

Roads, Transit, and the Denseness of São Paulo's Urban Development

Lecture by Zegras, Borges Costa, Zheng

Annotation by Manasa Acharya

Part I. Literature (for further reading the relationship between transit, density, and spatial patterns)

Costa, A., Zegras, C. and Bidermand, C. (2021). Chasing the city that cannot stop: Exploring transportation and urban co-development in São Paulo's history. *The Journal of Transport and Land Use*, V. 14 N. 1 [2021] pp. 1075–1097.

https://pesquisa-eaesp.fgv.br/sites/gvpesquisa.fgv.br/files/arquivos/ciro_2_-_costa_1969_v3.pdf

Harris, S. (2014). São Paulo Spatial Structure and Mobility from 1997 to 2012 and Beyond: Transformation through Urban Policies. *School of Architecture and Urbanism, University of São Paulo*.

https://t2m.org/wp-content/uploads/2014/09/Sabrina%20Harris_Sao%20Paulo%20Spatial%20Structure%20and%20Mobility.pdf

Vazquez, E., Rodrigues, B., Najjar, M.K., Haddad, A., WA Hammad, A. (2022). A framework to locate new medium and high capacity stations for public transportation modes of transport in Rio de Janeiro. *Cleaner Engineering and Technology*, Volume 10, 100537, ISSN 2666-7908.

<https://doi.org/10.1016/j.clet.2022.100537>

Costa, A., Sonnenschein, T. and Zheng, S. (2021). Subway Expansion and the Rise in the Spatial Disparity of Consumer Amenities. *MIT Center for Real Estate Research Paper No. 21/09*.

<http://dx.doi.org/10.2139/ssrn.3881397>

Costa, A., Ramos, C. & Zheng, S. (2021). Subway Expansion, Jobs Accessibility and Home Value Appreciation in Four Global Cities: Considering Both Local and Network Effects. *MIT Center for Real Estate Research Paper No. 21/01*.

https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3784735

Kumar Mishra, A. (2019). Cities, transport and agglomeration: Addressing the urban mobility challenges in India. *Growth and Change: A Journal of Urban and Regional Policy*.

<https://doi.org/10.1111/grow.12321>

Suzuki, H., Cervero, R., Iuchi, K. (2013). Transforming Cities with Transit – Transit and Land Use Integration for Sustainable Urban Development. *World Bank*.

<https://documents1.worldbank.org/curated/en/947211468162273111/pdf/Main-report.pdf>

Part II. Similar topics of discussion in the News

Patel, S., Kapadia, O., Saluja, J. (2017, May 19). *Low-cost transport is vital to affordable housing – and a Bus Rapid Transit System is the best bet*. Scroll.Com.
<https://scroll.in/article/837672/low-cost-transport-is-vital-to-affordable-housing-and-a-bus-rapid-transit-system-is-the-best-bet>

Tsivanides, N., Lall, S., Ngulube, M. (2022). *Creating virtuous circles between urban planning and urban transit*. The Daily Star and World Bank blogs.
<https://www.thedailystar.net/business/economy/opinion/news/creating-virtuous-circles-between-urban-planning-and-urban-transit-3135616>
<https://blogs.worldbank.org/transport/creating-virtuous-circles-between-urban-planning-and-urban-transit>

Ge, Y. (2017). *The Chicken-Egg Problem of Transit and Density*. University of Washington.
<https://sites.uw.edu/stlab/2017/06/07/the-chicken-egg-problem-of-transit-and-density/>

Florida, R. (2021, May 14). *The Death and Life of the Central Business District*. City Lab. Bloomberg.com
<https://www.bloomberg.com/news/features/2021-05-14/the-post-pandemic-future-of-central-business-districts>

Part III. Post-Presentation Questions

Kay Axhausen questions

Q: Why did the public not give up on transit the way they did in the US? What is Sao Paulo's plan for net-zero by 2050? What is the impact of the virtual on spatial development?

- In terms of the new regime, Sao Paulo has grown very quickly, covering in 50 years the magnitude of growth that New York experienced in 110 years. Additionally, it is a very poor and unequal city, and thus, car purchase is not common despite significant road development that occurred during this time. However, in the last 25 years, we have tripled the number of cars in Sao Paulo. Currently, public transit makes for 1/3rd of the trips in the city, but this share has been declining over the past few years. Thus, there is a need for the city to ensure that it does not lose the existing share. It is also a lower share as compared to many European and Asian cities, and can perform better in that regard.

There is no clear plan of action for net-zero carbon emissions achievement. One of the upcoming papers, Adriano and Siqui are trying to explore how the city can promote accessibility through zoning changes.

Regarding the final question, there is a possibility that we will arrive at a point when virtual will counterintuitively increase the value of tacit, face-to-face interactions and add a premium to that. When that will happen remains a question. But remote and in-person

are likely to remain complementary, with nearby smaller cities becoming the new suburbs of the cities.

Jinhua's questions

Q: If we were to apply the study's insights in new cities, do we have to replicate the study or can we facilitate generalized takeaways from it?

- The context of this research was very specific to Sao Paulo and its history, but there are other papers by the authors that analyze and compare transit across different cities. These papers can help evaluate what insights can be generalized and what is contextual. It is important to note that the desire to apply learnings across contexts would require researchers to make the tradeoff between internal and external validity.

Q: How do we translate the takeaways from the study into a meaningful argument that supports public sector action in Sao Paulo?

- If we can show how transit is affecting the value of land, it will allow us to make arguments related to opportunities for value capture. This needs to be thought about beforehand and communicated to the public as the city government's plan for improving their neighborhoods, so that taxes applied after are not perceived as unjust by the residents.

Audience questions:

Q: What is the radius of a transit station's impact? At what distance does the impact start to diminish?

- Although this study did not work with a buffer around the station, the authors have analyzed ½ km, 1 km, and 2 km grid cells. They noticed more impact at the local and neighborhood levels up to 2 kms. It is important to note that context matters – the physical characteristics of the station affect the impact. For example, is the station in a dense area or a suburban location? A major factor that was thought to make a difference is also how attractive the walkability to and from the station is (although this can vary culturally).

Q: How are we factoring the cost of externalities if we were to include societal and climate related costs?

- The study did not do a social cost benefit analysis. However, past empirical evidence provides clear data to support that cars and sprawl result in higher emissions and cost more to the society and public services. On the other hand, mass transit leads to more dense, sustainable cities.

Part IV. Summary of Memos.

Themes from Other Memos:

1. David Hong found some of the audience questions to be interesting – namely, what the boundaries or limits of TOD impacts are and at what distance from transit stations the impact begins to diminish? Whether we should collectivize the cost of transportation rather than leave it individual? Why did Sao Paulo not experience a massive reduction in transit in favour of cars in the 1960s-1980s and beyond? What kind of impact does this type of study have on project evaluation?
2. Tushar Kanade also had two questions that arose from the talk: How would Sao Paulo look if development trajectories differed? How much/what portion of these hypotheses can be transferred to other cities' development plans?
3. Yen-Chu Wu was surprised by the land-use specialization hypothesis since it was in contrast to his experience in Taiwan, where people preferred living close to employment opportunities. Similarly, Michael Leong and Ao Xu were also surprised at the second hypothesis, that transit development had led to the specialization of land uses, causing commercial densification at the urban core and residential densification outside the core. They both reflected on its impact on decentralization and “15-minute cities” that are gaining momentum now.
4. Ao Xu suggested that land use specialization predicted as a result of transit might move away from making life more convenient through ideas like “15-minute city” where people can enjoy most resources they need within an accessible distance. Ao Xu was curious if the correlation between transit and land use specialization was simply driven by the fast-growing urban population and the demand for efficiency. Additionally, even public transit was more developed near the city center, which includes both commercial and residential activities. Thus, they wondered if these results also vary by location, culture, and land size.
5. Paul Twijukye's takeaway was that since transportation and land use are inextricably intertwined, real-estate developer and transportation decision-makers in any given city need to work together to come up with a coordinated plan that takes into account future implications of any proposed transportation/real-estate development plans/lines of action. They also found it interesting that despite Sao Paulo's avenue plan leading to the creation of a city today that struggles with congestion, high emission levels, and lengthy commutes, many other developing cities (especially in Africa) are taking a similar line of action today.
6. Similarly, Jason Luo thought that the talk had lessons for cities that look at transportation infrastructure as a means to achieve public welfare. They were of the opinion that railways lead to clustering of the population which is inherently an inefficient use of land offering a lower quality of living than the alternative.
7. Samuel Chin's takeaway from the talk was about how if we want to build a city like Manhattan, subways are the way to go and wondered if verticalization might be the future of cities.
8. Spencer MacDonald was interested to further explore what the impact of financial wealth and valuation of travel time across income groups would be on the two hypotheses.
9. McKenzie Humann had a couple questions about the methodological choices that the authors made. Firstly, based on local context they asked if it is possible that areas along the historical trolley lines and along the original river networks have had different development patterns over the years, as the answer is important for evaluating the validity

of the instrumental variables. Secondly, they wondered if the authors considered spatial regressions that would be able to capture the relationship of transportation network expansion on neighboring cells on the urban development, since expansion was not defined in the conventional way in this study. Finally, they were curious about the different time horizons for the two main transportation infrastructure networks, roads and rail, since urban rail was not added until the second half of the 50 year evaluation timespan and roads were likely added earlier and continued throughout the time frame. McKenzie asked if it was possible that the effect of expanding the rail network is underestimated in their analysis because there was less time for the effects to be realized in comparison to the effects of the road network expansion which took place earlier.

