Distributional effects of transport policies on inequalities in access to opportunities in Rio de Janeiro

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ABSTRACT

The evaluation of the social impacts of transport policies is attracting growing attention in recent years. Yet, this literature is still predominately focused on developed countries. The goal of this research is to investigate how investments in public transport networks can reshape social and geographical inequalities in access to opportunities in a developing country, using the city of Rio de Janeiro (Brazil) as a case study. Recent mega-events, including the 2014 Football World Cup and the 2016 Olympic Games, have triggered substantial investment in the city’s transport system. More recently, though, bus services in Rio have been rationalized and reduced as a response to a fiscal crisis and a drop in passenger demand, giving a unique opportunity to look at the distributional effects this cycle of investment and disinvestment have had on peoples’ access to educational and employment opportunities. Based on a before-and-after comparison of Rio’s public transport network, this study uses a spatial regression model and cluster analysis to estimate how accessibility gains vary across different income groups and areas of the city between April 2014 and March 2017. The results show that recent cuts in service levels have offset the potential benefits of newly added public transport infrastructure in Rio. Average access by public transport to jobs and public high-schools decreased approximately 4% and 6% in the period, respectively. Nonetheless, wealthier areas had on average small but statistically significant higher gains in access to schools and job opportunities than poorer areas. These findings suggest that, contrary to the official discourses of transport legacy, recent transport policies in Rio have exacerbated rather than reduced socio-spatial inequalities in access to opportunities.

Keywords:
Equity, Accessibility, transport policy, Rio de Janeiro, distributive justice, Spatial scale

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1. Introduction

Researchers have long discussed the importance of transport policies in tackling social exclusion and improving people’s access to out-of-home activities (Kwan, 2000; Lucas, 2012; Van Wee & Geurs, 2011). In recent years, transport equity has been increasingly recognized as a crucial component of the sustainable mobility paradigm (Banister, 2008), attracting wider attention to the social impacts of transport policies. As a result, there has been a growing interest in the distributional effects of transport investments on socio-spatial inequalities in access to opportunities (Blair, Hine, & Bukhari, 2013; Bureau & Glachant, 2011; Foth, Manaugh, & El-Geneidy, 2013).

While many researchers and transport planners in developed countries are concerned with improving accessibility (Boisjoly & El-Geneidy, 2017; Papa, Silva, Brömmelstroet, & Hull, 2015) and equity (Karner & Niemeier, 2013; Manaugh, Badami, & El-Geneidy, 2015), these issues have received much less attention in the global south (Keeling, 2008; Vasconcellos, 2001). The literature on justice in transport policy is still predominately focused on developed countries in North America and Europe, with a few notable exceptions (Bocarejo & Oviedo H., 2012; Delmelle & Casas, 2012; Vermeiren et al., 2015).

The aim of this paper is to investigate the distributional effects of transport policies recently implemented in Rio de Janeiro (Brazil), looking specifically at how those policies have changed social and spatial inequalities in access to employment and educational opportunities in the city across different income groups. Several mega-events have been hosted in Rio in the past few years, such as the 2014 Football World Cup and the 2016 Olympic Games. These events triggered substantial investment in the city’s public transport infrastructure, including the expansion of a subway line, the construction of two new bus rapid transit (BRT) corridors and a light-rail system.

The infrastructure works associated with such events played a central role in the justification used by public authorities to host those mega-events (Kassens-Noor, Gaffney, Messina, & Phillips, 2016). According to Rio’s candidature files to host those events, those infrastructure projects would leave a positive legacy that would fast-track urban development and help improve transport conditions in the city, particularly for low-income people living in
deprived areas (BOC, 2009; Rio de Janeiro, 2008). However, it is not clear which income groups and areas of the city have benefited from that promised legacy because these projects were followed by a reorganization of many bus lines and by cuts in service levels in response to a drop in passenger demand (see section 2). Overall, these policies have brought significant changes to the city’s transport system in a relatively short period of time, giving a unique opportunity to assess its equity impacts on urban accessibility to various types of activities for different population groups.

This study estimates how access to public high-schools and formal jobs have changed for different income groups before and after the transport policies driven by mega-events in Rio de Janeiro (2014 and 2017). Employment and educational opportunities were chosen because of their central role for human development and in the reproduction of socioeconomic inequalities in society. In Brazil, public education is considered a basic constitutional right that should be accessible to all, regardless of personal income. Accessibility levels are calculated using geolocated timetables of Rio’s public transport organized in GTFS format combined with fine-grained sociodemographic data from the population census and geolocated data on schools and jobs. The spatial association between accessibility changes and household income per capita is tested using spatial regression and cluster analysis. The investigation is conducted using multiple geographical scales and zoning schemes to verify that results are robust to the modifiable area unit problem (MAUP), i.e. whether the conclusions of the evaluation change when the data is aggregated in space using different geographical scales and areal units.

The paper is organized as follows: Section 2 presents the study area of Rio de Janeiro and how its public transport network evolved between 2014 and 2017. Data and methods are presented in Section 3 and results presented in Section 4. Finally, Section 5 brings a discussion of the main conclusions about the case study of Rio and some lessons that can be drawn for future studies on the equity impacts of transport policies in other cities.
2. Literature Review – Transportation equity

Equity is a multidimensional concept and it has been addressed in the transport literature in relation to various issues such as environmental externalities (Schweitzer & Valenzuela, 2004), affordability (Eliasson, 2016; Farber, Bartholomew, Li, Páez, & Nurul Habib, 2014) and the fair distribution of benefits from transport investments and services (Delbosc & Currie, 2011; Foth et al., 2013). There is thus no standard definition of equity across studies that evaluate the social impacts of transport policies (Martens, Golub, & Robinson, 2012; Van Wee & Roeser, 2013).

There is, however, a growing consensus in both transport planning practice (Boisjoly & El-Geneidy, 2017; Manaugh et al., 2015) and in the academic literature (Pereira et al., 2017; Van Wee & Geurs, 2011) that improving people’s access to key destinations such as employment, healthcare, and educational opportunities should be among the primary goals of equitable transport policies; and moreover, that such policies should prioritize improving accessibility for disadvantaged groups such as the elderly, disabled and low-income people who are typically more dependent on public transport. This convergence in the literature derives from moral concerns related to the satisfaction of basic needs, the protection of disadvantaged groups and the reduction in inequalities of opportunities (Lucas et al., 2015; Pereira et al., 2017).

These moral concerns have been largely influenced by or are in line with the theory of justice as fairness proposed by John Rawls (Rawls, 1999, 2001). A core idea in this theory is that morally arbitrary factors such as being born with a physical disability, in a poor family or ethnic group should have no bearing on people’s life chances and opportunities. Rawls is particularly concerned with how institutions in society should be arranged in order to mitigate the negative effects those factors may have on people’s life chances and thus minimize inequalities of opportunities that arise from arbitrary circumstances to the benefit the better off groups and at the expense of the worse off.

While Rawls’ theory relates more directly to the definition of society’s basic institutions, it is this high-level definition that ultimately should serve as a reference against which the fairness of proposed laws and policies should be assessed (Rawls, 1999, pp. 174–175, 314–317). It has thus provided influential insights to assess equity in urban (Fainstein, 2010; McKay,
Murray, & Macintyre, 2012) and transport policies (Pereira et al., 2017; Van Wee & Geurs, 2011). From a Rawlsian perspective, for example, governmental investments on transport infrastructure and services can only be considered just if they benefit those disadvantaged groups whose transport experience is systematically undermined by unchosen personal traits and by the social circumstances into which they are born. The concern with social justice thus requires researchers to move beyond descriptive cross-sectional analysis of how different groups have different levels of access to opportunities towards a better understanding of what role governmental policies can play in reducing such inequalities (Pereira et al., 2017).

Another core idea in Rawls’ theory of justice is the absolute priority and inviolability of people’s basic rights and liberties such as the physical and psychological liberty and integrity of the person, freedom of thought, political liberties and the rights and liberties covered by the rule of law (Rawls, 2001, p. 44). Accordingly, no governmental policy can be considered fair if it violates these basic rights and liberties, even for the sake of general welfare. Although this idea might be more often embedded in the principles that guide transport policies in the developed world, it is much less so in countries in the global South, as the case of Rio de Janeiro illustrates.

3. Study area: Rio de Janeiro

Rio de Janeiro is one of the largest and richest cities in the global South and yet one of the most unequal (UN-HABITAT, 2010). In different ways, Rio is an exemplar of what more and more cities may become in the future, the result of rapid population growth coupled with stark socio-spatial inequalities and poor transport infrastructure where there is a strong increase in automobile use and dependence with all the negative externalities it creates (Ribeiro, 2014; UN HABITAT, 2013). Like many other cities in the global South, Rio has a history of uneven urban development marked by spatial segregation (Préteceille & Cardoso, 2008; Ribeiro, Rodrigues, & Corrêa, 2010) and an unequal distribution of public transport infrastructure (Câmara & Banister, 1993). Public transportation in Rio has been found to be among the most expensive in the world (UN HABITAT, 2013), with costs being particularly expensive if not prohibitive for lower-income classes (Table 1). Moreover, traffic conditions have been deteriorating over the past
decade, as reflected by the rise in average one-way commute time from 41.5 minutes in 2001 to 49.6 minutes in 2014 (Pereira & Schwanen, 2013).

