Social justice and the gap between potential and realized accessibility

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Accessibility is increasingly regarded as an object of social distribution, but the applicability of this premise to public policy depends on the extent to which the indicators of accessibility used actually measure people's wellbeing. This paper addresses this question by studying social inequalities in the realization of the accessibility potential offered by the places where people live. The hypothesis is that social differences in observed commuting outcomes depend not only on the locations of residences, employment centres, and transport facilities, but also on the daily destinations and travel modes of the population in each neighbourhood. The analysis relates demographic and socio-economic variables with indicators of job accessibility and commuting outcomes, and incorporates aspects that are often neglected in the estimation of commuting time, such as road congestion, walking trips, and public transport schedules, waiting and interchange time. This approach is used to assess the effect of a series of projects that radically expanded the road network in the Lisbon metropolitan area. The results suggest that inequalities are explained by a mix of geographic factors related with transport policy and of household decisions that are the product of wider economic and social forces. These findings have implications in the debate regarding the role of urban policy in addressing social justice.

Keywords: Urban transport; social justice; job accessibility; commuting time; network travel times

1. Introduction

The estimation of levels or changes in accessibility is a method to assess the performance of transport system and of transport and land use policies (Handy and Niemeier, 1997; Geurs and Van Wee, 2004). The concept has also become central to the evaluation of equity aspects, given increased evidence that lack of accessibility may reinforce processes of social exclusion (Hine, 2003; Lucas, 2004; Lucas and Stanley, 2009). A case of special concern is accessibility to jobs, as the employment outcomes of underprivileged groups are in part explained by problems in accessing job opportunities (Weinberg, 2004). Inequalities in job accessibility tend to be related with urban characteristics such as residential segregation, employment dispersion, low population densities, and orientation towards car travel (Kawabata and Shen, 2006; Hu, 2014).

The analysis of this issue has traditionally centred on differences in potential accessibility, looking at the spatial mismatch between jobs and residences (Gobillon and Selod, 2014), but recent efforts have recognized the role of the mismatch between the provision of transport and the accessibility needs of the population living each place (Kwok and Yeh, 2004;

Kawabata, 2009; Grengs, 2010) and the mismatch between the schedules of public transport and the time constrains faced by the individuals (Weber, 2003; Dong and Ben-Akiva and Bowman and Walker, 2006).

This paper seeks to integrate these different strands of the literature, assessing the relative importance of factors determining differences in commuting time, including accessibility, commuting distance, and the effects of modal choice and congestion. The objective is to separate the inequalities explained by poor provision of transport from those explained by the forces that shape the households' decisions in the housing, job, and transport markets. The study also looks into the role of walking trips to access workplaces and as a part of private and public transport trips, an aspect which is often overlooked in studies in this field. The analysis is applied to the case of the Lisbon metropolitan area during a period of employment decentralization and fast growth in the road network.

The paper is organised as follows. Section 2 reviews the literature on inequalities in job accessibility and commuting and proposes a framework of analysis to integrate the questions asked in this literature. Section 3 introduces the case study and the methods used to construct indicators of accessibility and commuting outcomes. Section 4 analyses maps of some of these indicators and Section 5 presents the result of regression models relating the indicators with census variables. Section 6 concludes the paper by discussing the implications for policy and research.

2. Accessibility, commuting and inequality

2.1.Research context

The study of social differences in accessibility has a long history (Gobillon and Selod, 2014). The ‘spatial mismatch hypothesis’ (Kain, 1968) is that some groups live far from the jobs for which they are qualified. The bulk of evidence on this issue comes from cities in the USA, where the poor and racial minorities tend to live in the central parts of the cities, far from the jobs in the suburbs. However, the hypothesis increasingly applies to cities in Europe and in Asia, given tendencies for population and employment decentralization (Korsu and Wenglenski, 2010; Matas and Raymond and Roig, 2010; Wang and Song and Xu, 2011; Lau, 2011).

The spatial mismatch hypothesis relies on the concept of potential accessibility (the possibility of moving from one’s neighbourhood and reach other places), which may not correspond to realized accessibility (the ease of reaching the places to where one actually travels). The latter depends not only on the distance between home and destinations but also on the actual destinations and the suitability of the travel modes used to reach them. The gap between both types of accessibility is made clear by the results of theoretical and empirical studies finding that the relationship between spatial mismatch and commuting distance is indeterminate (De Rango, 2001) and that the relationship between commuting time and distance is mediated by socio-economic factors (Wang, 2001).