My Reflections:

Zegras, Borges Costa and Zheng's presentation on the development of transportation infrastructure on densification and land use was interesting to reflect on, especially from the perspective of a Global South context. Their study established evidence suggesting that transit leads to verticalization, whereas construction of roads leads to sprawl. While this finding focuses on Sao Paulo, based on our discussions in the US, I believe it might be equally applicable to the US as well which has actively developed sprawling suburbanization through prioritization of highways over transit. It got me thinking that if transit leads to density, are investments in new transit lines that do not currently have travel demand (but the government hopes to encourage it in the future) a good way to encourage balanced regional growth?

A second hypothesis that was presented was how transit development causes specialization of land uses in the center, primarily in favor of commercial centers. In my own city of Mumbai, I have seen a similar pattern as well. While this is admirable for reduced emissions, I always wrestled with the question of how sustainable and livable it is to have people living 2-3 hours away having to travel, even if by transit, to the central core for employment (6 million passengers travel by Mumbai local trains every day). This presentation raised multiple questions for me in this regard. Is transit the only or one of the drivers of such spatial patterns? Is there a way in which the findings of this research can be planned in a way that facilitates decentralization? In other words, can decentralized employment hubs in a region be planned and strengthened via transit connections? Alternatively, are there any actions, beyond transit connections that can be taken to balance growth, or do legacy connections dictate the region's destiny?

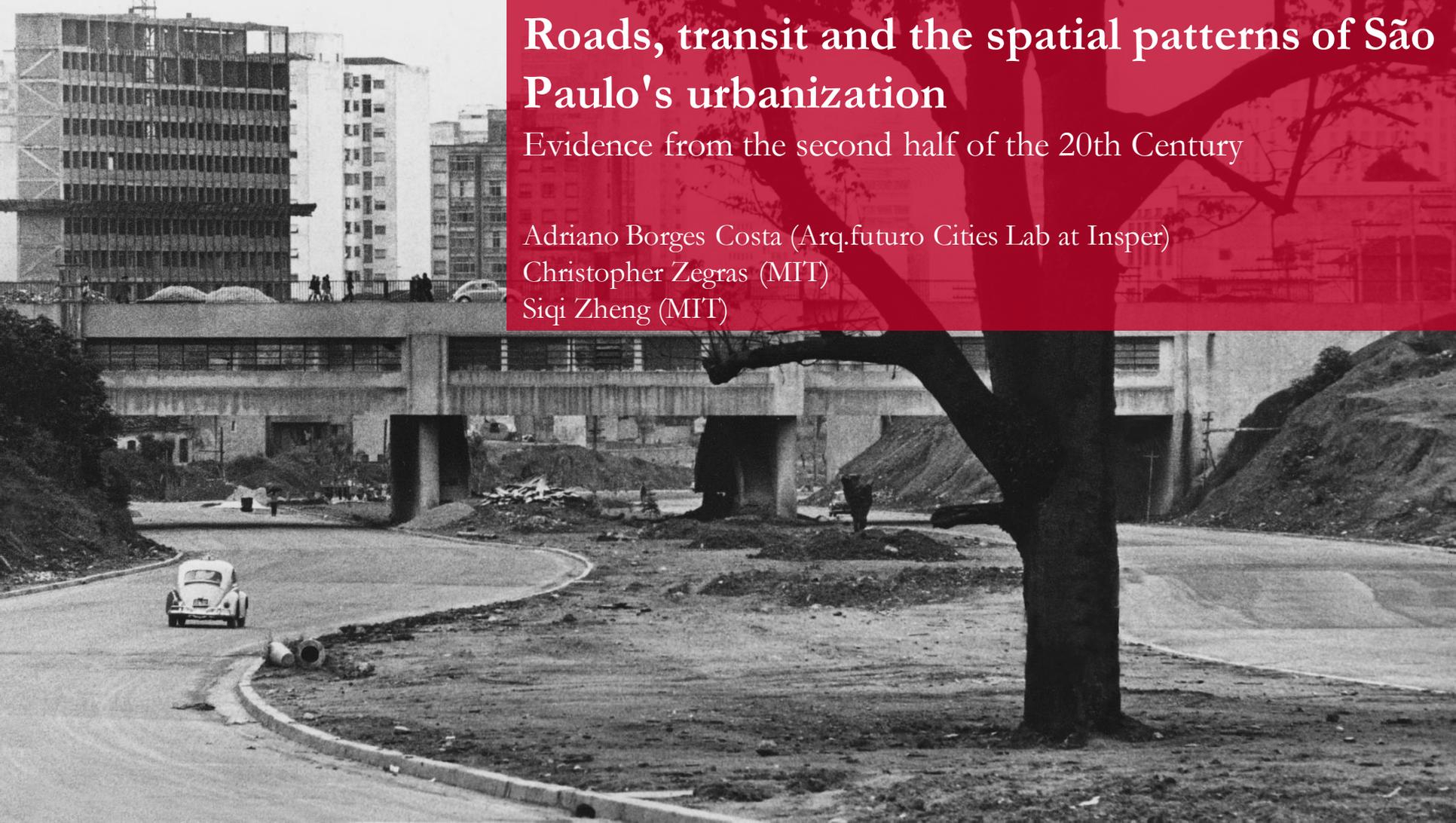
Roads, transit and the spatial patterns of São Paulo's urbanization

Evidence from the second half of the 20th Century

Adriano Borges Costa (Arq.futuro Cities Lab at Insper)

Christopher Zegras (MIT)

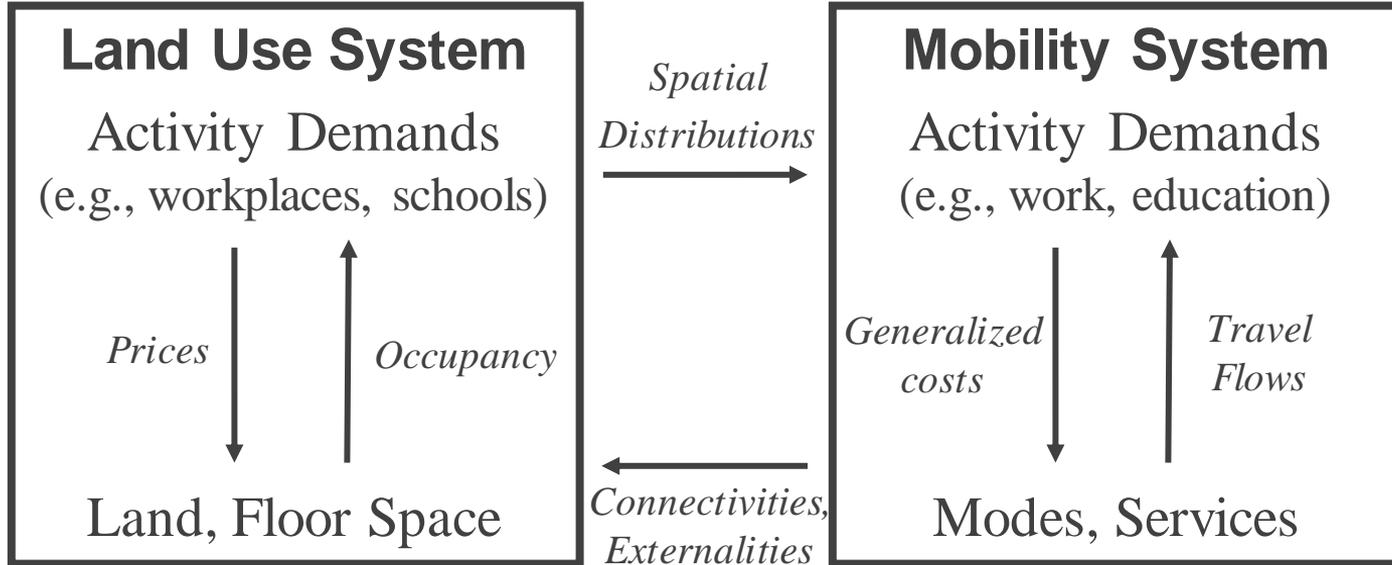
Siqi Zheng (MIT)