Table 1. Affordability index of public transportation by income decile. Rio de Janeiro.

| Income Decile | Average household income per capita in R$ | Affordability index a | Integration between bus, BRT and light rail b | Integration between bus / BRT and train / subway c | Integration between subway and train d |
|---------------|------------------------------------------|-----------------------|---------------------------------------------|-------------------------------------------------|---------------------------------------|
| 1             | 448.0                                    | 43%                   | 94%                                         | 107%                                            |                                       |
| 2             | 732.3                                    | 26%                   | 57%                                         | 66%                                             |                                       |
| 3             | 989.1                                    | 19%                   | 42%                                         | 49%                                             |                                       |
| 4             | 621.8                                    | 31%                   | 68%                                         | 77%                                             |                                       |
| 5             | 847.4                                    | 23%                   | 50%                                         | 57%                                             |                                       |
| 6             | 532.8                                    | 36%                   | 79%                                         | 90%                                             |                                       |
| 7             | 1699.3                                   | 11%                   | 25%                                         | 28%                                             |                                       |
| 8             | 1217.5                                   | 16%                   | 34%                                         | 39%                                             |                                       |
| 9             | 2934.8                                   | 7%                    | 14%                                         | 16%                                             |                                       |
| 10            | 5448.9                                   | 4%                    | 8%                                          | 9%                                              |                                       |
| Average       | 1550.7                                   | 12%                   | 27%                                         | 31%                                             |                                       |

Source: Population Census 2010 (IBGE). Info on fare values come from https://www.cartaooriocard.com.br/rcc/institucional/tarifas, accessed on Sept. 2017
Notes: (a) percentage of income required to undertake 60 trips per month, Transport fares prices on September 2017: (b) R$3.2, (c) R$7, (d) R$8.

When the city of Rio bid to host the 2014 Football World Cup and the 2016 Olympic Games, one of the key motivations of public authorities was to use those mega-events to leverage urban development and improve the city’s transport conditions (Gaffney, 2010; Kassens-Noor et al., 2016; Silvestre, 2012). In preparation for the events, the city invested more than 4.5 billion dollars in its public transport system (Castro et al., 2015). Some of the most significant investments included the extension of a subway line, the construction of a light-rail system and two BRT corridors that together stretch approximately 108 kilometers across the city (see Figure 1). Along with this new infrastructure, local authorities have also reorganized many bus lines to streamline the transport system.

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1 Initial transportation plans for the 2016 Olympic Games also included the TransBrasil BRT corridor, which remains unfinished and construction works suspended as of the writing of this paper.
According to Rio’s candidature files to host the World Cup and the Olympics, the aim of those investments was to create a high-capacity transport ring connecting key areas in the city where most of the sports competitions would take place and, above all, to benefit “low-income workers, who live in the most distant neighborhoods and spend more time in traffic.” (Brazil, 2009, p. 54). Nonetheless, one year after the Olympics, these investments have already been widely criticized for being over-budgeted and involved in corruption investigations (Cuadros, 2016; Guimarães & Leitão, 2017; Sandy, 2016). Academics and grass roots movements have also claimed that those projects were elaborated with little social participation and transparency (Legroux, 2014; Sánchez & Broudehoux, 2013) and that many BRT stations present barriers to people with physical disabilities and poor integration with other transport modes (ITDP Brasil, 2014, 2015). Moreover, those investments involved the violation of human rights, with 2,125 families evicted from their homes between 2009 and 2015 to create space for transport infrastructure (CPCORJ, 2015; Gaffney, 2016; Rio de Janeiro, 2015). Despite the utilitarian discourse that those evictions were justifiable because the transport investments would bring...
large benefits to a great number of people, the violation of rights and the other issues mentioned are of central importance from a social justice point view and go explicitly against a Rawlsian conception of justice (Pereira et al., 2017). Although these issues are not addressed in this study, we recognize they would need to be considered in a comprehensive equity assessment of the transport legacy left by mega-events in Rio.

Another important equity issue to consider involves the distributional effects those investments have had in improving the transport conditions of different social groups in the city. While the official rhetoric proposed prioritizing low-income groups in line with the design of equitable transport policies (Lucas & Jones, 2012; Pereira et al., 2017; Van Wee & Geurs, 2011), the extent to which the investments have effectively improved the accessibility of low-income neighborhoods is a question that has received less attention and remains largely unanswered (Kassens-Noor et al., 2016; J. M. Rodrigues & Legroux, 2015).

More recently, a severe economic crisis led to a 70% cut in the budget of the secretary of transport (Magalhães & Rodrigues, 2017), which coupled with a drop in the number of passengers in the public transport system (França, 2016; R. Rodrigues, 2017) has led the government to adopt fiscal austerity measures that affected transport services. In total, 70 bus lines were eliminated, 41 lines were rerouted or shortened and 16 new bus lines were created (G1, 2017). These measures can potentially undermine the positive effects of the new transport investments and cast doubt on which socioeconomic groups and areas in the city have benefited from the accessibility changes brought about by this cycle of investment and disinvestment.

4. Methodology

Accessibility is understood broadly as the ease with which a person can reach places and opportunities from a given location in space and it results from the interaction between the transport system, land use patterns, and the various constraints of individuals (Van Wee & Geurs, 2011). This paper conducts a before-and-after comparison of Rio’s transport system to estimate the change in accessibility that resulted from recent policies implemented in Rio between 2014 and 2017. The purpose is to compare the effect of those policies on accessibility
changes for different social groups and areas of the city and analyze whether wealthier areas in 2010 have gained more accessibility than poorer ones. The method used in this study involved five secondary data sources and two main steps as detailed below.

4.1. Data Sources

Population count data comes from the 2010 Brazilian Census, organized in a regular grid of 200x200 meters (IBGE, 2016). The resident population in each grid cell was categorized according to income decile based on the average household income per capita of each grid cell. This was imputed from census data organized in 1,136 relatively homogeneous socioeconomic polygons known as Human Development Units (Ipea, UNPD, & FJP, 2015). The data on household income per capita collected in the census account for all members of the household and all their sources of income (including formal or informal jobs, unemployment benefits, pensions, social transfers, etc.). Although the census has some limitations in terms of capturing the upper extreme of income distribution (Souza, 2015), it is still the best data source to account for income distribution in Brazil. This method needs to be used with caution because it incurs ecological fallacies by disregarding socio-economic heterogeneity within Human Development Units.

Data on schools come from the School Census conducted by the Brazilian Ministry of Education, covering all of the 278 public high schools in the municipality of Rio de Janeiro in 2015. Data on formal jobs come from RAIS, a dataset organized by the Ministry of Labor and Employment. RAIS is a national register that brings the full address of all public and private institutions and the socioeconomic characteristics of their employees working in the formal labor market. In the year 2015, there were 2,914,238 formal workers employed in 227,362 institutions in Rio. In this database, workers are associated with the address of their respective workplaces. Exceptionally, some institutions with multiple offices (such as outsourcing firms or public secretaries of police, health and education) report all their employees to be working from the institution headquarters. Among the 50 largest employers in Rio, 17 institutions were found to do this and were removed from the analysis. The location of 83,589 employees working for the secretary of education could be recovered from the school census. In the end, a database
covering 92.3% of all formal workers in the city was used in the study. Both datasets on schools and jobs were geolocated using the full address information available in their respective datasets.

A limitation of this study is that it does not cover job opportunities in the informal labor market because there is no data source with the addresses of informal jobs. Although a significant share of workers in Rio work in the informal labor market (approximately 36% in January 2016), informal jobs are relatively more accessible with shorter commute times and distances than formal jobs (Motte-Baumvol et al., 2016), and it is reasonable to assume that formal jobs are generally preferable given the associated labor rights and social benefits. Moreover, the 2003 household travel survey of Rio shows that the numbers of formal and informal jobs in each traffic zone are correlated at 0.78 (Pearson correlation statistically significant at 0.001), suggesting that the spatial distribution of formal and informal jobs in the city are not radically different.

Spatial information on road network and pedestrian infrastructure comes from OpenStreetMap. Finally, we use data on the public transport network organized in General Transit Feed Specification (GTFS) format, as provided by Fetranspor (Federation of Passenger Transport Companies in Rio de Janeiro) for the months of April 2014 and March 2017. GTFS data provides detailed geolocated information of routes, stops and timetables of the public transport system.

