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LUIZ PEDRO COUTO SANTOS SILVA

Three essays on the economic value of the geographic proximity

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Tese apresentada ao programa de Pós-Graduação em Economia da Faculdade de Economia da Universidade Federal de Juiz de Fora, como requisito parcial a obtenção do título de Doutor em Economia. Área de concentração: Economia.

Orientador: Prof. Dr. Fernando Salgueiro Perobelli
Coorientador: Dr. Rafael Henrique de Morais Pereira

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Abstract

This thesis investigates how geographic proximity is economically valued in cities, focusing on the forces of agglomeration economies and the spatial interactions they generate. Drawing on theories from urban economics, urban planning, and transport geography, and applying them to Brazil's two largest metropolitan areas, the research examines how shocks to transport networks and access to consumer markets reshape locational choices, travel behavior, and the spatial distribution of opportunities. The thesis is structured in three essays. Essay 1 reviews and synthesizes the literatures on urban accessibility, agglomeration economies, travel behavior, and spatial interaction models. This cross-fertilized review shows how recent advances in quantitative spatial models integrate these fields to explain how transport infrastructure and the spatial distribution of amenities influence welfare and urban inequality. Essay 2 provides empirical evidence on the relationship between land use and transport connectivity by exploiting the expansion of São Paulo's mass public transit network between 2007 and 2017. Using fine-grained spatial data and a refined station catchment area approach, the study demonstrates that improvements in speed and accessibility drive shifts from private car use to rail-based transit. It also shows that land-use, alongside transport connectivity, is critical to shift travel behavior, underscoring the need for integrated transport and land-use policies. Essay 3 examines the impact of the short-term rental platform Airbnb on local labor markets in Rio de Janeiro between 2010 and 2019. Through an econometric design with instrumental variables and highly disaggregated spatial data, the analysis finds that Airbnb's expansion boosted employment and wages in the gastronomy sector, while other sectors—including hotels—showed no measurable effects. This investigation provides the first evidence for a developing country city of how digital platforms can reshape urban economic geography through localized agglomeration effects. Taken together, the findings highlight the central role of access to amenities and transport networks in shaping the spatial organization of cities. They show that fine-grained spatial interactions matter for understanding the sustainability of urban systems and the distribution of opportunities. The thesis offers reflections on the role of transport–land use integration in cities and provides new empirical evidence on shocks to urban infrastructure in Brazil, with particular emphasis on public transport and the entry of digital platforms.

Keywords: Agglomeration economies, Transport, Land use, Accessibility, The Geography of jobs.

Resumo

Esta tese investiga como a proximidade geográfica é economicamente valorizada nas cidades, com foco nas economias de aglomeração e nas interações espaciais que elas proporcionam. Com base em teorias da economia urbana, do planejamento urbano e da geografia dos transportes, aplicadas às duas maiores regiões metropolitanas do Brasil, a pesquisa examina como choques nas redes de transporte e no acesso aos mercados consumidores afetam escolhas locacionais, comportamentos de viagem e a distribuição espacial de oportunidades. A tese é estruturada em três ensaios. O Ensaio 1 faz uma revisão de literatura sobre acessibilidade urbana, economias de aglomeração, comportamento de viagem e modelos de interação espacial. Essa revisão de literatura cross-fertilizada mostra como avanços recentes em modelos quantitativos espaciais integram esses campos para explicar como a infraestrutura de transporte e a distribuição de amenidades influenciam no bem-estar e em desigualdades urbanas. O Ensaio 2 investiga a relação entre uso do solo e conectividade espacial, explorando a expansão da rede de transporte público de alta capacidade de São Paulo entre 2007 e 2017. Utilizando dados com alta granularidade espacial e uma abordagem refinada das áreas de influência das estações de alta capacidade, o estudo demonstra que melhorias em velocidade e acessibilidade induzem a substituição do automóvel pelo transporte sobre trilhos. Além disso, a atratividade de localidades por meio do uso do solo é crucial para promover mudanças de comportamentos de viagem, ressaltando a importância de políticas integradas de transporte e uso do solo. O Ensaio 3 examina o impacto da plataforma Airbnb sobre os mercados de trabalho locais no Rio de Janeiro entre 2010 e 2019 e, por meio do uso de variáveis instrumentais e dados espaciais altamente desagregados, evidencia efeitos positivos sobre emprego e salários no setor de gastronomia, sem impactos mensuráveis em outros setores, incluindo hotéis. Em conjunto, os resultados destacam o papel central do acesso a amenidades e às redes de transporte na organização espacial das cidades, evidenciando que interações espaciais de alta granularidade são fundamentais para compreender a sustentabilidade urbana e a distribuição de oportunidades. A tese oferece reflexões sobre o papel da integração entre transporte e uso do solo nas cidades e apresenta novas evidências empíricas sobre choques em infraestruturas urbanas no Brasil, com ênfase no transporte público e na entrada de plataformas digitais.

Palavras-chave: Economias de aglomeração, Transporte, Uso do solo, Acessibilidade, Geografia do emprego.

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BRT	Bus Rapid Transit
CBD	Central Business District
CO_2	Carbon Dioxide
FIFA	Fédération Internationale de Football Association
GIS	Geographic Information System
GDP	Gross Domestic Product
GTFS	General Transit Feed Specification
IBGE	Instituto Brasileiro de Geografia e Estatística
METRO	São Paulo Metropolitan Authority
MNL	Multinomial Logit
NOAA	National Oceanic and Atmospheric Administration
OLS	Ordinary Least Squares
OD	Origin–Destination
OSM	OpenStreetMap
PT	Public Transit
RAIS	Relação Anual de Informações Sociais
RUM	Random Utility Model
QSM	Quantitative Spatial Models
SPMR	São Paulo Metropolitan Region
LRT	Light Rail Transit
2SLS	Two Stage Least Squares
2SFCA	Two-step floating catchment area

CONTENTS

Introduction

Cities exist because of the economic value of geographic proximity (Glaeser et al., 2001; Rosenthal and Strange, 2020). The spatial distribution of resources, such as transport infrastructure, employment, services, population, and other urban amenities, plays a decisive role in determining welfare (Koster and Thisse, 2024). People and economic activities concentrate where the benefit-cost relationship of proximity to these resources is most favorable, which imposes challenges for strategies of co-location and for the conditions of access to economic opportunities. A central difficulty lies in understanding what drives these incentives for co-location: which factors prompt households and firms to interact spatially, thereby generating agglomeration economies. Yet, relatively few studies have examined how shocks to these incentives affect location choices at fine geographic scales, particularly in cities of developing countries.

This thesis examines how shocks to transport networks and access to consumer markets affect spatial interactions and the internal structures of cities through the forces of agglomeration economies. Changes in urban connectivity and access to externalities reshape the incentives for concentration and spatial interaction, influencing both economic efficiency and the spatial organization of cities. These dynamics reflect broader global processes, as the spatial concentration of population is a well-established stylized fact, directly shaping the daily lives of the roughly 56% of the world's inhabitants who live in urban centers[1], a phenomenon extensively explained by the principles of spatial economics (Henderson and Thisse, 2024; Koster and Thisse, 2024).

Late in the 19th century, advances in motorized transport technologies substantially improved urban mobility, reshaping patterns of spatial interaction and expanding the distances between households, employment, and services (Anas et al., 1998; Brooks and Denoeux, 2022). By reducing the time required to cover the same distances, these advances enhanced urban welfare and spurred city population growth as the results of agglomeration forces (Donaldson, 2018; Duranton and Turner, 2012; Redding and Sturm, 2008). Yet the same advances that facilitated urban growth also produced adverse consequences, as increasing distances between economic agents can undermine the efficiency of urban infrastructure. Since some of the greatest economic challenges of cities involve the management of space, a scarce resource, land use becomes decisive in this optimization

[1] https://ourworldindata.org/urbanization

process, as it must align with the complexity of the demand for space (Duranton and Puga, 2015; Lee and Bencekri, 2021).

One consequence of the pursuit for space optimization is competition among economic agents for its use, resulting in urban density, which composition is central to levels of welfare (Duranton and Puga, 2020). On the one hand, economic productivity is positively associated with density through the facilitation of mechanisms of agglomeration economies (Ahlfeldt and Pietrostefani, 2019; Duranton and Puga, 2004; Quigley, 1998). On the other hand, increased urban density can generate adverse effects, such as noise and visual pollution, crime, and other negative externalities that create forces of dispersion (Duranton and Puga, 2020; Fujita and Thisse, 1996). Ultimately, when urban density is characterized by diversity in people and local goods, the resulting increases in welfare through better production and consumption levels justify the higher costs of living and producing in cities (Glaeser et al., 2001; Koster and Thisse, 2024). Yet the benefits of density ultimately depend on the capacity of cities to facilitate spatial interactions among agents, which varies in geographic scale depending on the type of economic activity of those involved (Rosenthal and Strange, 2020).

Consequently, the attraction forces generated by agglomeration economies have a spatial scope, as the benefits of interactions among economic agents are geographically limited and shaped by the connectivity between land use and transport networks. In this context, urban form features (i.e., the spatial configuration of streets, buildings, and land uses) become critical, particularly given the increasing challenge of making urban infrastructure more sustainable by aligning its provision with demand (Ewing and Cervero, 2010; Handy et al., 2002).

This relationship between urban density, transportation, and land use is evident in the case of public transit systems. For instance, higher densities of residents, jobs, and services around public transit infrastructure encourage its use, reduce the number of trips made by private vehicles, and increase the efficiency of transport systems (Duranton and Turner, 2018; Lee and Bencekri, 2021; Owen and Levinson, 2015; Vale, 2021).

The access to urban amenities is crucial for decisions regarding interactions and co-location among people, firms, and services (Levinson and Wu, 2020). Improved integration between land use and transportation networks reduces the friction of spatial movement across urban amenities and translates into increased accessibility and convenience, which in turn encourages spatial interaction between locations by raising utility levels (Geurs and Van Wee, 2004; Levinson and Wu, 2020). Because the forces of agglomeration economies decay with distance, certain economic relationships occur only at relatively small geographic scales (Rosenthal and Strange, 2020). Therefore, reduced travel cost to amenities at specific locations facilitate their spatial interactions, making them accessible through low cost travel modes, such as walking.

The land use patterns of Brazilian large cities reflect broader global dynamics but are marked by high spatial concentration of urban amenities and insufficient capacity to meet the needs of large populations, especially the poorest (Boisjoly et al., 2020; Pereira et al., 2022). Because these rapid urban growth processes were followed by the lack of urban planning and insufficient economic resources, the sorting for desirable locations segregated large populations to peripheral areas with low levels of urban infrastructure and of access to opportunities (Brueckner et al., 2019; Klink and Denaldi, 2014; Moreno-Monroy and Posada, 2018).

According to the literature in urban economics and urban and transportation planning, two aspects could help mitigate such challenges. First, more efficient transportation infrastructures may reduce the congestion levels in large Brazilian cities, improve the spatial connectivity of peripheral individuals with more opportunities (Bryan et al., 2020; Tomasiello et al., 2025), and the worker's productivity (Haddad et al., 2015). Second, a more evenly spatial distribution of employment opportunities may improve the access to new income sources in cities with high levels of informality (Moreno-Monroy and Posada, 2018) and redistribute residential welfare through labor force relocation (Allen et al., 2020; de Campos, 2019). Building on these motivations, the research presented in this thesis is organized into three essays, focusing on land use, transport connectivity, and economic agglomeration.

Essay 1 is a literature review that integrates research on urban accessibility, agglomeration economies, travel behavior, and spatial interaction models. It highlights how these literatures explain the economic incentives generated through access to amenities, which in turn shape urban spatial configurations. While historically fragmented, these literatures have recently been brought together through quantitative spatial models that examine shocks to internal urban structures, particularly transport infrastructure, and their effects on urban welfare. The review highlights the importance of the spatial distribution of amenities and the efficiency of transport systems in creating incentives for interactions, demonstrating how expansions of public transit networks can reduce spatial frictions and redistribute opportunities to peripheral populations. The essay also highlights how recent advances in the availability of georeferenced data and computational methods provide new opportunities to model spatial interaction more precisely and better evaluate the mechanism through which transport investments can impact urban inequality.

Essay 2 aims to understand the operationality and sustainability of the public transit system in large Global South cities. It empirically investigates the role of land use connectivity with the transport network by exploiting the expansion of mass public transit in the São Paulo Metropolitan Region between 2007 and 2017 as a quasi-experiment. Using a refined longitudinal spatial database, the study computes station catchment areas that account for the street network and the locations of people, stations, and opportunities over that decade. Results show that speed, accessibility, and convenience of access are key drivers of shifts from private car use to public transit. These factors, combined with local economic attraction forces such as wages and the number of opportunities, generate agglomeration economies and redirect travel flows toward areas better connected to the transit system. The analysis also highlights the importance of spatial interactions at small geographic scales, demonstrating that placing new stations in high-density or opportunity-rich areas—and vice versa—can maximize accessibility and sustainable travel behavior patterns.

Essay 3 is concerned with the recent shocks of disruptive technologies on the urban structure of Global South cities. It examines how proximity to spatial concentrations of tourists can generate spillovers in economic activity in the city of Rio de Janeiro between 2010 and 2019. The study exploits the entry of the short-term rental platform Airbnb as an exogenous shock that creates new tourist accommodation locations. It tests the hypothesis that this spatial reallocation of tourists' accommodations affects demand for local services in specific sectors (i.e., restaurants, hotels, retail, and bakeries) through convenient, walkable access. The quasi-experimental analysis shows that the restaurant sector experienced positive effects on employment and hourly wages, while other sectors showed no measurable response. These findings illustrate how disruptive platforms can affect city-block-level sociodemographic composition, generate firm-level agglomeration forces, and reshape the spatial distribution of opportunities through sector-specific gains in urban labor markets.

In addition to this introduction, the thesis proceeds with Essay 1, a literature review that builds on the discussion presented above. This is followed by the two empirical essays, Essays 2 and 3, which leverage high-resolution spatial data to assess how geographic proximity is economically valued in different contexts within Brazil's largest cities. The thesis concludes with a final chapter synthesizing the findings and implications of the three essays.

1 The role of transportation and land use on spatial interaction and agglomeration economies

Resumo

As aglomerações urbanas surgem porque firmas e domicílios obtêm ganhos econômicos ao se localizarem próximos uns dos outros. Embora se reconheça que os sistemas de transporte e o uso do solo facilitam essas interações, a discussão sobre o papel da fricção espacial no acesso às oportunidades e nas escolhas individuais permaneceu dispersa por décadas entre os campos da economia e da ciência regional. Consequentemente, poucos estudos se dedicaram a explorar como os vínculos conceituais entre a economia da aglomeração, o transporte e o uso do solo podem determinar as interações espaciais nas cidades. Este estudo realiza uma revisão da literatura com o objetivo de oferecer uma perspectiva integrada sobre como o tema das interações espaciais tem sido abordado nos campos da economia, dos estudos de transporte, da geografia, da ciência regional e do planejamento urbano. Foi realizado um mapeamento da evolução teórica de cinco vertentes interconectadas da literatura relacionadas às economias de aglomeração e às interações espaciais: (i) acessibilidade baseada em modelos gravitacionais, (ii) modelos microfundamentados de estrutura urbana, (iii) modelos de interação espacial, (iv) modelos de escolha discreta e (v) modelos espaciais quantitativos. A discussão destaca o vínculo entre economias de aglomeração e fricção espacial, enfatizando como a facilidade de deslocamento proporcionada pelos sistemas de transporte determina a distribuição espacial do acesso às oportunidades, afetando, assim, as vantagens locacionais e as escolhas de viagem. Ao combinar contribuições dessas diferentes literaturas, evidencia-se como a interação entre os benefícios econômicos da aglomeração e a fricção espacial molda as escolhas locacionais e, em última instância, a organização espacial das cidades. Com foco na interação entre intervenções em transporte público, incentivos à interação e a distribuição de bem-estar nas cidades, o artigo destaca oportunidades de fertilização cruzada e identifica fronteiras de conhecimento na pesquisa que podem ser avançadas por meio de um diálogo mais intenso entre essas disciplinas.

Palavras-chave: Economias de aglomeração; densidade urbana; acessibilidade; modelos de interação espacial; comportamento de viagem; modelos espaciais quantitativos.

Abstract

Urban agglomerations emerge because firms and households reap economic gains from locating near one another. Although transportation and land use are known to facilitate these interactions, the discussion on the role of spatial friction to reach opportunities on individual choices remained sparse over decades in economics and regional science. Consequently, few studies are dedicated to explore how the conceptual links between agglomeration economics, transportation, and land use can determine spatial interaction in cities. This study conducts a literature review to provide an integrated perspective on how the topic of spatial interaction has been examined in the fields of economics, transportation studies, geography, regional science, and urban planning. We trace the theoretical evolution of five interconnected literature streams related to agglomeration economies and spatial interaction: (i) gravity-based accessibility, (ii) microfunded models of urban structure, (iii) spatial interaction models, (iv) discrete choice models, and (v) quantitative spatial models. Our discussion highlights the link between agglomeration economies and spatial friction, emphasizing how the ease of movement through transportation systems determines the spatial distribution of access to opportunities, thereby, affecting locational advantages and travel choices. By combining insights from these literatures, we clarify how the interplay between agglomeration benefits and spatial friction shape locational choices and ultimately the spatial organization of cities. Focusing on the interplay of public transit interventions on the incentives for interaction and distribution of welfare in cities, the paper highlights opportunities for cross-fertilization and identifies research frontiers that could be advanced through greater dialogue across disciplines.

Keywords: Agglomeration economies, urban density, accessibility, spatial interaction models, travel behavior, quantitative spatial models.

1 Introduction

The location choices of households and firms are not randomly distributed in urban space. Households tend to prioritize locations that offer amenities such as green areas, good schools, shopping areas, leisure facilities, labor markets, etc. (Brueckner et al., 1999; Glaeser et al., 2001). Firms, on the other hand, seek local production advantages, including great access to consumer markets, abundant and skilled labor force, and well-developed infrastructure (Combes et al., 2008). Notably, when these diverse incentives for location overlap, co-location occurs and plays a significant role in shaping the spatial configuration of cities.

This interplay between household and firm location choices has been central to understanding the spatial organization of cities, and it has been extensively explored in the spatial economics literature (Anas et al., 1998; Brueckner, 1987; Henderson and Thisse, 2024). It is widely recognized that transportation costs to access amenities are internalized within urban markets —whether for land, labor, goods, or services— and that, by contrast, reducing such spatial friction increases the potential benefits of geographic proximity, fostering agglomeration economies (Koster and Thisse, 2024; Proost and Thisse, 2019).

On the other hand, land and time constraints drive competitive bidding processes for locations among households and firms (Duranton and Puga, 2015; Lucas and Rossi–Hansberg, 2002), which shape not only where firms and households locate but also the nature of their interactions (Rosenthal and Strange, 2020). A central feature of agglomeration economies is thus the role of transportation costs in influencing the extent and intensity of economic interactions across locations. These spatial frictions determine how easily individuals and firms can access various destinations, which in turn affects productivity, firm-worker matching, and learning dynamics (Duranton and Puga, 2020). The concept of accessibility captures this by encompassing access to business districts, inputs, and markets, as well as a broader interpretation originally proposed by Hansen (1959), as “the potential of opportunities for interaction”.

However, gravity-based accessibility measures inspired by Hansen (1959) primarily estimate the potential to overcome geographic distance and reach destinations, which reflects potential for interactions rather than the actual locations that agents choose for interaction. Alternatively, studies on spatial interactions aim to model bilateral trip flows between locations, trying to predict the spatial distribution of travel patterns based on information on the spatial distribution of opportunities and travel costs (Haynes and Fotheringham, 2020; Roy and Thill, 2004). However, both spatial accessibility measures and spatial interaction models lack a robust theoretical foundation, making it hard to rationalize their gravitational patterns and limiting their capacity to explain how internal urban structural changes affect the individual incentives for interaction (Anas, 1983; Anderson, 2011; Niedercorn and Bechdolt Jr, 1969).

Meanwhile, a large body of literature in transportation has advanced our understanding of individuals' choice behavior grounded on the rationality of utility maximization (Ben-Akiva et al., 1985; Hasnine and Nurul Habib, 2021; McFadden, 1974; Wu and Levinson, 2020). Building on these frameworks of agglomeration economies, gravity-based interactions, and discrete choice, recent literature on quantitative spatial models try to more explicitly predict how shocks in transportation costs impact the relocation choices of individuals and firms by reshaping agglomeration and dispersion forces (Ahlfeldt et al., 2015; Redding and Rossi-Hansberg, 2017).

Research on agglomeration economies, gravity-based accessibility, and spatial interaction models remained fragmented for decades. Whereas the former contributed with elegant mathematical models based on strong assumptions, the gravity-based literature enhanced the use of observational data to explain urban settings, and the later, with statistical predictions of geographic human interactions. These approaches proved to be complementary, particularly after integrating utility maximization to explain location and travel choices based on observational data (Ahlfeldt, 2011; Ahlfeldt and Wendland, 2016; Anas, 1983). Only recently have quantitative spatial models (QSM) integrated these frameworks, yet they often overlook key concepts such as location potentials, accessibility, and discrete choice modeling, which could enhance their scope of investigation. Moreover, the recent and growing set of evidence of the emerging branch of QSM studies on the impact of public transit expansion on transportation costs, travel behavior, agglomeration forces and welfare distribution has not been systematically studied.

This study systematically reviews spatial interaction-related literature, examining its connections to transportation, land use, and agglomeration economies. Using a cross-disciplinary approach, we bridge insights from economics, transportation geography, regional science, and urban planning in a discussion that highlights how spatial interaction incentives shape urban structure. Drawing on various economic perspectives, we discuss concepts of potential interaction, accessibility, their links to residential and labor markets, and how transportation conditions determine the co-location between firms and households.

The review extends across economics and transport-related literature to discuss how spatial interaction and discrete choice modeling can help explain determinants of urban structure[2]. Building on this conceptual foundation, we review empirical studies on gravity-based indexes and QSM that assess the impact of public transit interventions on urban markets, spatial structure, and welfare. This review allows us to identify key contributions and gaps in the literature of urban economics, transportation geography, regional science, and urban planning, thus integrating insights to advance the assessment of shocks in spatial interaction conditions on the internal structure of cities.

The essay is organized as follows. Besides this introduction, Section 2 reviews a class of urban theoretical models from the perspective of interaction in space. Section 3 discusses how the ease of interaction with opportunities concept evolved and resulted in meaningful measures of access. Section 4 reviews the evolution of spatial interaction models, travel behavior and their fusion into spatial quantitative models. Section 5 discusses the gaps and promising research avenues at the intersection of these literatures. Section 6 concludes the essay pointing to potential opportunities for cross-fertilization that could be advanced through greater dialogue across disciplines.

2. The ease of potential for interaction and the urban structure

The literature on urban economics often predicts how production and consumption externalities and travel costs shape spatial interactions and urban structure (Anas et al., 1998; Duranton and Puga, 2020; Lucas and Rossi–Hansberg, 2002). A related literature in urban planning highlights how accessibility is a key metric for land use development by encompassing the role of transportation and land use integration in facilitating location-based interactions. This section explores how the concept of urban accessibility pursuits the goal of translating how easy locations can access amenities in cities.

[2] This review does not aim to exhaustively cover the mathematical properties of the numerous models of agglomeration economies, accessibility, spatial interaction, and discrete choice discussed here, as related literature has already addressed these aspects. Notable works on the mathematical modeling of urban structure and agglomeration economies include (Brueckner, 1987; Combes et al., 2011; Combes and Gobillon, 2015; Duranton and Puga, 2004, 2015; Fujita et al., 2001; Fujita, 2013; Glaeser, 2010a). Studies on the properties of accessibility models include (Koenig, 1980; Weibull, 1976; Wu and Levinson, 2020), while spatial interaction models have been analyzed by (Anderson, 2011; Roy and Thill, 2004; Wilson, 1971), and discrete choice models by (Anas, 1983; Ben-Akiva et al., 1985; Hensher and Greene, 2002; Wen and Koppelman, 2001). Finally, Dingel and Tintelnot (2020) extend mathematical properties of spatial quantitative models to test how they can be effective in predicting spatial equilibrium responses to urban shocks.

The spatial structure of urban development emerges from the interplay between land use and transportation systems, mediated by accessibility to economic opportunities. Drawing from Ricardo’s (1815) classical rent theory principle that land value is determined by its marginal productivity, Hurd (1903) is among the first authors to argue that the productivity, usage, and utility of urban land are determined by its relative location. Thus, land located farther from the urban core typically holds lower economic value due to the higher travel costs to reach economic activities. As utility influences land value, rental prices reflect access to services, driving a competition that shapes land value and land use hierarchies (Hurd, 1903).

Hurd’s principles of urban growth emphasize two key factors: *Central growth*, which is centripetal clustering around key nodes, and *Axial growth,* a centrifugal extension along transportation corridors. These growth patterns occur simultaneously, with axial growth transforming the city’s radial core into a star shape as transport infrastructure facilitates the access to urban services and the emergence of subcenters.

Haig (1926) further analyzed these urban dynamics by documenting the decentralization of economic activities and income groups in New York City between 1900 and 1922. He observed that firms in certain sectors benefited from size advantages and production structures that allowed activity fragmentation. These dynamics of out-bidding rely on a "package" of activities inherent to a firm's production system, where accessibility plays a crucial role in reducing friction for firms to reach customers. Maximum accessibility, typically found in city centers, correlates with higher rental values. However, according to Haig, not all activities can translate accessibility into profit, thereby establishing an economic mechanism underlying the out-bid process. Besides, infrastructure improvements should be pursued by urban planners only when their benefits outweigh their costs in reduced travel time and expenses (Haig, 1926).

Building on this foundation, Hansen (1959) presented a more rich definition of the concept of accessibility as *“the potential of opportunities for interaction”*. His formulation aimed to capture not only the physical possibility of reaching other zones, but also the desirability of such interactions. Accessibility A_i for a given origin zone *i* was modeled as:

$$A_i = \sum_{i=1}^{n} \frac{O_j}{T_{ij}^{\alpha}}, \ \alpha \geq 0, \quad \text{if } i \neq j \qquad (1.1)$$

where O is the scale of the opportunities at destination zone j (e.g., number of jobs), which is balanced by T, the travel time between the zone i and j. In Hansen's original specification, this function was exponential and calibrated using empirical data on travel behavior, with parameters α varying by trip purpose and duration.

Hansen's (1959) *gravity-based potential* model was empirically validated by testing the relationship between accessibility indices (based on employment, population, and retail activity) and changes in residential land use in Washington, D.C., between 1948 and 1955. His findings confirmed that accessibility measures can predict urban development patterns, giving more support to the earlier theoretical insights by Hurd (1903) and Haig (1926).

Subsequent work has highlighted the sensitivity of accessibility measures to the choice of impedance function. While Hansen employed an exponential decay form, alternative specifications (e.g. power, logistic, or piecewise-linear functions) can reflect differing tolerances and behaviors in reaching opportunities (Geurs and Van Wee, 2004; Ingram, 1971; Levinson and Wu, 2020; Pereira and Herszenhut, 2023; Tomasiello et al., 2023). Using an inappropriate functional form may misrepresent accessibility levels and distort behavioral interpretations, particularly in policy evaluations (Handy and Niemeier, 1997; Ingram, 1971).

The concept of accessibility, as developed by Hansen (1959), is a travel cost-weighted measure of density that reflects the internal structure of cities. Beyond its spatial-economic interpretation, accessibility has also been increasingly conceptualized as a social indicator, sensitive to variations in travel capacity across gender, age, race, physical mobility, and access to transport resources. Building on this, Wachs and Kumagai (1973) introduced a contour measure approach that defines accessibility based on a cumulative count of reachable opportunities within a specified travel time threshold. Their formulation is given as:

$$CMA_{iw} = \sum_{j=1}^{j} \sum_{e=1}^{e} O_{jew} f(T_{ij}) \tag{1.2}$$

$$f(T_{ij}) = \begin{cases} 1 \; if \; t_{ij} \leq T \\ 0 \; if \; t_{ij} > T \end{cases}$$

where CMA is a cumulative index for the zone i of the total number of job opportunities O, in the economic sector e, with wage w. These opportunities can be reached according to the travel cost function, by which t is the travel time between zone i and j, and T is a time threshold to be arbitrarily defined.

This approach facilitates the interpretation of accessibility estimates, allowing analysts and policymakers to define acceptable travel durations to essential opportunities and segment job opportunities by sector and wage level. It allows a more straightforward evaluation of how land use translates into differential access to urban amenities, assesses the quality of life across diverse social groups, and diagnoses spatial inequities in opportunity distribution (Wachs and Kumagai, 1973).

More recently, different authors have proposed more sophisticated measures of accessibility that also try to account for spatial competition effects (Paez et al., 2019). These include a number of indicators under a family of Floating Catchment Area accessibility metrics, of which the most well known is the two-step floating catchment area (2SFCA), originally proposed by Shen (1998) and popularized by (Luo and Wang, 2003). The general intuition behind these metrics is that one's level of access to a given service (e.g. school seat, hospital bed) must be discounted not only by the distance to reach it but also by the extent to which that service is accessible by other *potential concurrent users*. This way, these measures try to discount one's access to a service by the potential demand competition for that service.

Enhancing the accuracy of accessibility measures to reflect heterogeneous needs across individuals is both data-intensive and operationally costly. As a result, much of the empirical literature relies on location-based accessibility indices, which focus on geographic areas rather than individual agents and are guided by typical data availability (Geurs and Van Wee, 2004; Levinson and Wu, 2020). Within this framework, Levinson and Wu (2020) propose a general representation under which most location-based accessibility measures can be expressed as:

$$A_{i,h}^{k,m,e,t} = \sum_{j} = O_j^k f\left(T_{ij}^{h,m,e,t}\right) \tag{1.3}$$

where accessibility at location iii is defined with respect to opportunities O_j^k of type k available at destination j, discounted by a travel impedance function $f(\cdot)$ that depends on travel time, mode, generalized cost, and time of day.