Agenda

- Mobility & Urban Development – Inextricably intertwined
- São Paulo: A quick history
- Mobility & Urban Development – A method to disentangle
- São Paulo's Mobility & Urban Development: Results from a novel analytical approach
- Some implications

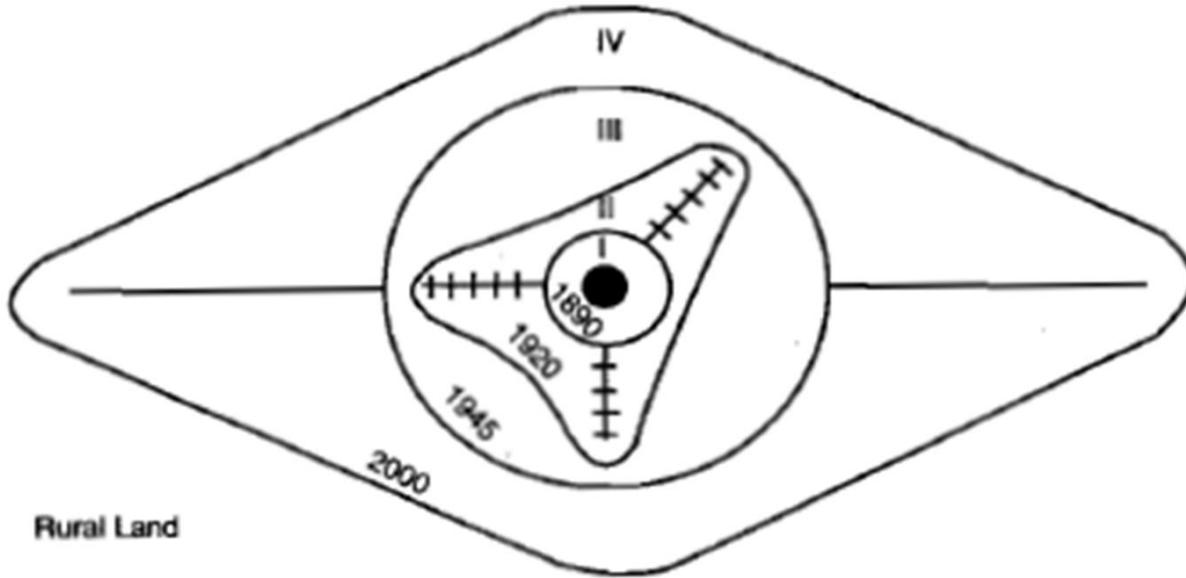
Land Use-Transport Interaction: Theoretical Framework



Mobility = f (City Form)?

or

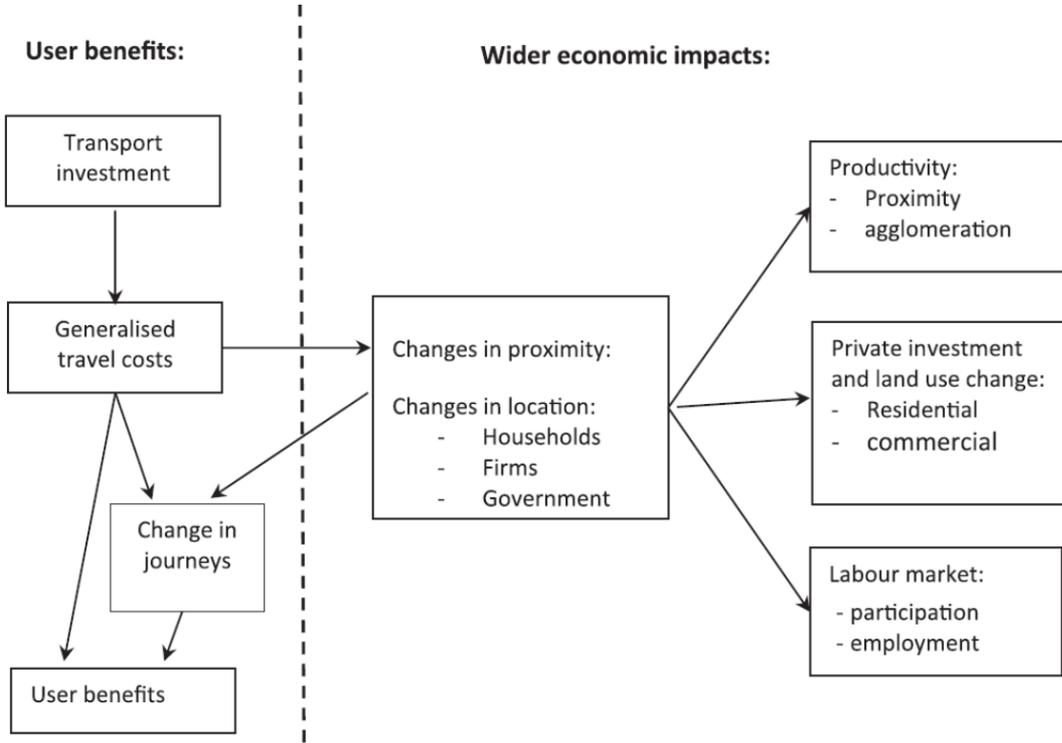
City Form = f (Mobility)?



Muller, 2004

Mobility = f (City Form)?
or
City Form = f (Mobility)?

Not just theoretically interesting...



Mobility = f (City Form)?
or
City Form = f (Mobility)?

Not just theoretically interesting...

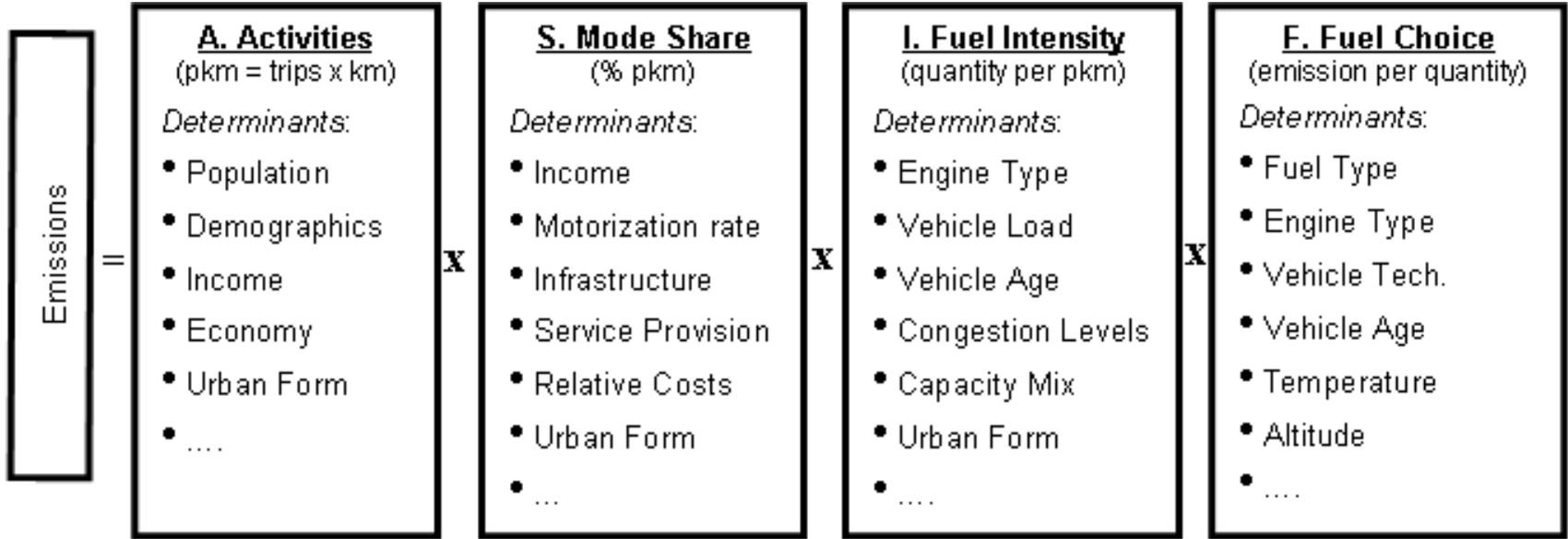


Mobility = f (City Form)?

or

City Form = f (Mobility)?

Not just theoretically interesting...



Mobility = f (City Form)?

or

City Form = f (Mobility)?

And, analytically challenging

- Pre/post studies (e.g., land price changes)
- Granger models
 - King (2011): New York subway did not lead to building densification;
 - Xie and Levinson (2010): streetcar network development preceded residential real estate development in Minneapolis-
 - Levinson (2008): rail transport densified London's periphery
 - Costa et al (2021): Sao Paulo's roads and urbanization "pushed and pulled" each other over time; rail transit densified the city
 - Endogeneity...
- Instrumental variables
 - Baum-Snow (2007): highways in USA induced an 18% decline metropolitan area's central city populations
 - Baum-Snow, et al (2017): in China highways decentralized urban populations and GDP; railroads only affected industrial activities

Mobility = f (City Form)?