In the before-and-after comparison of Rio’s transport network conducted in this paper, the spatial distribution of the population and its income distribution, as well as the location of schools and jobs were kept constant. This assumption allowed us to isolate the effect of the recent transport policies on the variations in accessibility levels between 2014 and 2017. This assumption obviously disregards changes in the spatial distribution of socio-economic groups and schools/jobs that may have occurred over the period, but previous research has shown that such phenomena are fairly stable over time in Rio, particularly over short timescales as the one used in the current analysis (Lago, 2000; Ribeiro, 2014); changes during the 2014–2017 period are thus highly unlikely to have significantly affected the overall results of the current analysis.

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2 Source: PNAD survey, available at [http://www.ipeadata.gov.br/](http://www.ipeadata.gov.br/)
4.2. Estimating Accessibility levels

A cumulative opportunity measure was used to estimate accessibility in terms of how many schools and job opportunities people could reach from their households via public transport and walking under 60 minutes. A growing number of transport agencies particularly in North America and Europe use similar accessibility analysis to compare the benefits of potential transportation investments and evaluate their social impacts (Boisjoly & El-Geneidy, 2017). In most cases, these agencies use accessibility measures based on cumulative opportunities with time thresholds that vary between 30 and 60 minutes (ibid.). In this study, a threshold of 60 minutes was used given that Rio has relatively higher commute times when compared to international metropolitan areas (Pereira & Schwanen, 2013). Some advantages of this type of accessibility measure are that it does not require prior information about people’s travel behavior, it is computationally inexpensive to calculate and it produces results that are easy to communicate to policy makers and stakeholders. This measure has limitations, though, since it assumes that all opportunities are equally desirable, regardless of the time spent on travelling; it does not take competition effects into account and it involves the selection of an arbitrary cut-off travel time (Geurs & van Wee, 2004).

Spatial analyses like the one conducted in this study can be sensitive to the ad-hoc ways in which data are aggregated in space according to different geographical scales and zonal schemes such as census tracts or traffic analysis zones (Apparicio, Abdelmajid, Riva, & Shearmur, 2008; Kwan & Weber, 2008). This is known in the literature as the modifiable areal unit problem (MAUP) and its effects have been widely documented in the urban and transport literature where, in many occasions, the conclusions of an analysis and subsequent policy recommendations can be significantly different depending on the spatial scale and shape of areal units employed (Liao, Hsueh-Sheng, & Tsou, 2009; Omer, 2006; Tan & Samsudin, 2017). Following the recommendation of previous studies (Horner & Murray, 2004; Páez & Scott, 2005), the analysis in this paper was conducted using multiple spatial scales and zoning schemes in order to test whether the results found are robust to MAUP and not a simple artefact of the ways in which data are arranged in space.

As a first step for the accessibility analysis, the municipality of Rio was divided using hexagonal grids of four different sizes, 500 meters, 1km, 2km and 4km and the traffic zones of
Rio’s latest household travel survey of 2013. Following the recommendation of Stepniak and Jacobs-Crisioni (2017), the population-weighted centroids of each polygon were used as origin and destinations in order to minimize aggregation errors. Next, OpenTripPlanner\(^3\) was used to estimate various travel-time matrices by public transport and/or walking between every pair of zone centroids for each spatial grid. We used a uniform sample of departure times, calculating departures every 20 minutes between 7am and 7pm for a total of 36 departure times in that period. These travel-time matrices grasp door-to-door estimates that consider temporal variations in public transport services and incorporate walking time from the point of origin to the transit stop, waiting time for the vehicle, actual travel time through the transport network and eventual transfers, and the walking time from the transit stop to the final destination. To test whether the results are robust to the modifiable areal unit problem, both accessibility estimates and spatial analysis were conducted separately for each hexagonal grid and traffic zone level.

Next, these travel-time matrices are combined with the geolocated data on population, school and jobs. Based on equation (1), we calculated the median number of opportunities (schools or jobs) that can be accessed from each grid cell via public transport in under 60 minutes across the 36 travel-time matrices for each year (2014 and 2017). In order to account for a qualitative match between socioeconomic levels of workers and jobs, estimates of access to jobs were based on an assumption of a proxy match between household income and educational qualification of jobs. For residents in households above the 5th income decile, accessibility estimates only considered employment opportunities that required high or secondary education, while for households below the 5th income decile only jobs that required secondary or primary education were considered.

\[
A_{o,i,T} = \text{median} \left( \sum_{o=1}^{n} P_d \cdot f(t_{odr}) \right) \quad (1)
\]

\[
f(t_{odr}) = \begin{cases} 
1 & \text{if } t_{odr} \leq T \\
0 & \text{if } t_{odr} > T 
\end{cases}
\]

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\(^3\) OpenTripPlanner is an open-source multimodal trip planner available at [https://github.com/opentripplanner/OpenTripPlanner](https://github.com/opentripplanner/OpenTripPlanner)
Where:

- $A_{o,T}$ is the accessibility level at origin $o$ for population of income $i$ within time threshold $T$.
- $P_d$ is the number of opportunities (e.g., jobs or schools) in location $d$.
- $t_{o,d,r}$ is the travel time in minutes between origin $o$ and destination $d$ at departure time $r$.
- $f(t_{o,d,r})$ is a time threshold function that varies between one and zero, depending on whether travel time ($t_{o,d,r}$) is larger or smaller than time threshold $T$.

It is likely that the positive accessibility gains brought about by the new infrastructure investments in Rio have been offset by the reorganization of the bus lines and also by the austerity measures adopted including the reduction of service levels in some areas of the city. In order to measure what would have been the sole effect of the new transport investments, we have also estimated accessibility changes in a quasi-counterfactual scenario. This scenario assumes all public transport services provided in April 2014 would have been kept constant, so the only changes to Rio’s public transport system would have been the addition of the new infrastructure, i.e., the BRTs Transcarioca and Transolímpica and the new subway and light-rail lines.

Due to data availability constraints, the accessibility analysis deployed in this study has not considered issues related to affordability, safety, age, gender or disability. It is widely documented in the literature how transport disadvantages related to these issues can hinder people’s ability to use public transportation, particularly among low-income groups (Casas, 2007; El-Geneidy et al., 2016; Ryan, Wretstrand, & Schmidt, 2015). By not considering these issues the analysis conducted in this study is likely to underestimate accessibility inequalities between high- and low-income groups.

### 4.3. Analyzing association between income and accessibility change

The final step was to statistically test the association between average household income per capita and the accessibility variation that occurred between 2014 and 2017. It is well-known that many social, transport and land use processes are spatially dependent in the sense that the characteristics of a location are related to its neighboring areas (Páez & Scott, 2005). Similarly, the transport accessibility level of one location is affected by the characteristics of the transport system and land use in nearby areas. Although this issue has generally been overlooked by previous studies that evaluate the impacts of transport policies, spatial dependence in the data
violates basic assumptions of conventional statistical analysis and leads to “information loss, biased and/or inefficient parameters and the possibility of seriously flawed conclusions and policy prescriptions” (Páez & Scott, 2005, p. 55).

In order to control for spatial autocorrelation in the data, a spatial regression model was used to estimate whether wealthier areas in 2010 were able to attract more accessibility gains from the transport policies implemented in Rio between 2014 and 2017.

The baseline model without spatial effects is written as:

$$\log(R_{io}) = \beta_0 + \beta_1 \log(I_i) + \beta_2 \log(P_i) + \beta_3 \log(O_{o_i}) + \beta_4 \log(E_i) + \epsilon_i$$  \hspace{1cm} (2)

$$R_{io} = \frac{A_{io}^{2017}}{A_{io}^{2014}}$$

Where:

- $R_{io}$ is the relative change in accessibility level from polygon $i$ to opportunities of type $o$ between 2014 and 2017
- $A_{io}^{2017}$ is the number of opportunities of type $o$ that could be accessed from origin $i$ under travel-time threshold $T$ in the year 2017
- $o$ opportunities of type jobs or schools
- $I_i$ is the average household income per capita in polygon $i$
- $P_i$ is the population density in polygon $i$
- $O_{io}$ is the density of jobs or number of schools in polygon $i$
- $E_i$ is the average terrain elevation in meters of polygon $i$

Variation in accessibility was measured as the ratio between accessibility levels in 2017 and 2014. This approach means that changes in accessibility have proportionally lower impact in those areas that already had higher accessibility in 2014, in line with decreasing marginal returns. In other words, it implies that for a person living in an area with access to 100 jobs, an increase of, for example, 50 jobs adds more to this person’s utility than for a person who already had access to a 1000 jobs.

The spatial dependence underlying the baseline model was evaluated following standard methods used in the literature (Elhorst, 2010; LeSage, 2008), which indicated a spatial lag regression to be the most appropriate model. The specification of this type of model assumes
there is a spatial dependence in the dependent variable. In our case, it assumes that the gain in accessibility in a polygon is associated to the accessibility gains in its neighboring polygons. Polygons were defined as neighbors if they share at least one boundary point using a standard queen contiguity matrix.

