Avoiding public transport? Assessing the relationship between accessibility, income and commuting mode in Recife, Brazil

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1. INTRODUCTION AND LITERATURE REVIEW

Accessibility, the ease of reaching destinations (Handy & Niemeier, 1997), plays a significant role in developing human scale cities. Planning for increased access to destinations, rather than higher travel speeds only, implies bringing origins and destinations closer to one another and supporting higher speeds and convenience for a variety of transport modes. In doing so, dense, mixed-use liveable neighborhoods are prioritized, enabling all individuals to have access to a variety of destinations by active and public transport.

Accessibility is increasingly being used as a measure of land use and transport performance (Boisjoly & El-Geneidy, 2017; Handy, 2005; The World Bank, 2016; van Wee & Geurs, 2016). From a travel behavior perspective, previous research has shown a positive association between accessibility by public transport to jobs and commuting by public transport mode share in several cities in the Global North (Legrain et al., 2015; Moniruzzaman & Páez, 2012; Owen & Levinson, 2015), especially among low-income households who often rely on public transport (Lucas, 2012; Stanley & Lucas, 2008). In contrast, a low level of accessibility by public transport can result in forced car ownership, which is a major financial burden for low-income families (Curl et al., 2018; Mattioli, 2017).

While this reality is well documented in the Global North, cities in the Global South did not receive much attention with respect to the relationship between accessibility, travel behavior and social equity. Looking specifically at Latin America, recent research has highlighted the socio-spatial segregation patterns that characterize many large metropolitan regions (Blanco et al., 2018; Keeling, 2008). There exists significant mobility disparities across income groups, as low-income individuals often depend on public and active transport modes for there everyday mobility needs, although they are facing disadvantageous conditions in terms of access to destinations by public and active transport modes (Bocarejo & Oviedo, 2012; Delmelle & Casas, 2012; Hernandez, 2018; Hernandez & Rossel, 2015; Jaramillo et al., 2012). This can result in either longer travel times, suppressed trips, and/or limited access to opportunities (Falavigna & Hernandez, 2016; Martínez et al., 2018; Ureta, 2008; Vasconcellos, 2018).

Recent research has more specifically focused on accessibility and equity in Brazil. For example, using accessiblity measures, researchers have demonstrated how various policies, namely school agglomeration policies in São Paulo and the development of transport infratsructure for mega-events in Rio de Janeiro, have contributed to exacerbating existing inequalities (Moreno-Monroy et al., 2018; Pereira, 2018). The relationship between accessibility to employment and informal employment in São Paulo has also been explored, demonstrating the importance of supporting accessibility by public transport for low-income individuals (Boisjoly et al., 2017). In a qualitative study in Recife, Maia et al. (2016) emphasized the important of local land use mix and transport interventions for meeting the needs of low-income individuals.

The current study complements these studies by taking a travel behavior perspective. Given the important social disparities and spatial segregation characterizing many of these cities, understanding this relationship across income groups is particularly important. The aim of this research is, therefore, to assess the relationship between accessibility by public transport, mode choice, and income in Recife, Brazil. This study is amongst the first to combine accessibility data with individual-level origin-destination (OD) survey data to shed light on the relationship between income, accessibility, and travel behavior in the Global South. In doing so, the study provides quantitative evidence to support researchers, planners and policy-makers in developing equitable land use and transport systems, while highlighting the need for more context-specific research on accessibility and travel behavior in the Global South.

2. METHODS

The Recife metropolitan region, in the Northeast Region of Brazil, comprises 14 municipalities, with a total population of around 3.7 million inhabitants in 2011 (Prefeitura da cidade do Recife, 2016). The public transport system consists of a metro and light rail system, complemented by a bus network.