Recognizing the limitations of studying equity issues in job accessibility based only on geographic factors, a strand of the literature has directed its attention to the constraints faced by the individuals to the realization of the accessibility potential of the neighbourhood where they live. The hypothesis is that the utility of the transport system depends on the transport modes the individuals can consider as options, and in particular on levels of car ownership and use. A mismatch can then exist between the type of accessibility provided by each place and the modes of transport used by the population. This problem tends to affects low-income households and racial minorities (Shen, 1998; Hess, 2005; Grengs, 2010) but varies considerably within (Kwok and Yeh, 2004; Kawabata, 2009) and across urban areas (Kawabata and Shen, 2006). The existence of this type of mismatch means that groups more reliant on public transport will be at disadvantage in the job market (Kawabata, 2003; Ong and Miller, 2005).

This perspective is particularly useful when evaluating the redistributive aspects of changes in the transport system. Theoretically, gains in accessibility from new roads tend to favour private transport users, as the design of bus routes may not be compatible with the use of motorways, especially in areas close to city centres. Improvements in public transport may favour disadvantaged groups, if their residence and employment locations are spatially concentrated and become better connected. The improvements in accessibility following projects such as railways can be extensive, benefiting the population living along bus routes that connect to the new stations (Fan and Guthrie and Levinson, 2012). On the other hand, there is also evidence that the restructuring of public transport networks may have a detrimental effect on areas populated by groups such as the elderly and families without car, when bus routes are changed in order to underpin the development in the train or underground networks (Wu and Hine, 2003).

The disadvantage of underprivileged groups caused by higher reliance on public transport can be compounded by geographic factors, if these groups live in areas with lower public transport accessibility than the rest of the city. Existing evidence does not seem to confirm this hypothesis. For example, in a study in Toronto, Foth and Manaugh and El-Geneidy (2013) found that socially disadvantage areas tend have better public transport accessibility and shorter public transport times to the actual destinations of the population. In the context of a developing country, Delmelle and Casas (2012) found that the middle income groups are the best served by public transport. Regardless of the type of patterns occurring at the city level, pockets of areas can have both higher deprivation indices and low public transport accessibility (Pennycook and Barrington-Craggs and Smith and Bullock, 2001).

The gap between potential and realized accessibility also depends on the quality of the transport available. Benenson and Martens and Rofé (2010) suggest that the incorporation of more realistic hypothesis about public transport time may increase considerably the estimated accessibility differences between public and private transport. There are also socio-economic differences in the time restrictions to accessibility, such as the necessity of scheduling and trip chaining (Weber, 2003; Dong et al., 2006) and the variation of the availability and frequency of public transport services throughout the day (Weber and Kwan, 2002). These aspects have been mainly examined in the case of accessibility to urban services and facilities, while the case of accessibility to jobs still lacks definite evidence. Congestion is also an important factor limiting accessibility, but rarely considered in empirical studies (Weber and Kwan, 2002; Wang, 2003). The detailed modelling of network travel times is then a pressing issue in the study of equity issues in job accessibility.

2.2. Framework of analysis

This paper contributes to the literature by assessing how the characteristics of the population living in each neighbourhood explain differences in a series of indicators of job accessibility and commuting outcomes, including gravity-based measures, the ratio between public and private transport accessibility, jobs within walking distance, commuting distances and times, and the effects of modal choice and congestion on commuting time. This assessment provides insights on the extent to which differences in provision of transport generate inequalities in commuting time over and above those implied by differences in incomes, skills, preferences, and other factors that affect the individual choices in the housing, job and transport markets.

The framework of analysis is represented in Fig.1. Commuting time is the result of household decisions about residence and employment locations and travel mode. These decisions determine the average distances travelled from home to work in each neighbourhood, and the time losses faced by the part of the population not using the fastest modes and affected by congestion. Transport policies affect the provision of private and public transport, and in turn the relative accessibility provided by both modes in each neighbourhood and the time efficiency of each transport mode relative to other neighbourhoods.

The second contribution of the paper is to add detail in the assessment of accessibility and commuting outcomes. The analysis considers the role of walking to access nearby jobs and as a part of private and public transport trips. The modelling of public transport trips considers the walking, waiting and interchange sections and information about the availability and frequency of services, taking into account the starting time of jobs in different sectors. Car and bus travel times also include the effects of road congestion at different times of the day.