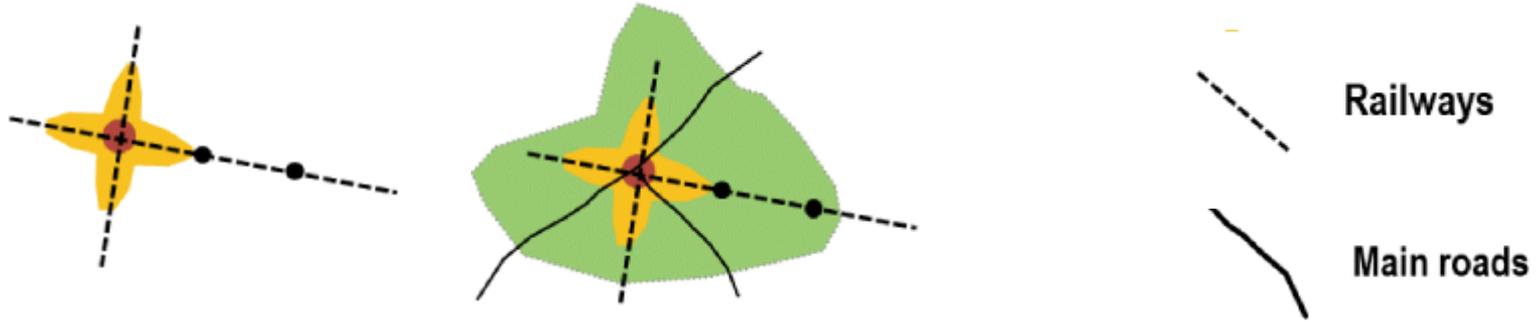
or

City Form = f (Mobility)?

Our case

- Instrumental variable approach
- First known study in Latin American context (most rapidly growing city in world, 1950-2000)
- Urban roads and transit rails
- Vertical and horizontal development

H1: Different accessibility gains - Transit vs Road



- Transit accessibility: concentrated & intense (around the stations), decreases quickly with distance from station
- Road accessibility: dispersed and less intense
- Reverse causality: compared to roads, mass transit depends on population density and demand

H1: Rail transit investments stimulate verticalization and densification; urban roads stimulate urban expansion.

H2: Mobility and Urban Development

- Locational push and pull: agglomeration economies vs costs of transportation
- Lucas and Rossi-Hansberg (2002): as commuting costs fall, workers move further from work to take advantage of lower relative rents
 - “In the limit, as commuting costs approach zero, the equilibrium takes the familiar form of the Mills city, with production in the center surrounded by a residential ring” (Lucas and Rossi-Hansberg, 2002, p. 1471).
- Heblich, et al (2020): London’s steam rail led to neighborhood specialization and job-home separation

H2: Transportation investments lead to land use specialization, with more commercial buildings towards city center and residential development towards peripheries.

Urban Development in Greater São Paulo

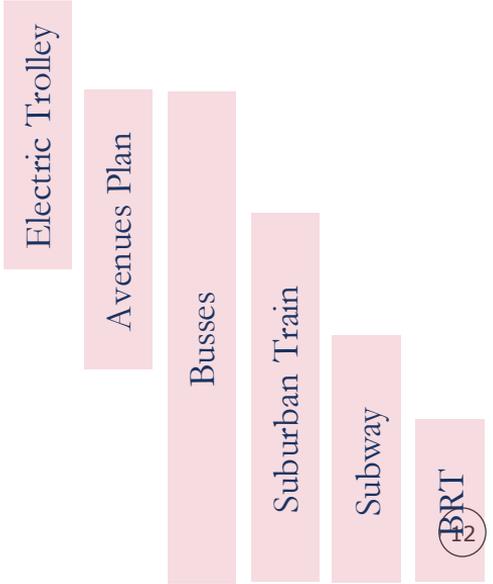
Source: IBGE

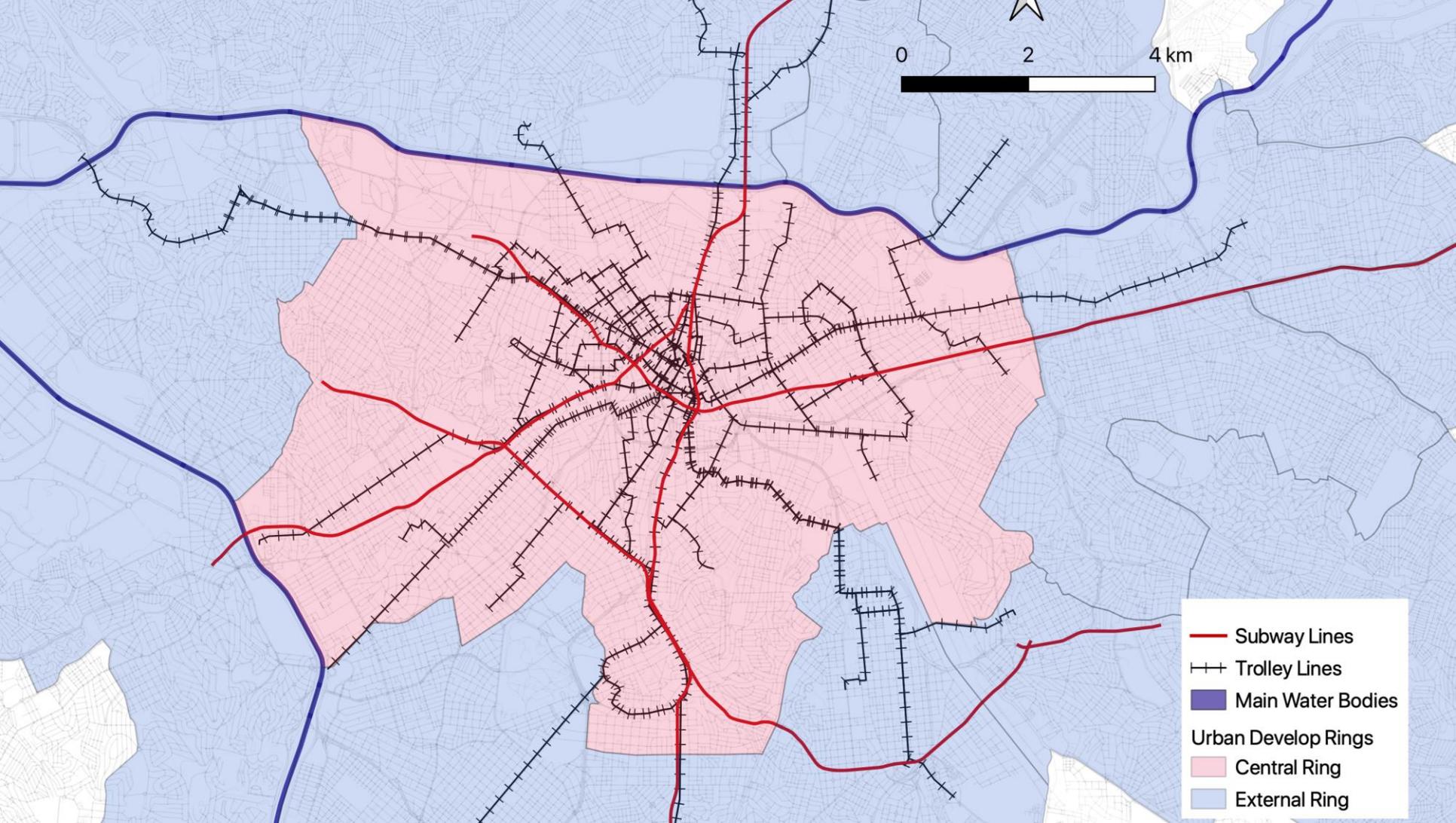
Year	São Paulo City		Other cities of the Metropolitan Region of São Paulo	
	Total Population	10 years Increase	Total Population	10 years Increase
1872	31,385	-	-	-
1890	64,934	59.39%	-	-
1900	239,820	269.33%	-	-
1920	579,033	70.72%	-	-
1940	1,326,261	64.52%	241,784	-
1950	2,198,096	65.74%	424,690	75.65%
1960	3,781,446	72.03%	957,960	125.57%
1970	5,924,615	56.68%	2,215,115	131.23%
1980	8,493,217	43.35%	4,095,508	84.89%
1990	9,646,185	13.58%	5,798,756	41.59%
2000	10,434,252	8.17%	7,444,451	28.38%
2010	11,253,503	7.85%	8,430,472	13.25%