This spatial lag model calculates the average global spatial association between income and changes in accessibility for the entire city. Nonetheless, it is possible that the strength and direction of this association may vary across space. To complement the global analysis, we also estimate the local correlation between those two variables using the local indicator of spatial association (LISA). The bivariate LISA analysis is an extension of its univariate version (Anselin, Syabri, & Smirnov, 2002) and it measures the correlation between one variable in an area and the average of another variable in its neighbors. In practice, this analysis is a useful technique to identify clusters of areas with high and low income that gained and lost access to opportunities. For this local correlation measure, a queen contiguity matrix was used to define neighboring areas. Pseudo p-values were estimated with a thousand random simulations in each round.

5. Results

5.1. Descriptive Results

Figure 2 presents the spatial distribution of income groups in the city of Rio according to different spatial scales and zoning schemes. It shows how lower-income families are mainly located in the north and particularly northwest areas of Rio while higher-income groups live mainly along the coast in the southwest close to the city center where most of the economic activity is concentrated. This figure also illustrates how spatial analysis at coarser resolutions can lead to information loss. With the aggregation of household income per capita one loses valuable detail regarding the spatial heterogeneity of the data and, in the most extreme cases, the income decile classification of some areas change from poor to rich and vice-versa.
Source: 2010 Population Census (IBGE). Note: white areas in the municipality of Rio represent polygons with no population, jobs nor schools.

**Figure 2. Spatial distribution of population classified by deciles of household income per capita. Rio de Janeiro, 2010.**

The next two figures illustrate for the year 2017 how median access to formal jobs and public schools by public transport varies substantially across space. For both types of opportunities, it becomes clear that accessibility levels are greater along the train and subway lines and part of the new Transcarioca BRT line. These figures also draw attention to the way spatial inequalities in accessibility are largely shaped by the unequal distribution of land use activities. The historical development of Rio, with high concentration of employment opportunities close to the city center helps explain, for example, why residents in the west region of the city have such low levels of access to opportunities. To some extent, this issue has been
minimized by the spatial planning of public schools, which has been relatively successful in allocating public high-schools more evenly across Rio. Moreover, these figures also show how spatial analyses at a higher resolution allows for accessibility estimates with more spatial detail, making the influence of transport corridors on spatial accessibility more visible.

FIGURE 3. Median proportion of formal jobs accessible within 1 hour by public transport and walking between 7am and 7pm. Rio de Janeiro, 2017
A crucial issue to consider from a social justice point of view is not only the level of inequality in access to opportunities but more importantly to what extent new policies contribute to reducing such inequalities, particularly by improving the access of lower-income groups. Figures 5 and 6 compare for each scale of analysis how the number of jobs and schools accessible have changed between 2014 (horizontal axis) and 2017 (vertical axis). In these figures, each dot represents a grid cell where dot size varies according to population size and color indicates its income classification. Dots located above the diagonal line have seen an improvement in accessibility by public transport.
FIGURE 5. Proportion of formal jobs accessible from each grid cell via public transport and walking under 1 hour in the years 2014 (X axis) and 2017 (Y axis). Rio de Janeiro.
FIGURE 6. Proportion of public high-schools accessible from each grid cell via public transport and walking under 1 hour in the years 2014 (X axis) and 2017 (Y axis). Rio de Janeiro.

From a simple visual analysis, these results look consistent across different spatial scales and zoning schemes, and suggest that the recent policies implemented in Rio had a limited and
ambiguous impact on people’s access to employment and educational opportunities. Average access to jobs and schools under 60 minutes dropped approximately -4.5% and -6.1% between 2014 and 2017 in the city of Rio. For those areas from which people already had access to between 20% and 50% of all jobs in the city, the transport policies had more substantial effects both positively and negatively as seen with various dots distributed above and below the diagonal line. This is somewhat expected given that most of the changes to the network have occurred in areas which were already better connected in 2014. Regarding access to schools, there are substantially more dots below the line, reflecting that access to schools has been affected more adversely than job access by the policies implemented (figure 6).

5.2. Global association between income and accessibility change

An important component of an equity evaluation of the policies implemented in Rio requires the identification of those income groups in the city that have benefited the most from the recent cycle of transport investments and disinvestments. Although a simple visual analysis of Figures 5 and 6 suggests that most gains in access to jobs and schools have accrued to richer areas (shown in blue), the answer to this question demands a more robust statistical analysis.

Tables 2 and 3 report the estimation results of the spatial lag regression model, measuring how changes in access to jobs/schools between 2014 and 2017 are associated with household income per capita in 2010. The results show a small but positive association between income and variation in access to opportunities. However, both the strength and statistical significance of this association vary across multiple spatial scales and zonings. Using 0.5 km hexagonal grid, for example, a 1% higher income is associated with an increase of 0.01% in the number of schools accessible by public transport. This effect is substantially larger when the analysis is conducted based on traffic zones – seven times larger, 0.07% – and 2 Km hexagonal grid, six times larger 0.06% (table 2). These results are similar in magnitude when analyzing the changes in access to job opportunities (table 3), although the latter are only statistically significant for the analysis based on 0.5 km and traffic zones. For both jobs and school opportunities, the spatial lag was not statistically significant when using the hexagonal grid of 4km. The statistical significance of the control variables used in the model also varied in an inconsistent way. Nonetheless, the direction of the associations shows that recent policies in Rio had on average larger accessibility benefits.
in those areas with higher population and job densities, and lower accessibility gains in communities located on hilly areas.

Table 2. Coefficients estimates of spatial lag model for various scales and zoning schemes showing association with gains in access to public high-schools.

| Dependent Variable: log(ratio) | 0.5 Km   | 1 Km    | 2 Km    | 4 Km    | Traffic Zones |
|--------------------------------|----------|---------|---------|---------|---------------|
| (Intercept)                    | -0.15*** | -0.27** | -0.73** | -1.74** | -1.04***      |
|                                | (0.03)   | (0.10)  | (0.27)  | (0.56)  | (0.23)        |
| log(income)                    | 0.01*    | 0.03*   | 0.07*   | 0.18*   | 0.06*         |
|                                | (0.00)   | (0.01)  | (0.03)  | (0.07)  | (0.02)        |
| log(pop.dens)                  | 0.01***  | 0.01    | 0.03    | 0.02    | 0.08***       |
|                                | (0.00)   | (0.01)  | (0.02)  | (0.03)  | (0.01)        |
| I(schools)                     | -0.00    | 0.00    | 0.02    | 0.00    | -0.01         |
|                                | (0.01)   | (0.02)  | (0.02)  | (0.01)  | (0.02)        |
| log(elevation)                 | -0.01*   | -0.01   | -0.04   | 0.05    | -0.05**       |
|                                | (0.00)   | (0.01)  | (0.02)  | (0.04)  | (0.02)        |
| Rho (spatial lag)              | 0.89***  | 0.78*** | 0.54*** | 0.01    | 0.58***       |
|                                | (0.01)   | (0.02)  | (0.06)  | (0.14)  | (0.05)        |
| Num. obs.                      | 3485     | 1068    | 313     | 96      | 390           |
| Parameters                     | 7        | 7       | 7       | 7       | 7             |
| Log Likelihood                 | 286.73   | -344.09 | -177.93 | -59.43  | -133.74       |
| AIC (Linear model)             | 4183.90  | 1415.29 | 427.96  | 130.87  | 369.31        |
| AIC (Spatial model)            | -559.46  | 702.19  | 369.87  | 132.87  | 281.48        |
| Pseudo R²                      | 0.76     | 0.52    | 0.27    | 0.10    | 0.34          |
| LR test: statistic             | 4745.36  | 715.11  | 60.09   | 0.00    | 89.83         |
| LR test: p-value               | 0.00     | 0.00    | 0.00    | 0.97    | 0.00          |

Notes: AIC, Akaike information criterion. Standard errors are in parentheses; ***p < 0.001, **p < 0.01, *p < 0.05
Table 3. Coefficients estimates of spatial lag model for various scales and zoning schemes showing association with gains in access to formal jobs.