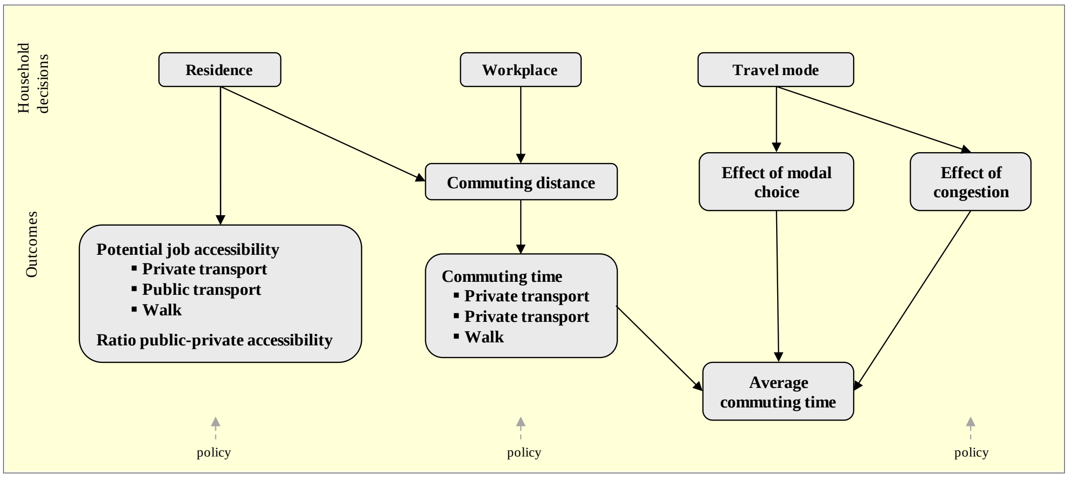

Figure 1. Framework of analysis

3. Study area and methods

The Lisbon metropolitan area provides an interesting case for the study of distributive aspects in accessibility, due to the combination of radical changes in the transport system and land use patterns during the 1990s. During that decade, priority was given to the expansion of the motorway network, when comparing with public transport (Fig.2), while suburbanization and employment decentralization accelerated. These changes have raised questions about the adequacy of the transport system for meeting the needs of individuals with no access to private vehicles. The changes in the decade that followed were of a much smaller scope. The study of the 1990s can inform the definition of future transport and land use policies, as there are still numerous semi-rural areas available for urban expansion relatively near to the metropolitan centre but lacking good public transport access.

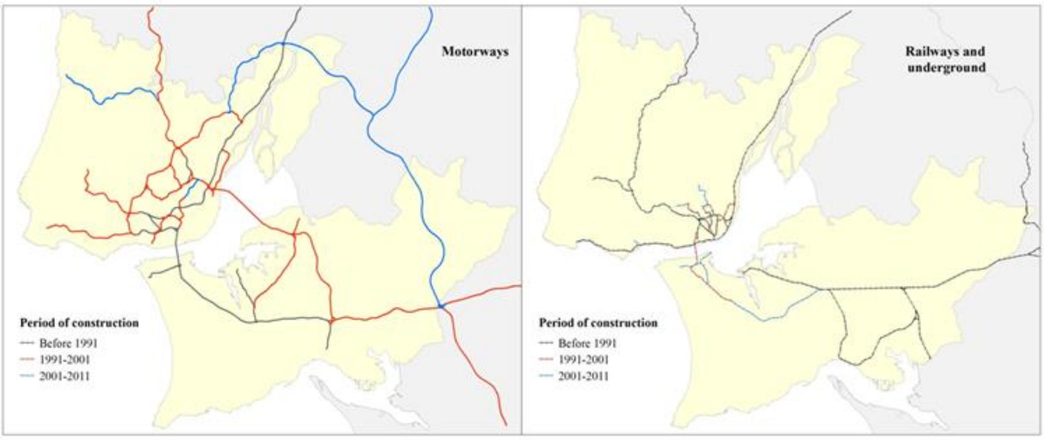

Figure 2. Evolution of the private and public transport networks in the Lisbon metropolitan area

The analysis is conducted at the level of the enumeration district, using variables calculated from the 1991 and 2001 Portuguese census. Qualification levels are given by the proportion of the adult population with no qualifications (illiterate) or with the lowest qualifications (primary school) and by the proportion with the highest qualifications (graduate). Information on employment is given by the proportions of workers in the secondary and tertiary sectors. Other variables about individuals and families include the proportions of males and of individuals aged 20-25 in the population aged 20-65 and the proportion of families with children (younger than 15). The remaining variables are indicators of socio-economic status, including families per dwelling, people per room, and the proportions of large dwellings (5 or more rooms), owned dwellings, informal dwellings, and dwellings without basic facilities.

3.1. Modelling commuting trips and the transport network

Commuting trips are modelled for each district, disaggregated by destination, travel mode, and time period (peak and off-peak). The proportion of workers in each sector of activity commuting by private and public transport to each municipality is obtained using census data, and the starting time of the jobs in each sector and municipality is given by the results of a mobility survey (DGTT and INE, 1998). The destinations of workers in each sector are assigned to lower administrative areas (civil parish) according to the number of employees of companies in each sector registered in those areas. Precise locations are then identified, using land use maps, municipal master plans, on-line geographic information systems, and the results of street-level surveys, producing a set of 207 and 240 destinations in 1991 and 2001 respectively. The destinations of workers walking to work are obtained by interpolating employment levels in those locations, taking into account data on land use. It is assumed that individuals walk to work if the workplace can be reached within 15 minutes.