Small Concentrated Heterogenous

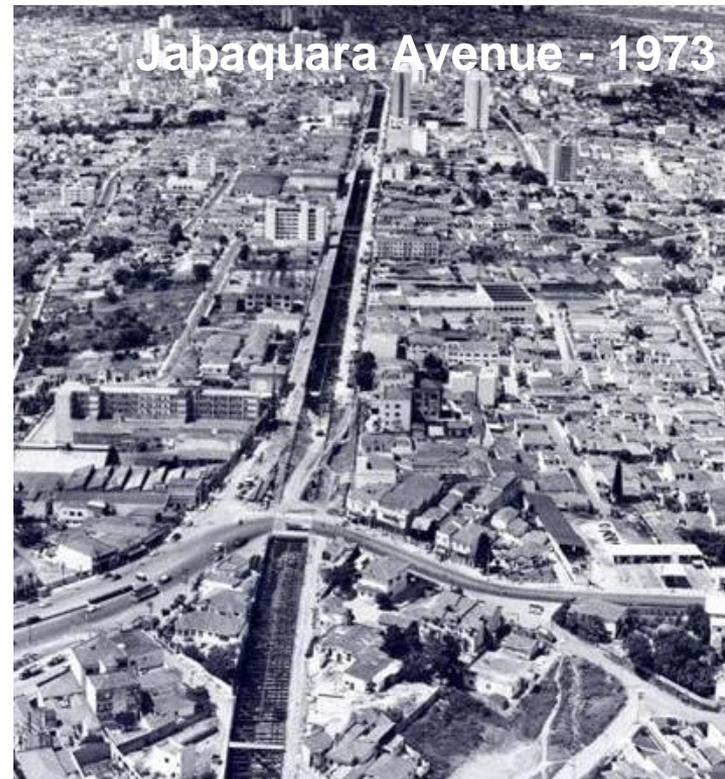
Urban sprawl Peripheral urbanization

Lower growth City of Walls Heterogenous peripheries





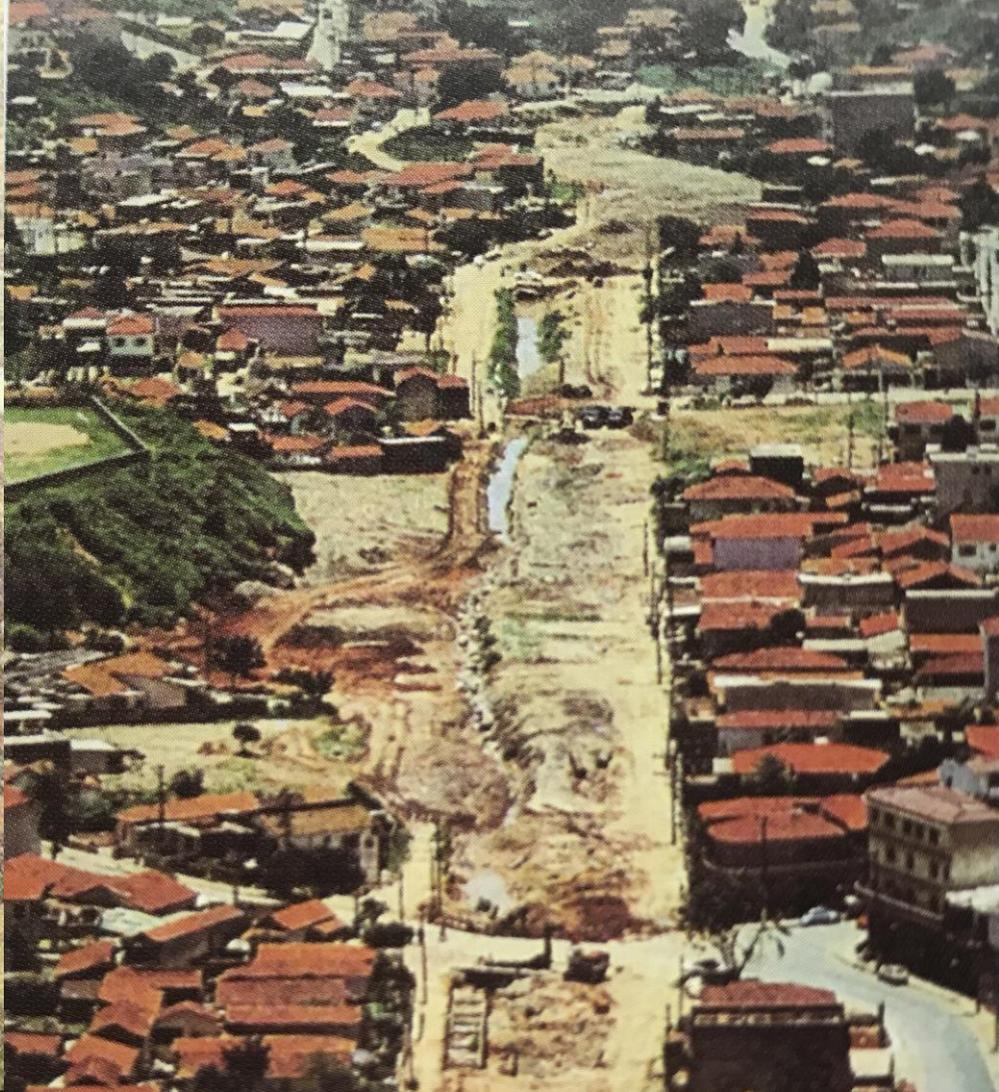
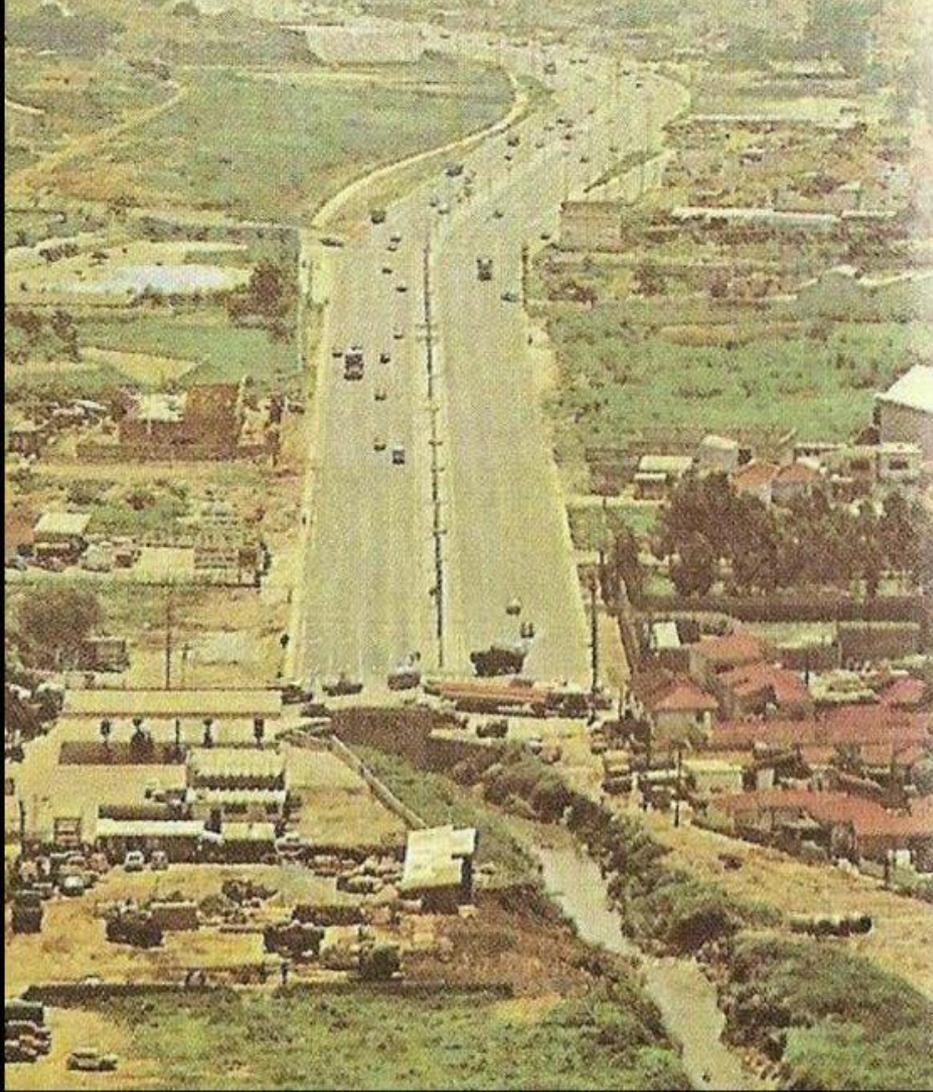
SUBWAY DEVELOPMENT IN SÃO PAULO