The main data source used for this study is the Recife 2016 OD survey (Prefeitura da cidade do Recife, 2016). The survey contains 58,644 valid observations, at the individual level, and includes socio-demographic individual and household characteristics such as income, home and work location and gender as well as questions related to work and study trips. Around 2.5% of the population is surveyed through a sampling technique ensuring a representative spatial distribution of the sample. For the purpose of this study, only respondents that commuted to work, from home, were selected. For example, students, children and unemployed individuals were suppressed from the sample. After removing missing data, a total of 15,862 respondents were included in this study. Based on the home and work locations of the OD survey, two additional variables were calculated: distance from home to CBD and commuting network distance. Note that commuting trips shorter than 100 m and longer than 50 km were excluded. The survey data was then combined with the 2010 census data and the neighborhood average income was attributed based on the home location.

Three types of accessibility measures were included in this study: local accessibility to amenities (walking), accessibility to jobs, from home, by public transport and accessibility to workers by public transport at place of work. The Walk Score measures, collected through the Walk Score API, were used to quantify local accessibility. Walk Score gives a score between 1

and 100 based on a variety of characteristics, namely street design and the number of amenities in the vicinity (Walk Score, 2016). Accessibility to jobs, by public transport, was calculated as the number of jobs or workers within a given travel time (cumulative opportunities). Travel times were obtained from the Google Distance Matrix application programming interface for morning peak travel times (Google Maps, Accessed February, 2018). Based on the OD survey, a travel time threshold of 45 minutes was selected, and departure time was set at 7 am.

Jobs and workers data was derived from the OD survey. To do so, we hypothesised that a respondent's commute trip destination corresponded to one job, while their home location represented one worker. Job locations were also obtained from the Ministry of Labour and gave consistent results in terms of accessibility to jobs. To be consistent with the measures of accessibility to workers, we decided to use the job locations from the OD in this study. The number of jobs and workers accessible were then divided by the total number of jobs and workers respectively, to obtain a share of jobs and workers. The accessibility values thereby range from 0 to 1.

Since the aim of this study is to assess the determinants of mode choice across income groups, three multinomial regressions were conducted, one for each income group specified in this study. The dependant variable was the mode used to commute to work. A series of independent variables were selected based on the literature and tested in a stepwise manner, including local and regional accessibility variables, trip characteristics and socio-economic characteristics. The summary statistics of the variables included in the final model are presented in Table 2.1.

For ease of interpretation and presentation, all income groups above two times the minimum wage were grouped in the high-income group. Accessibility to workers, to jobs, Walk Score, distance from home to CBD and commute distance were integrated in the model in a stepwise manner. We decided not to include accessibility to jobs, by public transport, in the final model since it appeared to be positively and significantly associated with the likelihood of commuting by car in the medium-income model. This result is inconsistent with the literature and is probably due to the fact that the variable captures some socio-spatial patterns that are not controlled for in the model. It was accordingly removed from the model. It is important to mention that the three models remained stable when removing the variable. Given the large income variations within income groups, the neighbourhood average income was included in the models to further control for poverty levels. Number of children, having a mobile with internet access, having a mobility impairment, gender and age group (as defined in the survey) were also included in the model. Finally, a variable indicating whether the individual commuted less than five days in the week is included to capture part-time employment or requirement to go to the place of work. The correlation between the variables were tested and variation inflation factors below two were found in all three models.

Table 2.1 Summary statistics of the variables included in the final model (15,862 observations)

	Mean	Standard deviation	Minimum	Maximum
Accessibility to workers at workplace	0.30	0.12	0	0.45
Accessibility to jobs**	0.34	0.24	0	0.75
Walk Score	82.36	16.16	1	100
Distance to CBD	7.84	4.18	0.59	34.39