| Dependent Variable: log(ratio) | 0.5 Km | 1 Km | 2 Km | 4 Km | Traffic Zones |
|-------------------------------|-------|------|------|------|--------------|
| (Intercept)                   | -0.11* | -0.23* | -0.70* | -1.82* | -1.06***     |
|                               | (0.04) | (0.11) | (0.29) | (0.84) | (0.20)       |
| log(income)                   | 0.01*  | 0.02  | 0.06  | 0.19  | 0.07**       |
|                               | (0.00) | (0.01) | (0.04) | (0.12) | (0.02)       |
| log(pop.dens)                 | 0.00   | 0.00  | -0.00 | 0.04  | 0.05***      |
|                               | (0.00) | (0.01) | (0.02) | (0.05) | (0.01)       |
| log(job.dens)                 | 0.00   | 0.01**| 0.03***| 0.03  | 0.02*        |
|                               | (0.00) | (0.00) | (0.01) | (0.04) | (0.01)       |
| log(elevation)                | -0.01  | -0.01 | 0.00  | -0.08 | -0.01        |
|                               | (0.00) | (0.01) | (0.02) | (0.06) | (0.02)       |
| Rho (spatial lag)             | 0.89***| 0.78***| 0.50***| -0.25 | 0.57***      |
|                               | (0.01) | (0.02) | (0.06) | (0.15) | (0.05)       |

| Num. obs.                     | 3580 | 1109 | 335  | 104  | 397          |
| Parameters                    | 7    | 7    | 7    | 7    | 7            |
| Log Likelihood                | 602.85 | -318.29 | -213.09 | -120.15 | -89.80      |
| AIC (Linear model)            | 3912.16 | 1407.14 | 498.14 | 254.73 | 281.09      |
| AIC (Spatial model)           | -1191.71 | 650.58 | 440.19 | 254.30 | 193.61      |
| Pseudo R2                     | 0.78  | 0.55  | 0.30  | 0.09  | 0.35         |
| LR test: statistic            | 5105.87 | 758.56 | 59.96  | 2.43  | 89.48        |
| LR test: p-value              | 0.00  | 0.00  | 0.00  | 0.12  | 0.00         |

**Notes:** AIC, Akaike information criterion. Standard errors are in parentheses; ***p < 0.001, **p < 0.01, *p < 0.05

Using a quasi-counterfactual scenario to isolate what would have been the sole effect of the new infrastructure investments, the analysis shows that between 2014 and 2017 average access to jobs and schools would have increased approximately 13.4% and 11.7% respectively. The results of the spatial lag regression model under this scenario (Tables 4 and 5) indicate that the magnitude of the coefficients do not change much but they do get more statistically significant for all spatial scales except for traffic zones, for which coefficients lose significance. These findings suggest that the rationalization of bus lines and recent cuts in service levels have played an important role in offsetting the positive impacts of the new transport infrastructure. Moreover, it also shows that even if there had been no reorganization of bus lines and austerity measures, wealthy areas in the city would still have benefited more from the new transport infrastructure than poor areas.
Finally, spatial regression analyses show that the direction of the relationship between income and accessibility change remains the same across spatial scale and zoning schemes. However, the magnitude and statistical significance of results are sensitive to the spatial scale and zoning scheme of choice. Ideally, the conclusions of policy evaluations should not be dependent on the ad-hoc ways in which the data are spatially aggregated (Kwan & Weber, 2008). This stability in the results is not observed in Rio and this case study illustrates the importance of using sensitivity analysis in the evaluation of transport policies. It is worth mentioning, though, that according to Log Likelihood and AIC tests (Tables 1 and 2), the regressions conducted using hexagonal grid of 0.5 km and traffic zones had the best fit to the data, showing to be more appropriate for the spatial analysis.

Table 4. Coefficients estimates of spatial lag model for various scales and zoning schemes showing association with gains in access to public high-schools in quasi-counterfactual scenario.

| Dependent Variable: log(ratio) | 0.5 Km | 1 Km | 2 Km | 4 Km | Traffic Zones |
|--------------------------------|--------|------|------|------|--------------|
| (Intercept)                    | -0.05**| -0.11**| -0.28*| -0.60*| -0.06       |
|                                | (0.02) | (0.04) | (0.11) | (0.29) | (0.12)       |
| log(income)                    | 0.01***| 0.01*| 0.05***| 0.07| 0.01         |
|                                | (0.00) | (0.01) | (0.01) | (0.04) | (0.01)       |
| log(pop.dens)                  | 0.00   | 0.01*| 0.00   | 0.03 | 0.01         |
|                                | (0.00) | (0.00) | (0.01) | (0.02) | (0.01)       |
| log(job.dens)                  | -0.00  | -0.01| 0.00   | -0.01| -0.01        |
|                                | (0.01) | (0.01) | (0.01) | (0.01) | (0.01)       |
| log(elevation)                 | -0.00  | -0.00| -0.02  | 0.00 | -0.01        |
|                                | (0.00) | (0.00) | (0.01) | (0.02) | (0.01)       |
| Rho (spatial lag)              | 0.86***| 0.76***| 0.62***| -0.09| 0.73***       |
|                                | (0.01) | (0.02) | (0.05) | (0.15) | (0.04)       |
| Num. obs.                      | 3546   | 1087 | 322   | 98   | 391          |
| Parameters                     | 7      | 7    | 7     | 7    | 7            |
| Log Likelihood                 | 2830.23| 616.64| 86.98 | -1.80| 91.00        |
| AIC (Linear model)             | -1657.29| -530.25| -63.98| 15.98| 26.23        |
| AIC (Spatial model)            | -5646.46| -1219.29| -159.95| 17.61| -168.00      |
| Pseudo R2                      | 0.69   | 0.50 | 0.36  | 0.05 | 0.43         |
| LR test: statistic             | 3991.17| 691.04| 97.98 | 0.37 | 196.23       |
| LR test: p-value               | 0.00   | 0.00 | 0.00  | 0.54 | 0.00         |

Notes: AIC, Akaike information criterion. Standard errors are in parentheses; ***p < 0.001, **p < 0.01, *p < 0.05
Table 5. Coefficients estimates of spatial lag model for various scales and zoning schemes showing association with gains in access to formal jobs in quasi-counterfactual scenario.

| Dependent Variable: log(ratio) | 0.5 Km | 1 Km  | 2 Km  | 4 Km  | Traffic Zones |
|--------------------------------|--------|-------|-------|-------|---------------|
| (Intercept)                    | -0.05**| -0.11*| -0.26*| -0.42 | -0.13         |
|                               | (0.02) | (0.04)| (0.11)| (0.33)| (0.11)        |
| log(income)                    | 0.01** | 0.01* | 0.04**| 0.05  | 0.02          |
|                               | (0.00) | (0.01)| (0.01)| (0.05)| (0.01)        |
| log(pop.dens)                  | 0.00   | 0.00  | 0.01  | 0.00  | 0.01          |
|                               | (0.00) | (0.00)| (0.01)| (0.02)| (0.01)        |
| log(job.dens)                  | 0.00   | 0.00  | -0.00 | 0.01  | -0.00         |
|                               | (0.00) | (0.00)| (0.00)| (0.01)| (0.01)        |
| log(elevation)                 | 0.00   | -0.00 | -0.01 | 0.01  | -0.01         |
|                               | (0.00) | (0.00)| (0.01)| (0.03)| (0.01)        |
| Rho (spatial lag)              | 0.90***| 0.80***| 0.68***| -0.03  | 0.73***       |
|                               | (0.01) | (0.02)| (0.05)| (0.15)| (0.04)        |
| Num. obs.                      | 3580   | 1109  | 335   | 104   | 397           |
| Parameters                     | 7      | 7     | 7     | 7     | 7             |
| Log Likelihood                 | 3467.41| 673.08| 92.79 | -23.43| 95.49         |
| AIC (Linear model)             | -1923.53| -425.83| -28.58| 58.90 | 10.29         |
| AIC (Spatial model)            | -6920.82| -1332.15| -171.59| 60.85 | -176.97       |
| Pseudo R2                      | 0.77   | 0.60  | 0.41  | 0.03  | 0.40          |
| LR test: statistic             | 4999.28| 908.32| 145.01| 0.04  | 189.27        |
| LR test: p-value               | 0.00   | 0.00  | 0.00  | 0.84  | 0.00          |

Notes: AIC, Akaike information criterion. Standard errors are in parentheses; ***p < 0.001, **p < 0.01, *p < 0.05

5.3. Local association between income and accessibility change

While, the spatial lag model gives global results for the entire city, it is important to identify which areas in Rio gained or lost access to opportunities, and how the association between accessibility gains and income varies across space. Figures 7 and 8 show bivariate cluster maps of the local association between household income per capita and the variation in access to jobs and schools observed between 2014 and 2017. Spatial clusters colored light-green are the sweet spot from a transport equity point of view as they represent areas of relatively lower income population that had relatively higher accessibility gains. In contrast, red clusters show locations
where higher accessibility gains accrued to higher-income groups. Darker green areas are also problematic as they represent clusters of low-income areas which lost accessibility in the period. This high/low classification of clusters is defined based on the mean of each variable.