This formulation makes explicit the dimensions along which accessibility can be conditioned: where it is measured, when interactions occur, how destinations are reached, why specific opportunities matter, and for whom access is evaluated (Levinson and Wu, 2020). To account for population heterogeneity, overall accessibility at location i can be expressed as a population-weighted average across groups:

$$A_i = \frac{\sum_c P_{i,c} A_i^c}{\sum_c P_{i,c}} \tag{1.4}$$

where $P_{i,c}$ denotes the number of residents at location *i* belonging to population group *c*. This aggregation highlights that accessibility is not a purely spatial attribute, but one that depends on the composition of the population and its alignment with available opportunities, thereby providing a natural bridge between urban structure, travel behavior, and distributional concerns.

3. Travel costs, agglomeration economies, and accessibility

Agglomeration economies refer fundamentally to the benefits that firms and individuals experience when they are located near one another (Glaeser, 2010a), making location choices purposeful rather than random. According to Duranton and Puga (2004) agglomeration economies arise from three mechanisms unlocked by co-location: sharing, matching, and learning. Sharing refers to the ability of proximate firms and workers to spread fixed, lumpy, or non-rival inputs (e.g., infrastructure, logistics platforms, specialized suppliers, and thick local consumer markets) and then reduce production costs with increased scale and density. Matching captures how thick labor and supplier markets improve the speed and quality of pairings, reduce search frictions, and enable finer specialization; proximity raises the probability of high-quality matches between heterogeneous firms and workers. Meanwhile, learning denotes the diffusion of tacit knowledge which is facilitated by face-to-face contact, job hopping, and networked interactions.

Transport accessibility is the spatial mediator of these processes. By lowering generalized travel costs, accessibility expands the effective set of trading partners, consumers, and workers, deepens competition and specialization, and increases opportunities for on-the-job learning. Accessibility captures how the land-use patterns and the transportation systems shape the ease of reaching opportunities, so locations with superior accessibility tend to command higher rents, reflecting the economic appeal of urban sites through the bid-rent mechanism. This section explores how urban microfounded models of agglomeration economies and accessibility are related, emphasizing different perspectives on spatial interactions among economic agents.

3.1 Travel costs, land use, and spatial equilibrium in cities

The notion of spatial accessibility has long shaped theories of agglomeration economies. Although urban and transport planning and theoretical urban economics models differ in how to grasp accessibility, they recognize transport cost and land use as central to the spatial sorting of agents (i.e., households and firms) and the determination of the internal urban structure. The concept of *iceberg costs* from Samuelson (1954) helps bridge the ideas behind accessibility and urban economics models, as it claims that productivity decreases with travel costs, making proximity to destinations, either rich in production or consumption amenities, more desirable.

The idea that iceberg costs shape spatial equilibrium traces back to Von Thünen (1826), who showed how transport costs and land value interact to produce concentric land-use zones around a central market. In this model, the implicit idea of accessibility declines monotonically with distance from the central market, and land is allocated based on the balance between access and production value. This foundational idea was later extended to urban settings through the Alonso–Muth–Mills (AMM) model, which formalized the monocentric city as a spatial equilibrium where households maximize utility by trading off commuting costs and housing size (Brueckner, 1987). In the AMM, the access to employment, quantified by the commuting cost in terms of distance to the central business district (CBD), drives the residential demand for locations and the bid-rent curve, determining household densities and city size.

While insightful, the AMM model treats the CBD's location as exogenous, lacking explanation for why employment concentrates where it does. Polycentric models, particularly from Fujita and Ogawa (1982), address this limitation by allowing firms and households to bid for locations anywhere in the city. Firms benefit from agglomeration economies that decay with distance through the *locational potential* function, while households face commuting costs. The role of transportation costs on the urban structure in this framework is bidirectional: firms value access to other firms due to production spillovers, while households value access to employment. The result is an endogenous spatial structure in which multiple centers can emerge, each shaped by the interplay of transportation costs, land prices, and agglomeration forces.

Other models in urban economics shift the focus to access to variety and scale. Models incorporating monopolistic competition and travel costs for consumption emphasize that households derive utility from access to diverse goods and services, while firms benefit from access to consumers and suppliers (Duranton and Puga, 2004; Fujita, 1988; Liu and Fujita, 1991; Papageorgiou and Thisse, 1985). However, congestion in the transport infrastructure can affect this interplay by increasing the spatial friction among firms, workers and customers, resulting in the emergence of new employment subcenters (Anas and Kim, 1996). In these contexts, the notion of accessibility encompasses the richness and ease of economic interaction within a broader consumption-based land use setting.

Transportation and land use are among the main forces that determine agglomeration and congestion forces in cities. In a canonical model with continuous space, Lucas and Rossi–Hansberg (2002) show that the decreasing labor supply with increased commuting costs determines the bidding for location from both firms and workers, as productivity will be affected (again, iceberg costs). Thus, higher levels of employment density increase firm's productivity and workers' wages. This further enhances the tension forces between firms and households on the bidding for locations, and the land use setting in equilibrium through bid-rent maximization. This model adds a more nuanced understanding of the relevance of travel costs in location decisions: firms value access to other firms and to workers, whereas households value access to employment.

Reduced travel costs facilitate interactions and enhance external agglomeration economies. Improvements in transportation services or infrastructure can expand the geographic scope of incentives for firm and household co-location as it eases the materialization of economic mechanisms such as sharing, matching, and learning, thereby promoting densification (Chatman and Noland, 2011). Thus, access shapes the location choices that emerge from the desire to be near or far from particular amenities (Levinson and Wu's, 2020). More desirable locations drive higher spatial densities of firms and populations, intensifying the use of areas with positive production and consumption externalities (Duranton and Puga, 2020). Improved access to these locations increases land value, as agents trade-off space for preferred locations. Thus, land use reflects economic incentives through the bid-rent curve, as land market equilibrium is determined by agents maximizing utility or profit.

3.2 Producers and the access to positive externalities

The economic incentives behind production location rely on externalities, such as learning from nearby producers, access to skilled labor, and proximity to input suppliers (Marshall, 1890). These externalities enhance firms' production efficiency and shape their location choices (Duranton and Puga, 2004; Fujita and Thisse, 1996). Marshallian externalities also underscore a key distinction: the increasing returns to scale that drive firm clustering can be either internal, arising within firms, or external, resulting from interactions among producers.

One channel through which these externalities operate is the labor market. Urban density raises the likelihood of interactions with skilled individuals, accelerating learning-by-observation processes (Glaeser, 1999), and skill diversity among workers generates knowledge spillovers (Jovanovic and Rob, 1989). While firms gain from locating in skill-rich labor markets, geographic distance limits the access to specialized workers, and the potential of knowledge exchange has spatial decay. Thus, besides knowledge spillovers, higher firm density improves the quality of skill-job matching and reduces mismatch costs, but also increases commuting costs, balancing the net benefits of agglomeration (Duranton and Puga, 2004; Helsley and Strange, 1990).

The pattern of firms' interactions with consumers may also lead to the spatial clustering of a single sector or a few sectors, such as retail and restaurants with minimal differentiation of goods. Hotelling (1929) demonstrated that the shopping costs linking firms and consumers can drive spatial price competition among monopolistic firms. Thus, firm clustering can improve the access to specific products and reduce overall search efforts of consumers for goods that match their preferences (Stahl, 1982). In markets with a demand for variety, price competition drives firms to differentiate their goods and cluster together to access larger consumer markets (Fujita and Thisse, 1996; Ottaviano and Thisse, 2004).

3.3 Transportation costs, land use, and household location

The AMM model aims to explain how the tradeoff between housing, consumption, and commuting costs determines individual utility and household location preferences. However, such aspects may not fully explain location choices, as interactions with residential amenities (e.g., urban services and green areas) also shape household location. A perspective on residential location preference is encapsulated in Lucas' (1988, p.30) question: "*What can people be paying Manhattan or downtown Chicago rents for, if not for being near other people?*". While preferences for social interaction vary among individuals, the high population densities in large cities suggest that many prioritize access to other people and other amenities.

The trade-off between the desire for social and recreational interactions and the need for residential space shapes residential choices, driving households to cluster in areas with better potential for personal interaction (Beckmann, 1976). The consumption of the externality of being close to people, either if it increases or decreases utility, rises with population density and fades with distance, determining location choices and household agglomeration (Papageorgiou and Smith, 1983). Moreover, the quality of individual's interactions may endogenously influence their preferences to interact, further explaining its role in urban agglomeration and spatial equilibrium (Helsley and Strange, 2007).

Besides potential for personal interaction, residential space, goods consumption and commuting costs, the household location choice can also be influenced by the income elasticity of demand for amenities such as coastlines, hills, historical monuments, green area, fine architecture, etc. This, in turn, determines the bid of rich and poor individuals for land near amenities (Brueckner et al., 1999). Within this framework that includes non-work activities, modern amenities (e.g., restaurants, theaters) can become endogenous to the locations of the exogenous amenities (e.g., topographic, historic), and the bid-rents resulting from these relationships can reinforce urban patterns of income-based spatial segregation.

The demand for non-tradable goods also influences household location choices, driving demographic-based sorting. For instance, young, unmarried, skilled individuals may prioritize shorter commutes and access to social amenities such as restaurants, bars, and nightlife over larger residential spaces (Couture and Handbury, 2023, 2020). Thus, shocks on the housing market may promote gentrification by altering neighborhood characteristics and making incumbents lack amenities aligned with their demographic needs (Almagro and Domínguez-Iino, 2024). Another explanation on how co-location feedback between amenities and households begins relies in the value of time among rich and poor individuals, as the ratio of commuting costs to residential consumption influences sorting near public transit[3] (Brueckner et al., 1999; Glaeser et al., 2008).

These dynamics on residential sorting not only influence urban structure but also have distributional consequences, especially for low-income and minority populations. Income-based segregation can restrict access to opportunities, particularly for low-skilled individuals in areas with poor commuting options, reinforcing Kain's (1968) spatial mismatch hypothesis.

Within this framework, Brueckner and Martin (1997) show that when Black residents are confined to central areas, their welfare levels decline as suburban job centers proliferate and commuting costs rise. Subsequent studies emphasize how this spatial separation reduces matching efficiency (Coulson et al., 2001), reinforces segregation through housing market discrimination (Brueckner and Zenou, 2003), and weakens labor market outcomes by lowering productivity and bargaining power among distant, low-skilled workers (Brueckner et al., 2002; Zenou, 2002). These theoretical models converge on the insight that rising commuting costs undermine labor market access, connecting spatial mismatch to the concept of accessibility, by highlighting how economic sorting mechanisms push individuals to locate in areas with greater potential for interaction with job opportunities.

3.4 Accessibility and the bid-rent curve

Despite the distinct origins of the AMM and accessibility concept — based on Von Thünen's and Ricardo's contributions, respectively—both frameworks aim to model tradeoffs in urban economics. The AMM model primarily focuses on commuting costs to the central business district (CBD), while Hansen's approach accounts for the multidirectional distribution of opportunities, weighted by travel costs.

Empirical studies conducted by Ahlfeldt (2011), Bowes and Ihlanfeldt (2001), Brandt and Maennig (2012), and Osland and Thorsen (2008), test the complementarity between these ideas. They show that incorporating Hansen's labor market accessibility concept into econometric models improves predictions of urban land price gradients compared to

[3] Glaeser et al. (2008) show that in 2000, public transit conditions in U.S. metropolitan areas drove sorting of lower-income individuals into central areas, where commuting by transit offered more advantages than driving. However, when the opportunity cost of travel outweighs the elasticity of land demand relative to income, wealthier individuals tend to settle near public transit (Glaeser et al., 2008), as observed in recent downtown gentrification trends in U.S. cities (Couture and Handbury, 2023).

CBD-focused measures. These studies employ a hedonic price function based on Rosen (1974) following the reduced form:

$$P = (A, I, N) \tag{1.6}$$

Where P is the total housing unit price, A is the level of accessibility to the job market (as in equation 1.1), I is a set of internal housing attributes, and N are other neighborhood characteristics external to the household. Their findings suggest that gravity-based accessibility indices outperform traditional monocentric models by better capturing dispersed employment and heterogeneous transport networks. However, these results also align with Alonso's (1964) theory that employment accessibility drives the bid-rent curve (Ahlfeldt, 2011).

Increased benefits promoted by accessibility tend to intensify the competition for land, whereas increased land value incentivizes improvements in accessibility. This raises joint determination on land price, challenges the identification of the impacts of accessibility as positive economic externalities, and becomes a shortcoming in cross-section analyses such as those conducted by (Ahlfeldt, 2011; Bowes and Ihlanfeldt, 2001; Brandt and Maennig, 2012; Osland and Thorsen, 2008). To address this, some studies have leveraged exogenous variations in transportation networks to isolate their effects on land prices (Baum-Snow and Kahn, 2000; Cervero and Kang, 2011; D'Elia et al., 2020; Gibbons and Machin, 2005; Lieske et al., 2021; Mayor et al., 2012; McMillen and McDonald, 2004).

However, these studies typically focus on changes in linear distances to transit stations or reductions in commuting times, overlooking the role of land use sets on the gains of potential for interaction, and capturing only part of the benefits provided by public transit systems. Few notable exceptions, summarized in Table 1A, include studies that use more modern gravity-based accessibility measures to assess the impact of transit interventions on property values.

Table 1A - Studies that estimate the impact of improvements of new transit infrastructure on gravity-based accessibility using longitudinal data.

Study	Urban intervention	Econometric identification	Measure of access (A)	Main results
Ahlfeldt (2013)	subway expansion in London	Semi-log longitudinal linear regression	$A_i = \sum_j \frac{E_j}{\sum_j E_j} g(t_{ij})$	doubling A increases housing prices by 12%
He (2020)	rail system expansion in Hong Kong	Difference-in-difference hierarchical model	$A_i = \sum_j E_j^{-\beta t_{ij}}$	elasticity of price to A of 0.36

Source: Author's own elaboration. Notes: in column "Measure of access (A)", i is the index's location, j is a destination location, E is the number of job opportunities, β is a calibrated parameter, and t is the travel cost by transit by summing walking to stations and in car times.

Ahlfeldt (2013) estimates the effect of London's subway network expansion on housing markets, finding that utility gains from proximity to new stations were capitalized into land values. Similarly, He (2020) evaluates the impacts of a railway expansion in Hong Kong across multiple geographic scales (property, neighborhood, and submarket). Both studies underscore the significant role of accessibility improvements in shaping urban land values and contribute to emphasizing the body of evidence of accessibility and land use development.

3.5 Accessibility and labor market outcomes

Another branch of research employs gravity-based accessibility indexes to predict individual labor market outcomes, such as potential wages or employment probabilities. These models typically follow Mincer's (1974) framework, where human capital stock represented by a set of observable characteristics (such as age, education level, gender) determines individual earnings and its marginal productivity.

Studies investigating the spatial mismatch hypothesis often examine how the accessibility level at the household location, given individual characteristics, affects labor market outcomes. To address joint determination between earnings and residential location, different studies have used instrumental variables that explain accessibility levels such proximity to river bodies (Batista Duarte et al., 2023; Haddad and Barufi, 2017; Silva and Porsse, 2024), population density (Bastiaanssen et al., 2022), alternative transport networks (Duarte et al., 2023; Jin and Paulsen, 2018), and employment subcenters (Delmelle et al., 2021; Jin and Paulsen, 2018).

As shown in Table 2A, studies that investigate the effects of accessibility to job opportunities on wages using travel conditions by public transit include Duarte et al. (2023), Haddad and Barufi, (2017), Silva and Porsse (2024), and on employment rates, Bastiaanssen et al. (2022) Batista Duarte et al. (2023), Delmelle et al. (2021), Hu (2017), and Jin and Paulsen (2018). Pacheco (2019) employs a quasi-experimental design to assess how housing policies influence accessibility, and how it affects employment rates. Table 2A also shows that these studies evidence mixed results regarding the importance of accessibility in shaping labor market outcomes through agglomeration economies.

Table 2A - Summary of studies that estimated the effects of gravity-based accessibility indexes on spatial mismatch dealing with joint determination issues.

Study and region	**Empirical strategy**	**Accessibility measure (A)**	**Accessibility effects on job market performance**
Pacheco (2019) in Rio de Janeiro	being randomly assigned to a housing program	$A_i = \sum_j^n E_i f(T_{ij})$, 1 if $T_{ij} \leq 60$ min 0 if $T_{ij} > 60$ min	*A* decreased, but had no effects on employment rates of the treated individuals
Bastiaanssen et al., (2022) in Great London	instrumental variable	$A_i = \sum_j^n E_j e^{-\beta d_{ij}}$	each 10% increase in *A* improves the employment probability by 0.13% in urban areas
Duarte et al., (2023) in Recife city			each 10% increase in *A* reduces the probability of being a low-wage worker by 2.6%
Duarte et al., (2023) in São Paulo metropolitan area			elasticities of employment probability to *A* ranging between 0.05 and 0.15
Haddad and Barufi (2016) in São Paulo metropolitan area			elasticity of wage to *A* of 0.41

Silva and Porsse (2024) in Curitiba metropolitan area			elasticity of wage to *A* of 0.01
Delmelle (2021) in Charlotte metropolitan area			*A* increases employment rates on low-income households
Jin and Paulsen (2021) in Chicago metropolitan area		$A_i = \sum_j \frac{E_j e^{-\beta d_{ij}}}{\sum_j P_k e^{-\beta d_{ij}}}$	each 10% increase in *A on* improves the employment probability by 0.39 of african american households
Hu (2017) in Los Angeles metropolitan area			one standard deviation of *A* increases the probability of being employed by 10.5% for medium to low-income households

Source: Author's own elaboration. Notes: In column "Accessibility measure", *i* is the index's location, *j* is the destination location, *E* is the quantity of jobs, β is an impedance parameter to be calibrated, *t* is travel time (geographic distance in Jin and Paulsen, 2021), and *P* is the total number of job seekers in location *k*. Low-wage workers in Recife refers to individuals whose earnings were .

A significant strand of literature in regional and urban economics examines the effects of agglomeration economies through the elasticity of firm productivity to gravity-based accessibility to employment, often used as a proxy for market potential (Holl, 2012; Lall et al., 2004; Le Néchet et al., 2012; Martín‑Barroso et al., 2015; Melo et al., 2017). In this sense, matching effects are estimated on workers' earnings, focusing on productivity gains from relocating to areas with stronger agglomeration economies (Combes et al., 2008; Combes and Gobillon, 2015). Recent studies use gravity-based accessibility indexes at workplaces to account for agglomeration economies at the labor market, such as Börjesson et al. (2019), Knudsen et al. (2022), and Lee (2021). These studies at the city level[4], summarized in Table 3A, use public transit expansions as exogenous sources of variation in agglomeration forces and address joint determination between gravity-based accessibility to jobs and firm productivity with instrumental variables.

[4] Although the analysis of Knudsen et al. (2022) is conducted in Denmark, its geographic scale, divided in 907 zones, is comparable to internal urban geographic scale.

Table 3A - Summary of studies that estimated the effects of gravity-based accessibility indexes on labor firm productivity dealing with joint determination issues.

Study and region	Empirical strategy	Accessibility measure (A)	Main results
Knudsen et al. (2022) in Denmark	fixed effects instrumental variable	$A_i = \sum_j^n E_j e^{-\beta t_{ij}}$	elasticity of wage to A ranging between 0.025 and 0.029
Böjerson et al. (2019) in Stockholm metropolitan area			elasticity of wage to A of 0.28
Lee (2021) in Seoul	spatial interaction model and first-difference instrumental variable	$A_i = \sum_j \frac{L_j E_j e^{-\alpha t_{ij}}}{\sum_j E_m e^{-\alpha t_{mj}}}$	elasticity of wage to A of 0.04

Source: Author's own elaboration. Notes: In column "Accessibility measure", i is the index's location, j is the destination location, E is the quantity of jobs, β is an impedance parameter to be calibrated, t is travel time, and P is the total number of job seekers in location k. α.

Two approaches stand out among this specific branch of studies on matching. First, Knudsen et al. (2022) uses longitudinal changes in job quantities and travel times, offering a more complex perspective on agglomeration economies. Second, Lee (2021) employs a gravity-accessibility index that integrates both job demand and labor supply as competitive components. This approach also incorporates deterrence parameters estimated from spatial interaction models, allowing for a more precise representation of commuting behavior.

An emerging class of quantitative spatial models combines the set of empirical and theoretical modeling discussed in the text to estimate the effects of shocks on the urban transit infrastructure on agglomeration and congestion forces, which we will expose later. Before, we will highlight the bridge between the potential for interaction to revealed choices based on economic rationality: the evolution of spatial interaction and travel behavior modelling.

4 Transport systems, choices for interaction, and agglomeration economies

This section extends our literature review from the modeling of potential interactions to the analysis of choices for spatial interactions. We examine how geographic proximity and the attractiveness of opportunities shape patterns of mobility through spatial interaction models. Then we turn to discrete choice models, which rationalize individual decisions through a microeconomic lens. While early spatial models lacked a strong theoretical foundation for human behavior, this limitation was addressed with the integration of utility maximization principles. We conclude by discussing how these frameworks converged to recent quantitative spatial models, particularly in applications evaluating the effects of public transit infrastructure.

4.1 Spatial interaction models

Drawing on Newtonian analogies, Carey (1859) offered an early conceptual framework that likened human and economic interactions to attraction forces between regions, influenced by distance and economic mass. This perspective anticipated the mathematical structure of later spatial interaction models. Among these, Reilly (1929) introduced a model through his "law of retail gravitation," which predicts consumer behavior based on the relative attractiveness of competing urban centers. His model suggests that residents of smaller towns may travel to larger cities for goods and services, creating a spatial hierarchy of market influence that reflects population size and service availability[5].

The effort to estimate the probability of consumers choosing specific shopping locations culminated in the concept of *spatial behavior* (Huff and Haggerty, 1962). This gave basis for Huff's (1964) model to estimate the likelihood of a consumer traveling to a given shopping center:

$$P_{ij} = \frac{S_j/T_{ij}^{\lambda}}{\sum_{k=1}^{n} S_k/T_{ik}^{\lambda}} \tag{1.8}$$

where P is the probability of a consumer at an origin i, traveling to a particular shopping center of size S located at j, among possible k destinations. T represents travel time between i

[5] The first half of the 20th century had significant advancements on the understanding of the patterns of population distribution. Among these, the *central place theory* of Christaller (1933), which proposes that settlements form a hierarchical spatial order to efficiently distribute goods and services across a region, Stewart's (1948) concept of *demographic energy*, which posits that the potential level of human interactions declines with increasing distance, and Zipf's (1949) law, which describes the inverse relationship between a city's rank and its population size, revealing a systematic regularity in urban hierarchies.

and j or k, while λ is a parameter to be estimated empirically capturing the deterrence effect of travel time on shopping trips. This model estimates spatial gradients of consumer demand by predicting the expected number of shoppers at each location (Huff, 1964).

A key stream within the literature on spatial interaction models has focused on improving the predictive accuracy of trip distribution. Wilson (1969) introduced entropy-maximizing methods, borrowing from statistical mechanics, to estimate trip flows by identifying the most probable distribution of trips subject to constraints such as travel costs, origin populations, and destination attractiveness. He later extended this framework to incorporate individual heterogeneity, multiple transport modes, and route choices, allowing for the analysis of modal splits within trip distribution (Wilson, 1971). These models apply constraints to ensure consistency between observed totals and predicted flows: *production-constrained* models fix the number of trips originating from each zone, *attraction-constrained* models fix trips attracted to destinations, and *doubly-constrained* models incorporate both, making them particularly effective for modeling commuting behavior (Roy and Thill, 2004; Soukhov et al., 2025). Anas (1983) later demonstrated that entropy-based formulations and stochastic utility maximization models (despite originating from distinct theoretical foundations) can yield equivalent solutions under the multinomial logit form, reinforcing their practical and empirical convergence.

Modern spatial interaction models inspired by the foundational work of Reilly, Huff, and Wilson (e.g., Anderson, 2011; Erlander and Stewart, 1990; Fisk and Brown, 1975) generally rest on two core principles: trip flows are influenced by the attractiveness of destinations and the travel cost, typically proxied by distance (Haynes and Fotheringham, 2020; Roy and Thill, 2004). As an alternative, the *intervening opportunities* framework proposed by Stouffer (1940) posits that interaction levels are determined not by distance per se, but by the number of competing opportunities encountered along the way. Thus, the probability of a trip between two locations declines with the availability of similar opportunities closer to the origin (Akwawua and Pooler, 2001; Gonçalves and Ulysséa-Neto, 1993; Lemos et al., 2023).

Building on this idea, Simini et al. (2012) proposed the *radiation model*, which predicts commuting flows based on the distribution of population rather than travel cost. The model assumes that the number of people between origin and destination reflects the quality and saturation of opportunities available, such as income, working conditions, or hours. By shifting focus from geographic distance to opportunity competition, this approach claims to outperform gravity models (Kotsubo and Nakaya, 2021; Simini et al., 2012). However, despite its innovation, the radiation model lacks a strong theoretical grounding in behavioral economics or utility maximization.

Gravity-based approaches, while often empirically motivated, have been shown to be consistent with utility maximization under certain formulations, particularly when cast within logit models or entropy-maximizing frameworks. These derivations offer a complementary behavioral interpretation, bridging aggregate trip flows with the principles of individual choice, and provide theoretically grounded and empirically robust tools for analyzing spatial interactions.

4.2 Travel behavior and discrete choice models

Human choice behavior can be rationalized using economic principles that assume individuals select the alternative that maximizes their utility from among a set of feasible options. McFadden (1974, 1972) formalized this idea by introducing the random utility model (RUM), in which the utility of each alternative is composed of an observable component (based on measurable attributes) and a random, unobserved component.

This logic allows assuming that the unobserved components are independently and identically distributed following a Gumbel (Type I extreme value) distribution, resulting in a statistical model with a multinomial logit (MNL) form. The probability of choosing an alternative is then a function of its attributes relative to other available options. Using maximum likelihood estimation to use sample-based qualitative data to infer population-level preferences, this formulation enables researchers to estimate behavioral parameters, including elasticities of demand, supporting policy evaluations and demand forecasting at the intensive margin[6] (Handy and Niemeier, 1997; McFadden, 1974).

Discrete choice models, particularly the MNL, have been widely applied in transport economics to understand how travelers respond to changes in attributes such as travel time, cost, and service frequency (Ben-Akiva, 1973; Ben-Akiva et al., 1985; Geurs and Van Wee, 2004). However, individual travel decisions fall into different decision categories, with

[6] It reflects the intensity of individual demand rather than the number of individuals demanding (extensive margin). For example, a shift in intensive margin demand may indicate an increase in how frequently an individual travels, while a shift in extensive margin demand refers to changes in the number of individuals choosing a destination or transport mode.

short-term choices (e.g., travel time, mode) and long-term choices (e.g., residential location, auto ownership) being jointly determined. Williams (1977) proposed the nested logit model to embed choice complexity by estimating different parameters between choice nodes (nests) such as choosing travel destination before choosing a transportation mode. This approach is less restrictive than the MNL, as it allows dependencies among choices within nests. By incorporating nest-specific scale parameters, it enables more flexible error structures, improving estimation accuracy (Hensher and Greene, 2002; McFadden, 1978; Wen and Koppelman, 2001).

Another line of research examines how individuals' demand for multiple activities across the city (e.g., work, shopping, leisure, child care) incentivizes sequential trips, emphasizing the role of "chains of activities" (Hasnine and Nurul Habib, 2021). For instance, trip sequences and mode choices may be shaped by activity patterns (Bowman and Ben-Akiva, 2001), or individuals' order dynamic activity planning (Auld and Mohammadian, 2012; Shabanpour et al., 2018). Tour-based (or activity-based) models often underscore how non-work activities are jointly determined with travel behavior and personal constraints, affecting utility levels (Hasnine and Nurul Habib, 2021; Rasouli and Timmermans, 2014). This framework also aligns with the concept followed by intervening opportunities models, as it often highlights the role of opportunities located between or near home and work.

4.3 Quantitative spatial models and the assessment of public transit interventions

Economic incentives play a central role in urban density. While transportation and land use shape the links between residential and workplace locations, the urban models discussed in section 3 often assume specific sources of agglomeration economies, limiting their ability to fully capture the complexities that determine the spatial distribution of agents across locations[7]. In contrast, spatial interaction models and accessibility indexes, though useful for identifying trip flow patterns, have long lacked a solid theoretical foundation in human behavior, a limitation that has seen substantial progress in recent years[8].