Urban Development in Greater São Paulo

AVENUES AND
ARTHERIAL
ROADS
DEVELOPMENT
IN SÃO PAULO











Data

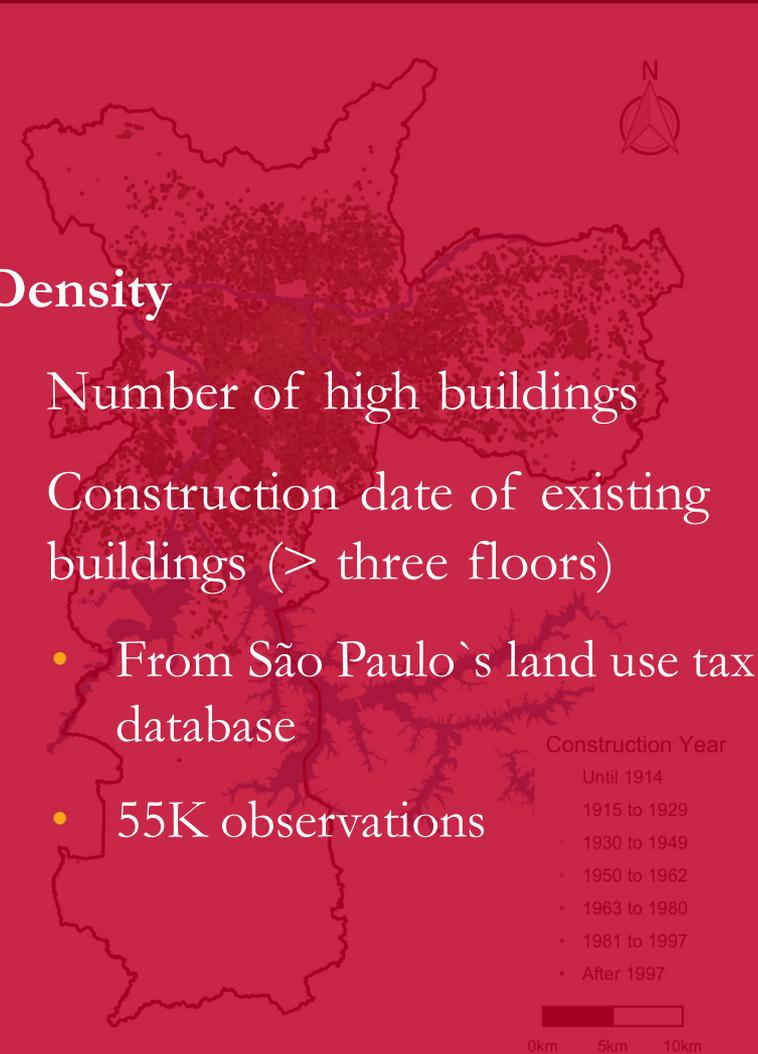
Urban Sprawl

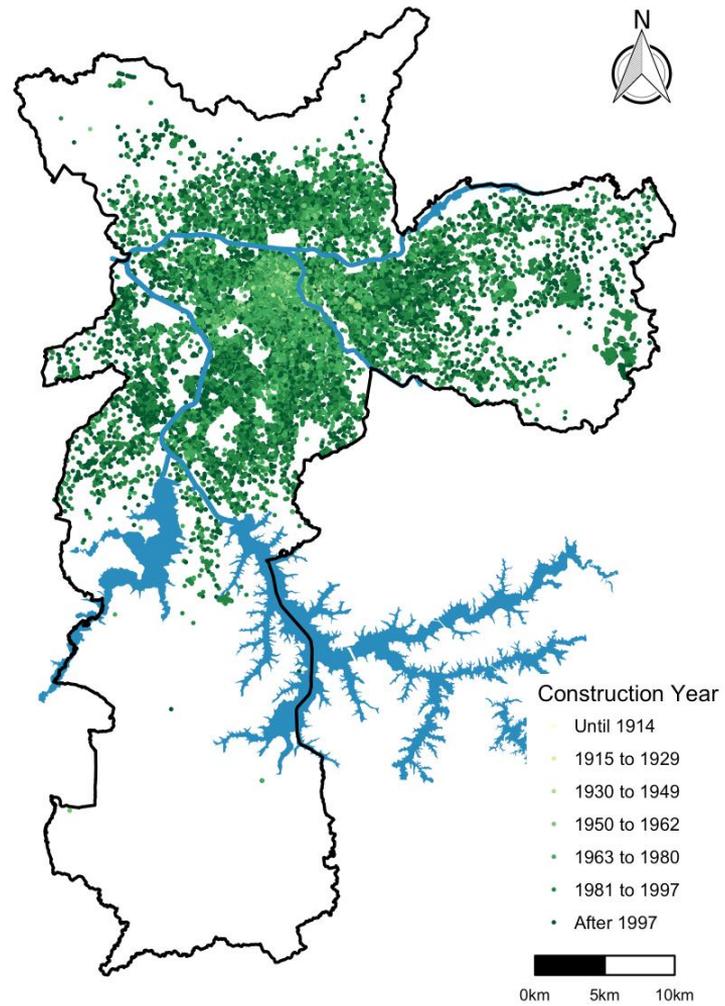
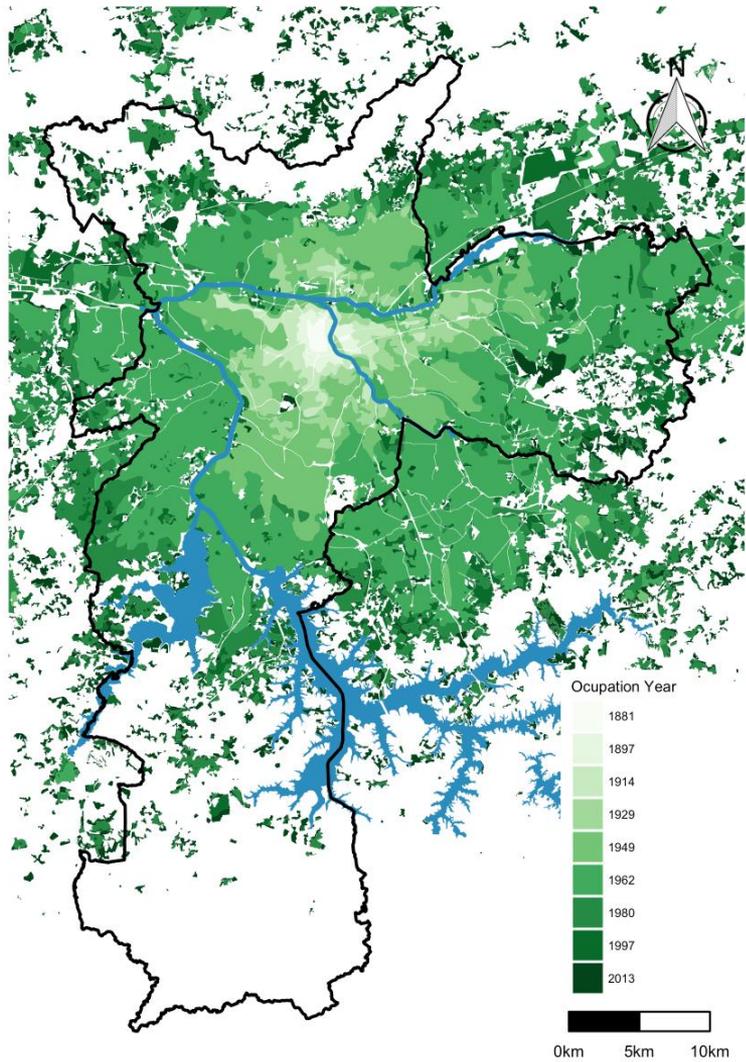
- Urban footprint in selected years
 - Digital cartography of old maps (developed by EMPLASA, the São Paulo State Metropolitan Planning Company)
 - Remote sensing analysis (by EMPLASA and the authors)



Density

- Number of high buildings
- Construction date of existing buildings (> three floors)
 - From São Paulo's land use tax database
- 55K observations