Commute distance	6.62	4.89	0.10	50.00
Neighborhood median income	1228122	1171066	640	6612581
Number of children	0.65	0.98	0	8
Proportion of users (categorical variables)				
Mobility impairment	0.01			
Access to internet on cellphone	0.89			
Commuting less than 5 days	0.17			
Gender (woman = 1)	0.51			
Age category				
16 to 24 years	0,08			
25 to 39 years	0,47			
40 to 59 years	0,41			
60 + years	0,04			
Income				
Below 1 MW* (low)	0,12			
1 to 2 MW* (medium)	0,33			
2 to 3 MW* (high)	0,15			
3 to 5 MW* (high)	0,13			
5 to 10 MW* (high)	0,15			
More than 10 MW* (high)	0,13			
Commuting mode				
Motorized modes (car and motorcycle)	0,52			
Public transport	0,42			
Walking and cycling	0,06			

*MW: Minimum wage

**As noted in the methodology, this variable is not included in the final model.

3. RESULTS

3.1. Discrepancies in mode share and accessibility levels across income groups

The mode share across income groups is presented in Figure 3.1 (top). As expected, public transport use is generally higher across individuals from low- and medium-income households, while car use is predominant within high-income individuals. This is consistent with the literature that suggests the low-income individuals are more likely to rely on public transport for commuting. Walking and cycling mode share is relatively low in all three income groups, with the lowest proportion among high-income individuals.

Figure 3.1 (bottom) presents the level of accessibility, by public transport, to jobs (from home) and to workers (from place of work) for the three income groups. Accessibility to workers within each income groups exhibits lower variations compared to accessibility to jobs. This is likely due to the dispersion of workers across the territory, whereas jobs are more concentrated spatially, namely in the central areas of the metropolitan region. Accordingly, workers residing in peripheral have very low accessibility to jobs and those residing in central areas have a much higher accessibility to jobs.

Comparing the levels of accessibility to jobs, it is typically higher for high-income individuals. Furthermore, the 25th percentile, the median and the 75th percentile are higher than for the other income groups, suggesting that a lower proportion of high-income individuals experience very low levels of accessibility. In contrast, several low- and medium-income individuals experience relatively low levels of accessibility to jobs. Note that low-income individuals are characterized by a higher accessibility to jobs than medium-income individuals, which potentially results from land use policies that were implemented in the 1980s to allow low-income individuals remain in central locations (Maia, 1995). In terms of accessibility to workers at the place of work, the differences are less pronounced. The level of accessibility is comparable across income groups, suggesting lower discrepancies in workplace locations of different income groups, whereas residential segregation appears to be more pronounced.

In a nutshell, it is difficult to conclude that the higher public transport usage among low- and medium-income individuals is associated with a greater accessibility to jobs and to workers. In fact, although close to 50% (47% for accessibility to jobs and 51% for accessibility to workers) of the low-income workers have accessibility levels below the regional median (33% and 32% respectively), 79% commute to work by public transport. For medium-income household, this proportion is 71%.

