretical models

Floorspace use allocation: They receive r_{Ri} per unit of floorspace destined to residential use, but land use regulations limit the returns to commercial use $(1-\tau_i)r_{Fi}$

$$\theta_i = 1 \;\; if \;\; r_{Ri} > (1-\tau_i)r_{Fi}$$

$$\mathrm{r}_{Ri} = (1-\tau_i)r_{Fi} \;\; \forall \left[i : \theta_i \in (0,1)\right]$$

$$\theta_i = 0 \;\; if \;\; r_{Ri} < (1-\tau_i)r_{Fi}$$

Elements of theoretical models

Implications of this model:

- Commute costs differ by car ownership because car owners can choose between commuting by car or public transit, whereas individuals without cars can only choose public transportation.
- When cars are quicker than public transportation, the rich are more willing to pay fixed cost since their value of time is higher.
- Since housing is expensive in high amenity locations in equilibrium, the poor (rich) sort into low (high) amenity neighborhoods.
- Workers choose to work in the location that offers the highest income net of commute costs.
- Firms attract workers when they have better access to them through the commuting networks.
- The supply of residents to a location rises when it is close to well-paid jobs.

Elements of theoretical models

Guiding empirical work:

- Log-linear relationships between endogenous outcomes and Commuter Market Access.
- Residence
- Effective employment