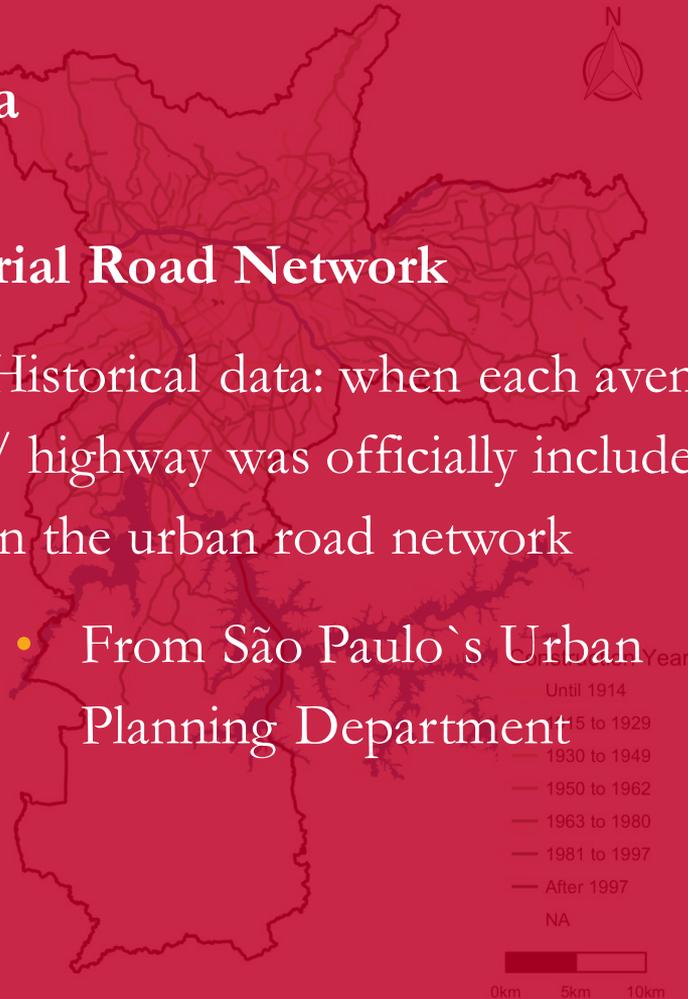




Data

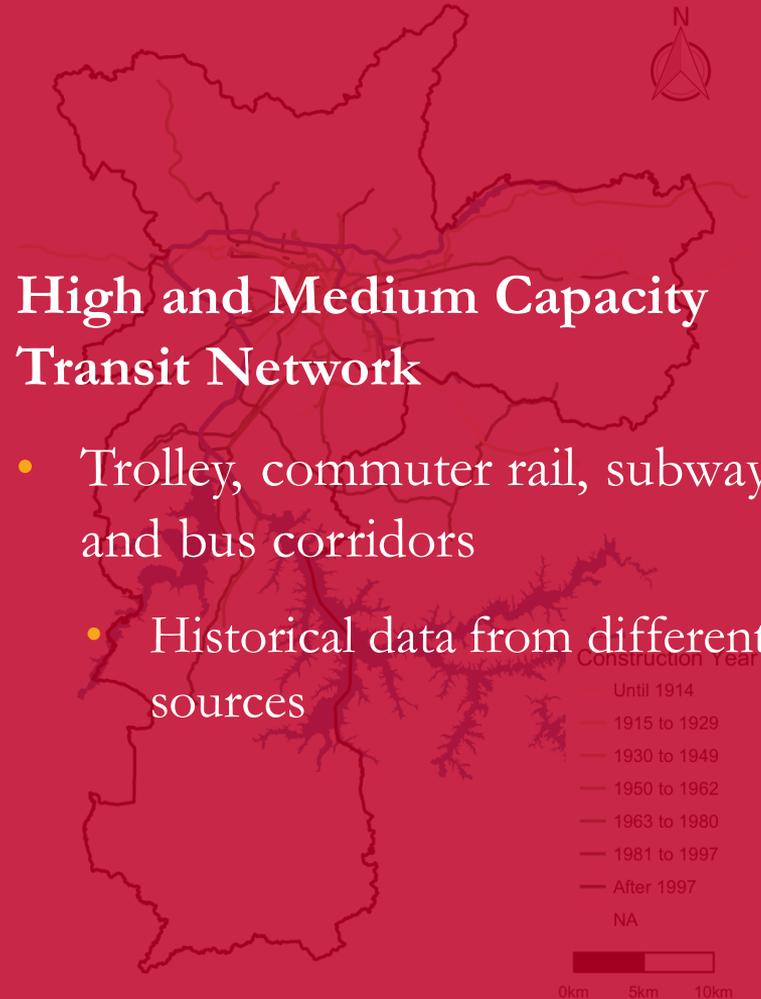
Arterial Road Network

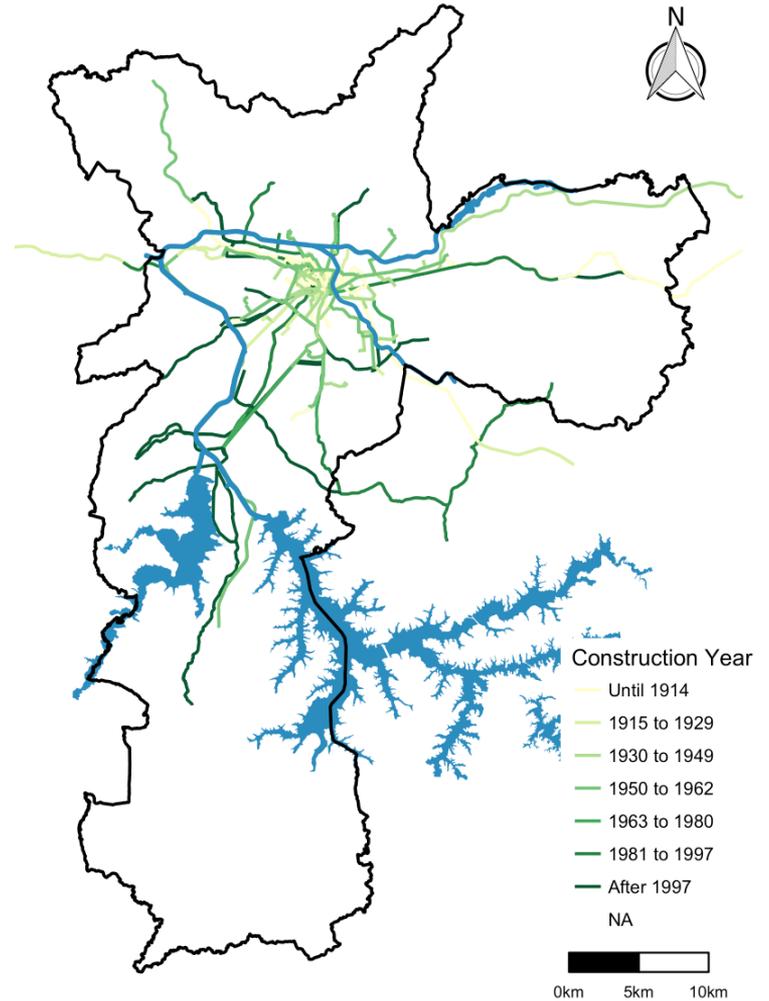
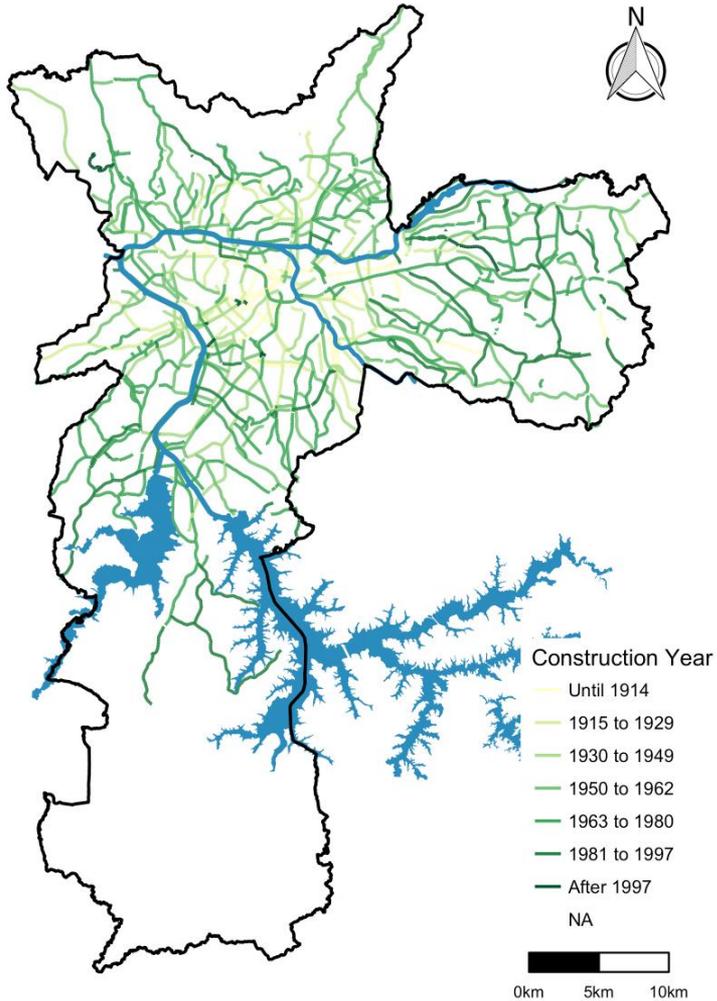
- Historical data: when each avenue / highway was officially included in the urban road network
- From São Paulo's Urban Planning Department