The cluster analysis shows for example how the new light-rail system in the city center had little effect on people’s access to schools and jobs. This is partially explained by its small network which is still not properly connected to the rest of the public transport system. On the other hand, the new subway line in the south has mostly improved access to opportunities for higher-income groups (red clusters). The analyses at higher resolution (0.5km, 1km and traffic zones), nonetheless, indicate that the new subway line has also improved accessibility levels of two poor favelas, Vidigal and Rocinha shown in light green. Again, the results demonstrate how analyses at coarse scales lead to information loss and potential issues of ecological fallacy and aggregation error.

Furthermore, there are a few clusters of both high- and low-income people that have gained access due to the new Transcarioca BRT line and its connection to the subway line. The Transolímpica BRT, on the other hand, has had no significant effect on people’s access to either schools or employment opportunities. This is closely related to the fact that the passenger demand in Transolímpica is only at 41% of the demand originally projected for the investment, which has led the company that runs this corridor to close some stations (Magalhães & Rodrigues, 2017). Finally, there are various clusters of low income areas that experienced a decrease in accessibility in the urban fringes in the west region of the city. This likely the result of worsening traffic conditions combined with service cuts in those areas.
FIGURE 7. Bivariate LISA based spatial clusters showing the local association between average household income per capita and gains in access to formal job opportunities by public transport between 2014 and 2017. Rio de Janeiro.
FIGURE 8. Bivariate LISA based spatial clusters showing the local association between average household income per capita and gains in access to public high-schools by public transport between 2014 and 2017. Rio de Janeiro.
6. Conclusion

This paper has evaluated, on multiple spatial scales, the public transport policies recently implemented in Rio de Janeiro to assess their distributional effects on people’s access to schools and employment opportunities. Overall, the results show that infrastructure investments related to the 2014 World Cup and the 2016 Olympic Games, combined with cuts in service levels were followed by a small loss in average accessibility levels in Rio. A quasi-counterfactual analysis indicates that the reorganization of bus lines and reduction in services have offset the potential benefits of new transport infrastructure and were just as important as the new investments in reshaping accessibility levels. Moreover, the results show that the areas which were wealthier in 2010 had on average small but statistically significant higher gains in access to opportunities between 2014 and 2017 than poorer areas. Contrary to the official discourses of transport legacy, there has been little accessibility improvement in the most deprived areas, which are doubly disadvantaged with low income and low accessibility.

It is unrealistic to demand that new transport investments equally benefit every neighborhood in a city. From a social justice point of view, however, the least one would expect is that such governmental policies would improve the transport conditions of people in the worst situations and not reinforce inequality (Pereira et al., 2017). Nonetheless, the findings of this study indicate that the transport legacy of recent mega-events in Rio are in direct conflict with the Rawlsian principles of justice. If anything, these policies have violated basic rights with the forced eviction of families and further exacerbated socio-spatial inequalities in access to employment and educational opportunities.

The case of Rio exemplifies how the uneven nature of urban and transport development tends to create place-based advantages for higher income groups that are hard to tackle even with large infrastructure investments. Reducing socio-spatial inequalities in people’s access to opportunities is a challenging long-term task which can only have limited results without a full integration between transport and land use planning. The findings of this study are specific to this case study of Rio and how recent policies interacted with the city’s spatial patterning of land-use and social classes. Nonetheless, the austerity measures adopted in Rio’s public transport systems might resonate well with the experience of local authorities elsewhere, particularly in developing countries, which have to invest and manage their transport systems under severe
budgetary constraints. Moreover, the method used in this paper relies mostly on datasets that are organized in standardized formats and commonly available for different cities in the world, allowing for the replicability of this research method to transport projects in other urban contexts.

As an advance from previous studies that analyze the social effects of transport policies, this paper has taken spatial autocorrelation and the modifiable areal unit problem (MAUP) into account. It has shown that the conclusions of the equity assessment of recent policies in Rio can vary depending on the spatial scale and aerial units of analysis. While the direction of the association between accessibility gains and income remains positive in every analysis, the magnitude and statistical significance of this association changed considerably when using different spatial schemes. This finding reinforces the importance of sensitivity analysis in this type of evaluation. It also shows how the analysis based on traffic zones captured the geography of poverty and wealth and its relation to uneven access to opportunities. The statistical tests indicated that the 05. Km grid and the traffic zones were best attuned to capture the socio-spatial differences of the changes in accessibility brought about by recent policies. However, it is unclear whether these spatial scales and zonings would still be appropriate if one used different regression specifications or measured accessibility differently. It may well be possible that there are particular scales that are more or less appropriate for different types of activities – such as local grocery stores or healthcare services.

This paper has focused on physical accessibility and its limitations need careful attention in future studies. The analysis of access to employment opportunities does not consider jobs in the informal labor market, an issue that may be particularly important in other cities in the Global South given the size of the gray economy in these cities. Secondly, this analysis has not considered the influence of personal characteristics such as physical disabilities, age or gender and how they can hinder people’s ability to use public transportation. As noted in section 2, the question of affordability is particularly relevant in Rio, where public transport costs can be prohibitive to low-income families. Moreover, the results presented are based on timetables of services. These timetables are not fully reliable given the number of traffic accidents and congestion levels in Rio. Future research would benefit from instead using GPS data of vehicles, which would render more accurate travel times for accessibility estimates.
Farber, 2017). Finally, future research is also needed to examine the long-term economic and social consequences of such transport developments for Rio’s metropolitan area, for example in terms of air quality, reallocation of jobs, real estate appreciation and gentrification.

A lesson that can be drawn from the case of Rio de Janeiro is that policy makers should incorporate accessibility scenario analysis in the early phases of transport planning to give a more complete picture of who benefits from new investments and subsequent changes in service levels. While it is a common practice to evaluate transportation projects based on cost-benefit analysis, transport planners seldom take into consideration the impact a project could have on the population’s access to out-of-home activities.

Finally, the case of Rio de Janeiro is not an exception when it comes to the way in which official rhetoric seeks to justify transport projects based on promised benefits to society as a whole and to low-income groups in particular. It serves as a cautionary tale about how the potential benefits of new infrastructure projects can be undermined when these projects are seen in isolation from rest of the city and its transport system, and when governments do not sustain the level of spending necessary to maintain and run services at affordable prices. The recent experience of Rio with the transport investments related to mega-events illustrates how governments have significant capacity to reshape inequalities of access and opportunities in cities through the provision of public transport services and investments but often do not deliver what was promised.

7. Acknowledgements

The authors thank Fetranpor for providing GTFS datasets. This work was funded by Capes Foundation, Ministry of Education, Brazil [Grant Number BEX 1397/13-3]; Institute for Applied Economic Research (Ipea - Brazil) and by the WRI Ross Center for Sustainable Cities [2017 Lee Schipper Memorial Scholarship].
8. References

Anselin, L., Syabri, I., & Smirnov, O. (2002). Visualizing multivariate spatial correlation with dynamically linked windows. In New Tools for Spatial Data Analysis: Proceedings of the Specialist Meeting (p. 61801). Santa Barbara: Center for Spatially Integrated Social Science (CSISS), University of California. Retrieved from https://pdfs.semanticscholar.org/bfc5/e6683bf0d4d6ea197d95309d0545e8969e64.pdf

Apparicio, P., Abdelmajid, M., Riva, M., & Shearmur, R. (2008). Comparing alternative approaches to measuring the geographical accessibility of urban health services: Distance types and aggregation-error issues. International Journal of Health Geographics, 7(1), 7. https://doi.org/10.1186/1476-072X-7-7

Banister, D. (2008). The sustainable mobility paradigm. Transport Policy, 15(2), 73–80. https://doi.org/10.1016/j.tranpol.2007.10.005

Blair, N., Hine, J., & Bukhari, S. M. A. (2013). Analysing the impact of network change on transport disadvantage: a GIS-based case study of Belfast. Journal of Transport Geography, 31, 192–200. https://doi.org/10.1016/j.jtrangeo.2013.06.015

BOC. (2009). Rio de Janeiro's Candidature File to host the 2016 Olympic and Paralympic Games (No. 1, 2 and 3). Brazilian Olympic Committee. Retrieved from http://www.rio2016.com/en/organising-committee/transparency/documents

Bocarejo, J. P., & Oviedo H., D. R. (2012). Transport accessibility and social inequities: a tool for identification of mobility needs and evaluation of transport investments. Journal of Transport Geography, 24, 142–154. https://doi.org/10.1016/j.jtrangeo.2011.12.004

Boisjoly, G., & El-Geneidy, A. M. (2017). How to get there? A critical assessment of accessibility objectives and indicators in metropolitan transportation plans. Transport Policy, 55, 38–50. https://doi.org/10.1016/j.tranpol.2016.12.011

Brazil, S. M. (2009). Caderno de Legados Urbano e Ambiental. Rio 2016 Cidade Candidata. Sport Ministry. Retrieved from http://www.esporte.gov.br/arquivos/rio2016/cadernoLegadosUrbanoAmbiental.pdf

Bureau, B., & Glachant, M. (2011). Distributional effects of public transport policies in the Paris Region. Transport Policy, 18(5), 745–754. https://doi.org/10.1016/j.tranpol.2011.01.010
Câmara, P., & Banister, D. (1993). Spatial inequalities in the provision of public transport in Latin American cities. *Transport Reviews, 13*(4), 351–373. https://doi.org/10.1080/01441649308716857

Casas, I. (2007). Social exclusion and the disabled: An accessibility approach. *Professional Geographer, 59*(4), 463–477. https://doi.org/10.1111/j.1467-9272.2007.00635.x

Castro, D. G., Gaffney, C., Novaes, P. R., Rodrigues, J. M., Santos, C. P. dos, & Santos Junior, O. A. dos (Eds.). (2015). *Rio de Janeiro: os impactos da Copa do Mundo 2014 e das Olimpíadas 2016* (1st ed.). Rio de Janeiro: Letra Capital.