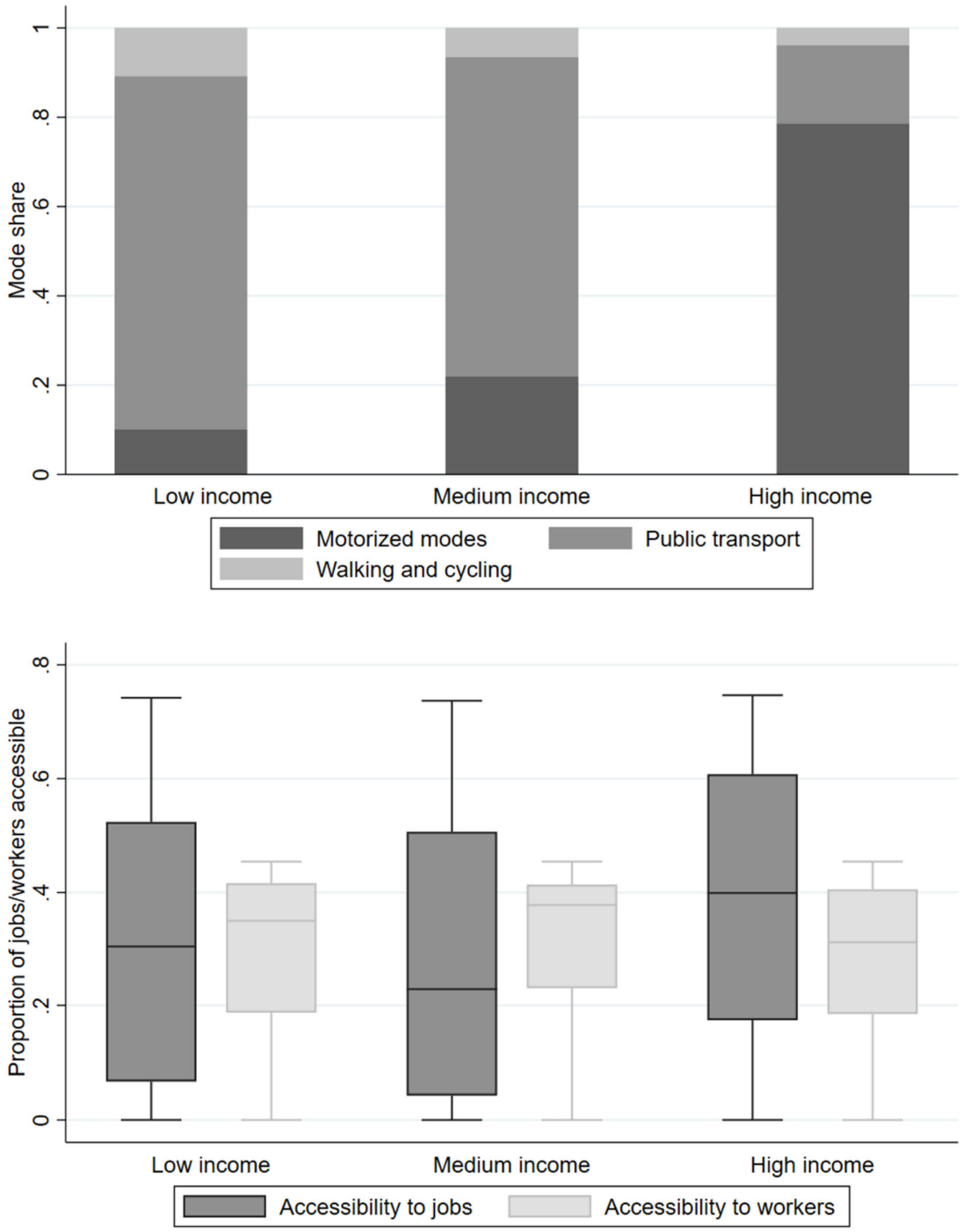

Figure 3.1 Mode share and accessibility to jobs (from home) and to workers (from place of work) by public transport in Recife, Brazil for low-, medium- and high-income individuals

3.2. Determinants of mode choice across income groups

Three multinomial regressions were conducted, one for each of the income groups specified in this study. The results are presented in Table 3.1. The reference category is public transport. The top part of the table presents the odds ratio for driving while the bottom part presents the

odds ratio for walking or cycling. In other words, the top part refers to the likelihood of commuting by car as compared to public transport and the bottom part refers to the likelihood of commuting by walking or cycling as compared to public transport.

We now concentrate on the results associated with the likelihood of **commuting by car**. Looking first at the low-income workers, we observe that the variables related to the characteristics of the land use and transport systems (accessibility to workers, Walk Score and distance to the CBD) are not significant. In contrast, variables that can be related to socio-economic conditions appear to be strong determinants of mode choice: higher neighborhood average income and having a mobile phone with internet access are strongly associated with a higher likelihood of commuting by car. Furthermore, gender is statistically significant and consistent with the literature: being a woman is strongly associated with a lower likelihood of commuting by car. Overall, the results demonstrate that for low-income individuals, characteristics associated with poverty and gender are the major determinants of mode choice.