High and Medium Capacity Transit Network

- Trolley, commuter rail, subways and bus corridors
- Historical data from different sources





Variables

Urban Development Variables

Horizontal Urban Development: Urbanization rate - the percentage of the cell's total area that is covered by the urban footprint

Vertical Urban Development: FAR of 3+ story buildings

Transportation Development Variables

Road Transportation Development: Network length of road system (highways and avenues)

Rail Transportation Development: Rail transit network length

Long difference (1947-1997) with instrumental variables

$$(1) \quad \Delta Urb_i = f(\Delta Road_i, \Delta Rail_i, Urb^{1947}_i, D^{CBD}_i, Age_i, Z_i, N_i)$$

$$(2) \quad \Delta FAR_i = f(\Delta Rail_i, \Delta Road_i, FAR^{1947}_i, D^{CBD}_i, Age_i, Z_i, N_i)$$

ΔUrb_i : change in urbanization rate in cell i

ΔFAR_i : change in floor to area ratio (verticalization) in cell i

$\Delta Road_i$: change in road network length in cell i

$\Delta Rail_i$: change in rail network length in cell i

Urb^{1947}_i : baseline urbanization rate in cell i

FAR^{1947}_i : baseline FAR in cell i

D^{CBD}_i : cell i distance to city center

Age_i : average age of buildings in cell i

Z_i : zoning restrictions in cell i

N_i : natural restrictions (e. g., lakes) in cell i

2SLS regression of avenues and transit on urbanization rate and FAR with river courses and streetcar routes as instrumental variables

	Variation from 1947 to 1997					
	ΔUrbanization Rate			ΔFAR		
	(1)	(2)	(3)	(4)	(5)	(6)
Change on Avenues Net Length	0.08*** (0.02)	0.07*** (0.02)	0.05*** (0.02)	0.001 (0.02)	0.001 (0.02)	-0.02 (0.02)
Change on Transit Net Length	-0.14*** (0.04)	0.04 (0.03)	0.005 (0.03)	0.52*** (0.04)	0.50*** (0.13)	0.32*** (0.10)
Baseline Urbanization Rate		-0.65*** (0.05)	-0.72*** (0.05)			
Baseline FAR					0.40 (2.76)	3.22** (1.64)
Distance to CBD			-0.005 (0.01)			-0.04*** (0.01)
Buildings Construction Year			-0.001 (0.01)			0.01 (0.01)
Zoning Limits			-0.18 (0.14)			0.09 (0.12)
Natural Restrictions			-0.02 (0.96)			0.74** (0.29)
Constant	0.11 (0.10)	0.29*** (0.09)	2.11 (10.29)	-0.04 (0.11)	-0.03 (0.12)	-19.30 (14.02)
Observations	162	162	155	162	162	155

Note:

*p<0.1; **p<0.05; ***p<0.01

Diagnostic tests:

	Statistic	p-value		Statistic	p-value	
Weak instruments (Avenues)	20.64	0.00 ***	Pass	19.512	0.00 ***	Pass
Weak instruments (Transit)	20.31	0.00 ***	Pass	3.682	0.03 ***	Pass
Wu-Hausman	19.80	0.01 ***	Pass	3.26	0.04 **	Pass

19% increase in FAR
because of every
additional kilometer

*H1: Rail transit investments
stimulate verticalization and
densification; urban roads
stimulate urban expansion.*

rivers and streetcar routes
instrumenting for avenues and
rail transit passed on weak
instruments tests

COMMERCIAL VS. RESIDENTIAL

2SLS regression of avenues and transit on residential and commercial FAR with river courses and trolley lines as instrumental variables

		Variation from 1947 to 1997						
		ΔResidential FAR			ΔCommercial FAR			ΔBalance Index
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Average impact term	Change on Transit Ntw Length	0.15*** (0.04)	0.17*** (0.06)	0.31*** (0.11)	0.33*** (0.07)	0.32*** (0.03)	0.16*** (0.04)	-0.13*** (0.05)
	Transit * Distance to CBD		0.20* (0.11)			-0.14*** (0.05)		
Interaction impact terms	Transit * Baseline Residential FAR			-5.90* (3.30)				
	Transit * Baseline Commercial FAR						1.27*** (0.20)	
Observations		155	155	155	155	155	155	155

Note: *p<0.1 **p<0.05 ***p<0.01

H2: transportation investments lead to land use specialization, with more commercial buildings towards city center and residential development towards peripheries. In other words, transportation tends to negatively impact jobs-housing balance.

as anticipated from the findings of Lucas and Rossi-Hansberg (2002)

Implications

- Each kilometer of new avenues → 5% increase in the local urbanization rate between 1947 and 1997 = 0.2 km² of horizontal development in a cell
- Each additional kilometer of rail transit → 20% increase in local FAR = 1.32 km² of additional floor area in a cell.
 - Commercial real estate react more intensely to investments in transit than the residential real estate market
- 700km of arterial roads from 1947 to 1997 → responsible for 136 km² increase in São Paulo's urban footprint over the 50 years of analysis = explains more than 50% of the total urban expansion observed
- 65km of mass transit from 1947 to 1997 → stimulated the creation of 83km² of floor area

Implications

“As If” scenario: If 136km of the subway lines proposed in the 1968 plan were built in exchange for half the 350km of arterial roads built:

- São Paulo would be 2.7 times more vertical (compact) than today
- Increase of ~200% in transit use (elasticities from Ewing & Cervero, 2010)
- Reduction of 78% in household travel CO₂e emissions (elasticities from Santiago; Zegras & Hunter, 2011)

Implications

- First joint causal inference of urban roads and transit impacts on horizontal and vertical urban development
 - First known study in Latin American context
 - São Paulo's idiosyncratic transportation development provides unique instrumental variable opportunity
- Empirical support for pro-transit arguments
 - Sustainable mobility and sustainable urbanization.

Appendix – additional slides

SHORTER PERIODS

2nd-stage regression of urbanization rate and FAR on avenues and transit with river courses and streetcar routes as instrumental variables (shorter periods)

	Variation from 1962 to 1997					
	ΔUrbanization Rate			ΔFAR		
	(1)	(2)	(3)	(4)	(5)	(6)
Change on Avenues <u>Ntw</u> Length	0.02** (0.01)	0.04*** (0.01)	0.04** (0.01)	-0.01 (0.03)	-0.01 (0.02)	-0.05 (0.04)
Change on Transit <u>Ntw</u> Length	-0.03*** (0.01)	0.01 (0.02)	0.01 (0.02)	0.37*** (0.04)	0.37*** (0.12)	0.24* (0.30)
	Variation from 1980 to 1997					
	ΔUrbanization Rate			ΔFAR		
	(1)	(2)	(3)	(4)	(5)	(6)
Change on Avenues <u>Ntw</u> Length	0.07* (0.04)	0.09* (0.05)	0.10* (0.05)	-0.02 (0.07)	-0.62 (1.39)	-0.76 (1.33)
Change on Transit <u>Ntw</u> Length	-0.003 (0.02)	0.02 (0.03)	0.02 (0.03)	0.19** (0.08)	2.33 (3.18)	2.04 (2.41)

Lower and less significant impact coefficients in the 35-year period between 1962-1997

For the last 17-year (1980-1997) period the results are mixed or less significant

Note: *p<0.1; **p<0.05; ***p<0.01

INNER RING VS. OUTER RING

2SLS regressions of avenues and transit on urbanization rate and FAR with river courses and streetcar routes as instrumental variables for both grid cells in the central ring and external rings.

		Variation from 1947 to 1997					
		ΔUrbanization Rate			ΔFAR		
		(1)	(2)	(3)	(4)	(5)	(6)
Central Ring (A)	Change on Avenues <u>Ntw</u> Length	0.03 (0.03)	0.01 (0.02)	-0.02 (0.02)	0.02 (0.06)	0.02 (0.08)	0.02 (0.06)
		Instrument tests = Pass			Instrument tests = Pass		
	Change on Transit <u>Ntw</u> Length	-0.09** (0.04)	-0.01 (0.01)	-0.04 (0.03)	0.49*** (0.06)	0.45** (0.19)	0.30*** (0.11)
		Instrument tests = Pass			Instrument tests = Pass		
External Ring (B)	Change on Avenues <u>Ntw</u> Length	0.23** (0.11)	0.15 (0.15)	0.11*** (0.04)	-0.01 (0.08)	0.01 (0.02)	0.003 (0.01)
		Instrument tests = Pass			Instrument tests = Pass		
	Change on Transit <u>Ntw</u> Length	-4.74 (13.29)	-1.72 (4.27)	-0.76 (1.12)	0.73 (2.42)	0.09 (0.53)	0.02 (0.21)
		Instrument tests = Fail			Instrument tests = Fail		

Note: *p<0.1; **p<0.05; ***p<0.01