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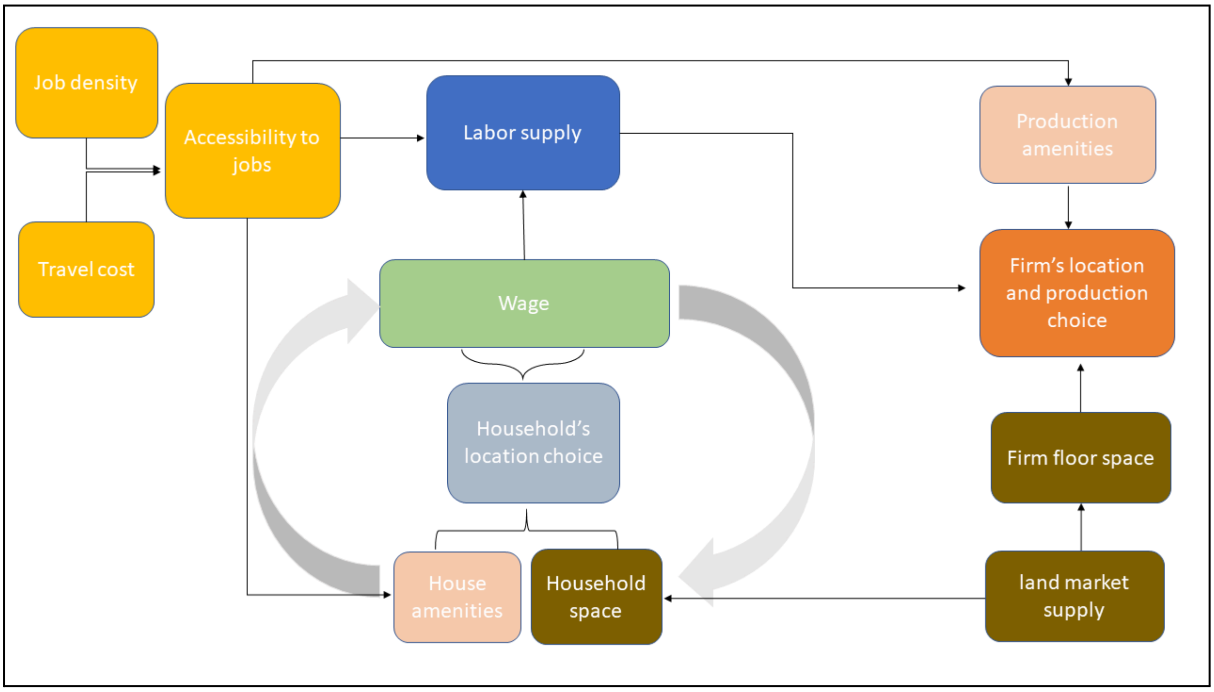
[7] Exceptions are (Anas and Kim, 1996; Fujita and Ogawa, 1982; Lucas and Rossi–Hansberg, 2002), which incorporate spatial interactions as drivers of agglomeration economies without explicit mechanisms (e.g., sharing, matching, learning). However, they assume symmetric regions and continuous spaces, which are difficult to observe empirically.

[8] Niedercorn and Bechdolt (1969) took an initial step in this direction by analyzing the utility maximization problem with time and money as constraints on interaction levels, demonstrating how elasticities of aggregated bilateral flows can be empirically estimated from equation (1.8). Later, Eaton and Kortum (2002) estimated international trade based on countries' production efficiency and bilateral distance in a tractable theoretical framework that analyzes general equilibrium responses to changes in structural parameters, which inspired the subsequent approach of quantitative spatial models.

A major advancement in economic interaction modeling was the study of Ahlfeldt et al. (2015), which developed a structural tractable urban model in which both residential and production amenities shape location choices. The city is divided into discrete blocks endowed with heterogeneous amenities. Workers choose a residence, a workplace, and a consumption bundle that maximizes utility, trading off housing, commuting, and local amenities. Idiosyncratic (individual-specific) location preferences follow a Fréchet distribution, while commuting costs enter through an iceberg formulation that lowers effective wages with distance.

Figure 1A - Flowchart for the quantitative spatial model proposed by Ahlfeldt et al. (2015).



Source: Author's own elaboration.

In this model by Ahlfeldt et al. (2015), firms are fully mobile, use labor and land as inputs, and compete for land on locations that offer great production advantages, which depend on block-specific fundamentals as well as externalities from surrounding employment concentrations. Equilibrium employment in each block emerges when commuting flows balance labor demand, with more productive firms outbidding competitors for central land due to the bidding process for locations with better levels of accessibility. Thus, the land market sets a bidding competition between firms and households to determine land use, as a competitive construction sector supplies floor space until residential and commercial bids align.

Crucially, the framework embeds endogenous agglomeration forces to rationalize the choices for location. Production and residential amenities consist of both exogenous fundamentals (e.g., natural advantages, local green space) and externalities from spatial concentration of activity. These are modeled as distance-weighted interaction functions with exponential decay parameters estimated in econometric models, capturing how the attractivity to interact with opportunities decline with travel time. While consistent with the iceberg-cost tradition in urban theory, the model does not specify the precise micro-mechanisms, such as sharing, matching, or learning, through which externalities operate. The partial equilibrium of shocks in travel cost on floor prices, residential and employment flows, capital, and commuting costs are also estimated in econometric models. This framework deals with unobserved locational characteristics by mapping and uniformly adjusting key factors within blocks to align with the distribution of production and residential amenities that follows a Fréchet distribution. These parameters are claimed to be sufficient to obtain a vector of unobserved location amenities as the data is consistent with an economic equilibrium in the (tractable) model (Ahlfeldt et al, 2015).

The model is tested in an experiment using Berlin's division and unification as exogenous shocks. Ahlfeldt et al. (2015) demonstrate that the multi-year changes in travel costs to blocks with better employment density affected productivity and caused dispersion and agglomeration effects. This dynamics is shown to have consequences on the available choices for locations to live and work, affecting utility and welfare levels.

Building on the framework developed by Ahlfeldt et al. (2015), a growing body of literature examines the quantitative effects of transit policies on economic outcomes. These studies assess whether reductions in travel costs influence the spatial relocation of workers and firms, shaping labor and residential market equilibria, and impacting urban welfare. Table 4 summarizes the model settings of this emerging literature.

Among these branch studies, Severen (2023) analyzes the expansion of Los Angeles' rail system as an exogenous shock to travel costs, finding that census tracts with improved rail access had positive elasticities on labor and housing supply. However, his study reports no significant effects of new rail stations on residential or production amenities. Focusing on travel time, Gaduh et al. (2022) examine how a BRT expansion in Jakarta affected travel behavior. Their findings indicate no effects on mode shift from private vehicles to public transit nor on bilateral trip flows between areas with increased BRT connectivity. They attribute the failure of this BRT expansion to its inability to improve travel conditions compared to private vehicles.

Table 4A - Summary of model settings of QSM for shocks on travel costs.

Study	Worker dilemma	Firm maximization problem	Structural Shock	Transportation shock's effect identification	Welfare components
Ahlfeldt et al. (2015)	Where to live and work	Perfect competition with no trade cost	Berlin division and unification	Berlin division sets commuting costs to CBD to infinite	Commuting costs, agglomeration externalities
De Campos (2019)			BRT and VLT expansion in Rio de Janeiro	250-1000 linear distance to a BRT station	
Balboni et al. (2020)			BRT expansion in Dar es Salaam	Households within 2 kilometer radius from a station	
Severen (2023)			Rail expansion in Los Angeles	250-500 meters linear distance to a BRT station	Agglomeration externalities, commuting behavior, Air pollution
Tsivanidis (2022)	Where to live and work, and the transport mode		BRT expansion in Bogota	500 meters linear distance to a BRT station	commuting costs, congestion,
Gaduh et al. (2022)	Where to live and work, mode, and the commuting route	Perfect competition with no floor space and trade costs	BRT expansion in Jakarta	1 kilometer linear distance to a BRT station and market access indexes	How transport costs affect workplace and residential populations
Zárate (2022)	Where to live and work, and the economic sector (formality)	Monopolistic competition and iceberg trade costs	Subway expansion in Mexico city	Census tracts within 1.5 kilometer of a subway line	Cost-time saving, allocative efficiency, agglomeration externalities

Notes: Author's own elaboration.

Tsivanidis (2022) examined how Bogotá's BRT expansion reduced travel costs and improved public transit accessibility for both workers and firms. The study finds that better access to well-paid jobs and a larger workforce increased residential demand and labor supply in census tracts with reduced travel costs by public transit, leading to higher residential and commercial floor prices and greater population densities. The study of de Campos (2019) estimates the impacts of Rio de Janeiro's BRT and Subway expansion on the spatial distribution of jobs and wages, evidencing a large positive impact on grids within 2 kilometer radius distance from new stations. Her study further shows that such economic impacts were heterogeneous across workers with different skills and firm economic sectors.

Examining the impact of a BRT expansion in Dar es Salaam, Balboni et al. (2020) found that households within a 2 km radius of new stations had reduced travel costs to reach denser job markets, especially for the high-skilled workers, thereby, increasing their potential earnings. However, their findings suggest gentrification effects due to increased rent prices in households close to the new BRT lines. Finally, Zárate (2022) investigates the expansion of the subway system of Mexico City and shows increases in the rate of formal workers living in census tracts that received a new station, as a consequence of improved access to the formal job market. Because informal workers are more sensitive to longer commutes and live in peripheral areas of Mexico City, this transport policy had an important effect by increasing their accessibility to formal job markets[9].

Welfare gains in such models often stem from counterfactual policy effects on commuting costs and agglomeration externalities, which shape the spatial relocation of residences and workplaces through changes in amenities (Redding and Rossi-Hansberg, 2017). These gains may vary across socioeconomic groups. For instance, low-income workers may benefit from transitioning to the formal sector (Zárate, 2022) or improved transit connectivity (Balboni et al., 2020; Gaduh et al., 2022), while high-skilled workers may gain more from enhanced production externalities (de Campos, 2019; Tsivanidis, 2022) and housing price adjustments (Tsivanidis, 2022).

[9] A common feature of Latin American large cities is the spatial concentration of formality, either for jobs, households, infrastructure, and basic services in more central areas, whereas peripheral areas often face the opposite. For more details, see (Guzman et al., 2017; Hernandez, 2018; Pereira et al., 2022).

Another key driver of welfare gains from transit policies is reduced travel time, which fosters agglomeration economies (Gaduh et al., 2022; Severen, 2023). The allocation of road infrastructure between public and private transport affects welfare by influencing congestion levels (Gaduh et al., 2022) and air pollution (Severen, 2023). However, such studies fail to fully capture broader transit policies' effects on congestion: they observe spillover effects of the improved transit network on the transportation system using spatial radius road distances around new stations, thereby neglecting broader congestion dynamics across the road network.

It is also important to point out that QSM has challenges to deal with granular spatial data for urban settings. Dingel and Tintelnot (2020) show that using large amounts of origin-destination (disaggregated) information in a continuum of individuals increases the risk of overfitting the data if the spatial links that incentivize their spatial interaction are not well observed. This mismatch creates a problem: QSM models overestimate how much observed geographic variation truly reflects fundamentals (like productivity or amenities) rather than *idiosyncratic noise*. Consequently, when using spatial granular data, the models can have poor predictions of the shocks on the internal urban structure (e.g., reduction in travel cost) on individual's decisions, in terms of matching the shares of observed commuting choices of residential and work locations (Dingel and Tintelnot, 2020).

Dingel and Tintelnot (2020) show that the variance and covariance structure of spatial data can be decomposed into components driven by structural forces (e.g., accessibility and productivity), and components driven by idiosyncratic randomness. In this sense, the urban economics literature can advance on solutions to properly include information on the spatial links between urban locations, which could emerge from the literature of transportation and urban planning.

5 Conclusions

The incentives for spatial interaction between individuals and economic activities provide valuable insights into urban density. For decades, the lack of strong theoretical foundation along with the limited availability of granular geographic data and computational capacity has limited our understanding of how the incentives for spatial interaction shapes urban structure, diminishes over distance, and affects economic agents. We conduct a literature review of the evolution of agglomeration, gravity-based, and discrete choice models in urban settings and their explanations on how spatial interaction influences the internal urban structure. Urban economics should engage more with urban planning and transportation research since integrating insights from these fields can refine both of their methodologies for assessing incentives for spatial interaction and welfare impacts.

For instance, identifying agglomeration effects through how changes in market access affects commuting flows has limitations, which could be addressed using more refined gravity-based accessibility indexes. None of the reviewed QSM studies consider competition for opportunities, despite its recognition in transportation literature (Shen, 1998; Weibull, 1976). A more refined measure could follow Levinson and Wu's (2020) insights on access by pursuing the use of information that accurately represents the incentives of those locations benefited by transit interventions. One step that the QSM literature is taking in this direction is made by Zárate (2022), by distinguishing between formal and informal employment sectors on his market access measures.

Although crowding may decrease the potential for interaction because of the user's travel time perception (Levinson and Wu, 2020), the QSM models still overlook transit system capacity's impact on commuting flows. The increasing use of Smart Card data in transportation research (Arbex and Cunha, 2020; Hörcher et al., 2017; Yap et al., 2020) offers a way to capture such qualitative factors, potentially refining QSM findings on travel choice and welfare distribution.

Additionally, the use of statistical models that deal with the complexity of choices that are related to travel would allow more reliable welfare estimates of shocks on travel costs. The works of Gaduh et al. (2022), Tsivanidis (2022), and Zárate (2022) stand out by using nested models to predict the counterfactual effects of the interventions on commuting behavior. However, more steps could be made towards the inclusion of non-work activities on the incentives for spatial interaction and the internal urban structure, by following the insights from Spatial Radiation and Tour-based choice models. On the other hand, these latter approaches still require more theoretical development to explain their predictions, thus showing a potential cross-fertilized learning process.

The increased availability of spatially refined data also allows for further assessment on how urban form features may affect the incentives for interaction in cities, such as the transportation system network, population density, and their locational choice for travel.

Because public transit travel often starts (finishes) with walking to (from) the transit station, it should be of interest to investigate how walking distance conditions affect travel decisions.

In the next essay, we examine whether increasing the passive accessibility of public transit stations (i.e., the ease with which more people can access the system at specific locations) predicts transport-related structural changes. Specifically, we assess whether population density within the mass public transit system coverage serves as an indicator of potential interaction between individuals (potential users) and the transit network, thereby revealing its effects on urban structure.

2 Reaching potential users: the effects of a rapid transit expansion on travel behavior

Resumo

Este estudo investiga como a expansão das áreas de influência do transporte público, por meio da abertura de novas estações, afeta a demanda por transporte coletivo e os fluxos bilaterais de viagens. Utilizando a expansão da rede de transporte de alta capacidade na Região Metropolitana de São Paulo (RMSP) ao longo de um período de dez anos, foram combinados dados da pesquisa origem-destino com informações espaciais detalhadas em modelos econométricos para estimar mudanças no comportamento e nas condições de viagem. Os resultados mostram que aumentos de populações residentes nas áreas de influência das estações de trilhos influenciam positivamente na demanda por viagens de transportes sobre trilhos e afeta o padrão espacial dos seus fluxos de viagens, enquanto a expansão das áreas de influência de estações de BRT não apresenta efeitos sobre a demanda ou os fluxos de viagens por ônibus. Esses resultados heterogêneos são consistentes com a evidência de que a diferença de tempo de viagem entre o automóvel e o transporte coletivo tornou-se mais favorável ao transporte sobre trilhos, mas não aos ônibus, ao longo do período analisado. Os resultados indicam que a expansão de sistemas de transporte de alta capacidade afeta o comportamento de viagem de forma mais efetiva quando combinada com melhorias na velocidade do transporte coletivo, no acesso às estações e na acessibilidade às oportunidades por meio do transporte público.

Palavras-chave: Área de influência das estações, Economias de aglomeração, Região Metropolitana de São Paulo, Padrões de mobilidade, Comportamento de viagem

Abstract

This study investigates how expanding transit catchment areas through new station openings affects transit ridership and bilateral trip flows. Using the expansion of the rapid transit network in the São Paulo Metropolitan Region (SPMR) over a 10-year period, we combine data from the household travel survey with spatially detailed information in econometric models to estimate changes in travel behavior and conditions. Our findings reveal that increases in the population within rail station catchment areas positively influence rail ridership and trip flows, whereas expanding BRT station catchment areas has no effect on ridership or trip flows by bus. These heterogeneous results align with our finding that the travel time gap between car and transit modes has become more favorable for rail but not for buses during this period. The results highlight that expanding rapid transit systems affects travel behavior most effectively when coupled with improved transit speeds, better station access, and enhanced accessibility to opportunities via public transit.

Keywords: Station catchment area, Agglomeration economies, São Paulo Metropolitan Region, Mobility patterns, Travel behavior

1 Introduction

Transport systems are fundamental in shaping spatial interactions and travel patterns in cities by fostering proximity and enabling agglomeration economies (Chatman e Noland, 2011). However, rapid urban growth has strained infrastructure capacity, contributing to the widespread reliance on private automobiles (Bryan et al., 2020; Pojani e Stead, 2018; De Vasconcellos, 2005). Encouraging a shift from private vehicles to public transit remains a major challenge, as it requires local governments to improve transit systems' travel speed, spatial connectivity, and access to transit stations (Bocarejo, 2020; Brooks e Denoeux, 2022). The success of public transit policies in increasing ridership thus depends on their ability to effectively reach potential users. Despite this, few studies have assessed how expanding the catchment area of transit systems through the opening of new transit stations affect travel behavior, particularly using an urban form-based approach.

This study examines how changes in population and opportunities densities within the catchment area of rapid transit stations influence individual travel decisions. Using the expansion of the rapid transit system in the São Paulo metropolitan region between 2007 and 2017 as a case study, we assess how improvements in physical access to rapid transit stations shape public transit ridership and the spatial pattern of urban trip flows. The São Paulo metropolitan region, one of Latin America's largest urban areas, has seen a substantial increase in car use in the last few decades, with the share of car trips increasing from 37% in 1977 to 46% in 2017 (Metro, 2017). This shift has overburdened the city's transportation infrastructure, increasing average commute times from 37 minutes in 1992 to 44 minutes in 2015 (Pereira et al., 2021b) and reducing individual labor productivity by 2.7% for every 10 additional minutes of commuting (Haddad et al., 2015).

At the same time, SPMR operates one of the most intensively used rapid transit networks worldwide, transporting approximately 5.7 million passengers per kilometer of rail in 2018, a magnitude comparable to major systems such as New York and Paris[10]. However, rapid transit coverage is limited in SPMR, as only 27% of its residents lived within a 20-minute walkable distance to the rapid transit system.

[10] The São Paulo metropolitan region reports about 2.2 billion passenger journeys in 2018, in a subway and commuter rail network length of 384 (Metro, 2019). Major systems in the western world such as the Paris Métro and New York City rail systems, performed with 7 million (1.5 bn /214 km) 4.2 million passengers per km per year (1.68 bn / 400 km), respectively (Statista, 2025; MTA, 2019).

In response to these constraints, local governments substantially expanded the rapid transit network between 2007 and 2017, adding 43 new BRT, subway, and rail stations. This expansion increased the proximity between rapid transit infrastructure, population, and opportunities, offering an urban intervention setting to examine how changes in station catchment areas, and the resulting improvements in accessibility, translate into shifts in travel behavior.

We leverage a rich spatial dataset to conduct a quasi-experimental analysis of São Paulo's rapid transit expansion between 2007 and 2017. By combining the location and opening dates of all rail and BRT stations with detailed street network data, we provide novel measures of passive accessibility by calculating network-based walking times from residential and employment areas to nearby stations. First, we assess whether increases in population within newly established station catchment areas influenced public transit ridership at the zone level. Next, we incorporate these refined catchment metrics into spatial interaction models to examine how improved connectivity between potential riders and the system affects the spatial distribution of trip flows. Finally, we investigate whether the expansion of the rapid transit system narrowed the travel time gap between cars and multiple public transit modes, thereby enhancing the system's competitiveness.

Because walking to stations is a fundamental component of transit use, ridership depends not only on service quality but also on broader urban form conditions—population density, land use, street design, and accessibility (Brooks e Denoeux, 2022; Ewing e Cervero, 2010; Handy et al., 2002; Moniruzzaman e Páez, 2012; Owen e Levinson, 2015; Vale, 2021). Thus, the ability of the transit system to improve speed, connectivity, and integration with urban form affects the size and effectiveness of station catchment areas, defined as the geographic zones from which passengers can be drawn (El-Geneidy et al., 2014; Estupiñán e Rodríguez, 2008; Kamruzzaman et al., 2014; Vale, 2021). However, few studies integrate detailed urban form and travel behavior data to assess how policy interventions shape transit access and travel decisions across multiple transportation modes. This paper addresses this gap in the context of a major metropolis in the global south.

At a broader scale, spatial interaction models have long helped explain bilateral travel flows in response to travel costs (Anderson, 2011; Roy e Thill, 2004; Wilson, 1971). More recent work links residential and employment location choices to travel behavior, emphasizing how shocks to travel costs influence urban interactions (Ahlfeldt et al., 2015;

Ahrens e Lyons, 2021; Dingel e Tintelnot, 2020). A growing body of studies on this branch of literature aims to identify such shocks by measuring changes in Euclidean distances from administrative unit centroids or boundaries to new transit stations (Gaduh et al., 2022; Severen, 2023; Tsivanidis, 2023; Campos, 2019; Balboni et al., 2020). These studies often explain how transit infrastructure affects travel behavior and internal urban structure focusing on welfare implications (Redding e Rossi-Hansberg, 2017; Dingel e Tintelnot, 2020). Our approach, by contrast, focuses on a more refined measure of the density of potential users and destinations reachable within multi-walking-distance thresholds, accounting for street-network distance and land use patterns, thereby reflecting urban form aspects in that metropolitan region.

Our results show a positive impact of 6.4% on the share of rail trips among motorized modes for every 10% of population within the rail station catchment areas of 5 minutes walking. Such impact drops to 1.9% for the rail catchment areas of 15 minutes and is absent for BRT stations at any walking time. We also find that increased population and employment within 5- to 15-walking minute rail catchment areas are positively associated with trip flow probabilities, but these effects diminish sharply with walking distance. By contrast, no effects of increased percentage of population or opportunities within BRT station catchment areas are observed on trip flows. Finally, our analysis on the travel time gap between private and transit modes show that rail trips became 3.9% faster than car trips during this period, whereas the car-bus gap remained stable. This reduction partly explains rail ridership and trip flow increases. Robustness checks confirm these findings.

Together, these results highlight the role of land use–transit integration in shaping urban mobility. By evaluating whether transit investments in the São Paulo metropolitan region have altered spatial connectivity and commuting behavior, this study underscores that effective transit policy must consider not only service attributes but also the spatial distribution of population and opportunities.

The remainder of the study is organized as follows. The next section describes the study area and motivations, followed by the methods section that details the data and the econometric models used in the paper. Sections 4 and 5 present the results and the final remarks of the study.

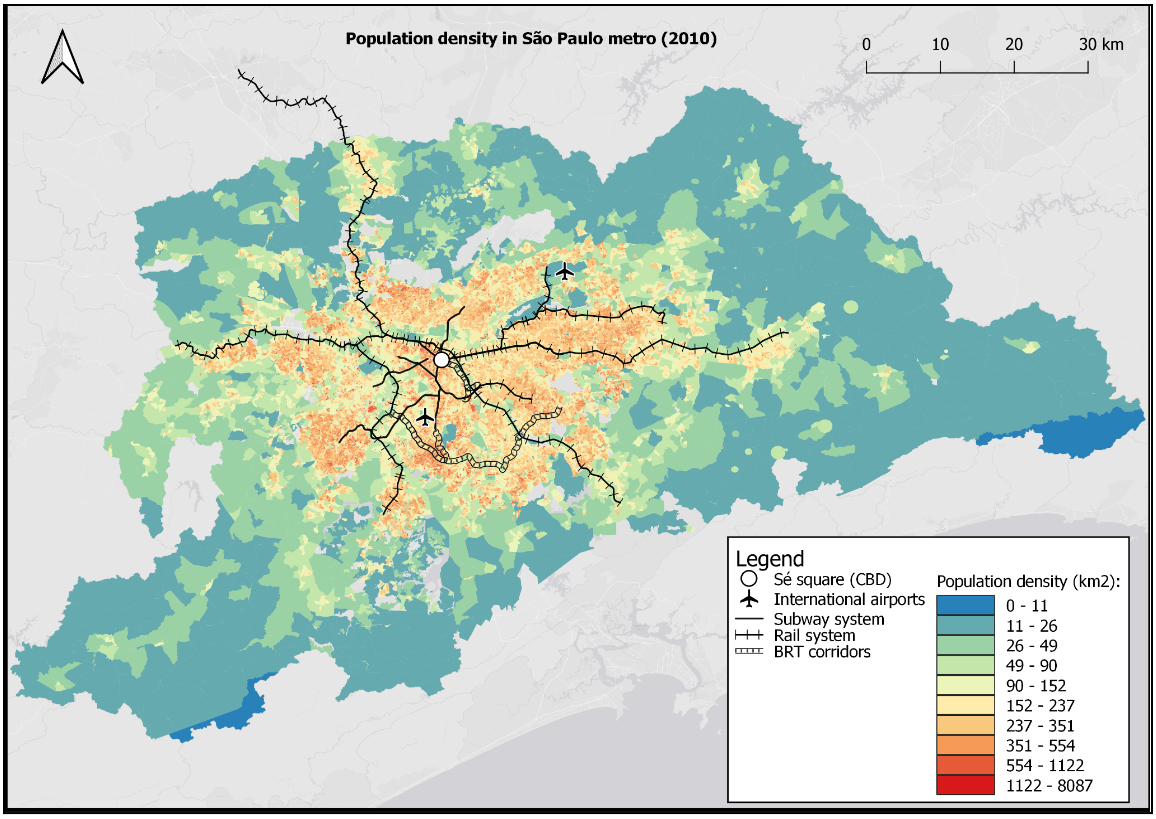
2 The recent expansion of rapid transit in São Paulo

With 22 million inhabitants, the São Paulo metropolitan region is one of the largest urban agglomerations in the world, and it concentrates approximately 19% of the Brazilian GDP (IBGE, 2021). The rapid population growth of São Paulo has increased the economic pressure in the residential market, has burdened its population with housing and transportation costs, and led this region to reach the second highest living cost in Brazil (Acolin e Green, 2017; Almeida e Azzoni, 2016).

Figures 1B and 2B show that although the population is significantly dispersed throughout the metropolitan area, the jobs are more concentrated near the core of São Paulo city. The spatial dispersion of population towards peripheral areas of SPMR challenges the provision of transport infrastructure for commuting, and inhabitants of its peripheral areas have significantly lower levels of accessibility to job opportunities (Vieira e Haddad, 2015; Giannotti et al., 2021). This spatial mismatch between residences and employment not only increases commuting distances but also raises the importance of how effectively rapid transit systems penetrate outskirt areas and connect residents to the metropolitan core.

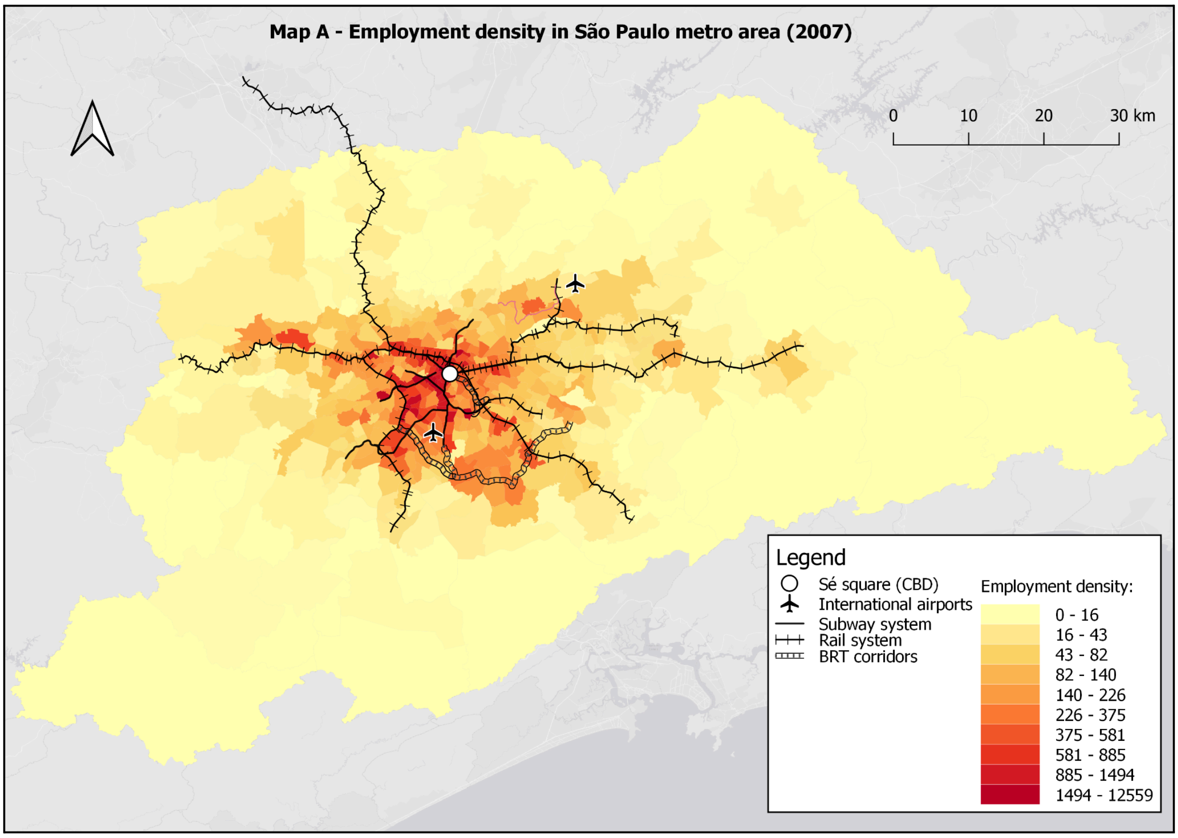
In recent years, São Paulo has undergone a substantial expansion of its public transit infrastructure. As shown in Figure 3B, by 2017, the subway system had extended from the central area toward the west via the Yellow line, to the east through the Green line, and from the southwest to the central-southern zone along the Purple line, while the rail network expanded further into the eastern and southern regions. Together, these constructions added 30 km of new tracks and 24 stations over the decade. In the same period, the city’s BRT network grew by 26 km with 19 new stations opened between the south and southwest, although key BRT stations intended to connect São Paulo to Guarulhos International Airport before the 2014 FIFA World Cup experienced significant delays and remained unopened in 2017.