In contrast, for the medium-income individuals, we find that higher accessibility by public transport at place of work is highly significant and associated with a lower likely of choosing car over public transport. This suggests that a having a workplace which is well connected by public transport potentially influences medium-income individuals' commute decisions. Poverty-related variables (neighborhood average income and access to internet on mobile) and gender are strongly significant, as is the case for the low-income individuals. In addition, the number of children is positively associated with the likelihood of commuting by car, which is consistent with the literature. Part-time commuting is also positive and significant. Note that these two variables were not significant in the low-income model.

Finally, the magnitude and significance of the variables in the high-income model are overall similar to the ones in the medium-income model. There are, however, two notable differences. First, accessibility to workers is not significant (this was also the case in the low-income model). Second, the gender variable is not significant. Finally, it is important to highlight a higher income being is strongly associated with a higher likelihood of commuting by car, confirming that the economic situation plays an important role in mode choice.

Other results are worth mentioning for the three models. The commuting distance is significant (although marginally in some models), with a higher distance reducing the likelihood of commuting by car. Since it is probable that this variable captures socio-spatial patterns, rather than an actual explanatory factor of decision-making, these results suggest that further data (namely more detailed income and transport and land use data) should be collected to gain a better understanding of this relationship.

We now turn to the **walking and cycling results** of the three regression models. For low-income individuals, the likelihood of commuting by walking or cycling is largely explained by variables reflecting local commutes, namely lower commute distances and lower accessibility to workers at the place of work (which is likely to reflect a place of work that is not centrally located). The number of children is also associated with a higher likelihood of walking or cycling, which might be associated to additional constraints that refrain workers from commuting outside the neighborhood. In contrast, Walk Score does not appear to be statistically significant, while a higher distance from CBD decreases the likelihood of cycling or walking. This is also the case in the high-income model. Again, it is unclear whether distance from CBD accounts for socio-spatial patterns that are not currently considered in the models.

With respect to the medium- and high-income individuals, the likelihood to walk or cycle is also explained by variables that can be associated with local commutes (accessibility to workers, commute distance and number of children). Gender is also a significant determinant: women are less likely to walk and cycle (as compared to using public transport) then men. The Walk Score is also a significant determinant of mode choice for the medium-income model, with a higher Walk Score being associated with a higher likelihood of walking or cycling. Interestingly, for high-income individuals, a higher household income is associated with a higher likelihood of walking or cycling, while a higher neighborhood average income is associated with a decreased likelihood. It is important, however, to note the low number of walking and cycling trips among high-income individuals, which may affect the results obtained here.

Table 3.1 Multinomial regression results for the commuting mode choice (bold coefficients are significant at the 95% confidence level)