CPCORJ. (2015). *Rio 2016 Olympics: The Exclusion Games - Mega-Events and Human Rights Violations in Rio de Janeiro Dossier*. Rio de Janeiro: Comitê popular Copa e Olimpíadas Rio - World Cup and Olympics Popular Committee of Rio de Janeiro. Retrieved from https://comitepopulario.files.wordpress.com/2016/03/dossiecomiterio2015_eng1.pdf

Cuadros, A. (2016, August 1). The Broken Promise of the Rio Olympics. *The Atlantic*. Retrieved from http://www.theatlantic.com/international/archive/2016/08/building-barra-rio-olympics-brazil/493697/

Delbosc, A., & Currie, G. (2011). Using Lorenz curves to assess public transport equity. *Journal of Transport Geography, 19*(6), 1252–1259. https://doi.org/10.1016/j.jtrangeo.2011.02.008

Delmelle, E. C., & Casas, I. (2012). Evaluating the spatial equity of bus rapid transit-based accessibility patterns in a developing country: The case of Cali, Colombia. *Transport Policy, 20*, 36–46. https://doi.org/10.1016/j.tranpol.2011.12.001

El-Geneidy, A., Levinson, D., Diab, E., Boisjoly, G., Verbich, D., & Loong, C. (2016). The cost of equity: Assessing transit accessibility and social disparity using total travel cost. *Transportation Research Part A: Policy and Practice, 91*, 302–316. https://doi.org/10.1016/j.tra.2016.07.003

Elhorst, J. P. (2010). Applied Spatial Econometrics: Raising the Bar. *Spatial Economic Analysis, 5*(1), 9–28. https://doi.org/10.1080/17421770903541772

Eliasson, J. (2016). Is congestion pricing fair? Consumer and citizen perspectives on equity effects. *Transport Policy, 52*, 1–15. https://doi.org/10.1016/j.tranpol.2016.06.009

Fainstein, S. S. (2010). *The just city*. Ithaca: Cornell University Press.
Farber, S., Bartholomew, K., Li, X., Páez, A., & Nurul Habib, K. M. (2014). Assessing social equity in distance based transit fares using a model of travel behavior. *Transportation Research Part A: Policy and Practice, 67*, 291–303. https://doi.org/10.1016/j.tra.2014.07.013

Foth, N., Manaugh, K., & El-Geneidy, A. M. (2013). Towards equitable transit: examining transit accessibility and social need in Toronto, Canada, 1996–2006. *Journal of Transport Geography, 29*, 1–10. https://doi.org/10.1016/j.jtrangeo.2012.12.008

França, R. (2016, December 11). Ônibus perdem passageiros durante a crise. *O Globo*. Retrieved from https://oglobo.globo.com/rio/onibus-perdem-passageiros-durante-crise-20625497

G1. (2017, February 6). Confira as novas mudanças de linhas de ônibus no Rio. Retrieved January 15, 2017, from http://g1.globo.com/rio-de-janeiro/noticia/2016/02/confira-novas-mudancas-de-linhas-de-ônibus-no-rio.html

Gaffney, C. (2010). Mega-events and socio-spatial dynamics in Rio de Janeiro, 1919-2016. *Journal of Latin American Geography, 9*(1), 7–29. https://doi.org/10.1353/lag.0.0068

Gaffney, C. (2016). Gentrifications in pre-Olympic Rio de Janeiro. *Urban Geography, 37*(8), 1132–1153. https://doi.org/10.1080/02723638.2015.1096115

Geurs, K. T., & van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography, 12*(2), 127–140. https://doi.org/10.1016/j.jtrangeo.2003.10.005

Guimarães, A., & Leitão, L. (2017). Ex-secretário de obras de Paes é preso em desmembramento da Lava Jato no Rio. *G1*. Retrieved from http://g1.globo.com/rio-de-janeiro/noticia/pf-cumpre-mandados-em-mais-um-desmembramento-da-lava-jato-no-rio.html

Horner, M. W., & Murray, A. T. (2004). Spatial Representation and Scale Impacts in Transit Service Assessment. *Environment and Planning B: Planning and Design, 31*(5), 785–797. https://doi.org/10.1068/b3046

IBGE. (2016). Grade Estatística 2010. Retrieved from http://mapas.ibge.gov.br/interativos/grade.html

Ipea, UNPD, & FJP. (2015). Atlas do desenvolvimento humano nas regiões metropolitanas brasileiras. Retrieved November 20, 2015, from http://www.atlasbrasil.org.br/
ITDP Brasil. (2014). **Análise do Fluxo de Pedestres nas Estações do BRT Transbrasil**. Rio de Janeiro: ITDP Brasil. Retrieved from http://itdpbrasil.org.br/wp-content/uploads/2014/11/Pedestrian-Flow-Analysis-Transbrasil_FINAL.pdf

ITDP Brasil. (2015). **Análise de Impacto do BRT TransCarioca na Mobilidade Urbana do Rio de Janeiro**. Rio de Janeiro: ITDP Brasil. Retrieved from https://www.itdp.org/wp-content/uploads/2015/04/ITDP-Brasil_An%C3%A1lise-Impacto-BRT-TransCarioca_em-PT_vers%C3%A3o_WEB-para-site.pdf

Karner, A., & Niemeier, D. (2013). Civil rights guidance and equity analysis methods for regional transportation plans: a critical review of literature and practice. *Journal of Transport Geography*, 33, 126–134. https://doi.org/10.1016/j.jtrangeo.2013.09.017

Kassens-Noor, E., Gaffney, C., Messina, J., & Phillips, E. (2016). Olympic Transport Legacies: Rio de Janeiro’s Bus Rapid Transit System. *Journal of Planning Education and Research*, 0739456X16683228. https://doi.org/10.1177/0739456X16683228

Keeling, D. J. (2008). Latin America’s Transportation Conundrum. *Journal of Latin American Geography*, 7(2), 133–154. https://doi.org/10.1353/lag.0.0005

Kwan, M.-P. (2000). Gender differences in space-time constraints. *Area*, 32(2), 145–156. https://doi.org/10.1111/j.1475-4762.2000.tb00125.x

Kwan, M.-P., & Weber, J. (2008). Scale and accessibility: Implications for the analysis of land use–travel interaction. *Applied Geography*, 28(2), 110–123. https://doi.org/10.1016/j.apgeog.2007.07.002

Lago, L. C. do. (2000). **Desigualdades e segregação na metrópole: o Rio de Janeiro em tempo de crise**. Observatório IPPUR/UFRJ-FASE. Retrieved from http://web.observatoriodasmetropoles.net/new/images/abook_file/desigualdade_metropol erj_lucianalago.pdf

Legroux, J. (2014). From discourse to reality: impacts of Rio’s “transportation revolution” on socio-spatial justice. In L. C. de Q. Ribeiro, *The Metropolis of Rio de Janeiro: a space in transition* (1st ed., pp. 343–372). Rio de Janeiro: Letra Capital.