Figure 1B – Population density in SPMR (2010)



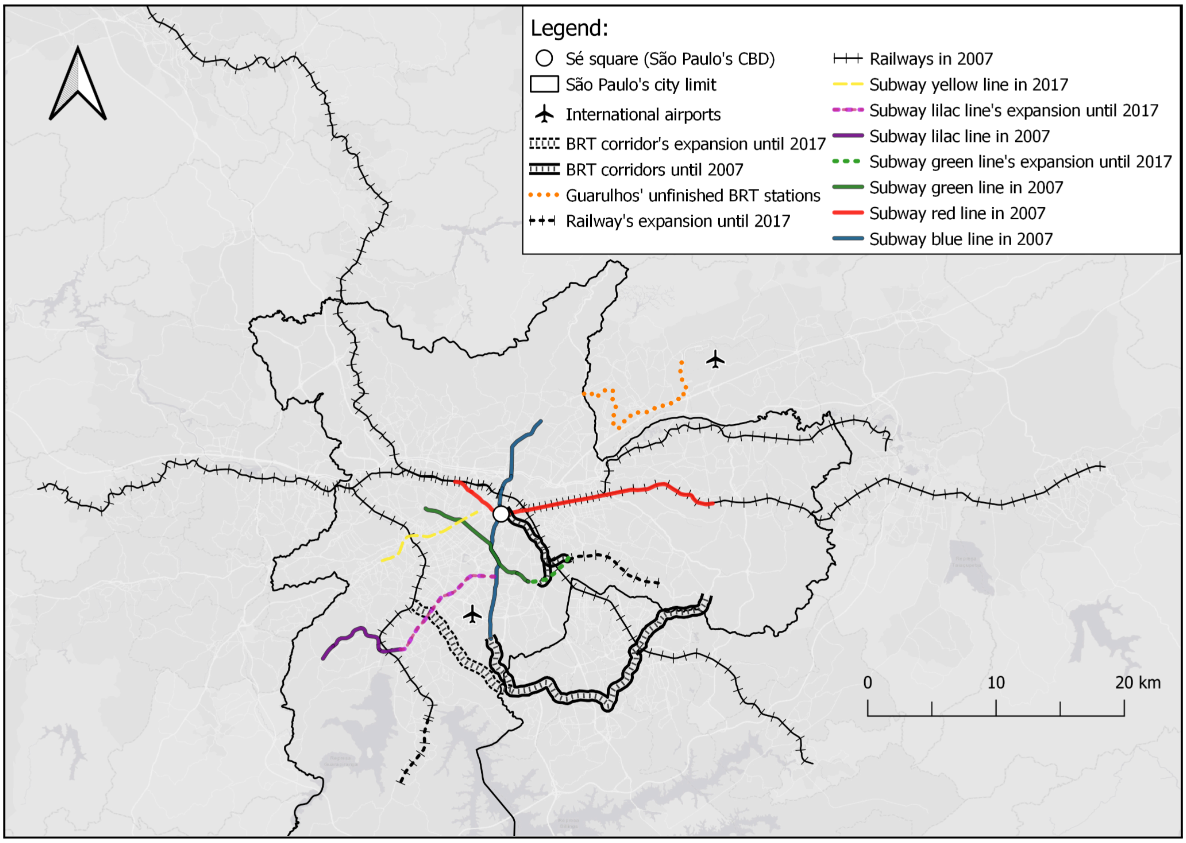
Notes: Author's own, from Brazilian census of 2010. Spatial units are census tracts.

Figure 2B – Job density in SPMR (2007)



Notes: author's own, from the Annual Social Information Report. Spatial units are census tracts.

Figure 3B - Rapid transit expansion in SPMR between 2007 and 2017.



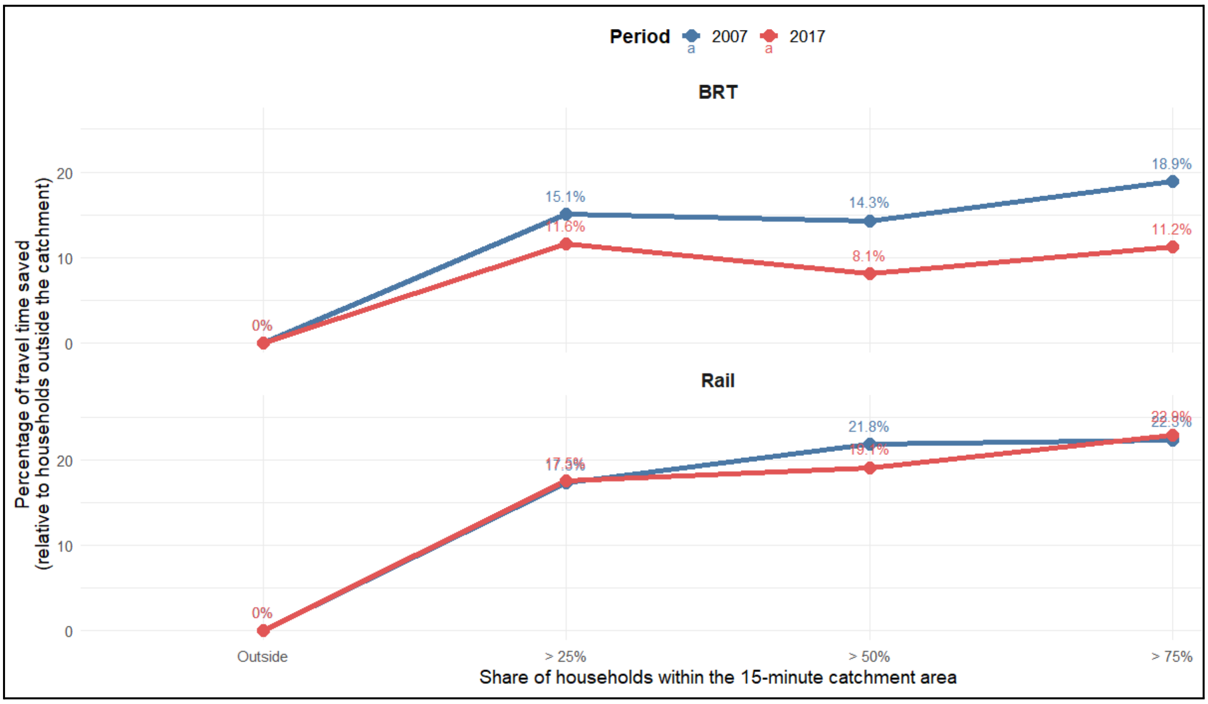
Note: Author's own, from MOBILIDADOS and OpenStreetMaps.

Promoting competitive travel cost with private motorized modes is particularly challenging in large cities of developing countries, where the mismatch pattern of rapid population growth with investment in road infrastructure contributes to reduced average travel speeds (Akbar et al., 2023; Bryan et al., 2020; Gaduh et al., 2022).

In the context of the SPMR, Origin–Destination survey data suggest that proximity to rapid transit plays a central role in shaping travel conditions. Figure 4C shows that areas with larger shares of population covered by 15 minute walk rapid transit station catchment areas exhibit substantially lower average travel times. Notably, locations where more than 75% of residents live within a 15-minute walk of rail stations experienced trips that were approximately 23% faster in 2017, whereas the corresponding reduction in passive accessibility to the BRT system areas was more modest.

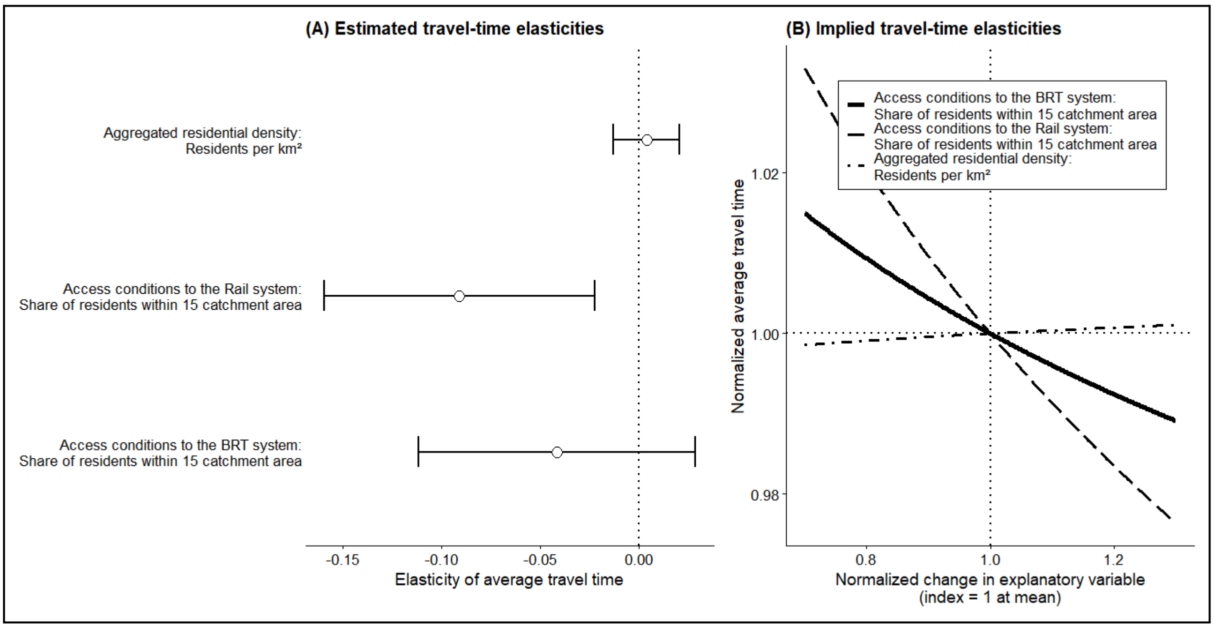
This heterogeneity is reinforced by Figure 5C, which shows a statistically significant negative elasticity of average travel time with respect to rail station access, but no comparable relationship for BRT access or aggregate population density.

Figure 4C - Differences in average travel time per population covered by the rapid transit system in SPMR.



Note: Author's own elaboration.

Figure 5C - Travel-time elasticities to urban form measures in SPMR.



Notes: Panel A reports estimated elasticities of average travel time with respect to the percentage of households within rapid transit catchment areas of 15 minutes and residential density from log–log linear regression models using repeated cross-sections of 2007 and 2017 OD data. In each model, the dependent variable is the average commuting time by zone level using any motorized mode for working or studying purposes. Control variables are: the average of the linear distance traveled, the average quantity of cars and motorbikes per household, % of population between 16 and 65 years old, % of women, % of bus, and % of rail commuters, and year fixed effects. Standard errors are clustered at the zone level. Transit catchment areas are the shares of households within rail and BRT station catchment areas (see section 3), while residential density is measured as residents per km². Panel B illustrates the implied normalized travel-time responses associated with these elasticities, evaluated around the sample mean (index = 1) and holding other covariates constant. Solid, dashed, and dotted lines correspond to % of population within rail and BRT catchment areas, and residential density, respectively.

Recent research in urban economics emphasizes the role of generalized commuting costs and accessibility in shaping commuting patterns and spatial interactions within cities (Ahlfeldt et al., 2015; Allen and Arkolakis, 2020; Redding and Rossi-Hansberg, 2017). Spatial equilibrium frameworks highlight how improvements in transport infrastructure reduce commuting frictions and, over time, influence residential and employment location choices and urban structure (Allen and Arkolakis, 2020; Akbar et al., 2023; Severen, 2023; Tsivanidis, 2024). While this literature primarily focuses on welfare implications from the spatial adjustments to shocks on urban structure, the present analysis examines a complementary and more immediate margin that is central to transport policy: how travel behavior responds to changes in the capillarity of the rapid public transit, which is a more competitive travel mode with private cars.

Despite the significant expansion of the rapid transit network between 2007 and 2017, many areas of the São Paulo metropolitan region continue to face considerable generalized travel costs by public transit. In a survey covering nine major Brazilian cities, including São Paulo, Barcelos and Buarque (2018) report that 23% of public transit users were dissatisfied with the walking time to the nearest station, while only 8% were very satisfied.

This is expected, since despite substantial network expansion the majority of residents remained spatially disconnected from the rapid transit system. The OD survey shows that only 17% of the SPMR population lived within a 15 minute walk of a rapid transit station in 2017. Importantly, dissatisfaction also arises from the overall duration of trips, as around 27% of users reported dissatisfaction with total travel time, compared to only 3% who were very satisfied, reflecting dissatisfaction with multiple components of the trip, including access time, waiting time, and in-vehicle travel. (Barcelos and Buarque, 2018).

These travel conditions suggest that the recent expansion of SPMR's rapid transit system may affect travel behavior through multiple, interrelated channels with direct policy relevance. By increasing the share of residents within walking distance of stations, network expansion can shift mode choice toward public transit; by improving connectivity across multiple areas of the city, it can reduce transit travel times relative to private vehicles; and by lowering generalized travel costs between origins and destinations, it can reshape spatial interaction patterns across the metropolitan area. Understanding the magnitude and relative importance of these channels is central for evaluating how public transit investments can effectively affect travel behavior in dense, unequal metropolitan regions.

3 Data and methods

3.1 Data

A key variable throughout the analysis is access to rapid transit, measured by the share of population, jobs, and study opportunities located within walking-based catchment areas of rail and BRT stations. This measure allows us to capture changes in passive accessibility induced by the expansion of the rapid transit network across locations and over time.

Information on trips and the characteristics of individuals as well as their home, work and study locations are drawn from the 1997, 2007 and 2017 household travel surveys conducted in the São Paulo metro area (Metro, 1997; 2007; 2017). These surveys were sampled across geographic zones[11] (See Figure A1). Information on respondents' household and workplace locations are available as point coordinates for 2007 and 2017. This data was used to quantify the number and duration of trips between zones or districts by transportation mode. To reduce the sparsity of information about the bilateral trip flows, the spatial interaction analyses are collapsed into the 134 household travel survey districts of the metropolitan region displayed in Figure A2.

We used a set of location characteristics to observe heterogeneous patterns of urbanization. It consists of longitudinal refined spatial data on night lights data from the National Ocean and Atmospheric Administration[12] as a proxy to economic activity between 1995 and 2005. With the aim to measure the spatial pattern of urbanization growth for the study area, we used information from the Global Human Settlement Layer on built volume between 1975 and 1995. The Brazilian census of 2000 was used to obtain sociodemographic and urban infrastructure information at census tract level.

Data on rapid transit stations was obtained from the MOBILIDADOS data portal[13]. This data includes information on rail and BRT transit stations, including their spatial

[11] These household surveys had 389 geographic zones in 1997, 460 zones in 2007, and 517 zones in 2017. All of the surveys have the 39 municipalities of the São Paulo metropolitan region as the total area. The surveys also make available tables that indicate where the new zones were located on the previous surveys.
[12] https://www.ngdc.noaa.gov/eog/dmsp/download_radcal.html.
[13] https://mobilidados.org.br/rms/rmsp.

coordinates and dates of inauguration. Data from OpenStreetMap (OSM) was used to obtain information on the street network of São Paulo for the year 2019, which requires the assumption that the street network has not significantly changed between 2007 and 2019.

The OSM street network was used to calculate the shortest route by walking from the location of each household to every rapid transit station and from each rapid transit station to each opportunity using the r5r package in R (Pereira et al., 2022). Average walking speed is assumed to be 4.6 km/h. We computed for 2007 and 2017 the total number of jobs and residential population within the catchment areas of rapid transit stations considering different walking time thresholds to reach the stations, ranging between 5 and 15 minutes. This allowed us to calculate how the number of people and jobs that fall within the catchment area of rapid transit stations in each district changed between the two household surveys of 2007 and 2017.

Some descriptive statistics for the household travel surveys data are presented in Table 1B. They show that the average commuting times and distances for all transport modes decreased between 2007-2017. The mean Euclidean distance from the household location to the closest BRT and rail stations also decreased for individuals who commute by transit modes, but for car users, which reflects how significant the expansion of the rapid transit system has been in the period. It is also worth noting that while car and bus trips have had marginal decreases between 2007 and 2017, rail trips have increased by 3.9 percentage points.

Table 1B – Descriptive statistics of commuting trips and travelers between districts for all purposes. São Paulo metropolitan region, 2017 and 2017.

Transportation mode	**Bus**				**Car**				**Rail**			
Year	**2007**		**2017**		**2007**		**2017**		**2007**		**2017**	
Variable	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Travel time (Minutes)	53	31	44	25	30	26	26	21	47	28	43	22
Euclidean Distance of the trip (meters)	6,356	5,609	5,201	4,508	5,551	6,241	5,438	6,278	7,746	6,735	6,727	5,556
Euclidean Distance to the nearest BRT station (meters)	10,669	9,055	8,399	8,140	7,811	7,122	7,198	7,456	6,214	6,233	4,657	4,421
Euclidean Distance to the nearest Rail station (meters)	4,848	5,144	4,752	5,068	3,215	3,812	3,769	4,521	1,922	2,901	1,460	1,827

Household Income (R$)	2,534	2,254	3,946	3,368	5,777	4,575	7,833	6,863	3,738	3,127	6,293	5,378
Age	36	17	39	19	40	18	43	19	37	17	40	17
Cars per household	0.6	0.74	0.55	0.65	1.6	0.93	1.4	0.77	0.78	0.82	0.72	0.73
Number of trips	33,304		26,972		67,588		53,562		16,893		17,004	
% of motorized trips	28.2		27.6		57.3		54.9		14.3		17.4	

Notes: Author's own elaboration, from the OD surveys of SPMR of 2007 and 2017. Individuals are subset on the table based on the main transportation mode. Household income information is in nominal values.

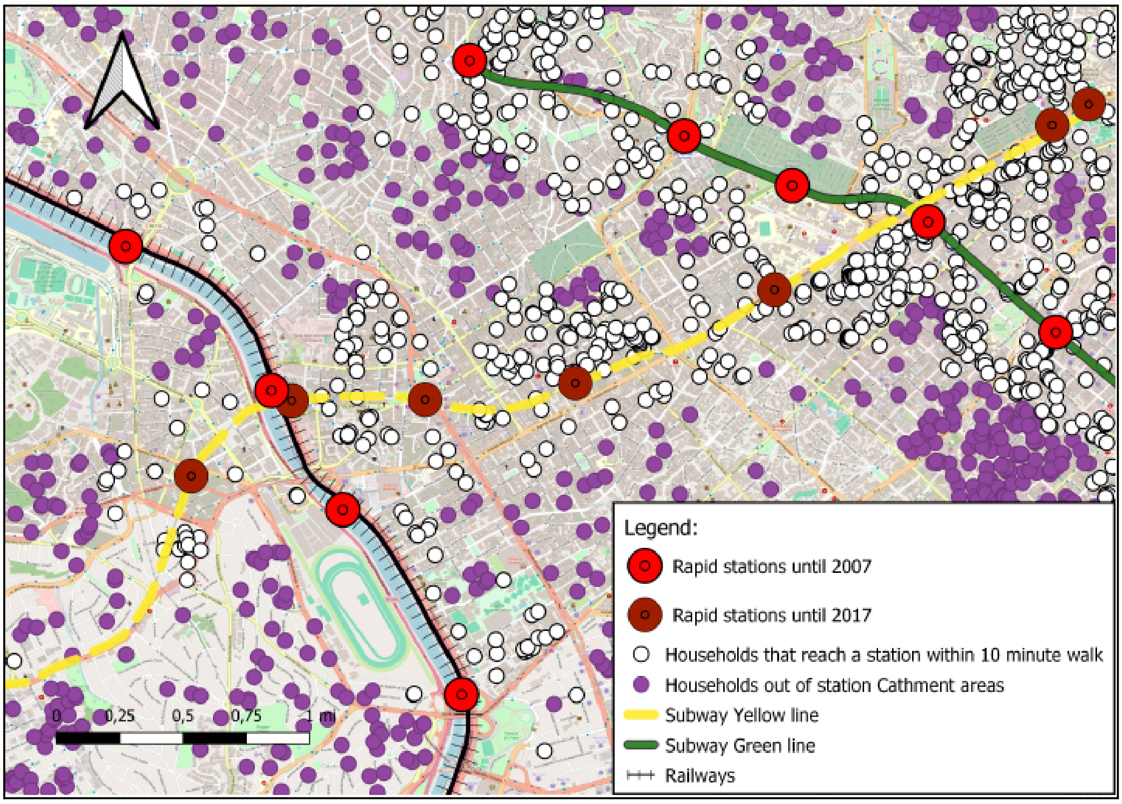
3.2 Econometric models

We used econometric models to examine (1) the extent to which the expansion of the rapid transit system has affected the share of transit trips by zone, (2) the travel time gap between transit and cars, and (3) the spatial pattern of bilateral trip flows by transit between districts.

Investigation 1) Estimation of the impact of rapid transit expansion on transit ridership

We define the increase in the share of households within a geographic unit (zone or district) that fell within a station catchment area of the rapid transit system of SPMR as the treatment. This spatially refined measure of passive accessibility to the rapid transit expansion is illustrated in Figure 6C, highlighting how the street design determines travel cost to reach the system.

Figure 6C - Example of 10 minute walk rail station catchment areas in the northwestern region of São Paulo city.



Note: Author's own elaboration, from OpenStreetMaps, OD surveys, and Mobilidados data.

Since the location of new rapid transit infrastructure is not randomly assigned, comparing heterogeneous groups to estimate the impact of the expansion of the infrastructure on outcomes has potential bias (Baum-Snow and Ferreira, 2015). To deal with selection bias, we used a rich set of variables in a propensity matching score strategy to estimate the likelihood of untreated zones being treated (as in Figure 6C) (Rosenbaum and Rubin, 1983). The logit models follow:

$$Pr(T = 1|A)_i = \beta_n A_i + \varepsilon_i \quad (2.1)$$

where *Pr (T=1)* is the probability of the zone *i* being treated, that is, experiencing an increase in the share of population within a catchment area between 2007 and 2017. *A* is a set of variables at zone level before 2007 that contains: shares of trips made to or from São Paulo city, of population between 16 and 64 years old (active age), of households with housemaids, of population with high school degree, of households with school students, of households with water supply, average household income, terrain elevation range, night lights luminosity level in 1995, change in night lights luminosity level between (1995-2005), change in built area volume between (1975-1995), cumulative accessibility to job opportunities by public transit within the travel time interval between 30 and 85 minutes (as described in equation E1), average quantity of cars by household, and population density. This parsimonious vector of variables A was chosen based on the literature on transit expansion (D'Elia et al., 2020; Gaduh et al., 2022; Ostrensky et al., 2020; Taylor et al., 2009).

This causal identification strategy assumes: $[Y_i(T=0), Y_i(T=1)] \perp T_i | b(A_i)$, where Y is the outcome variable (mode share) and $b(A)$ is the balancing score function, given the covariates set A. That is, the treatment assignment is ignorable given covariates A. We check the violation of this assumption by t-means tests and parallel pre-treatment trends estimates.

After estimating the propensity score weights of matching with treated units, we use a first-difference model to estimate the causal impacts of the treatment on the share of trips for work or study purposes by public transit in each zone between 2007 and 2017. The first-differences linear regression model is:

$$\Delta MS_i = \beta_0 + \beta_1 \Delta\%Covered_i + \beta_2 A_i + \varepsilon_i \qquad (2.2)$$

where ΔMS_i is the first-difference in the mode share of public transit users between 2007 and 2017 in the OD zone i. $\Delta\%Covered_i$ is the difference between 2007 and 2017 of the percentage of population that fall within the walking catchment area of rapid transit stations in OD zone i. The treated zones were assigned as those with any increase of population within the catchment areas, by considering catchment areas of different sizes (5, 10 and 15 walking minutes). With the aim of properly observing the straight link between household proximity to rapid transit station type and transit mode share, to calculate MS in equation 2, we considered the main transit mode used on the trip and trips with a single transit mode[14]. We treated the selection bias by reweighting the sample in (2) with the estimated propensity-score for each zone in (1) using a nearest neighbor with a balance ratio of 5.

[14] Public transit trips using a single mode represented 61% and 58% of the total in 2007 and 2017, respectively.

Additionally, we conducted distinct analyzes considering as the dependent variable the share of trips by bus (BRT and buses) and by rail (train and subway) separately. In the latter case, the types of rapid stations considered in $\Delta\%Covered_i$ is selected accordingly. A_i is the set of pre-treatment control variables at the zone level described in equation (1), and ε_i is an error term.

Investigation 2) Travel conditions: estimation of the travel time gap between transit and cars

In the second investigation, we aim to understand whether the expansion of São Paulo's rapid transit network has contributed to making its transit system more attractive relative to cars. We used OLS models to estimate the gap in travel times between different transit modes and cars. This investigation uses cross-section data of 2007 and 2017 and compares the travel time gap each year separately. The Linear regression to be estimated is:

$$LogTime_{iodm} = \beta_0 + \beta_1 PT_{im} + \beta_2 B_i + \varepsilon_{iodm} \tag{2.3}$$

Where *Time* is the total travel time for trip *i*, from origin point *o* to destination point *d*, using transport mode *m*. The sample is restricted for public transit and car trips. The dummy *PT* indicates trips made by a public transit mode. The analysis used different regression models to compare *PT* with cars. In each of these regressions, *PT* is represented by bus (all types), trips with origin nearby BRT[15], or trips made by rail (subway and train). Another regression compares the aggregated public transit modes with cars. Each regression restricts the sample with the public transit mode in *PT* and cars. *B* is a set of control variables: log of euclidean distance between the origin and the destination points, and dummies for hour of departure, weekday, origin zone, destination zone, and an interaction dummy between hour and weekday. Finally, ε_{iodm} is an error term.

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[15] The household travel survey data does not differentiate trips using regular buses from BRT. In order to differentiate these trips in our analysis, we consider as likely BRT trips those commuting trips that are registered as bus trips in the data and whose departure location is within a walking distance of 15 minutes from a BRT station. Inspired in the framework of Gaduh et al. (2022), we assigned a dummy variable in equation (1) to those likely *BRT* trips.

Investigation 3) Estimating decisions on travel location by public transit

Finally, we used a spatial interaction model to predict the extent to which the bilateral trips flows between districts were affected by the opening of new rapid transit stations, considering the expansion of the number of people, jobs and study opportunities within the catchment areas of rapid transit stations.

The model follows the framework proposed by Ahlfeldt et al. (2015) to predict the spatial interaction between urban blocks. It assumes that the observed quantity of bilateral trip flows from home to the destination place reflects a spatial equilibrium determined by the demand and supply of amenities located at the origins and destinations of trips. The probability of bilateral trips drawn from this equilibrium is:

$$\pi_{ijm} = \frac{W_{ijm}}{\sum_{k=1}^{n} W_{ikm}} \equiv \frac{T_i E_j (w_{ijm}/d_{ijm})}{\sum_{r=1}^{r}\sum_{s=1}^{s} T_r E_s (w_{rsm}/d_{rsm})}$$

(2.4)

where π_{ijm}, the probability of interaction between the district of origin *i* and the district of destination *j*, by transit mode *m,* is equal to the number of residents *W* in *i* who traveled to *j* among the *k* possible destination districts.

The probability π is balanced by pull and push factors for the trips, *T* and *E*, respectively, such as the quantity and quality of opportunities at *i* and *j*, compared to those available at districts *r* and *s*. The transport network also shapes these gravitational forces by determining the connectivity through the travel cost *d* from *i* to *j* with an iceberg cost *(*$d_{ijm} = e^{-\kappa\tau_{ijm}}$*)*, where κ and τ are impedance and travel time, respectively. Thus, *d* reduces the utility level achievable through the interaction between *i* and *j*.

We extend the framework of Ahlfeldt et al. (2015) and Gaduh et al. (2022) by using transit station catchment areas as a measure of passive accessibility of the transit system. The spatial interaction model is estimated using the following log-linear Poisson regression:

$$log\pi_{ijmt} = \beta_0 + \beta_1(\%Covered_{imt} * \%Covered_{jmt}) + \beta_2 logC_{ijt} + \delta_i + \gamma_j + \varphi_{ij} +$$

$T_t + \varepsilon_{ijmt}$ (2.5)

where π_{ijmt} is the probability of a trip between the origin district i and the destination district j by the rapid transit mode m, at year t, where the log of this probability is explained by $\%Covered$, the share of population and opportunities within the catchment area of transit stations in each year at origin and destination. Thus, the interaction between $\%Covered_{imt}$ (origin) and $\%Covered_{jmt}$ (destination) is a continuous variable that equals the product of the coverage ratios at the origin and destination over the years 2007 and 2017. C_{ijt} is a vector of variables that contains the total population and average income at i and the total number of jobs and average wages at j *in year t*. Moreover, δ_i and γ_j are fixed effects for the origin and destination, respectively, and φ_{jit}, and T_t are origin-destination and year fixed effects, respectively. These origin and destination fixed effects control for push and pull effects related to unobserved characteristics within each district that are constant over the years. Finally, ε is an error term.

In this model, the sample is restricted to trips from the household place to work and study (opportunities) by public transit. Additionally, due to data sparsity, in this regression model we aggregated the data at the district levels as origins and destinations. To avoid sample noise that may reduce the precision of the estimates, we only considered those bilateral trips that had at least 10 observations in the raw sample (Ahfeldt et al., 2015; Ahlfeldt and Wendland, 2016; Gaduh et al., 2022; Dingel and Tintelnot, 2020).

The measure of passive accessibility to transit used in equation 5 has a few advantages when compared to previous identification strategies of transit expansion on trip flows: First, we use the latitude and longitude coordinates of households, jobs, and study locations, which provides geographically detailed information about the starting and ending points of trips; Second, we count the number of people and jobs or study destinations within the catchment area of transit stations based on walking times along the road network, which is more precise and realistic than Euclidean distances because it captures the influence of urban form on walking access to the transit system. Moreover, this approach allows us to conduct sensitivity analysis considering different sizes of the catchment areas given varying walking times.

Although the model of equation (5) does not properly estimate causal inference of station catchment areas on trip flows, the C set of time-variant variables isolate the effects of potential economic agglomeration sources over the period.

4 Results

4.2 The impact of transit station catchment areas on transit ridership

The results of the logit models are reported in Tables (A1B-A2B). The percentage of trips to and from São Paulo city, the average number of cars per household and the educational level were consistently the most relevant factors in predicting treatment across all rapid transit modes. These key variables likely indicate higher demand for rapid transit infrastructure in these zones.