Driving (ref: public transport)						
	Low income		**Medium income**		**High income**	
	OR	P>z	OR	P>z	OR	P>z
Access. to workers at workplace	0.43	0.208	**0.19**	0.000	0.86	0.567
Walk Score	1.01	0.296	1.00	0.323	1.00	0.801
Distance to CBD	1.02	0.422	0.99	0.396	0.99	0.276
Commute distance	**0.96**	0.042	0.98	0.059	**0.98**	0.007
Neighbhorhood median income	**1.63**	0.000	**1.51**	0.000	**1.61**	0.000
Mobility impairment	1.81	0.263	0.86	0.617	0.75	0.294
Access to internet on cellphone	**2.40**	0.001	**1.90**	0.000	**2.75**	0.000
Number of children	0.94	0.524	**1.14**	0.000	**1.26**	0.000
Commuting less than 5 days	1.32	0.129	**1.56**	0.000	**1.76**	0.000
Gender	**0.49**	0.000	**0.34**	0.000	0.98	0.742
Age (ref: 25 to 39 years)						
16 to 24 years	0.75	0.154	0.79	0.058	**0.46**	0.000
40 to 59 years	0.90	0.597	**0.64**	0.000	**0.75**	0.000
60 + years	0.47	0.344	0.86	0.531	0.86	0.342
Income (ref: 2 to 3 MW)						
3 to 5 MW					**3.23**	0.000
5 to 10 MW					**8.28**	0.000
More than 10 MW					**24.39**	0.000
Constant	**0.00**	0.000	**0.00**	0.000	**0.00**	0.000
Walking or cycling (ref: public transport)						
	Low income		**Medium income**		**High income**	
	OR	P>z	OR	P>z	OR	P>z
Access. to workers at workplace	**0.00**	0.000	**0.01**	0.000	**0.09**	0.004
Walk Score	1.00	0.804	**1.02**	0.000	1.01	0.093
Distance to CBD	**0.84**	0.000	1.01	0.681	**0.92**	0.030
Commute distance	**0.70**	0.000	**0.57**	0.000	**0.40**	0.000
Neighbhorhood median income	1.04	0.638	1.06	0.497	**1.39**	0.001
Mobility impairment	1.05	0.935	0.44	0.279	0.33	0.158
Access to internet on cellphone	0.74	0.143	1.02	0.898	0.89	0.646
Number of children	**1.23**	0.013	**1.29**	0.000	**1.20**	0.009
Commuting less than 5 days	**0.39**	0.001	0.75	0.167	1.15	0.537
Gender	0.76	0.112	**0.33**	0.000	**0.49**	0.000
Age (ref: 25 to 39 years)						
16 to 24 years	1.14	0.559	1.16	0.452	**0.33**	0.008
40 to 59 years	1.22	0.334	0.84	0.232	0.76	0.056
60 + years	1.13	0.920	0.94	0.875	0.44	0.019
Income (ref: 2 to 3 MW)						
3 to 5 MW					**1.41**	0.050
5 to 10 MW					**2.33**	0.000
More than 10 MW					**4.09**	0.000
Constant	9.02	0.109	0.53	0.575	**0.05**	0.022
Log-Likelihood	-1043		-3319		-3973	
Number of observations	1875		5181		8806	

4. DISCUSSION AND CONCLUSION

Combining OD survey data with local and regional accessibility measures, this study investigated the relationship between accessibility, mode choice and income in Recife, Brazil. The results highlight that commuting mode choice is not closely tied to accessibility, contrary to what is observed in several cities in the Global North. While high-income groups tend to have higher accessibility by public transport at their place of home, they largely commute by car. Conversely, low- and medium-individuals mainly commute by public transport, although their level of accessibility is not significantly higher.

The multinomial regression models demonstrate that income and poverty-related variables are amongst the main determinants of mode choice, as found in previous studies. Yet, contrary to the literature, land use and transport variables, namely accessibility to workers by public transport and Walk Score are found to be non-significant both for the low-income and high-income individuals. The results suggests that, on one hand, low-income individuals depend on public transport, regardless of their accessibility conditions. On the other hand, it appears that high-income individuals decide not to use public transport, for reasons other than the lack of accessibility. Namely, a recent study conducted in Recife demonstrated that public safety is the main motivation behind car use (dos Santos, 2017). It is also important to mention that gender is an important predictor of mode choice, women being generally more likely to use public transport. This is an important equity concern that should be considered in future research.

These findings have several implications. From a modal shift perspective, providing higher accessibility at place of work for medium-income individuals has the potential to support higher public transport use. Conversely, providing higher accessibility to high-income individuals does not appear to be an effective approach to support higher public transport usage. Other factors, namely safety and comfort, should be explored, as pointed out in previous studies (dos Santos, 2017; Jaramillo et al., 2012). This is also true for other income groups. From an equity perspective, while improvements in accessibility are not likely to yield changes in travel behavior for low-income individuals, improving accessibility by public transport is likely to improve the quality of the commute and offer new opportunities in terms of jobs accessible.

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