LeSage, J. P. (2008). An Introduction to Spatial Econometrics. *Revue D’économie Industrielle*, (123), 19–44. https://doi.org/10.4000/rei.3887

Liao, C.-H., Hsueh-Sheng, C., & Tsou, K.-W. (2009). Explore the spatial equity of urban public facility allocation based on sustainable development viewpoint. Presented at the 14th
International conference on urban planning and regional development in the information society, Spain, Sitges. Retrieved from http://realcorp.at/archive/CORP2009_48.pdf

Lucas, K. (2012). Transport and social exclusion: Where are we now? Transport Policy, 20, 105–113. https://doi.org/10.1016/j.tranpol.2012.01.013

Lucas, K., & Jones, P. (2012). Social impacts and equity issues in transport: an introduction. Journal of Transport Geography, 21, 1–3. https://doi.org/10.1016/j.jtrangeo.2012.01.032

Lucas, K., Wee, B. van, & Maat, K. (2015). A method to evaluate equitable accessibility: combining ethical theories and accessibility-based approaches. Transportation, 1–18. https://doi.org/10.1007/s11116-015-9585-2

Magalhães, L. E., & Rodrigues, R. (2017, June 6). Sistema BRT completa 5 anos sem motivos para comemorar. O Globo. Retrieved from https://oglobo.globo.com/rio/sistema-brt-completa-5-anos-sem-motivos-para-comemorar-21439782

Manaugh, K., Badami, M. G., & El-Geneidy, A. M. (2015). Integrating social equity into urban transportation planning: A critical evaluation of equity objectives and measures in transportation plans in North America. Transport Policy, 37, 167–176. https://doi.org/10.1016/j.tranpol.2014.09.013

Martens, K., Golub, A., & Robinson, G. (2012). A justice-theoretic approach to the distribution of transportation benefits: Implications for transportation planning practice in the United States. Transportation Research Part A: Policy and Practice, 46(4), 684–695. https://doi.org/10.1016/j.tra.2012.01.004

McKay, S., Murray, M., & MacIntyre, S. (2012). Justice as Fairness in Planning Policy-Making. International Planning Studies, 17(2), 147–162. https://doi.org/10.1080/13563475.2012.672798

Motte-Baumvol, B., Aguilera, A., Bonin, O., & Nassi, C. D. (2016). Commuting patterns in the metropolitan region of Rio de Janeiro. What differences between formal and informal jobs? Journal of Transport Geography, 51, 59–69. https://doi.org/10.1016/j.jtrangeo.2015.10.019

Omer, I. (2006). Evaluating accessibility using house-level data: A spatial equity perspective. Computers, Environment and Urban Systems, 30(3), 254–274. https://doi.org/10.1016/j.compenvurbsys.2005.06.004
Páez, A., & Scott, D. M. (2005). Spatial statistics for urban analysis: A review of techniques with examples. *GeoJournal, 61*(1), 53–67. https://doi.org/10.1007/s10708-005-0877-5

Papa, E., Silva, C., Brömmelstroet, M. te, & Hull, A. (2015). Accessibility instruments for planning practice: a review of European experiences. *Journal of Transport and Land Use, 0*(0). Retrieved from https://www.jtlu.org/index.php/jtlu/article/view/585

Pereira, R. H. M., Schwanen, T., & Banister, D. (2017). Distributive justice and equity in transportation. *Transport Reviews, 37*(2), 170–191. https://doi.org/10.1080/01441647.2016.1257660

Pereira, Rafael Henrique Moraes, & Schwanen, T. (2013). *Commute Time in Brazil (1992-2009): differences between metropolitan areas, by income levels and gender* (p. 29). Institute for Applied Economic Research – ipea. Retrieved from http://repositorio.ipea.gov.br/handle/11058/964

Préteceille, E., & Cardoso, A. (2008). Río de Janeiro y Sao Paulo: ¿ciudades duales? comparación con Paris. *Ciudad Y Territorio: Estudios Territoriales, (158)*, 617–640.

Rawls, J. (1999). *A theory of justice* (revised edition). Cambridge, Mass.: Belknap Press of Harvard University Press.

Rawls, J. (2001). *Justice as fairness: a restatement*. Cambridge, Mass; London: Harvard University Press.

Ribeiro, L. C. de Q. (Ed.). (2014). *The Metropolis of Rio de Janeiro: a space in transition* (1st ed.). Rio de Janeiro: Letra Capital.

Ribeiro, L. C. de Q., Rodrigues, J. M., & Corrêa, F. S. (2010). Segregação residencial e emprego nos grandes espaços urbanos brasileiros. *Cadernos Metrópole. ISSN (impresso) 1517-2422; (eletrônico) 2236-9996, 12*(23). Retrieved from http://revistas.pucsp.br/index.php/metropole/article/view/5921

Rio de Janeiro. (2008). *Plano de Legado Urbano e Ambiental: Olimpíadas Rio 2016*. Rio de Janeiro: Comitê Especial de Legado Urbano - Secretaria Municipal de Urbanismo. Retrieved from http://www.rio.rj.gov.br/web/smu/exibeconteudo?article-id=138922

Rio de Janeiro. (2015). *Explaining Rio de Janeiro habitational policy*. Rio de Janeiro: City Hall of Rio de Janeiro. Retrieved from https://drive.google.com/file/d/0B1x0_cNhKxbDb094M1hraGVNekU/view
Rodrigues, J. M., & Legroux, J. (2015). A questão da mobilidade urbana na Região Metropolitana do Rio de Janeiro: reflexões a partir dos projetos de infraestrutura para megaeventos esportivos. In D. G. Castro et al. (Ed.), Rio de Janeiro. Os impactos da copa do mundo 2014 e das Olimpíadas 2016 (1st ed.). Rio de Janeiro: Letra Capital.

Rodrigues, R. (2017, June 28). Metrô faz oferta promocional após queda de 14,5% nas viagens - Jornal O Globo. Retrieved from https://oglobo.globo.com/rio/metro-faz-oferta-promocional-aos-145-nas-viagens-21527565

Ryan, J., Wretstrand, A., & Schmidt, S. M. (2015). Exploring public transport as an element of older persons’ mobility: A Capability Approach perspective. Journal of Transport Geography, 48, 105–114. https://doi.org/10.1016/j.jtrangeo.2015.08.016

Sánchez, F., & Broudehoux, A.-M. (2013). Mega-events and urban regeneration in Rio de Janeiro: planning in a state of emergency. International Journal of Urban Sustainable Development, 5(2), 132–153. https://doi.org/10.1080/19463138.2013.839450

Sandy, M. (2016, March 24). The Rio Olympics Could Be the Next Victim of Brazil’s Corruption Scandal. Time. Retrieved from http://time.com/4271376/brazil-corruption-scandal-olympics/

Schweitzer, L., & Valenzuela, A. (2004). Environmental Injustice and Transportation: The Claims and the Evidence. Journal of Planning Literature, 18(4), 383–398. https://doi.org/10.1177/0885412204262958

Silvestre, G. (2012). An Olympic city in the making: Rio de Janeiro mega-event strategy 1993-2016. IOC Olympic Studies Centre. Retrieved from http://doc.rero.ch/record/32218

Souza, P. H. G. F. de. (2015). Income distribution according to Brazilian household surveys: harmonization and comparison of Census, PNAD and POF data. Revista Brasileira de Estudos de População, 32(1), 165–188. https://doi.org/10.1590/S0102-30982015000000009

Stępniak, M., & Jacobs-Crisioni, C. (2017). Reducing the uncertainty induced by spatial aggregation in accessibility and spatial interaction applications. Journal of Transport Geography, 61, 17–29. https://doi.org/10.1016/j.jtrangeo.2017.04.001

Tan, P. Y., & Samsudin, R. (2017). Effects of spatial scale on assessment of spatial equity of urban park provision. Landscape and Urban Planning, 158, 139–154. https://doi.org/10.1016/j.landurbplan.2016.11.001
UN HABITAT. (2013). *Planning and Design for Sustainable Urban Mobility: Global Report on Human Settlements 2013*. London: Routledge: UN HABITAT. Retrieved from http://www.unhabitat.org/pmss/listItemDetails.aspx?publicationID=3503

UN-HABITAT. (2010). *State of the World’s Cities 2010/2011- Cities for All: Bridging the Urban Divide* (State of the World’s Cities Report) (p. 244). UN-HABITAT. Retrieved from http://unhabitat.org/books/state-of-the-worlds-cities-20102011-cities-for-all-bridging-the-urban-divide/

Van Wee, B., & Geurs, K. (2011). Discussing equity and social exclusion in accessibility evaluations. *European Journal of Transport and Infrastructure Research, 11*(4). Retrieved from http://www.ejtir.tbm.tudelft.nl/issues/2011_04/abstracts/2011_04_01.asp

Van Wee, B., & Roeser, S. (2013). Ethical Theories and the Cost–Benefit Analysis-Based Ex Ante Evaluation of Transport Policies and Plans. *Transport Reviews, 33*(6), 743–760. https://doi.org/10.1080/01441647.2013.854281

Vasconcellos, E. A. de. (2001). *Urban transport, environment, and equity: the case for developing countries*. London, UK ;Sterling, VA: Earthscan.

Vermeiren, K., Verachtert, E., Kasaija, P., Loopmans, M., Poesen, J., & Van Rompaey, A. (2015). Who could benefit from a bus rapid transit system in cities from developing countries? A case study from Kampala, Uganda. *Journal of Transport Geography, 47*, 13–22. https://doi.org/10.1016/j.jtrangeo.2015.07.006

Wessel, N., Allen, J., & Farber, S. (2017). Constructing a routable retrospective transit timetable from a real-time vehicle location feed and GTFS. *Journal of Transport Geography, 62*, 92–97. https://doi.org/10.1016/j.jtrangeo.2017.04.012