Tables (A3B-A4B-A5B) show significant heterogeneity between the multiple treated and control groups. Specifically, zones with population increases within rail station catchment areas between 2007 and 2017 had significantly higher levels of luminosity, public transit accessibility, education, income, and percentage of trips to or from São Paulo city. The opposite trend is observed in zones with population increases within BRT station catchment areas, which is expected, as BRT infrastructure is commonly implemented in areas with lower population density than rail (Cervero and Kang, 2011; Deng and Nelson, 2011).

Additionally, Tables (A3B-A4B-A5B) demonstrate that the means of the matched sample are more statistically similar to the treated zones than those of the raw control sample, regardless of whether the catchment area is set at 5, 10, or 15-minute walking distances. Tables (2B-3B-4B) further confirm that the matched samples consistently exhibit pre-treatment parallel trends (1997 vs. 2007), indicating effective control over exogenous shocks that could have influenced outcome trajectories (Angrist and Pischke, 2010).

Table 2B – Parallel trends estimates of mode share by transit for 5-minute walk threshold.

Dependent Variable	Log share of bus riders	Log share of rail riders	Log share of bus riders	Log share of rail riders
Treated x Year	0.0026 (0.0188)	-0.0408* (0.0233)	0.0229 (0.0272)	-0.0364 (0.0330)
Treated	-5.201 (37.47)	82.95* (46.80)	-45.85 (54.34)	74.08 (66.25)
Year	-0.0367*** (0.0047)	0.1508*** (0.0141)	-0.0453** (0.0140)	0.1151*** (0.0173)
Psm weighted	NO	NO	YES	YES
Adjusted R^2	0.07	0.34	0.07	0.28
N	849	672	402	314

Notes: Author's own elaboration. Robust standard error are in parenthesis. Years are coded as a sequence from 1 to 2, corresponding to the period 1997 and 2007, respectively. * / ** / *** denotes significant at the 10% / 5% / 1%, respectively.

Table 3B – Parallel trends estimates of mode share by transit for 10-minute walk threshold.

Dependent Variable	Log share of bus riders	Log share of rail riders	Log share of bus riders	Log share of rail riders
Treated x Year	3.08e-5 (0.0137)	-0.0488* (0.0218)	0.0117 (0.0232)	-0.0360 (0.0268)
Treated	-0.0081 (27.30)	99.24* (43.65)	-23.25 (46.46)	73.50 (53.78)
Year	-0.0366*** (0.0048)	0.1615*** (0.0160)	-0.0382*** (0.0099)	0.1431*** (0.0176)
Psm weighted	NO	NO	YES	YES
Adjusted R^2	0.07	0.43	0.07	0.40
N	849	672	257	501

Notes: Author's own elaboration. Robust standard error are in parenthesis. Years are coded as a sequence from 1 to 2, corresponding to the period 1997 and 2007, respectively. * / ** / *** denotes significant at the 10% / 5% / 1%, respectively.

Table 4B – Parallel trends estimates of mode share by transit for 15-minute walk threshold.

Dependent Variable	Log share of bus riders	Log share of rail riders	Log share of bus riders	Log share of rail riders
Treated x Year	0.0085 (0.0135)	-0.0480* (0.0223)	-0.0059 (0.0212)	-0.0410 (0.0260)
Treated	-16.94 (27.00)	97.69* (44.67)	11.68 (42.35)	83.56 (52.08)
Year	-0.0372*** (0.0049)	0.1638*** (0.0179)	-0.0410*** (0.0095)	0.1475*** (0.0195)
Psm weighted	NO	NO	YES	YES

Adjusted R^2	0.07	0.46	0.07	0.42
N	849	672	297	543

Notes: Author's own elaboration. Robust standard error are in parenthesis. Years are coded as a sequence from 1 to 2, corresponding to the period 1997 and 2007, respectively. * / ** / *** denotes significant at the 10% / 5% / 1%, respectively.

Table 5B presents the estimated impacts of population increases within rail catchment areas on rail ridership, showing that rail transit system expansion promoted localized incentives for transit ridership.

Column 4 in Panel (A-B) of Table 5B show that the mode share increased by 6.4% and 2.5% for every 10% increase in population within the 5- and 10-minute walking thresholds between households and rail stations, respectively. Column 3 in Panel C shows that the effect within rail catchment areas dropped to 1.9% for a more flexible threshold of 15-minute walking.

The sensitivity of catchment area effects based on the walking thresholds shown in Table 2B reflects how system connectivity influences individuals' willingness to walk to access rail transit. The distribution of these incentives to use rapid transit is also associated with average changes in cumulative accessibility to job opportunities by public transit from 2007 to 2017.

Table 5B - Results of OLS models for the effects of new rail stations on the share of trips made by rail.

Panel A:	5-minute walking time threshold of rail catchment areas			
Dependent variable:	Delta percentage of motorized trips made by subway or train			
Model	(1)	(2)	(3)	(4)
Delta % houses covered	1.373*** (0.210)	0.987*** (0.220)	0.964*** (0.252)	0.647* (0.287)
N	489	214	478	214
Adj. R2	0.06	0.08	0.47	0.79
Panel B:	10-minute walking time threshold of rail catchment areas			
Dependent variable:	Delta percentage of motorized trips made by subway or train			
Model	(1)	(2)	(3)	(4)
Delta % houses covered	0.407***	0.352***	0.301***	0.256***

	(1)	(2)	(3)	(4)
	(0.062)	(0.067)	(0.067)	(0.066)
N	489	310	478	309
Adj. R2	0.08	0.13	0.49	0.65
Panel C:	15-minute walking time threshold of rail catchment areas			
Dependent variable:	Delta percentage of motorized trips made by subway or train			
Model	(1)	(2)	(3)	(4)
Delta % houses covered	0.321***	0.274***	0.245***	0.197***
	(0.032)	(0.032)	(0.035)	(0.033)
N	489	312	478	311
Adj. R2	0.13	0.19	0.51	0.65
Specification by model	(1)	(2)	(3)	(4)
Matching score weights	NO	YES	NO	YES
Pre-treatment controls	NO	NO	YES	YES
District level fixed effects	NO	NO	YES	YES

Notes: Author's own elaboration. Dependent variable is the difference in the percentage of trips made by rail among motorized transport between 2007 and 2017. Explanatory variable is the difference in the percentage of population zone within a rail catchment area between 2007 and 2017. Pre-treatment control variables are the same used in the propensity score models. Unit of analysis are travel survey zones. Standard errors are clustered by zones and reported in parentheses. * / ** / *** denotes significant at the 10% / 5% / 1%, respectively.

Zones with population increases in rail catchment areas within 5- and 15-minute walking distances also had increases of 7% and 4% in the total number of jobs reachable within 60 minutes by transit, respectively. However, zones with no population increase in rail catchment areas within the 5- and 15-minute walking thresholds experienced decreases in cumulative accessibility by transit of -1.7% and -2%, respectively. The level of potential interaction with land use is shown to influence transit ridership (Moniruzzaman and Páez, 2012; Owen and Levinson, 2015) and partially explains the impact of proximity to public transit on mode choice.

Regarding the various model specifications in Table 5B, since the treated zones tend to have denser and wealthier populations, selecting more comparable control zones makes the models with propensity score-matched, weighted samples show a lower magnitude in the rail catchment area coefficient. Therefore, our preferred models are those in column 4, as neglecting selection bias results in an upward bias in rail station catchment area effects.

Table 6B - Results of OLS models for the effects of new BRT stations on the share of trips made by bus.

Panel A:	5-minute walking time threshold of BRT catchment areas			
Dependent variable:	Delta percentage of motorized trips made by bus			
Model	(1)	(2)	(3)	(4)
Delta % houses covered	-0.442 (0.334)	-0.429 (0.587)	-0.228 (0.409)	-0.378 (0.884)
N	489	99	478	99
Adj. R2	0.004	0.009	0.55	0.93
Panel B:	**10-minute walking time threshold of BRT catchment areas**			
Dependent variable:	Delta percentage of motorized trips made by bus			
Model	(1)	(2)	(3)	(4)
Delta % houses covered	-0.163 (0.107)	-0.313 (0.207)	-0.01 (0.125)	-0.259 (0.237)
N	489	141	478	141
Adj. R2	0.005	0.029	0.55	0.88
Panel C:	**15-minute walking time threshold of BRT catchment areas**			
Dependent variable:	Delta percentage of motorized trips made by bus			
Model	(1)	(2)	(3)	(4)
Delta % houses covered	-0.115 (0.070)	-0.194* (0.103)	-0.005 (0.093)	-0.030 (0.096)
N	489	167	478	166
Adj. R2	0.006	0.029	0.55	0.81
Specification by model	(1)	(2)	(3)	(4)
Matching score weights	NO	YES	NO	YES
Pre-treatment controls	NO	NO	YES	YES
District level fixed effects	NO	NO	YES	YES

Notes: Author's own elaboration. Dependent variable is the difference in the percentage of trips made by bus among motorized transport between 2007 and 2017. Explanatory variable is the difference in the percentage of population zones within a BRT catchment area between 2007 and 2017. Pre-treatment control variables are the same used in the propensity score models. Unit of analysis are travel survey zones. Standard errors are clustered by zones and reported in parentheses. * / ** / *** denotes significant at the 10% / 5% / 1%, respectively.

In contrast to rail stations, the impact of BRT catchment areas on bus mode share, summarized in Table 6B, shows that increasing the population within BRT catchment areas did not have a positive, significant effect on bus ridership. Bus ridership has dropped dramatically in the São Paulo metropolitan region over the past decades. This lack of differentiation in bus ridership based on proximity to BRT stations over the period (2007-2017) may be due to the limited impact of the new 26 km of exclusive bus lanes on bus travel conditions. This will be checked in the next subsection.

4.2 The travel time gap between transportation modes

The results of the OLS regressions testing travel time differences between public transit and cars are reported in Table 7B. The coefficients in columns (1-2) show that the average travel time by bus was 56% longer than by car in 2007 and increased to 59% in 2017, indicating that bus trips became slightly slower compared to cars.

Conversely, the relative difference in travel time between rail and cars, shown in columns (3-4), decreased by 4 percentage points from 2007 to 2017, suggesting some improvement in rail services relative to cars in São Paulo. This improvement in rail performance (columns 3-4) is expected, given the significantly higher investment in rail infrastructure compared to bus infrastructure in the study area and the fact that rail services are unaffected by road traffic congestion.

A further analysis of the performance of BRT lines compared to cars is presented in columns (5-6) of Table 7B. Assuming that trips beginning and ending within 15 minutes of walking from BRT stations are likely BRT trips, we find that BRT trips are faster than regular bus trips. However, it also shows that in 2017, the travel time gap between car trips and those likely taken by BRT remained unchanged. Finally, the results of columns (7-8) of Table 7B indicate that the aggregated travel times for aggregated public transit (bus and rail) relative to cars increased by 2 percentage points.

We did robustness check analyzes using the unfinished BRT structure in Guarulhos as pseudo-placebo in Table A6B. Columns (1-4) in Table A6B show that the likely BRT pseudo-placebo trips had much higher travel time gap when compared to cars than the likely BRT users from the structure that was actually finished (See Figure 3). Moreover, columns (5-8) in Table A6B show that the likely BRT users from placebo stations didn't have any statistical difference on their travel times when compared to regular buses, whereas the likely BRT users from actually finished stations did.

Table 7B – OLS models for the differences in travel times between public and private transit.

Modes compared	Bus (including BRTs) vs Car		Rail vs Car		Likely BRT vs Car		Transit (all modes) vs Car	
Year	2007	2017	2007	2017	2007	2017	2007	2017
Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Public Transit	0.56***	0.59***	0.31***	0.27***	0.29***	0.29***	0.54***	0.56***
	(0.012)	(0.005)	(0.026)	(0.012)	(0.038)	(0.022)	(0.011)	(0.005)
Adjusted R^2	0.59	0.76	0.57	0.78	0.56	0.77	0.59	0.76
Sample (N)	92,729	61,086	72,816	45,163	69,138	41,858	98,125	66,002

Notes: Author's own elaboration. This table reports linear regression models that have the log of individual travel time as the dependent variable. Each model has a dummy variable indicating whether each trip observation was made by a public transit mode, compared with trips made by car. All of the regressions restrict the sample for trips made by public transit or car. Likely BRT trips in columns (5-6) were defined as the individuals whose trip by bus started within a walking time up to 15 minutes of a BRT station. The additional controls in the regressions are: log of Euclidean distance between the origin and destination, and dummies of hour time, week day, interaction dummy of hour and week day, origin zone, destination zone. Robust standard errors are clustered by an interaction of origin and destination zones and reported in parentheses. * / ** / *** denotes significant at the 10% / 5% / 1%, respectively.

The set of results for mode share dialogue with the results in travel conditions shown in Table 7B. Moreover, together with the placebo test results, they suggest that the poor performance of Guarulhos' unfinished BRT stations may be related to congestion effects due to the lack of adequate rapid transit infrastructure, which is a similar result found by Gaduh et al. (2022) to the case of Jakarta. Therefore, our evidence is in line with previous literature in the sense that, besides the land use setting, speed is crucial in fomenting transit ridership (Brooks and Denoeux, 2022; El-Geneidy et al., 2014; Gaduh et al., 2022; Moniruzzaman and Páez, 2012; Owen and Levinson, 2015).

4.3 The effects of rapid transit expansion on the trip flows of the SPMR

The results of the spatial interaction models presented in column 1 of Tables (10B-11B) support the gravitational relationship between the probability of trip flows and travel time. This deterrence effect is stronger in buses than in rail users, by which every 10 minutes of travel reduce the probability of travel to work or study by -0.13 and -0.037, respectively.

Table 10B – Results of spatial interaction models for rail trips

Dependent Variable:	Log of the probability of trip flows by train or subway			
Walking time threshold of the rail catchment areas	Any	5 minutes	10 minutes	15 minutes
Model:	(1)	(2)	(3)	(4)
(% of household within rail catchment area) vs (% of destinations within rail catchment area)		0.0106** (0.0050)	0.0015*** (0.0004)	0.0006*** (0.0002)
Average travel time between the origin and the destination	-0.0037*** (0.0011)			
Log of total population at origin district	-0.0076 (0.2776)	-0.3724 (0.0368)	-0.4662 (0.3669)	-0.5591 (0.3674)
Log of total jobs at destination district	0.9501*** (0.2029)	1.285*** (0.2819)	1.238*** (0.2823)	1.154*** (0.2827)
Log of average wage at destination district	1.161* (0.4817)	1.366** (0.658)	1.285** (0.6529)	1.178* (0.6676)
Log of average income at origin district	-0.4051 (0.2982)	-0.6836 (0.4453)	-0.6149 (0.4363)	-0.6203 (0.4362)
Observations	2,144	2,144	2,144	2,144
Squared Cor.	0.46	0.83	0.83	0.84
Pseudo R2	0.05	0.09	0.09	0.09
BIC	2,364	14,409	14,409	14,409
Origin fixed effects	YES	YES	YES	YES
Destination fixed effects	YES	YES	YES	YES
Origin and destination fixed effects	NO	YES	YES	YES
Year fixed effects	YES	YES	YES	YES

Notes: Author's own elaboration. The models only consider district pairs with at least 10 bilateral trips in the raw sample. Dependent variable considers trips made by rail as the main travel mode. Standard errors are clustered by origin and destination districts pair. * / ** / *** denotes significant at the 10% / 5% / 1%, respectively.

The models shown in columns (2-4) of Table 10B predict positive effects of the increase of population and opportunities for work and study purposes within rail station catchment areas on rail trip flows. Alternatively to the travel time, every 10% increase of population or opportunities to work or study within the catchment areas of 5-minute walking increases the probability of trip flows by 0.106%.

Table 11B – Results of spatial interaction models for bus trips

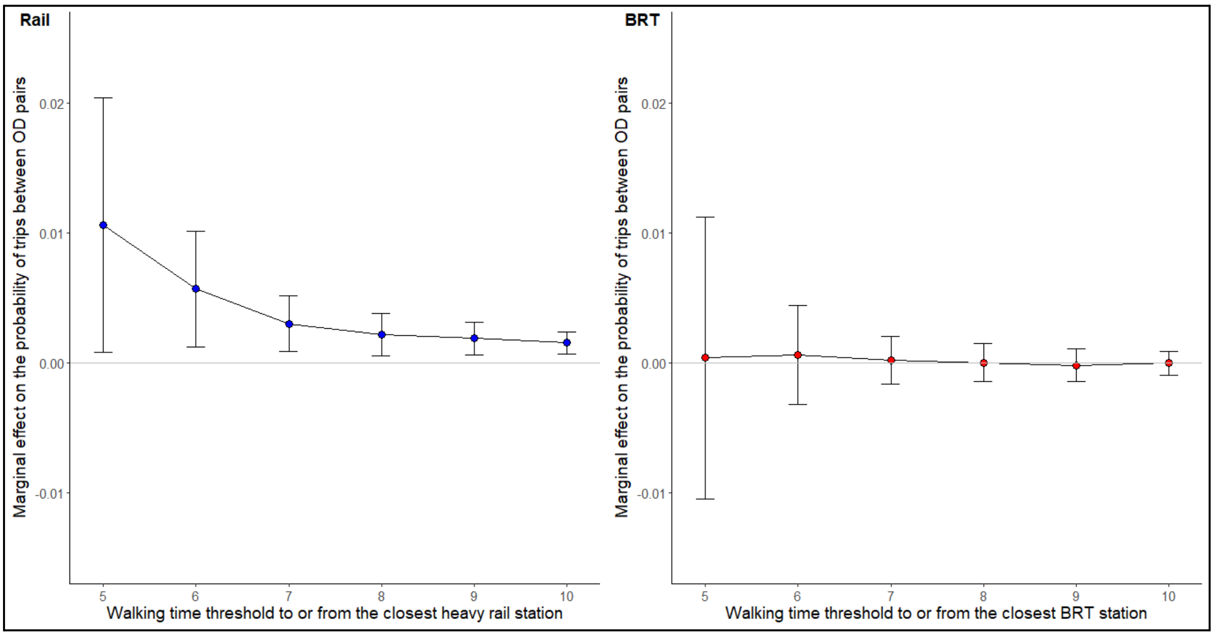
Dependent Variable:	Log of the probability of trip flows by bus			
Walking time threshold of the BRT catchment areas	Any	5 minutes	10 minutes	15 minutes
Model:	(1)	(2)	(3)	(4)
(% of household within BRT catchment area) vs (% of destinations within BRT catchment area)		0.0004 (0.0055)	-2.04e-5 (0.0005)	1.29e-5 (0.0001)
Average travel time between the origin and the destination	-0.0138*** (0.0014)			
Log of total population at origin district	0.1938 (0.1835)	0.0113 (0.1796)	0.0146 (0.1807)	0.0097 (0.1820)
Log of total jobs at destination district	0.6559*** (0.1566)	0.9767*** (0.1883)	0.9768*** (0.1885)	0.9761*** (0.1887)
Log of average wage at destination district	-0.3477 (0.2831)	-0.3945 (0.3028)	-0.3927 (0.3030)	-0.3955 (0.3037)
Log of average income at origin district	-0.3979* (0.1806)	-0.2168 (0.1899)	-0.2178 (0.1902)	-0.2165 (0.1901)
Observations	2,879	2,879	2,879	2,879
Squared Cor.	0.43	0.91	0.91	0.91
Pseudo R2	0.07	0.15	0.15	0.15
BIC	3,010	18,539	18,539	18,539
Origin fixed effects	YES	YES	YES	YES
Destination fixed effects	YES	YES	YES	YES
Origin and destination fixed effects	NO	YES	YES	YES
Year fixed effects	YES	YES	YES	YES

Notes: Author's own elaboration. The models only consider district pairs with at least 10 bilateral trips in the raw sample. Dependent variable considers trips made by bus as the main travel mode. Standard errors are clustered by origin and destination districts pair. * / ** / *** denotes significant at the 10% / 5% / 1%, respectively.

Figure 4B shows that these effects diminish as larger walking time thresholds are adopted, which supports that increased walking time among household place, station, and destination place, raises disutility, acting as a disincentive to travel to districts less connected to the public transit system.

However, Figure 4B and columns (2-4) in Table 11B show that the increase of population and opportunities within BRT station catchment areas did not affect the probability of trip flows by bus. These results are related to the absence of impacts of the new BRT infrastructure on transit ridership and on the travel time gap when compared to cars.

Figure 4B - Summary of the estimates of the marginal effects of station catchment areas on bilateral trip flows between districts in the São Paulo metro area by rapid transit mode.



Notes: Author's own elaboration. The figure presents the coefficient results of 12 different regressions following equation 4. Each regression considers different walking time thresholds for the refined station catchment variable on the interaction between origin and destination district. Vertical bars represent the 95% confidence intervals from each regression. Standard errors are clustered by origin and destination districts. Additional control variables on these regressions are travel time and fixed effects of destination, origin, year, origin and year, and destination and year.

The null effects of BRT expansion on bus ridership and bilateral trip flows by bus is in line with the findings of Gaduh et al. (2022) for the case of Jakarta. However, here we provide additional evidence on the mechanism behind such absence of effects: how fast are transit modes when compared with cars. Because subways and trains' network expansion have promoted positive impacts on riderships and positive relationship with trip flows in a context by which only these transit modes became faster when compared to cars, our set of results infer that speed is a key aspect for changes in travel behavior.

Finally, Tables (10B-11B) show that the number of jobs at the destination districts exert positive effects on either rail and bus trip flows. This is an alternative explanation for the relevance of accessibility to the job market on travel behavior. Furthermore, average wages at the destination district also had positive elasticity on rail trip flows. This set of results on the spatial interaction models support that the increase of spatial connectivity to rail enhanced agglomeration economies.

5 Conclusion

The growing use of private cars in cities poses major challenges to transportation systems. Promoting greater use of public transit becomes ever more important to encourage more sustainable mobility patterns. This study focuses on understanding the effects of expanding the rapid transit network on travel behavior in the São Paulo Metropolitan Region between 2007 and 2017, specifically through changes in connectivity among the population,the mass transit network, and opportunities, using spatially granular data.

We found a positive impact of increasing population within rail system catchment areas and rail ridership, particularly within a 5 to 15-minute walk. In contrast, the increase of population within BRT catchment areas did not impact bus ridership. The reduction in travel time due to rail expansion supports these findings, which were not observed for BRT. Placebo tests with an unfinished BRT corridor further validate this result. They also show that such delays had prevented the benefits of proximity between Guarulhos and São Paulo city to be fully realized. Additionally, trip flows became more intense in areas where the population and opportunities had easier access to the rail system. However, there was no relationship between the expansion of the BRT system and bus trip flows. Therefore, the influence on individual decisions on where to live and work and are highly sensitive to walking time between households, rail transit stations, and opportunities.

The limitations of this study include a broader investigation into how the mass transit system affects other economic variables, such as land prices and worker productivity, which have further implications for the spatial equilibrium. Future studies could explore policy scenarios that relate transit expansion to these economic variables and urban form dimensions, using the interaction among these elements to design policies that effectively change travel behavior in cities.

The study highlights the capacity of the mass transit system on decisions regarding whether to use the public transit and how the system can shape the trip flows and individual choices, such as where to live, work and study. Policies aimed at increasing public transit usage must consider the population size and opportunities near new transit stations and strategically promote connectivity, as each additional minute of walking reduces the likelihood of individuals choosing public transit. Moreover, accessibility to opportunities is crucial in promoting changes in travel behavior, and the travel time gap compared to other transportation modes should be minimized in order to make transit systems more attractive.

Annex

Tables

Table A1B - Results of logit models for propensity matching score estimates for rail station catchment areas' treatment.

Dependent Variable:	Treated = 1 if increase of population within 5-minute walking to the closest rail station	Treated = 1 if increase of population within 10-minute walking to the closest rail station	Treated = 1 if increase of population within 15-minute walking to the closest rail station
Constant	-5.27 (5.02)	-2.35 (3.47)	-3.79 (3.08)
% of total trips to/from São Paulo city (1997)	1.85 (1.68)	3.33** (1.25)	4.41*** (1.15)
% of population between 16 and 64 years old (1997)	-1.54 (3.91)	-5.42. (3.28)	-2.54 (2.87)
Log of household income (1997)	0.11 (0.55)	0.03 (0.35)	-0.01 (0.31)
Delta luminosity (1995-2006)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)
Luminosity (1995)	-0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)
Delta built area volume (1975-1995)	0.00 (0.00)	0.00 (0.00)	-0.00 (0.00
Cumulative accessibility by public transit	-1.26 (1.16)	-0.34 (1.02)	-0.93 (0.90)
% of households with housemaids (2000)	1.51 (1.20)	0.57 (0.98)	0.38 (0.86)
% of individuals with high school degree (1997)	9.58* (3.85)	5.12* (2.65)	4.84* (2.43)
Average quantity of cars per household (1997)	-2.4* (0.99)	-1.55* (0.70)	-1.36* (0.67)
% of households with kids under 18 years old at school	5.58 (3.43)	1.31 (2.50)	2.23 (2.31)
Log of terrain elevation range	-0.38 (0.44)	0.11 (0.31)	0.18 (0.28)
Population density (1997)	0.00* (0.00)	0.00 (0.00)	-0.00 (0.00)
% of household with supplied water (2000)	-0.56 (0.44)	-0.09 (0.40)	-0.32 (0.32)
N	412	412	412
Pseudo R2	0.11	0.08	0.07
Log-likelihood	361.09	487.44	540.27

Notes: Author's own elaboration. Robust heteroskedastic standard errors are reported in parenthesis. * / ** / *** denotes significant at the 10% / 5% / 1%, respectively.

Table A2B - Results of logit models for propensity matching score estimates for BRT station catchment areas' treatment.

Dependent Variable:	Treated = 1 if increase of population within 5-minute walking to the closest BRT station	Treated = 1 if increase of population within 10-minute walking to the closest BRT station	Treated = 1 if increase of population within 15-minute walking to the closest BRT station
Constant	-4.733 (5.92)	-3.876 (5.76)	-7.024 (5.37)
% of total trips to/from São Paulo city (1997)	1.17 (1.82)	1.694 (1.71)	1.156 (1.57)
% of population between 16 and 64 years old (1997)	9.76* (5.68)	6.518 (5.24)	5.664 (4.73)
Log of household income (1997)	-0.46 (0.54)	-0.4680 (0.47)	-0.5907 (0.41)
Delta luminosity (1995-2006)	-0.01* (0.00)	-0.01* (0.00)	-0.009* (0.00)
Luminosity (1995)	-0.00 (0.00)	-0.0023 (0.00)	0.0005 (0.00)
Delta built area volume (1975-1995)	0.0004** (0.00)	0.0002* (0.00)	0.0002* (0.000)
Cumulative accessibility by public transit	3.89 (2.91)	1.032 (2.99)	-2.350 (1.67)
% of households with housemaids (2000)	0.39 (1.73)	-0.3946 (1.85)	-3.056* (1.67)
% of individuals with high school degree (1997)	4.50 (5.002)	4.324 (4.59)	7.915* (4.59)
Average quantity of cars per household (1997)	1.11 (1.66)	1.452 (1.51)	2.620* (1.30)
% of households with kids under 18 years old at school	9.88* (4.85)	9.115* (4.87)	11.18* (4.57)
Log of terrain elevation range	-1.192* (0.51)	-0.92* (0.40)	-0.55 (0.39)
Population density (1997)	-0.01** (0.00)	-0.009* (0.00)	-0.003 (0.00)
% of household with supplied water (2000)	-0.91* (0.42)	-0.63 (0.46)	-0.73 (0.47)
N	412	412	412
Pseudo R2	0.23	0.15	0.15
Log-likelihood	361.09	487.44	540.27

Notes: Author's own elaboration. Robust heteroskedastic standard errors are reported in parenthesis. * / ** / *** denotes significant at the 10% / 5% / 1%, respectively.

Table A3B – Summary of balance of sample means for 5-minute walking.

Transportation mode	Rail			Bus		
Group	Treated (5 min catchment area)	Control (raw sample)	Control (matched)	Treated (5 min catchment area)	Control (raw sample)	Control (matched)
% of total trips to/from São Paulo city (1997)	0.33	0.28***	0.33	0.26	0.29	0.28
% of population between 16 and 64 years old (1997)	0.34	0.35	0.34	0.37	0.35**	0.37
Log of household income (1997)	7.41	7.23***	7.41	6.89	7.28**	6.85
Delta luminosity (1995-2006)	40	37	43	21	38	30
Luminosity (1995)	444	353***	447	271	370**	255
Delta built area volume (1975-1995)	2,745	2,250	2,348	3,469	2,245*	5,012
Cumulative accessibility by public transit	0.40	0.29***	0.43	0.22	0.31	0.17
% of households with housemaids (2000)	0.19	0.16	0.18	0.13	0.17	0.10
% of individuals with high school degree (1997)	0.38	0.31*	0.37	0.21	0.33***	0.18
% of households with kids under 18 years old at school	0.38	0.42	0.39	0.53	0.41**	0.55
Average quantity of cars per household (1997)	0.88	0.90	0.85	0.72	0.91*	0.63
Log of terrain elevation range	4.25	4.44	4.3	4.52	4.41	4.64
Population density (1997)	122	87***	123	55	93***	65
% of household with supplied water (2000)	0.65	0.64*	0.65	0.61	0.64	0.64
N	50	313	145	22	369	63

Notes: Author's own elaboration. Matched sample is based on propensity matching scores estimated by logit models using the nearest neighbor with ratio 5 described in equation 1. Results of t-test on means between treated and control groups are reported in parenthesis, in which the null hypothesis is statistically equal means. * / ** / *** denotes significant at the 10% / 5% / 1%, respectively.

Table A4B – Summary of balance of sample means for 10-minute walking.

Transportation mode	Rail			Bus		
Group	Treated (10 min catchment area)	Control (raw sample)	Control (matched)	Treated (10 min catchment area)	Control (raw sample)	Control (matched)
% of total trips to/from São Paulo city (1997)	0.33	0.28***	0.33	0.28	0.29	0.32
% of population between 16 and 64 years old (1997)	0.34	0.35**	0.34	0.37	0.35**	0.36
Log of household income (1997)	7.41	7.21***	7.34	6.89	7.28**	6.99
Delta luminosity (1995-2006)	39	37	37	22	39*	25
Luminosity (1995)	428	347***	414	266	371***	304
Delta built area volume (1975-1995)	2,576	2,236	2,597	3,017	2,258	3,349
Cumulative accessibility by public transit	0.38	0.28***	0.37	0.20	0.31**	0.23
% of households with housemaids (2000)	0.19	0.16	0.18	0.12	0.17	0.14
% of individuals with high school degree (1997)	0.37	0.31***	0.35	0.22	0.33***	0.25
% of households with kids under 18 years old at school	0.38	0.43***	0.40	0.52	0.41***	0.49
Average quantity of cars per household (1997)	0.92	0.89	0.89	0.77	0.91	0.82
Log of terrain elevation range	4.31	4.44*	4.35	4.51	4.41	4.30
Population density (1997)	111	85***	111	65	93***	81
% of household with supplied water (2000)	0.65	0.64**	0.65*	0.62	0.64	0.64
N	90	333	140	28	295	95

Notes: Author's own elaboration. Matched sample is based on propensity matching scores estimated by logit models using the nearest neighbor with ratio 5 described in equation 1. Results of t-test on means between treated and control groups are reported in parenthesis, in which the null hypothesis is statistically equal means. * / ** / *** denotes significant at the 10% / 5% / 1%, respectively.

Table A5B – Summary of balance of sample means for 15-minute walking.

Transportation mode	Rail			Bus		
Group	Treated (15 min catchment area)	Control (raw sample)	Control (matched)	Treated (15 min catchment area)	Control (raw sample)	Control (matched)
% of total trips to/from São Paulo city (1997)	0.34	0.27***	0.34	0.28	0.29	0.27
% of population between 16 and 64 years old (1997)	0.34	0.35**	0.34	0.37	0.35*	0.36
Log of household income (1997)	7.39	7.20***	7.35	7.00	7.28	7.14
Delta luminosity (1995-2006)	38	37	41	20	39**	18
Luminosity (1995)	429	339***	420	306	370*	335
Delta built area volume (1975-1995)	2,226	2,342	2,401	2,944	2,249	2,926
Cumulative accessibility by public transit	0.37	0.28***	0.35**	0.20	0.31***	0.23
% of households with housemaids (2000)	0.20	0.15**	0.20	0.14	0.17	0.17
% of individuals with high school degree (1997)	0.37	0.30***	0.36	0.27	0.32	0.31
% of households with kids under 18 years old at school	0.38	0.43***	0.39	0.48	0.41**	0.45
Average quantity of cars by household (1997)	0.94	0.88	0.93	0.903	0.904	0.97
Log of terrain elevation range	4.22	4.47	4.29	4.50	4.41	4.37
Population density (1997)	101	87**	101	80	92	79
% of household with supplied water (2000)	0.65	0.64***	0.64	0.63	0.64	0.64
N	115	215	138	36	268	109

Notes: Author's own elaboration. Matched sample is based on propensity matching scores estimated by logit models using the nearest neighbor with ratio 5 described in equation 1. Results of t-test on means between treated and control groups are reported in parenthesis, in which the null hypothesis is statistically equal means. * / ** / *** denotes significant at the 10% / 5% / 1%, respectively.

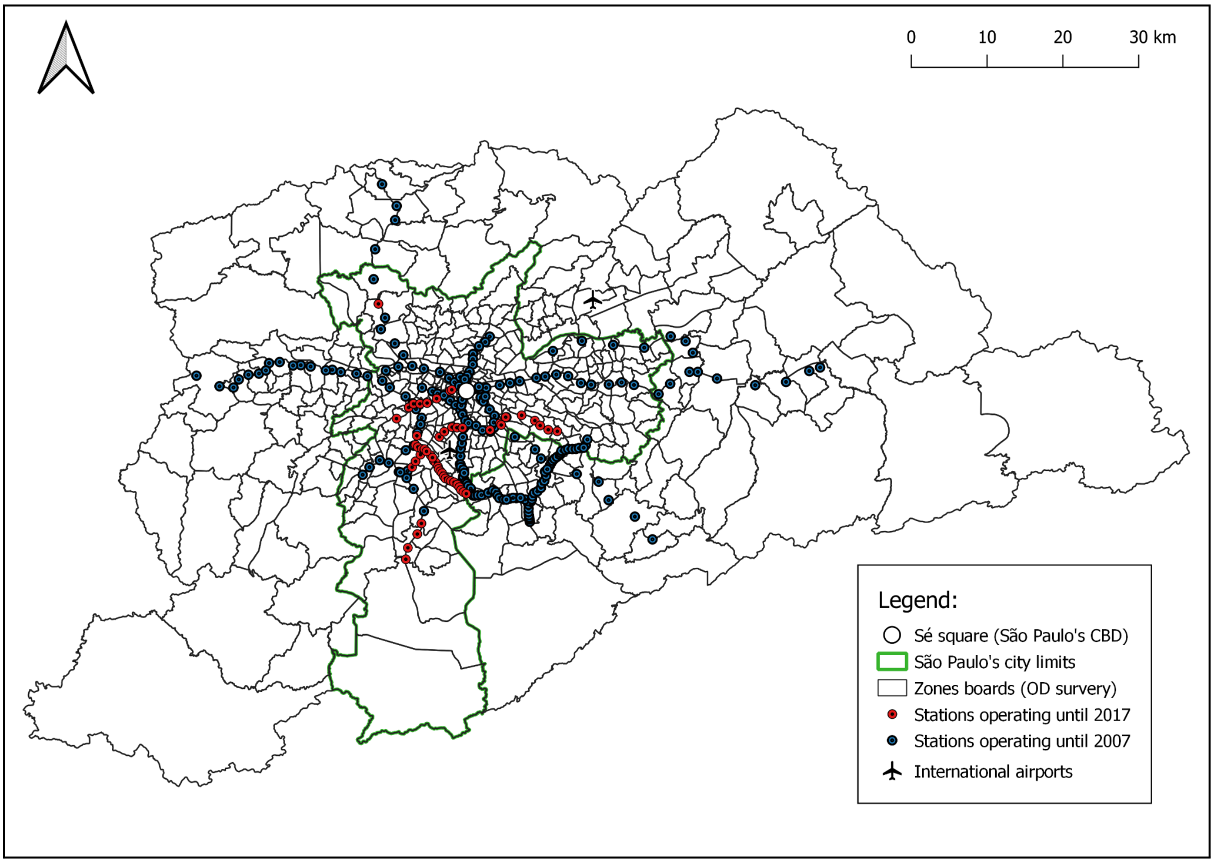
Table A6B – OLS models for the differences in travel times between trips with origin nearby BRT and other modes.

Modes compared	Trips with origin nearby BRT vs Car		Trips with origin nearby BRT vs Car		Trips with origin nearby BRT vs further BRT trips		Trips with origin nearby BRT placebo vs further BRT trips	
Year	2007	2017	2007	2017	2007	2017	2007	2017
Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Likely BRT (Dummy)	0.29***	0.29***	0.65***	0.79***	-0.07***	-0.05***	0.021	0.081
	(0.036)	(0.018)	(0.091)	(0.076)	(0.037)	(0.020)	(0.067)	(0.062)
Adjusted R^2	0.55	0.77	0.78	0.77	0.42	0.61	0.42	0.59
Sample (N)	70,808	43,742	40,306	40,399	25,309	20,839	25,309	20,839

Notes: Author's own elaboration. Dependent variable is the log of individual travel time. Each model has a dummy variable indicating whether each trip observation was made by a public transit mode, compared with trips made by car. All of the regressions restrict the sample for trips made by public transit or car. Likely BRT users were defined as the individuals whose travel by bus started within a walking distance of 15 minutes to the closest BRT station. The additional controls in the regressions are: log of Euclidean distance between the origin and destination, and dummies of hour time, week day, interaction dummy of hour and week day, origin zone, destination zone, and travel purpose. Robust standard errors are clustered by an interaction of origin and destination zones and reported in parentheses. * / ** / *** denotes significant at the 10% / 5% / 1%, respectively.

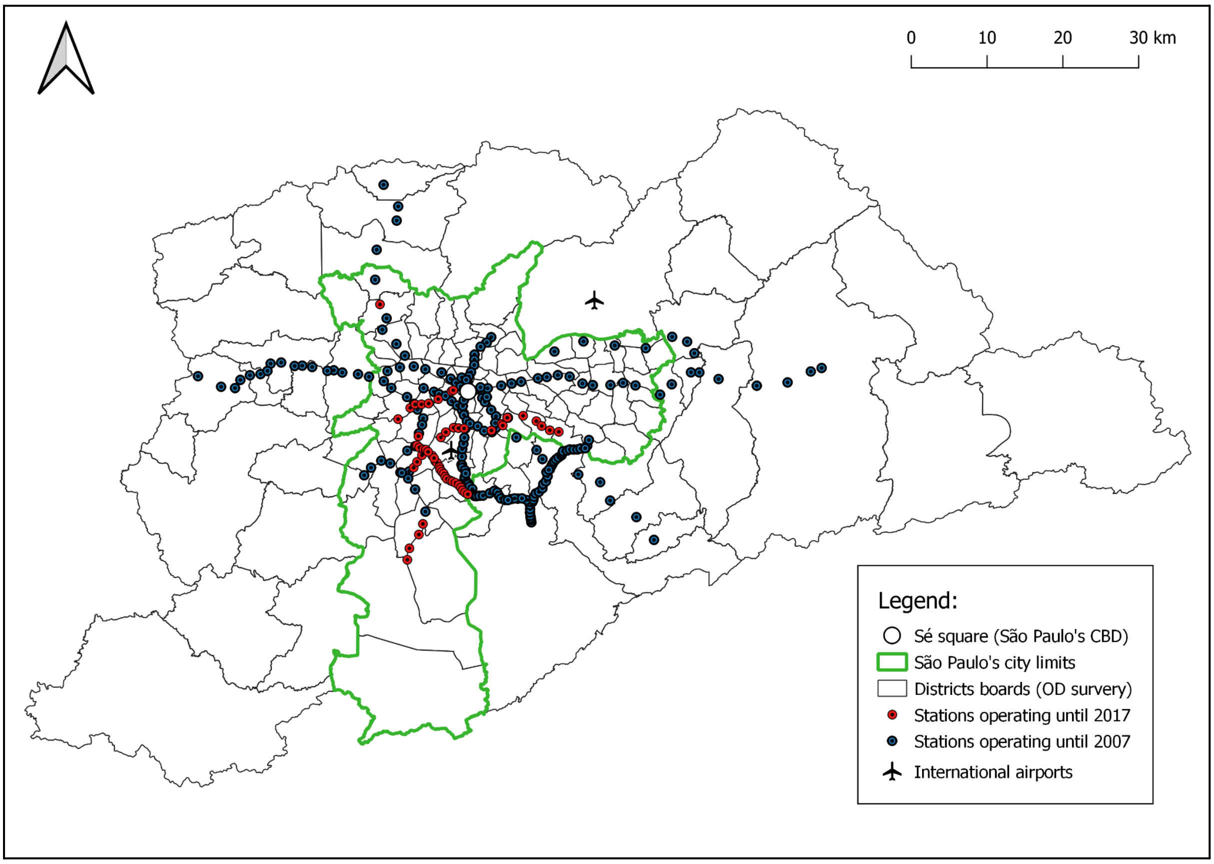
Figures

Figure A1B – The geography of the zone units from the Origin Destination surveys in 2017.



Notes: Author's own elaboration, from OD survey and MOBILIDADOS data.

Figure A2B – The geography of the district units from the Origin Destination surveys.



Notes: Author's own elaboration, from OD survey and MOBILIDADOS data.

Equations

E1 - Cumulative accessibility index by public transit

The accessibility index to formal job opportunities, conceptualized as “ease of reaching opportunities using the transport network”, follows the time interval approach proposed by Tomasiello et al. (2023):

$$ICA_{oI} = mean(\{TCA_{oT} \forall T \in I\}) \quad \text{(A1)}$$

$$I = [T_{min}, T_{max}] \quad \text{(A2)}$$

Where ICA is the interval cumulative accessibility of the origin o within the time interval *I*, which is a minute-by-minute distribution of travel time cutoffs within a given time interval between T_{min}= 30 minutes and T_{max}.= 85 minutes. This approach reduces arbitrary choice of travel cost to determine cumulative accessibility. The choice of this time interval was based on the statistical distribution of the total travel time by public transit in the household travel survey of 1997, as shown in Table E1. This travel time interval represents 58 % of the total trips made by public transit.

Table E1B - Summary statistics of travel time by public transit in 1997 within SPMR.

Min	1º quartile	Median	Mean	3º quartile	Max
1	30	55	61.25	85	370

Notes: Author’s own elaboration. Travel time data is obtained from the OD survey of 1997, by considering only trips made by public transit (buses, train or rail).

The accessibility index presented in equations A1 and A2 considers formal job opportunities of the year 2002, the earliest by which geographic information in RAIS data is available. Therefore, we hold on to the assumption that the changes in the public transit network between 1997 and 2002 did not significantly change the spatial distribution of the accessibility indexes. In fact, the rapid transit expansion over this period was limited to 7 kilometers of new subway lines. The BRT system only started to operate by the year of 2007.

3 The impact of Airbnb on the spatial distribution of economic activity

Resumo

Este estudo examina como a atividade de aluguel de curto prazo influencia a distribuição espacial do mercado de trabalho no Rio de Janeiro, Brasil. Utilizando dados longitudinais e espacialmente detalhados para o período de 2010 a 2019, foram estimados os efeitos de transbordamento espacial das avaliações de Airbnbs sobre a atividade econômica nos setores de lazer, gastronomia, comércio varejista e hospedagem, por meio de regressões em dois estágios com variáveis instrumentais. Os resultados indicam que a atividade do Airbnb beneficia principalmente o setor de restaurantes, aumentando a demanda por trabalho, sem evidências de forças de aglomeração ou dispersão nos demais setores econômicos. Além disso, evidenciou-se um efeito positivo sobre o salário-hora no setor de restaurantes, o que ajuda a elucidar os canais econômicos por meio dos quais operam os incentivos à aglomeração do emprego. O estudo conclui que a atividade de aluguel de curto prazo pode gerar renda e beneficiar setores econômicos específicos por meio dos ganhos associados à proximidade a um maior número de consumidores.

Palavras-chave: Airbnb, Rio de Janeiro, Economias de aglomeração, Geografia do emprego, Variáveis instrumentais.

Abstract

This study examines how short-term rental activity influences the spatial distribution of the labor market of Rio de Janeiro, Brazil. Using longitudinal, spatially detailed data from 2010 to 2019, we estimate the spatial spillover effects of Airbnb reviews on the economic activity in the leisure, gastronomy, retail, and lodging sectors with instrumental variables in two-stage least squares regressions. We find that Airbnb activity primarily benefits the restaurant sector, increasing labor demand, but no agglomeration or dispersion forces on the remaining economic sectors. We also find a positive impact on restaurant's hourly-wage, which helps rationalize the economic channels through which such incentives for employment agglomeration operate. The study concludes that short-term rental activity can generate income and benefit specific economic sectors through the gains of proximity to more customers.

Keywords: Airbnb, Rio de Janeiro, Agglomeration economics, The Geography of Jobs, instrumental variable.

1 Introduction

Cities facilitate the consumption of diverse–and often place-specific–goods and amenities, which yearly generate approximately 10 billion inter-city trips worldwide for tourism purposes (UNTWO, 2020). These consumption-driven trips generate money inflows that can determine internal urban structures, as certain economic sectors benefit from the geographic proximity to tourism spending. This spatial economic relationship can be enhanced in the context of the recent rise of the platform economy, which has begun to reshape land use in cities (Almagro and Domínguez-Iino, 2025). Among these, Airbnb has emerged as a key player, influencing housing availability, neighborhood composition, and the spatial distribution of economic activity (Almagro and Domínguez-Iino, 2025; Garcia-López et al., 2020; Garcia-López and Rosso, 2023; Hidalgo et al., 2024; Sheppard and Udell, 2016). However, no study has examined how the economic agglomeration forces generated by tourist spending affects the geographies of labor demand and of economic earnings for local workers in cities of developing countries.

This study investigates how tourism activity shapes employment locations in Rio de Janeiro by estimating whether Airbnb rentals have influenced the spatial distribution of demand for local services related to tourism and other sectors from 2010 to 2019. Rio de Janeiro has recently hosted two major global sporting events, the 2014 FIFA World Cup and the 2016 Olympic Games, with the expectation to increase its annual inflow of tourists. This happened in the context of Airbnb's entry in the lodging market, which disrupted this sector and created a shock that reallocated the spatial supply of tourist accommodation. This reconfiguration, in turn, reshaped where visitors circulate and consume within the city. We investigate which local sectors benefit from the resulting geography of tourist expenditure, the economic mechanisms—such as demand spillovers, input–output linkages, and agglomeration forces—that transmit these effects, and the implications for the number and location of job opportunities for local workers.

Rio de Janeiro is consistently ranked among the five most visited cities in Latin America (Euromonitor, 2020). The city received approximately 10 million visitors annually during the 2010–2019 period, with an estimated spending of about $3.5 billion, representing a significant source of income for local residents (Fipe, 2012; Ministério do Turismo, 2020). Since 2007, Airbnb has reshaped tourism dynamics in cities worldwide. In 2021, Rio de Janeiro ranked seventh globally, with 72,000 hosts[16], whereas the demand for its traditional

[16] https://www.searchlogistics.com/learn/statistics/airbnb-statistics/.

hospitality sector decreased by 29 percent between 2010 and 2017 (ABIH RJ, 2018[17]). However, Airbnb's rapid expansion has raised concerns about housing affordability (Sheppard and Udell, 2016), with evidence linking it to rising long-term rental prices in cities of Europe (Duso et al., 2024; Franco and Santos, 2021; Garcia-López et al., 2020), United States (Barron et al., 2018; Koster et al., 2021), and Asia (Chang, 2020; Liang et al., 2022).

These concerns have prompted regulatory responses in several cities across developed countries to limit short-term rental supply (Duso et al., 2024; Horn and Merante, 2017; Koster et al., 2021). Additionally, a growing body of literature explores Airbnb's effects on the traditional hospitality sector, although findings are mixed, with studies reporting negative (Dogru et al., 2020; Xie and Kwok, 2017; Zervas et al., 2017), null (Blal et al., 2018; Choi et al., 2015; Haywood et al., 2017), or even positive relationship (Aznar et al., 2017; Coyle and Yeung, 2016; Strømmen-Bakhtiar and Vinogradov, 2019).

A relatively less studied topic is about how growth in Airbnb supply can transform neighborhood demographics and reshape land use by increasing local demand for specific services (Almagro and Domínguez-Iino, 2025). The convenience for tourists of having access to services that meet their travel-related needs can boost economic gains in related sectors and generate agglomeration effects. As a result, gastronomy and leisure services in cities across developed countries have been shown to benefit from proximity to visitor-driven local markets (Alyakoob and Rahman, 2022; Basuroy et al., 2020; Garcia-López and Rosso, 2023; Hidalgo et al., 2024). More broadly, in some cases, rising housing rent due to tourism activity may be offset, and even result in net local benefits, if the relocation of amenities due to tourism expenditure leads to higher net wages for local workers (Allen et al., 2020; Almagro and Domínguez-Iino, 2025).

In this paper we use fine-grained spatial data to assess how a large platform for short-term rentals like Airbnb influences the spatial distribution of jobs and their respective wages within the city. We estimate the impact of Airbnb rentals, measured by the number of Airbnb reviews, on the number of formal jobs in the leisure, gastronomy, retail, and lodging sectors at the census tract level, using econometric models. To address potential simultaneity bias between local service supply and Airbnb activity, we employ shift-share instrumental variables. We find that Airbnb has a positive impact limited to employment in restaurants: each additional 100 Airbnb reviews per year in a census tract increases the number of restaurant jobs by 1.3 percent. We investigate the economic rationality for such spatial

[17] https://www.data.rio/documents/f8057e94b0724367a78fa859f5be9a76/about

agglomeration of restaurant benefits through the platform's impact on wages and find a positive effect with an elasticity of 0.25. We further run robustness checks through falsification tests that support our findings.

This study contributes to a growing body of research on Airbnb's effects on leisure and gastronomy activities (Alyakoob and Rahman, 2022; Basuroy et al., 2020; Garcia-López and Rosso, 2023; Hidalgo et al., 2024), and on the hospitality sector (Dogru et al., 2020; Xie and Kwok, 2017; Zervas et al., 2017). To the best of our knowledge, our study is the first to examine the economic impacts of Airbnb across a broad set of employment sectors in the context of a Global South city.

The remainder of the paper is organized as follows. Section 2 reviews the socioeconomic and labor market context of Rio de Janeiro. Section 3 presents the data used, while Section 4 outlines the methods and their rationale. Section 5 discusses the results, and Section 6 concludes.

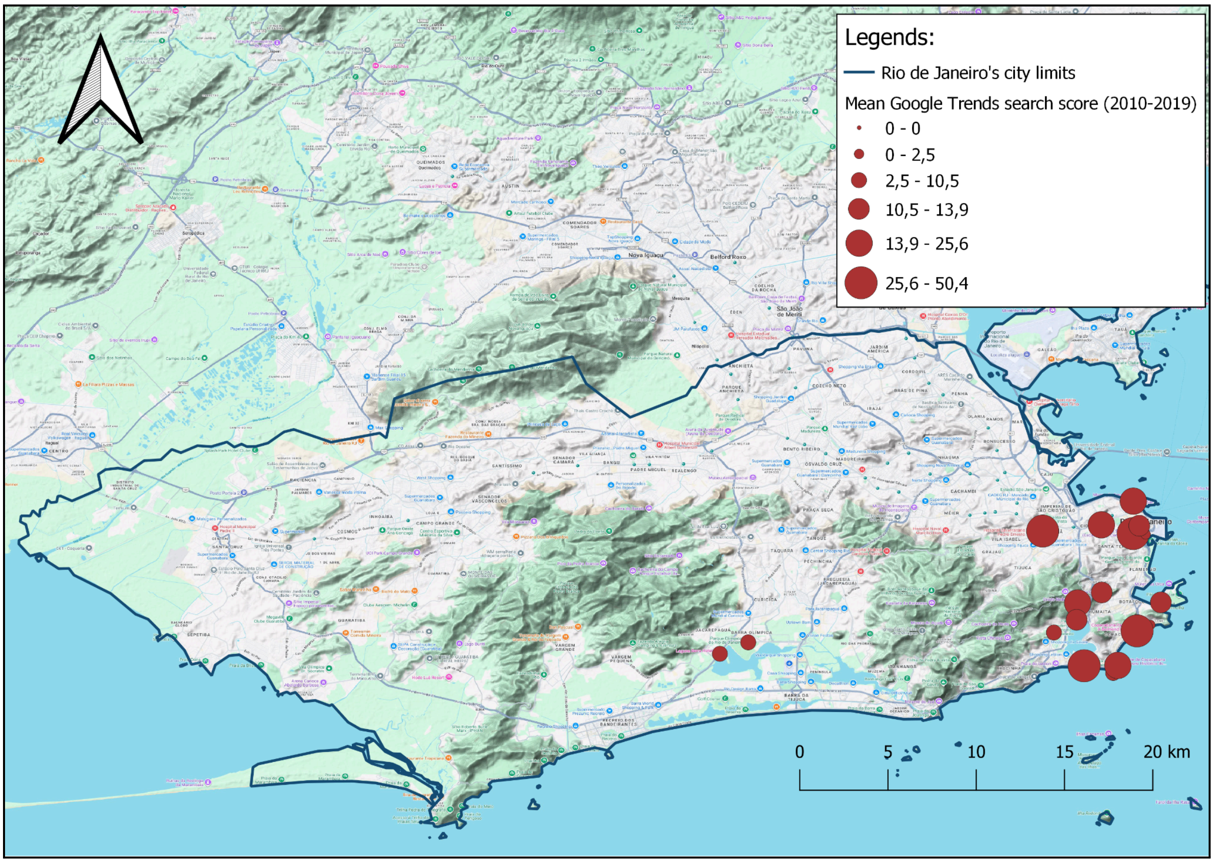
2 Rio de Janeiro and the rise of the Airbnb platform

2.1 Rio de Janeiro: a Tourism-Intensive and Economically unequal City

With approximately six million inhabitants, Rio de Janeiro is Brazil's second-largest city in terms of both population and GDP. Combining historical relevance with a large urban scale, the city has long been regarded as one of Brazil's most vibrant cultural centers (Marsh, 2016). In addition to its cultural prominence, Rio de Janeiro is characterized by a unique natural landscape composed of mountains, an approximately 197 km of coastline, and two of the three largest urban forests in the world, as shown in Figure 1. These geographic features, together with the city's cultural assets, have positioned Rio de Janeiro as Brazil's leading leisure tourism destination and the most visited city in South America (Euromonitor, 2020). In this context, Rio de Janeiro was selected to host major international sporting events during the 2010s, in particular, the 2014 FIFA World Cup and the 2016 Summer Olympic Games, as part of a strategy to enhance the city's global visibility and attractiveness as a tourism destination[18].

[18] Besides the goal of increasing tourist inflow to the city, the local administration aimed to boost urban development by significantly investing in infrastructure, such as airports and public transit network expansion.

Figure 1C - Rio de Janeiro city and its 20 main tourist attractions.



Notes: Google Trends search contains the searches for the following city amenities, from the highest to the lowest score groups: 1) Maracanã stadium, Lapa, Copacabana, Ipanema, Christ the Redeemer, Museum of Tomorrow, Sambodrome, Copacabana Fort; 2) Sugar Loaf, Dona Marta View Point, Lage Park, Municipal Theater; 3) Botanical Garden, Arpoador rock, Rock in Rio festival, Olympic Village; 4) Museum of Modern Art, Leme rock.

Despite this, Rio de Janeiro experienced a severe economic crisis beginning in 2015, within a broader national context marked by political instability and corruption scandals. Due to its reliance on oil and gas royalties from companies involved in such scandals, the city was particularly affected, with the unemployment rate rising sharply from 5.2% in 2014 to 15% in 2017. Even prior to this downturn, Rio de Janeiro ranked among the most economically unequal metropolitan regions in the world (Salata and Ribeiro, 2023; WorldAtlas, 2019), reflecting a long-standing pattern of social exclusion. In 2013, 53% of residents over the age of 18 lacked a high school diploma (PNUD/ONU, 2013), while only 34% of workers were employed formally, and half of the city's labor force earned no more than the minimum wage (IBGE, 2012).

2.2 Airbnb, Spatial Reallocation, and Tourist Consumption

Since the late 2000s, the expansion of the platform economy has reshaped urban land use and economic organization of cities through digital intermediaries that reduce transaction costs and reallocate the geography of the demand for some services (Zervas et al., 2017). Within this context, Airbnb represents a particularly disruptive innovation in the lodging sector. By enabling short-term rentals of residential units at scale, Airbnb expands accommodation supply beyond the traditional hotel sector, lowers entry barriers for hosts, and blurs the regulatory and functional boundaries between residential and commercial land use (Guttentag, 2015; Wachsmuth and Weisler, 2018).

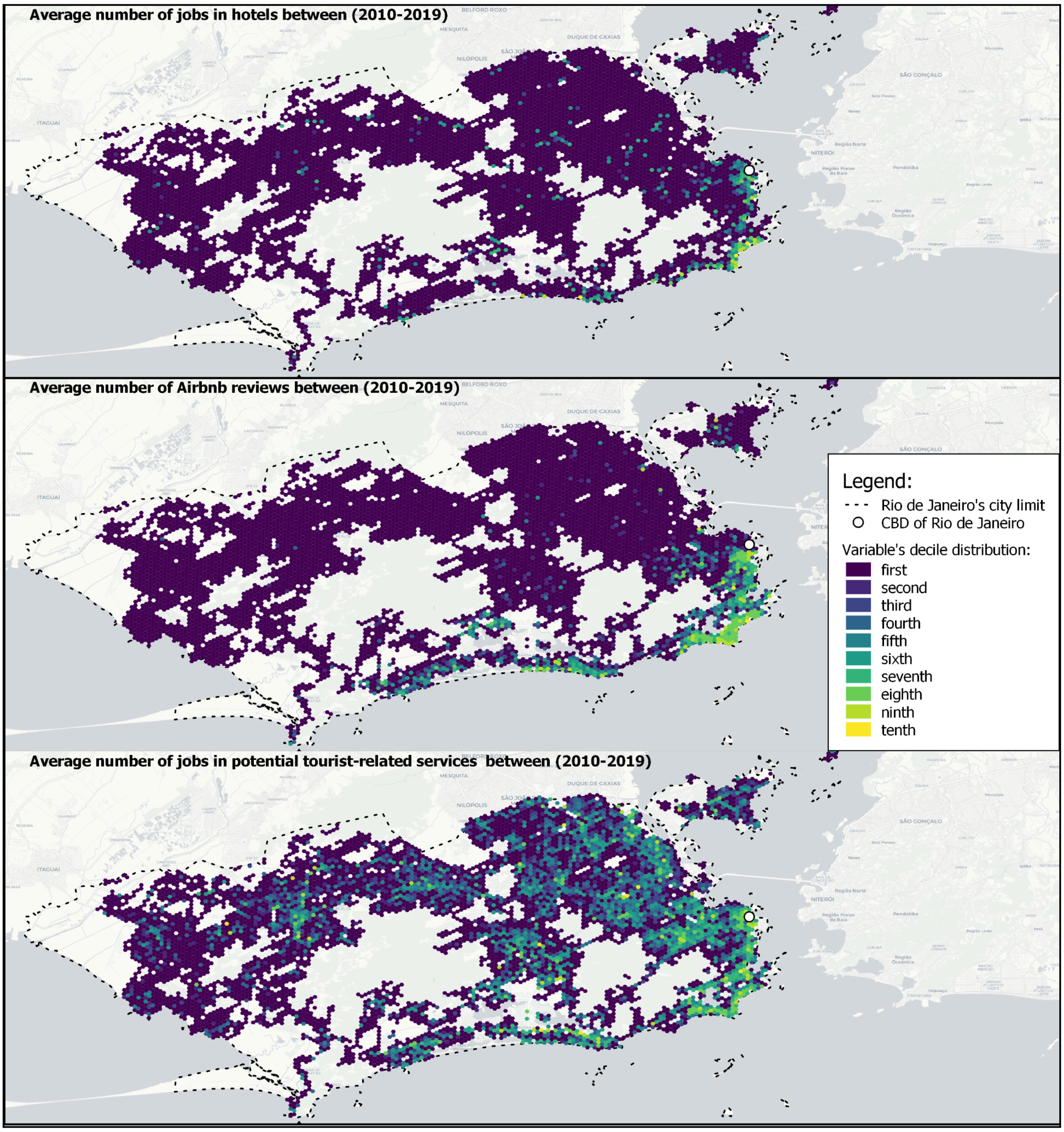
Unlike hotels, which are spatially concentrated, capital-intensive, and subject to zoning and labor regulations, Airbnb listings are geographically dispersed and highly responsive to short-run demand fluctuations, generating a decentralized and flexible lodging market (Zervas et al., 2017). Figure 2C confirms that in Rio de Janeiro Airbnb listings were more evenly spatially distributed than hotels, being more present towards the south area of the city, where the main tourism amenities are located. Figure 3C also shows an increased interest in Airbnb accommodation in Rio de Janeiro over the 2010 decade, whereas hotels had an opposite trend.

This spatial reconfiguration of tourist accommodation caused by the entrance of Airbnb not only affects competition within the lodging industry but also reshapes tourist circulation patterns within cities, redirecting visitor spending toward residential neighborhoods and thereby altering local demand conditions for services and labor (Garcia-López and Ramos, 2023; Almagro and Domínguez-Iino, 2025).

These structural differences between short-term rental platforms and traditional hotels are closely connected to differences in the characteristics and consumption behavior of their users. A growing body of literature shows that Airbnb users differ systematically from traditional hotel guests in terms of preferences, travel motivations, and consumption behavior. Airbnb travelers tend to be more price-sensitive, younger, and more likely to travel in groups or for longer stays, valuing access to larger spaces and residential amenities over standardized hotel services (Guttentag et al., 2018; Lutz and Newlands, 2018). They also display a stronger preference for “local” and “authentic” experiences, which translates into higher propensities to consume neighborhood-based goods and services such as restaurants, cafés, bars, and leisure activities outside traditional tourist districts (Guttentag, 2015; Dogru et al., 2020).

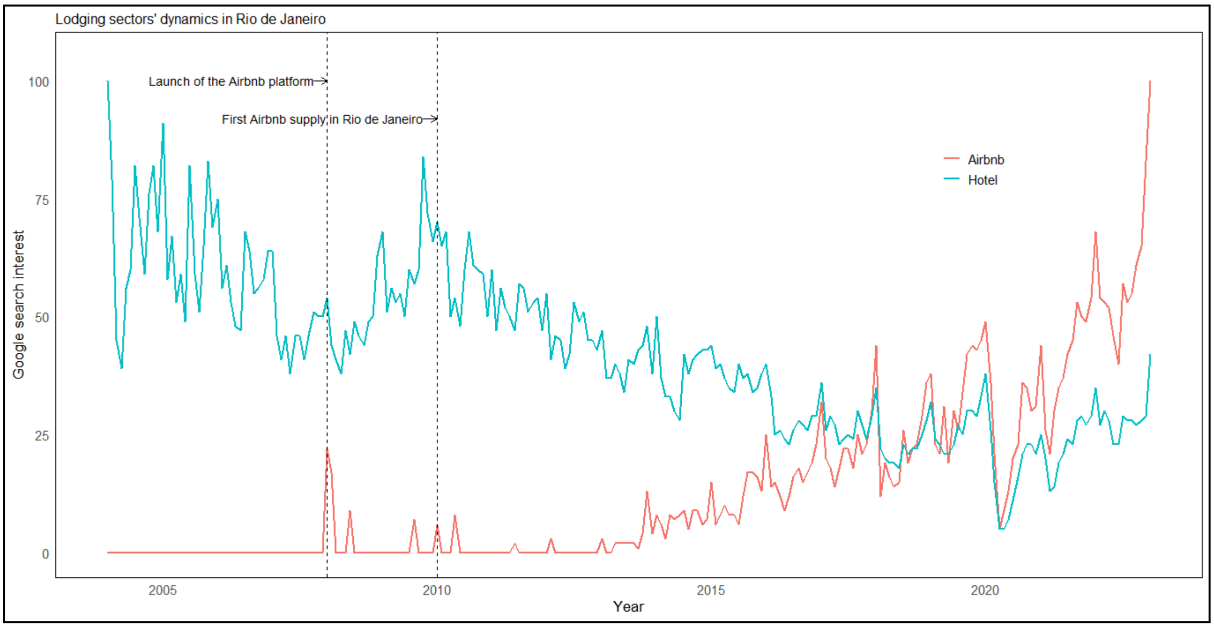
In contrast, hotel guests are more likely to concentrate spending within or near hotels and in established tourist zones, partly due to bundled services, concierge guidance, and spatial clustering of hospitality infrastructure (Zervas et al., 2017). As a result, Airbnb demand is more spatially diffuse and more tightly linked to local service economies, suggesting a distinct channel through which short-term rentals can reshape neighborhood-level economic activity and labor demand.

Figure 2C - Airbnb activity and tourist related jobs in Rio de Janeiro between (2010-2019).



Notes: Author's own elaboration. Unit areas are hexagons of H3jsr resolution 9 with 2.3 km² of total area. The variables values shown are their respective average over the period (2010-2019).

Figure 3C - The trajectory of searches in Google for Airbnb and hotels in Rio de Janeiro between 2004-2022.



Notes: Author's own elaboration, from GoogleTrends. The graphic plots the trajectories of Google trends research scores containing the words: "Hotel in Rio de Janeiro" and "Airbnb in Rio de Janeiro".

2.3 Motivation

Taken together, Rio de Janeiro's strong reliance on tourism, high economic inequality, and exposure to both a major economic downturn and the rapid diffusion of short-term rental platforms make it a relevant setting to study how digitally mediated tourism demand reshapes neighborhood-level economic activity in the Global South. Unlike cities where tourism is either marginal or highly regulated, Rio offers a context in which Airbnb expansion plausibly generates localized demand shocks with heterogeneous effects across space and sectors.

3 Data

This study uses data spatially aggregated at the census tract level (IBGE, 2016) . Information on short-term rental activity in Rio de Janeiro comprises 63,253 Airbnb reviews from 2010 to 2019, sourced from the InsideAirbnb project[19]. Formal employment data were

[19] https://insideairbnb.com/

obtained from *RAIS Identificada*—the *Relação Anual de Informações Sociais*—provided by the Brazilian Ministry of Labor. This dataset contains detailed information on firm addresses, number of employees, skill levels, economic sector classifications, and other characteristics of the formal sector. We used the address information to find the latitude and longitude coordinates using a commercial licence of ArcGIS StreetMap Premium. Demographic and housing characteristics were retrieved from the 2010 Brazilian Census. Additionally, we used Google Trends data to measure the intensity of searches for Airbnb and tourist amenities between 2004 and 2019. Information on the location and openings of rapid transit stations comes from the ITDP (Institute for Transit Development Policies). We aggregated all information at the census tract level for the analysis of Airbnb's impacts on employment.

Table 1C presents descriptive statistics of the key variables in our data set. Most formal jobs in tourism-related sectors increased between 2010 and 2019, with the exception of employment in bars. The proportion of workers with more years of education also increased over the period. Meanwhile, the average distance to rapid transit stations decreased, reflecting the significant expansion of the rapid transit network to accommodate the 2014 FIFA World Cup and the 2016 Olympic Games. Moreover, Airbnb reviews increased by 960% for entire-home listings and 450% for private-room listings, underscoring the platform's rapid growth as a preferred accommodation option in Rio de Janeiro.

Table 1C - Descriptive statistics.

Dataset 1: Formal employmment and Airbnb activity (census tract)						
Variable	**Min**	**Mean (2010–2014)**	**Mean (2015–2019)**	**Δ Mean (%)**	**Max (2010–2014)**	**Max (2015–2019)**
Formal jobs	0	193.440	162	−15	106.896	56.977
Restaurant jobs	0	0.28	0.36	28	90	118
Bar jobs	0	0.07	0.05	−28	24	15
Bakeries jobs	0	0.09	0.09	0	6	5
Retail jobs	0	0.28	0.33	17	71	86
Hotels jobs	0	0.03	0.04	33	10	9
Motels jobs	0	0.00	0.00	0	3	3
Apartment hotels jobs	0	0.00	0.00	0	1	1
% Elementary degree workers	0	0.75	0.83	10	1	1
% High school degree workers	0	0.43	0.56	30	1	1
% College degree workers	0	0.06	0.07	16	1	1
Airbnb entire-home reviews	0	0.10	1.06	960	52	98
Airbnb private-room reviews	0	0.02	0.11	450	46	83
Shift-share rental housing	0	14.31	174.00	1116	265	946
Shift-share elderly pop.	0	18.39	223.74	1116	213	761
Dist. $\leq$ *1km to rapid station*	0	0.40	0.52	30	1	1

Notes: Author's own elaboration, from the database of the study. We report nominal income.

4 Conceptual framework

This section outlines a simple framework that motivates the empirical specifications and clarifies the mechanisms linking short-term rental activity to local labor market outcomes. The framework is intentionally stylized and is not intended to characterize a full general equilibrium.

Consider a city composed of i discrete locations. In each location, firms operate in s economic sectors, and produce non-tradable services using local labor. Firms take local wages as given and face location-specific fixed costs, including commercial rents. Airbnb activity increases the temporary population of visitors in a location. Let $Airbnb_{itc}$ denote the intensity of short-term rental activity in location i, year t, and category c. Airbnb activity acts as a local demand shifter for proximity-dependent services, such as food, leisure, and retail, while potentially substituting for traditional accommodation services in the hospitality sector.

Firms choose labor to maximize profits. An increase in local demand raises the marginal revenue product of labor, shifting labor demand outward. When local labor supply is imperfectly elastic due to commuting costs, sector-specific skills, or mobility frictions, this demand shock leads to higher equilibrium wages. Employment adjusts through firm expansion and entry, yielding a positive relationship between Airbnb activity and local employment in sectors complementary to tourism consumption. This mechanism implies the following causal chain:

$$Airbnb_{itc} \rightarrow \ local\,demand \ \rightarrow \ w_{it} \ \rightarrow \ Jobs_{its} \qquad (3.1)$$

At the same time, increased demand for commercial space raises local land rents, which partially offsets firm expansion and may attenuate employment responses in land-scarce locations. Time-invariant differences in land rents, amenities, and baseline attractiveness are absorbed by location fixed effects in the empirical analysis.

The reduced-form specifications estimated in Section 5 can therefore be interpreted as partial equilibrium relationships arising from firms' labor-demand responses to localized tourism demand shocks. Differences in demand sensitivity and substitutability across sectors generate heterogeneous employment and wage effects, which we assess empirically.

5 Econometric model

Guided by the conceptual framework discussed in Section 4, this section presents the empirical strategy used to estimate the impact of Airbnb activity on the spatial distribution of employment. We begin by estimating a reduced-form relationship between short-term rental activity and local employment, and then address potential simultaneity bias using an instrumental-variable approach.

$$Jobs_{its} = f(Airbnbs_{itc}, X_{it}) \tag{3.2}$$

Where *Jobs* represents the formal employment in location *i* and year *t*, in the economic sector *s*. We focus on tourist-related economic sectors: restaurant, lodging (i.e., hotels, motels, apartment hotels, hostels, and campings), bakeries, bars, or retail[20]. *Airbnbs* are the number of Airbnb reviews in category c: entire listing or shared room. *X* is a vector of related urban externalities that attract jobs, such as the qualification level of the labor input, the proximity to the rapid transit system (rail or BRT)[21], and time-invariant local characteristics that may attract tourism-related activities and are absorbed by census-tract fixed effects.

Additionally, the relationship between Airbnbs and Jobs in equation (3.2) has potential simultaneity bias. The proximity to some tourist-related economic activities may influence Airbnb supply, as their services can drive demand for nearby accommodations and increase potential hosters' profit levels. To address this joint determination, we adopt 2SLS linear models using two Bartik-type instrumental variables inspired by the recent literature of Airbnb impact on urban markets (Garcia-López et al., 2020; Garcia-López and Rosso, 2023; Hidalgo et al., 2024):

$$ShiftShareRental_{it} = Share\ of\ rental\ households_{i,2010}$$

$$X\ Worldwide\ Airbnb\ Google\ Searches_{t} \tag{3.3}$$

[20] We use CNAE (Classificação Nacional de Atividades Econômicas) subclasses of economic activities of IBGE, which is divided in 1.330 subclasses.

[21] The study of Campos (2019) shows that the rapid transit expansion for the megaevents of Rio de Janeiro between 2012 and 2016 has reshaped the spatial distribution of employment, which became closer to rapid transit routes.

where the percentage of rented household units at census tract i in 2010 is the share component, and the shift component is the aggregate search intensity for the word "Airbnb" on Google Trends between 2010-2019. We further explore a novel instrumental variable for this literature by creating a shift share for elderly population:

$$ShiftShareElderly_{it} = Share\ of\ elderly\ population_{i,2010}$$

$$X\ Worldwide\ Airbnb\ Google\ Searches_{t} \quad (3.4)$$

where the share component is the percentage of individuals with 60 years old or above at census tract i in 2010, and the shift component is the aggregate search intensity for Airbnb between 2010-2019.

The relevance of these instruments operate through different but related channels. Long-term rented housing units have better potential to be transformed into Airbnb listings, as landlords realize they may have higher earnings on the short-term rent market (Duso et al., 2024; Garcia-López et al., 2020). On the other hand, the share of elderly population may affect Airbnb supply as retirees often face declining income, making Airbnb a potential source of additional earnings, and some seniors relocate or pass away, leaving entire apartments unoccupied. Moreover, as their children move out, vacant bedrooms become available. This later mechanism is supported by data showing that seniors represented the fastest-growing host demographic group (Airbnb, 2016).[22]

The first stage of the 2SLS models to estimate the impact of Airbnbs on formal employment is:

$$Entirehome\widehat{listing}Airbnbs_{it} = \beta_0 + \beta_1 ShiftShareRental_{it} + \beta_i X_{it} + \varphi_t + \Omega_i + \epsilon_{it}$$

(3.5)

$$Private\widehat{room}Airbnbs_{it} = \beta_0 + \beta_1 ShiftShareElderly_{it} + \beta_i X_{it} + \varphi_t + \Omega_i + \epsilon_{it} \quad (3.6)$$

[22] https://www.airbnbcitizen.com/wp-content/uploads/2016/03/Airbnb_60_Plus_Women_Report.pdf.

where Y can be the number of Entire-home or Private room Airbnb reviews at census tract i, year *t,* explained by *ShiftShareElderly* or *ShiftShareRental*. X is a vector of control variables at the census tract level: the percentage of formal workers with a college degree, a dummy variable with value 1 if the census tract's centroid is located within a 1 km euclidean distance of a rail (subway, light rail vehicle, and train) or BRT station, and the total number of formal jobs in i. Moreover, φ_t and Ω_i are census tract and year fixed effects, respectively, and ϵ is a random error term. The second stage of the 2SLS model is:

$$Jobs_{it} = \beta_0 + \beta_1 \widehat{Airbnbs}_{it} + \beta_i X_{it} + \varphi_t + \Omega_i + \mu_{it} \tag{3.7}$$

where *Jobs* is the number of jobs in the restaurant, hospitality, bakery, or retail sectors at census tract *i* and year *t*. Table A1 supports the relevance of the instruments, as their first stage F-statistics range between 89 and 309 and have strong explanatory power to predict the number of Airbnb space reviews (Stock and Yogo, 2002). While Table A2C suggests that the shift share of rented household units does not have enough explanatory power to predict the number of Airbnb room reviews—as its F-statistics are below the threshold value of 10—, the shift share of elderly population meets that criteria. These later results are expected, since there is not a clear mechanism through which rented housing units may affect the number of Airbnb room supply, whereas its relationship with the percentage of elderly population is more straightforward. This result thus justifies the use of each shift-share instrument according to the short-term rent type in equations (3.5-3.6).

The exclusion restriction of our instruments is assessed following (Garcia-López and Rosso, 2023; Goldsmith-Pinkham et al., 2020), by which the share component should not influence the dynamics of tourism-related jobs before the beginning of Airbnb activity in Rio de Janeiro. Otherwise, the necessary condition of an independent relationship between the instrument and dependent variable would be violated. Figures A1C and A2C show absence of relationship between the shares of rental households and elderly population in 2010 on the dynamics of tourism-related jobs between 2010-2019.

6 Results

6.1 The impact of Airbnb on tourist-related jobs in Rio de Janeiro

This section examines the effects of Airbnb activity on formal employment in tourism-related sectors. Tables 4C–6C present the second-stage results of the 2SLS models, indicating sector-specific agglomeration effects in areas with higher levels of tourism activity.

Panel A of Table 4C (columns 1–5) shows that among the tourism-related sectors analyzed, Airbnb reviews are statistically significant only for restaurant employment. Specifically, every additional 100 reviews of entire-home listings is associated with a 1.3% increase in the number of formal restaurant jobs at the census tract level. Panel B of Table 4C assesses the impact of private room listings. Again, only the restaurant sector shows a statistically significant effect—though at the 10% level—suggesting weak evidence of a positive relationship.

In contrast, columns 2–4 of Table 4C show no significant effects of Airbnb activity on employment in bars, bakeries, and retail. Although tourists are potential consumers of these services, as suggested by (Garcia-López and Rosso, 2023; Hidalgo et al., 2024), the demand generated by Airbnb tourists in Rio de Janeiro appears insufficient to raise labor demand in these sectors. Accordingly, the aggregate estimates across all tourism-related services in column 5 show no statistically significant effect, reinforcing the conclusion that the impact is concentrated in the restaurant sector.

This economic effect limited at a single economic sector in Rio de Janeiro may reflect the lower level of tourism activity than the European cities studied by Garcia-López and Rosso, (2023) for Turin-Italy with 7 million[23] and Hidalgo et al. (2024) for Madrid with 15 million. Although the former have roughly the same tourist flow of Rio de Janeiro, its lower population size (850 thousand) in a more compact urban structure may be more sensible for the spatial distribution of tourists promoted by Airbnb. This also helps explain the police motivation of the city in hosting the Olympic games and the FIFA world cup to attract more tourists and better explore the potential tourism market.

[23]https://turismotorino.org/en/convention-bureau/news/the-torino-meeting-industry-double-digit-growth.

Table 4C - Results for the regressions of the impact of Airbnb on jobs in tourist-related sectors.

Panel A: Effect of entire-home listings on service and commerce jobs (2010–2019)					
Economic subsector	Restaurants	Bars	Bakeries	Retail	Sectors aggregated
Model	(1)	(2)	(3)	(4)	(5)
Entire-home listings	0.0134**	-0.0217	-0.0014	-0.0040	-0.0057
	(0.0043)	(0.0035)	(0.0025)	(0.0043)	(0.0052)
Year Fixed Effects:	Yes	Yes	Yes	Yes	Yes
Census tract Fixed Effects:	Yes	Yes	Yes	Yes	Yes
Observations	70,447	70,447	70,447	70,447	70,447
R^2	0.85	0.54	0.75	0.82	0.88
F-stat (1st stage)	963.46	963.46	963.46	963.46	963.46
Panel B: Effect of private-room listings on service and commerce jobs (2010–2019)					
Economic subsector	Restaurants	Bars	Bakeries	Retail	Sectors aggregated
Model	(1)	(2)	(3)	(4)	(5)
Room listings	0.1370*	-0.2247	0.0211	-0.0417	-0.0779
	(0.0748)	(0.0897)	(0.0378)	(0.0585)	(0.0731)
Year fixed effects:	Yes	Yes	Yes	Yes	Yes
Census tract Fixed Effects:	Yes	Yes	Yes	Yes	Yes
Control variables:	Yes	Yes	Yes	Yes	Yes
Observations	70,421	70,421	70,421	70,421	70,421
R^2	0.76	0.52	0.74	0.81	0.86
F-stat (1st stage)	34.464	34.464	34.464	34.464	34.464

Notes: Author's own elaboration. Standard errors in parenthesis are clustered by census tract level. Control variables are the percentage of workers with a college degree, a dummy variable indicating whether the census's centroid is located within a 1km euclidean distance of a rail or BRT station, and the number of formal employment on the census tract, excluding the jobs on the sector of the dependent variable. Significance levels: * p<0.1, ** p<0.05, *** p<0.01.

We proceed with a detailed investigation of the impact of Airbnb activity on the traditional lodging sector, disaggregating it into hotels, motels, apartment hotels, and hostels/campsites. The results reported in columns (1–5) of Panels A and B in Table 5C indicate no significant impact of either entire-home or room listing reviews on employment in any of these segments.

Table 5C - Results for the regressions of the impact of Airbnb on jobs in hospitality sectors.

Panel A: Effect of entire-home listings on hospitality jobs (2010–2019)					
	Dependent variable: log number of jobs				
Economic subsector	Hotels	Motels	Apartment-hotels	Hostels & campsites	Sectors aggregated
Model	(1)	(2)	(3)	(4)	(5)
`Entire-Home reviews`	0.0004 (0.0017)	-0.0004 (0.0005)	0.0005 (0.0004)	0.0007 (0.0012)	0.0007 (0.0019)
Year fixed effects:	Yes	Yes	Yes	Yes	Yes
Census tract Fixed Effects:	Yes	Yes	Yes	Yes	Yes
Control variables:	Yes	Yes	Yes	Yes	Yes
R^2	0.88	0.80	0.59	0.65	0.84
F-stat (1st stage)	963.46	963.46	963.46	963.46	963.46
Panel B: Effect of private-room listings on hospitality jobs (2010–2019)					
	Dependent variable: log number of jobs				
Economic subsector	Hotels	Motels	Apartment-hotels	Hostels & campsites	Sectors aggregated
Model	(1)	(2)	(3)	(4)	(5)
`Room reviews`	0.0138 (0.0226)	-0.0014 (0.0053)	0.0004 (0.0058)	0.0072 (0.0152)	0.0166 (0.0280)
Year fixed effects:	Yes	Yes	Yes	Yes	Yes
Census tract Fixed Effects:	Yes	Yes	Yes	Yes	Yes
Control variables:	Yes	Yes	Yes	Yes	Yes
R^2	0.87	0.80	0.59	0.64	0.84
F-stat (1st stage)	34.459	34.459	34.459	34.459	34.459

Notes: Author's own elaboration. Standard errors in parenthesis are clustered by census tract level. Control variables are the percentage of workers with a college degree, a dummy variable indicating whether the census's centroid is located within a 1km euclidean distance of a rail or BRT station, and the number of formal employment on the census tract, excluding the jobs on the sector of the dependent variable. Significance levels: * p<0.1, ** p<0.05, *** p<0.01.

Finally, we conducted a robustness check by estimating the effects of Airbnb reviews on employment in sectors unrelated to tourism. Specifically, we examined the entertainment industry and auto manufacturing. Table 6C shows no statistically significant positive impact of Airbnb activity on these sectors. Thus, the positive effects observed in restaurant employment go in the opposite direction of the general trend of the labor market, which strengthens the interpretation of sector-specific agglomeration effects associated with Airbnb activity.

A further limitation of our study is that we do not account for the existence of spatial spillovers, which could drive downward bias on our estimates. However, the use of fixed effects at the census tract level helps to mitigate this source of bias. We also did such analysis aggregating our data on 0.11 km² hexagons, and the results remain qualitatively the same. A further analysis using more aggregated hexagon sizes such as 0.7 km² or larger (e.g., 5 km²) results in null effects, which reduces the concerns with spillover effects across census tracts.

Table 6C - Results for the regressions of the impact of Airbnb on jobs in unrelated tourist sectors.

Panel A: Placebo effect of entire-home listings on employment (2010–2019)		
Economic subsector	Entertainment industry	Auto manufacturing
Model	(1)	(2)
`Entire-home listings`	0.0016	0.0000
	(0.0015)	(0.0006)
Year Fixed Effects:	Yes	Yes
Census tract Fixed Effects:	Yes	Yes
Control variables:	Yes	Yes
Observations	70,447	70,447
R^2	0.738	0.711
F-stat (1st stage)	963.18	963.18
Panel B: Placebo effect of private-room listings on employment (2010–2019)		
Economic subsector	Entertainment industry	Auto manufacturing
Model	(1)	(2)
`Room listings`	-0.0183	0.0127
	(0.0242)	(0.0085)
Year Fixed Effects:	Yes	Yes
Census tract Fixed Effects:	Yes	Yes
Control variables:	Yes	Yes
Observations	70,421	70,421
R^2	0.720	0.649
F-stat (1st stage)	34.482	34.482

Note: Standard errors in parentheses. All models include census tract and year fixed effects. Standard errors are clustered by census tract. Significance levels: ·p¡0.1, *p¡0.05, **p¡0.01, ***p¡0.001

Notes: Author's own elaboration. Standard errors in parenthesis are clustered by census tract level. Control variables are the percentage of workers with a college degree, a dummy variable indicating whether the census's centroid is located within a 1km euclidean distance of a rail or BRT station, and the number of formal employment on the census tract, excluding the jobs on the sector of the dependent variable. Significance levels: * p<0.1, ** p<0.05, *** p<0.01.

6.2 The impact of Airbnb on wages of tourist-related jobs of Rio de Janeiro

We advance our investigation of the economic effects of Airbnb on tourism-related sectors in Rio de Janeiro by estimating the response of hourly wages in these firms. Table 7C shows that wages in the restaurant sector exhibit a positive elasticity of 0.25, indicating that, on average, a 10% annual increase in the number of entire-home Airbnb reviews per census tract is associated with a 2.5% increase in restaurant wages.

Regarding private room reviews, Panel B of Table 7C reports an elasticity for restaurant wages approximately half the magnitude observed for entire-home listings. This difference likely reflects both the lower intensity of private room activity (see Figure A3C) and the fact that private room rentals cost, on average, 39% less than entire-home rentals. This latter factor signals more constrained budgets among guests staying in private rooms, implying that restaurants located near entire-home listings face greater revenue potential, which may help explain the observed positive impact on wages and employment.

Finally, columns (2–4) of Panels A and B show no significant effects of Airbnb activity on wages in other tourism-related services, consistent with our earlier findings of no impact on employment in those sectors. Overall, the models shown in this section support the economic chain discussed in section 4, where an increase in the Airbnb activity has effects on the demand for labor in specificity sectors, which reflects on their wages.

Table 8C summarizes our analysis of the effects of Airbnb activity on wages in the hospitality sector. The results indicate only weak evidence of a positive wage elasticity in hotels: a 10% increase in entire-home Airbnb reviews is associated with a 0.23% rise in hotel wages, significant at the 90% confidence level. We interpret these modest effects as follows. Although Figure A3C shows that Google searches for hotels in Rio de Janeiro declined between 2010 and 2019, Figure A2C documents an overall increase in the number of hospitality jobs in the city. Two non-mutually exclusive factors may help explain this dynamic. First, upper-tier hotels may have responded to intensified competition from short-term rental platforms by increasing the intensive margin of labor demand, raising employees' working hours to improve service quality. (Dogru et al., 2020). Second, major events hosted in the city likely boosted tourist inflows, and the existing hotel capacity was sufficient to absorb this demand despite the growth of Airbnb listings.

Nevertheless, the limited magnitude and marginal statistical significance of these estimates suggest that any positive effects were confined to a small subset of hotels and were not strong enough to generate broader employment growth linked to the spatial distribution of Airbnb activity.

Table 7C - Results for the regressions of the elasticities between Airbnb and wages jobs in tourism-related sectors.

Panel A: Elasticity between entire-home listings and wages (2010–2019)				
Economic subsector	Restaurants	Bars	Bakeries	Retail
Model	(1)	(2)	(3)	(4)
`Entire-home listings`	0.2540***	-0.0438	-0.0319	-0.0166
	(0.0539)	(0.0219)	(0.0420)	(0.0604)
Year Fixed Effects:	Yes	Yes	Yes	Yes
Census tract Fixed Effects:	Yes	Yes	Yes	Yes
Control variables:	Yes	Yes	Yes	Yes
Observations	70,544	70,544	70,542	70,541
R^2	0.638	0.519	0.633	0.579
F-stat (1st stage)	308.01	308.01	308.00	307.85
Panel B: Elasticity between private-room listings and wages (2010–2019)				
Economic subsector	Restaurants	Bars	Bakeries	Retail
Model	(1)	(2)	(3)	(4)
`Room listings`	0.1385***	-0.0057	0.0242	-0.0122
	(0.0348)	(0.0161)	(0.0338)	(0.0510)
Year Fixed Effects:	Yes	Yes	Yes	Yes
Census tract Fixed Effects:	Yes	Yes	Yes	Yes
Control variables:	Yes	Yes	Yes	Yes
Observations	70,518	70,518	70,516	70,515
R^2	0.676	0.524	0.635	0.579
F-stat (1st stage)	654.91	654.91	654.89	654.78

Notes: Author's own elaboration. Standard errors in parenthesis are clustered by census tract level. Control variables are the percentage of workers with a college degree, a dummy variable indicating whether the census's centroid is located within a 1km euclidean distance of a rail or BRT station, and the number of formal employment on the census tract, excluding the jobs on the sector of the dependent variable. Significance levels: * p<0.1, ** p<0.05, *** p<0.01.

Table 8C - Results for the regressions of the elasticities between Airbnb and wages jobs in the hospitality sector.

Panel A: Elasticity between entire-home listings and wages (2010–2019)				
Economic subsector	Hotels	Motels	Apartment-hotels	Hostels
Model	(1)	(2)	(3)	(4)
`Entire-Home listings`	0.0234*	-0.0009	-0.0016	0.0038
	(0.0139)	(0.0037)	(0.0033)	(0.0026)
Year Fixed Effects:	Yes	Yes	Yes	Yes
Census tract Fixed Effects:	Yes	Yes	Yes	Yes
Control variables:	Yes	Yes	Yes	Yes
Observations	70,421	70,421	70,421	70,421
R^2	0.781	0.701	0.490	0.449
F-stat (1st stage)	654.37	654.37	654.37	654.37
Panel B: Elasticity between private-room listings and wages (2010–2019)				
Economic subsector	Hotels	Motels	Apartment-hotels	Hostels
Model	(1)	(2)	(3)	(4)
`Room listings`	0.0500	-0.0083	-0.0007	0.0070
	(0.0357)	(0.0120)	(0.0055)	(0.0109)
Year Fixed Effects:	Yes	Yes	Yes	Yes
Census tract Fixed Effects:	Yes	Yes	Yes	Yes
Control variables:	Yes	Yes	Yes	Yes
Observations	70,447	70,447	70,447	70,447
R^2	0.773	0.697	0.490	0.448
F-stat (1st stage)	306.62	306.62	306.62	306.62

Notes: Author's own elaboration. Standard errors in parenthesis are clustered by census tract level. Control variables are the percentage of workers with a college degree, a dummy variable indicating whether the census's centroid is located within a 1km euclidean distance of a rail or BRT station, and the number of formal employment on the census tract, excluding the jobs on the sector of the dependent variable. Significance levels: * p<0.1, ** p<0.05, *** p<0.01.

7 Conclusion

This study investigates the economic impact of Airbnb platform in the employment of multiple sectors in the city of Rio de Janeiro between 2010 and 2019. Specifically, we estimate the impact of Airbnb activity on economic sectors serving tourist demand, potentially generating agglomeration forces and reshaping the spatial distribution of formal employment opportunities through spillover economic effects.

Our results indicate that Airbnb activity generated sector-specific agglomeration effects, notably increasing employment and wages in the restaurant sector while leaving other sectors largely unaffected. No significant impacts were observed in bars, bakeries, retail, or traditional lodging segments such as hotels. The set of results suggest that in the context of the 2010 decade the Airbnb activity helped the restaurant sector to be resilient against the strong economic crisis that emerged in Brazil from 2015, as the aggregated formal job activity has shown a decrease in Rio de Janeiro from this period. Even though the Mega-events of Rio de Janeiro could drive an increase in tourist flow in the city per se, we believe that in the context of pre-entrance of Airbnb activity there would be a lower sectoral spillover effect if the traditional lodging sector had accommodated all of such tourist inflow.

Although interest in Airbnb's implications for urban markets has grown, the full range of its costs and benefits remains insufficiently understood, particularly in Global South cities. The present study shows that beyond benefiting short-term hosts, Airbnb may also create economic gains for the restaurant sector, while not affecting the traditional lodging sector.

Our discussion highlights that short term market regulations should carefully consider the benefits and losses of Airbnb supply constraint. While Airbnb promotes economic benefits on the restaurant sector and absent or non-negative influence on the remaining activity sectors, further analyses should extend the investigations of broader economic implications of Airbnb activity through the assessment of its impact on the long-term rental market. Since Rio de Janeiro presents the fourth most expensive Brazilian city in terms of housing cost (Almeida and Azzoni, 2016), and is among the most economically unequal cities in Latin America, it is of great interest to understand if the economic benefit for those workers in the restaurant sector can offset a potential increase in living cost. This extension could guide the design of policies for short-term regulation, as well as if they are actually necessary for developing country cities with large tourist flows.

Although rising housing costs may negatively impact low-income households, their proximity to tourism-driven consumer markets could offer potential income opportunities, including through informal channels. Future research could explore how increased access to Airbnb activity influences the labor market outcomes of low-income individuals. Overall, our study suggests that the spatial redistribution of tourism in developing cities can reshape consumption patterns for specific services and bolster economic resilience in some economic sectors during crises.

Annex

Tables

Table A1C - First stage models for the quantity of Airbnb space reviews on the shift share instruments of rented households and percentage of elderly population.

Model	(1)	(2)	(3)	(4)
Dependent variable:	*Quantity of Airbnb space reviews*			
`Shift share rented households`	0.0072***		0.0085***	
	(0.0005)		(0.0009)	
`Shift share elderly population`		0.0123***		0.0154***
		(0.0007)		(0.0011)
`Dummy 1 km euc distance to a transit station`			−0.0367	0.0453
			(0.1474)	(0.1411)
`Percentage of college educated workers`			0.1871	0.1611
			(0.2004)	(0.2064)
`log(employment)`			−0.0194	−0.0262
			(0.0271)	(0.0273)
Controls Included	No	No	Yes	Yes
Census Tract and Year FE	Yes	Yes	Yes	Yes
F-stat (var. of interest)	207.36	309.18	89.00	196.36
Observations	81,544	81,288	51,771	51,751
R^2	0.5518	0.5583	0.5584	0.5645
Within R^2	0.0148	0.0291	0.0114	0.0249

Notes: Clustered standard errors at census tract level in parentheses. Significance levels: *p < 0.1, **p < 0.05, ***p < 0.01

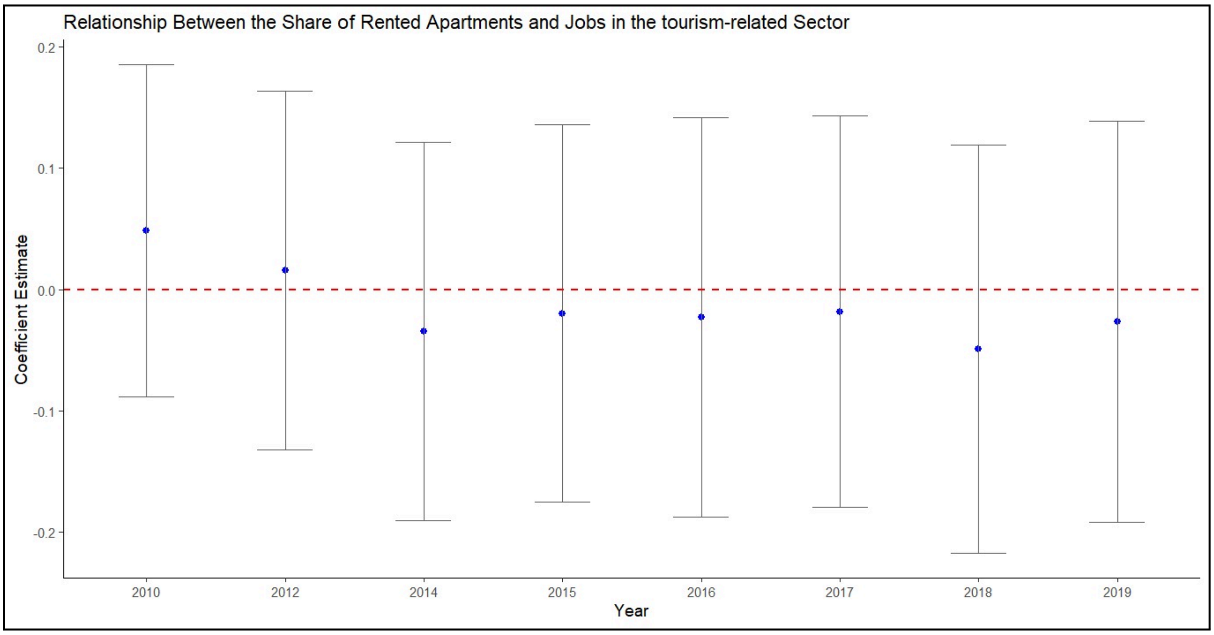
Table A2C - First stage models for the quantity of Airbnb room reviews on the shift share instruments of rented households and percentage of elderly population.

Model	(1)	(2)	(3)	(4)
Dependent variable:	*Quantity of Airbnb room reviews*			
Shift share rented households	0.0002*		6.4e-5	
	(0.0001)		(0.0002)	
Shift share elderly population		0.0007***		0.0007*
		(0.0002)		(0.0003)
Dummy 1 km euc distance to a transit station			−0.0286	−0.0240
			(0.0280)	(0.0274)
Percentage of college educated workers			0.0101	0.0076
			(0.0425)	(0.0427)
log(employment)			−0.0095	−0.0093
			(0.0068)	(0.0068)
First stage F-stat (var. of interest)	4.00	12.25	0.10	5.44
Controls Included	No	No	Yes	Yes
Census Tract and Year FE	Yes	Yes	Yes	Yes
Observations	81,544	81,288	51,771	51,751
R^2	0.3206	0.3210	0.3280	0.3283
Within R^2	0.0001	0.0006	0.0000	0.0004

Notes: Clustered standard errors at census tract level in parentheses. Significance levels: *p < 0.1, **p < 0.05, ***p < 0.01.

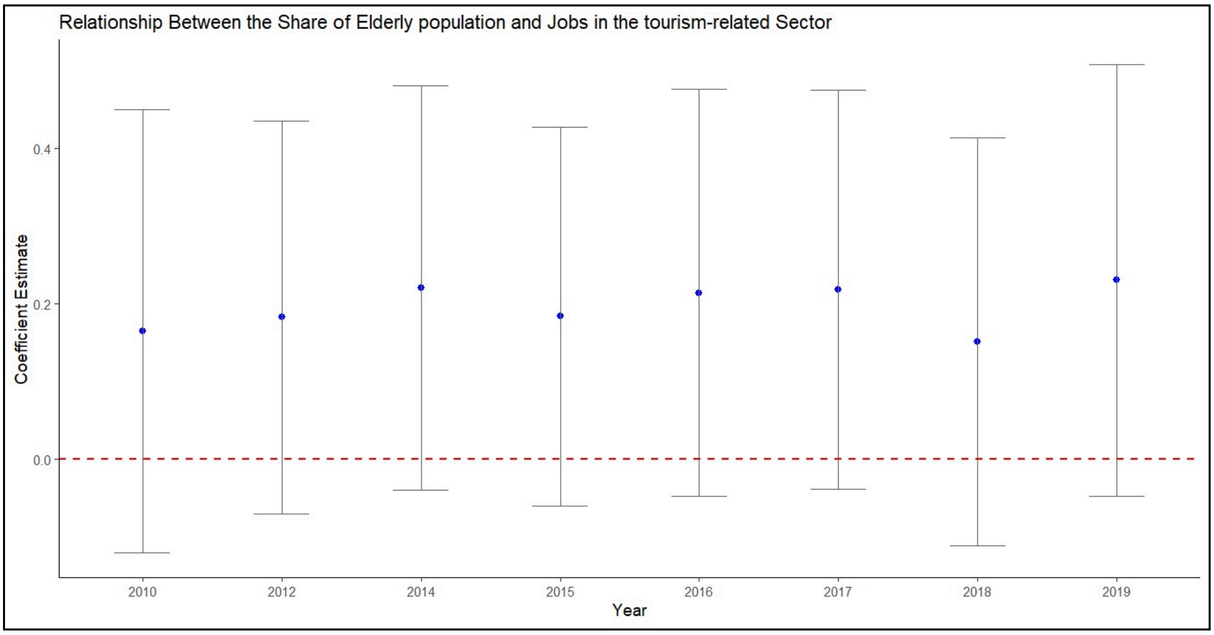
Figures

Figure A1C - Exclusion restriction tests for the share of rented apartments on jobs of tourism-related sectors.



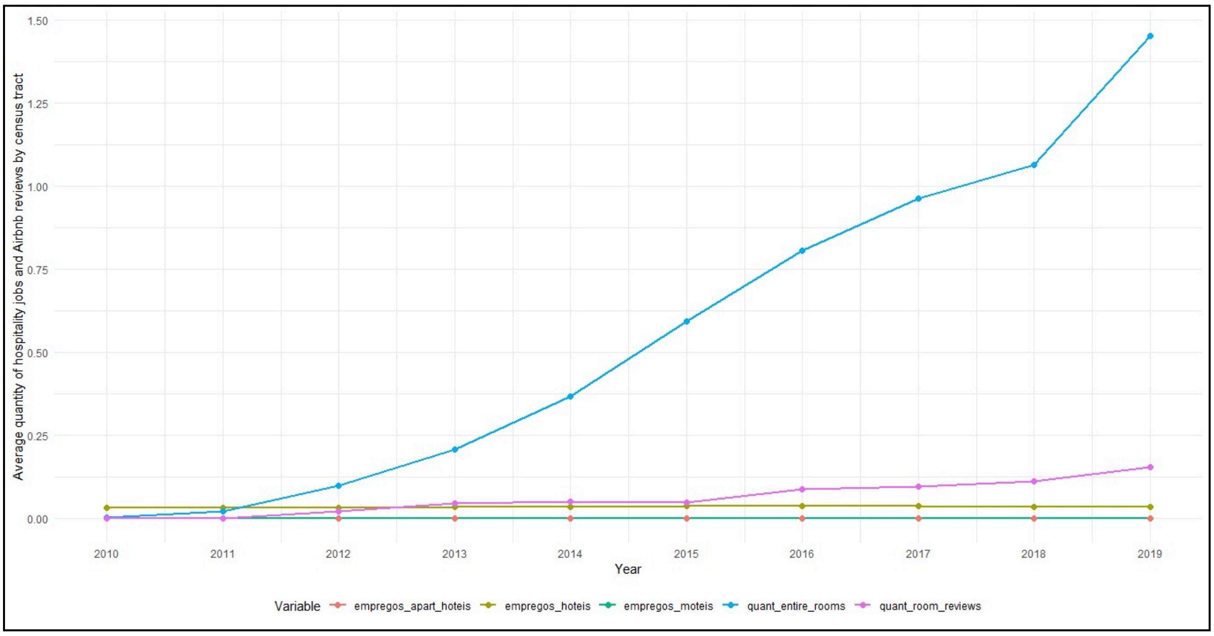
Notes: Each bar represents the coefficient of OLS estimates of the log of Jobs in the tourism-related sectors on the share of rented apartments at the census tract level and 95% confidence interval. Control variables are the percentage of college educated workers, the number of formal jobs, a dummy variable indicating whether the census tract's centroid was located within the 1 km euclidean distance of a rapid transit station, and neighborhood fixed effects. Standard errors are clustered at the neighborhood level.

Figure A2C - Exclusion restriction tests for the share of elderly population on jobs of tourism-related sectors.



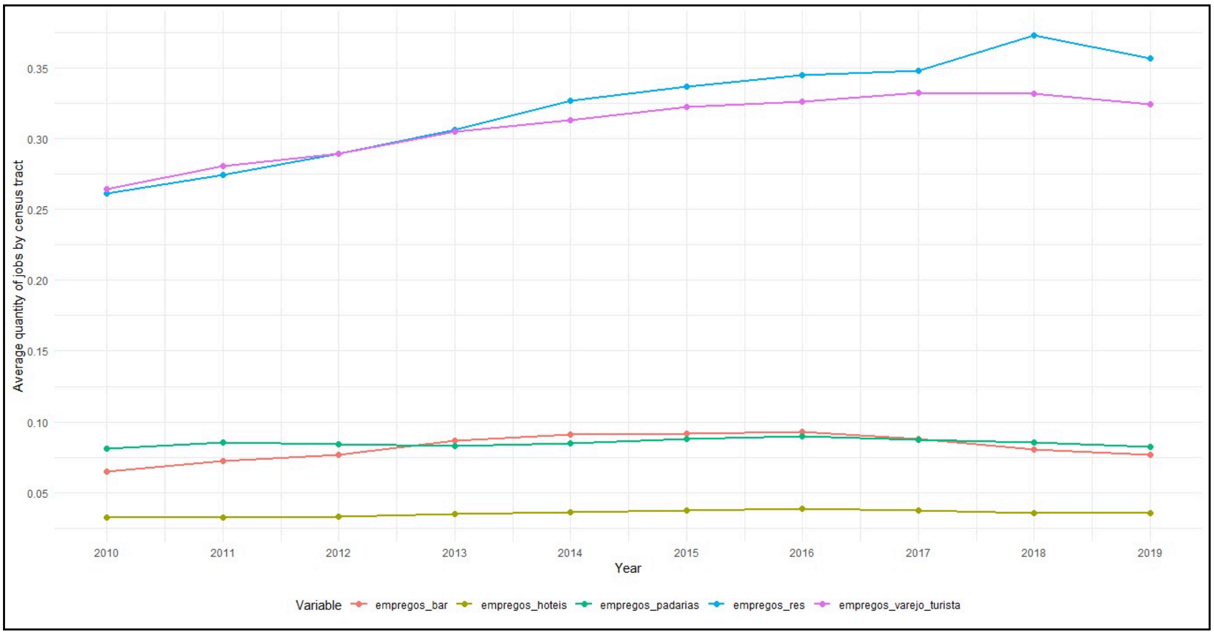
Note: Each bar represents the coefficient of OLS estimates of the log of Jobs in the tourism-related sectors on the share of elderly population at the census tract level and 95% confidence interval. Control variables are the percentage of college educated workers, the number of formal jobs, a dummy variable indicating whether the census tract's centroid was located within the 1 km euclidean distance of a rapid transit station, and neighborhood fixed effects. Standard errors are clustered at the neighborhood level.

Figure A3C - The trajectory of formal jobs in the hospitality sector over 2010-2019.



Notes: Author's own elaboration, from RAIS.

Figure A4C - The trajectory of formal jobs in the tourism-related service sectors over 2010-2019



Notes: Author's own elaboration, from RAIS.

Conclusions

This thesis examined how geographic proximity is economically valued in cities, providing a literature review on urban economics, urban planning, and transport geography, as well as empirical analyses in Brazil’s two largest metropolitan areas. The research explored the potential for spatial interactions within the urban structure across different dimensions, highlighting how the facilitation of such interactions influences the locational choices of households and economic activities.

Building on the economic rationale that spatial concentration emerges from the gains derived from the consumption of local amenities, the thesis focused on the interactions among temporary or permanent residences, jobs, and services, which are core determinants of both urban welfare and spatial configuration. Yet these amenities are unevenly distributed: places capable of meeting the demands of large populations are relatively scarce, leading to urban agglomeration.

Essay 1 deepened this debate by reviewing how the multiple determinants of residential and firm location and their productive interactions are discussed in urban economics and how it relates to spatial connectivity. In short, access is the key feature that determines household and firm (co)location choices, where the former consume environmental and service amenities, and the latter, externalities that facilitate sharing, matching and learning mechanisms. Insights from the urban planning and transport geography fields helped frame these agglomeration forces through the concept of accessibility (i.e., the potential for interaction with opportunities). We review empirical evidence from urban economics that reinforces the link between accessibility and urban markets, often showing that higher levels of the former are associated with increased land values, higher wages, and greater chances of employment. Thus, gravity-based accessibility indexes are a useful tool to empirically test theoretical urban models and detect agglomeration effects. However, this empirical framework does not necessarily capture actual choices of interaction between locations and typically rely on a narrow set of information to represent the distribution of urban amenities.

Spatial interaction models offer an advantage by estimating probabilities of interaction from observed choices, while discrete choice models provide a microeconomic foundation for these decisions under the assumption of utility maximization. The synthesis of agglomeration, spatial interaction, and discrete choice models has given rise to quantitative spatial models, which provide tractable theoretical models supported by high-resolution spatial data to predict how shocks in travel costs affect spatial equilibrium.

We further review how the QSM framework has spurred a growing literature demonstrating how public transit infrastructure investments shape household and firm location decisions, given the incentives for spatial interactions, thus reshaping the distribution of urban welfare. However, this literature could engage more with research in transportation and urban planning to balance the effects of shocks on travel costs on the welfare distribution with the competition to use the system, which leads to crowding and reduces agglomeration effects. Besides, the influence of non-work activities on spatial interaction could be addressed by more recent methods of transportation and urban planning and help enrich the information on spatial links between urban locations. On the other hand, the transportation and urban planning fields could use the sophisticated theories developed by economists to rationalize their predictions and assess further policy implications of public transit interventions.

Although promoting a rich cross-fertilized discussion among different knowledge fields, this literature review essay has a scope limited to topics related to urban agglomeration, access, and spatial interaction. Moreover, it does not develop or explore the mathematical properties of urban theoretical models, which must be considered when including some new features advocated to improve accuracy on observing spatial interactions. This is because such inclusions can affect the feasibility of computing the economic general equilibrium, and in some cases, result in multiple equilibrium and limit the predictions of welfare implication of counterfactual scenarios. Finally, QSM have a wide scope of investigations, including the housing market, firms allocation, place-based policies, trade policies, and etc. Our review on such models is limited to those that assess the shocks on transportation costs promoted by public transit expansions on welfare distributions at the city scale level.

To contribute further to understanding how enhancing convenience affects urban travel behavior, Essay 2 empirically investigated the effects of expanding the mass public transit network on travel behavior in the São Paulo Metropolitan Region between 2007 and 2017. The study employed fine grained spatial data on residential locations, job and educational opportunities, on the location of mass public transit stations, and the street network design. This allowed for a refined *station catchment area* approach that links urban form to travel behavior, predicting how increased accessibility to the transit system affects motorized modal share and trip flows.

The econometric models revealed that, among mass public transit modes, only the expansion of subway and trains increased the share of trips relative to car use, a pattern also observed in trip flows. The results suggest that, provided improvements in relative speed are achieved, strengthening the connection between densely populated areas and the transit network encourages greater public transit system usage. Furthermore, since trips are purpose-driven, the attractiveness of localities in terms of land-use configuration proved to be critical for promoting sustainable travel behavior.

Essay 2 faces limitations regarding causal identification and the temporal scope of analysis. The data does not allow us to understand if the increase of the percentage of population within station catchment areas is purely due to new transit stations or to sorting towards the proximity of the rapid transit system. Further, due to data limitations, our estimates of walking times assume individuals choose the closest rapid transit stations from the household and to the final destinations. Finally, we only observe a 10 year period change, from 2007 to 2017. Thus, these results must be carefully considered, especially due to the impact of COVID-19 of travel behavior on public transit systems worldwide.

Despite such limitations, our overall findings allow the interpretation that both public transit network expansion and urban land-use policies must be integrated in mobility planning through well connected systems and favouring greater population and opportunity densities around the system. These results are supported after we treat selection bias on our mode share analysis by using propensity matching score models, which balance our treatment and control sample's covariates and result in parallel trends. We also rationalize our findings of the heterogeneous impact on travel behavior across transit modes through a recent econometric approach to estimate travel time gap between public transit modes and private cars, with further placebo tests using unfinished rapid transit stations. Given the challenge for public transit to resiliate from the shocks on travel behavior due to COVID-19, the incentives for the use of public transit detected on this paper can shed light to policies that aim to incentivize more public transit usage, which we claim to be by reaching potential users.

This thesis further shows that, as with public transit access, other forms of urban amenity consumption require great convenience and geographic proximity. Demographic shifts in a given area can therefore reshape consumption patterns and the demand for specific services. Essay 3 explored how the spatial redistribution of tourists following the arrival of the short-term rental platform Airbnb affected the geography of formal employment in Rio de Janeiro between 2010 and 2019. Using highly disaggregated employment and sociodemographic data at fine spatial resolution, the study adopted a quasi-experimental econometric design with instrumental variables.

The findings suggest that agglomeration economies linked to Airbnb locations concentrate primarily in the gastronomy sector. Significant impacts were found on employment and wage levels in this sector, pointing to local economic benefits from proximity to tourists. By contrast, other sectors such as retail, bars, and hotels showed no significant response. Placebo tests conducted on non-tourism-related industries also indicated no measurable impact. Besides, all the results remain qualitatively the same when we use different data aggregation at 0.11 km hexagons.

The study provides the first evidence of Airbnb's economic effects in a city of a developing country using geographically detailed data, showing that, as in developed countries, the platform's spatial redistribution of tourists can raise local employment and income levels. It also brings a novel demographic-based shift-share instrument for the literature that assesses the impact of Airbnb activity: the share of elderly population, which presents theoretical and technical support to more specific analyses on bedroom supply (rather than entire housing space). This allows further understanding on the economic strength of Airbnb activity. It seems that, opposite to the entire listing, the lower travel budget of single bedroom guests isn't enough to exert an impact on restaurant employment.

The scope of Essay 3 leaves unanswered questions about broader economic impacts of the Airbnb platform, such as potential upward pressure on housing prices, despite the absence of negative effects on the traditional hotel sector. Besides, the study has limited assessment on the existence of spatial spillover effects among localities, although the fine spatial scale of our longitudinal data allows us to control for fixed effects and cluster the standard error of our estimates at the census tract level.

A further limitation of this study relies on the study period, which ranges from 2010 to 2019. It is of interest to understand whether the shocks of COVID-19 on the life expectancy of elderly population and on the rise of remote work further enhanced changes on local demographics and Airbnb dynamics, as well as its economic consequences. Additionally, the policy goal of the Mega-events in Rio de Janeiro to prompt a long term increase in the flow of tourists could change the magnitude of the impact on restaurants and also translate in economic gains to other sectors, such as bars and retail. However, these remain as hypotheses to be tested in future studies.

Individuals and cities face constraints in time and space, respectively, which give rise to economic dilemmas. Individuals weigh travel time when choosing destinations and compare time costs across transport modes when deciding how to travel. Tourists, in particular, have limited time during visits, which heightens the economic value of convenient access to essential services. This thesis examines how these dilemmas shape urban structure through individuals' joint decisions on residence and workplace locations, and through firms' incentives to locate near consumer markets. It also highlights how transportation and land-use conditions critically influence the co-location of economic agents, reflecting the interplay between the scarcity of time and space, and ultimately, the economic value of geographic proximity. Together, these relationships help explain urban agglomerations and the existence of cities.

Despite this thesis's contributions, several crucial avenues remain open for future research aimed at advancing our understanding of how better cities can emerge. As in economics more broadly, urban economics stands to benefit from deeper cross-fertilization with related spatial disciplines. It has become increasingly evident that urban models must consider factors beyond commuting time, which for decades dominated both theoretical and empirical work. Recent developments demonstrate a growing interest among economists in adopting more refined accessibility, spatial interaction, and travel choice models, drawing on sustained contributions from transportation and urban planning research that have introduced broader and more comprehensive indicators of incentives for interaction. The continued integration of urban economics with these related fields can be further strengthened by the expanding availability of spatially granular data.

Although agglomeration and crowding have long been central themes in urban and regional economics, empirical evidence on how congestion reduces the benefits of urban density remains relatively recent. For instance, one emerging topic concerns the long-term effects of the COVID-19 pandemic on public transit ridership worldwide, which are still insufficiently understood. The increasing use of smart card data offers valuable opportunities to quantify crowding within public transport systems and to advance understanding of service quality, travel behavior, and the spatial organization of urban mobility.

Moreover, integrating GPS data with General Transit Feed Specification (GTFS) information can support comparisons between scheduled and actual travel times across different periods of the day (e.g., peak versus off-peak hours), thereby offering deeper insights into system crowding. In addition, because large cities generate significant pollutant emissions from daily intra-urban travel, understanding how public transit policies can mitigate such impacts is of great importance. The effects of transit interventions on ridership may have consequential implications for CO_2 emissions, which should be systematically considered in future assessments to better inform policy design.

Economists should also engage with emerging approaches in the transportation field that emphasize how non-work activities influence travel and location choices within cities. Spatial radiation and tour-based models offer valuable complements to traditional frameworks such as spatial interaction and discrete choice models based on utility maximization. The growing availability of smartphone-based location data and more detailed travel surveys provides rich opportunities to capture these dynamics and to advance understanding of the role of non-work activities in shaping spatial behavior. Furthermore, these approaches may help address the lack of detailed information on spatial linkages between locations, which often introduces noise into counterfactual welfare estimates in QSM.

Relatedly, numerous spatial linkages between locations mediated by urban form remain underexplored. More pleasant and walkable streets can encourage individuals to adopt non-private modes of transport, such as walking and public transit, thereby fostering more sustainable transportation and land-use systems through improved spatial connectivity. The integration of granular spatial data with refined concepts of urban form developed in transportation and urban planning research can enhance economic analyses that capture these behavioral incentives, inform zoning and land-use policies, and support the creation of more sustainable built environments.

Finally, the long-term focus of the urban economics field on the location of households, jobs and transportation infrastructure have been challenged by recent disruptive platforms, which are affecting how individuals move, shop, and neighborhoods' demographics. In Brazil, mobility apps such as Uber and iFood have been competing with public transit systems and changing service-related land use dynamics. Moreover, such apps have been translating into job opportunities, thus challenging the classic urban structure mostly based on the spatial links between households and their respective work places. Thus, the effects of these apps on mobility patterns, land use and job market performance should be addressed in future studies.

The Airbnb platform has also been promoting disruption in cities, especially in those with great levels of tourism activity. Future studies could investigate the more broad economic effects of the activity of this platform, such as housing and labor markets and on land use. It should be of great interest to understand who are the winners and losers of short-term rental activities, especially in cities of developing countries with high economic inequality. An emerging literature has been using credit card data, information on the long-term housing market, and on the household and work location for locals to estimate the effects of Airbnb platforms on the spatial redistribution of urban amenities, as well as its repercussions on spatial equilibrium and distribution of welfare to locals. Alternatively, it is also worth investigating the economic linkages of such activities, as they may create spillover effects in different economic sectors. Thus, Input output analyses and computable general equilibrium models could help understanding further economic implications of Airbnb platform.

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