The private, public and pedestrian transport networks are modelled in both years. Travel times in each link of the networks are defined for two time periods (peak and off-peak) and in the case of road transport, for two types of conditions: uncongested and congested. The travel times of other public transport modes (railways, ferries, and underground) are derived from schedules. The estimation of times for pedestrians uses a formula that depends on slopes (European Commission, n.d.).

The uncongested travel times for cars and buses consider speed limits for each type of road, location and vehicle, the proportion of road users driving above the speed limit, the classification and characteristics of the road (lane width, surface quality and existence of central reservation), slopes, and time lost at intersections. Congested times are obtained using formulas relating speeds to traffic levels and compositions. Traffic is modelled by assigning commuting trips to the respective optimal routes obtained with uncongested travel times. Trips from home to destinations other than workplaces, freight transport, business trips, bus traffic, and traffic crossing the metropolitan area are also modelled, based on data from the mobility survey (DGTT and INE, 1998) and other information. The resulting passenger car units are compared with road capacity, to derive the travel times of cars and buses in the affected links.

It is assumed that individuals use the fastest route for the travel mode they chose. The routes for private transport trips consider the walking time from parking areas to final destinations. The routes for public transport users consider the walking time between origins and destinations and stations or bus stops, waiting time, and interchange time. The set of feasible public transport options includes only the services that allow passengers to arrive and return from work within the times the jobs start and end in each location and sector of activity.

3.2. Potential accessibility

The assessment of potential accessibility uses a gravity measure (Hansen, 1959), which is often used in the study of equity aspects in job accessibility (Manaugh and El-Geneidy, 2012; Foth *et al.*, 2013). This type of measures defines accessibility of a place as the sum of the number of opportunities (such as jobs) in a set of destinations, weighted by an impedance function measuring the separation between that place and each destination.

The indicator is defined separately for private and public transport and considers uncongested network times and the set destinations defined in the previous section. In the formula below, potential accessibility in the district i by mode m is the sum of the number of jobs E in each destination j starting in each period p (peak or off-peak) weighted by a function of travel times t to access that destination using that travel mode in that period.

$$A_{i,m} = \sum_{j,p} E_{j,p} * Exp(\beta t_{i,j,m,p})$$

The impedance function can take a variety of forms, with a possible impact on the estimated accessibility levels (Reggiani and Bucci and Russo, 2011). Some authors defend that the negative exponential form is more appropriate to represent travel flows at the urban scale, comparing with the power function, which usually works better in the modelling of migration flows at regional scale (Fotheringham and O'Kelly, 1989, p.11-13). In our case study, preliminary analysis revealed that the exponential form generates accessibility levels that produce better regression models, when related with census variables.

The parameter β defines the steepness of the decay of accessibility with travel time. The value β=0.05 is used. This value was obtained by modelling commuting flows between administrative areas as a function of travel times between their central points and using a trip-distribution gravity model (Ortúzar and Willumsen 2006, Ch.5) The estimation used the 1991 and 2001 pooled dataset of commuting flows, given by the Portuguese National Statistics Office.

3.3. Commuting outcomes

Commuting outcomes are the average commuting time and distance of the population in each district, based on their destinations and travel modes and the actual conditions of the transport network, including congestion. The average commuting time of the population living in district i is the weighted average of actual times to each destination by each travel mode in each period of the day. In the formula below, the first part represents motorized modes, with $t_{i,j,m,p}$ being the times to destination j by mode m (private or public transport) in period p and $F_{i,j,m,p}$ the corresponding proportions of flows in the total number of workers living in the district. The second part represents people walking to work, with $t_{i,k}$ being the walking time to destination k and $W_{i,k,p}$ the proportion of all workers walking to that destination in period p.

$$T_i = \sum_{j,m,p} F_{i,j,m,p} * t_{i,j,m,p} + \sum_{k,p} W_{i,k,p} * t_{i,k}$$

Additional indicators are obtained by modifying this formula. The commuting times of users of private and public transport are given by the first part of the formula, considering only the flows and travel times of those modes. The calculation of average commuting distance substitutes times by distances. It is also possible to derive ratios of average commuting times using different assumptions for travel times. The effect of modal choice on commuting time is the ratio between actual average commuting time and the hypothetical average time if all workers used the fastest travel mode available to access their job locations. In addition to the overall effect, an indicator is calculated for the effect on public transport users only. The effect of congestion on commuting time is the ratio between the actual average time and the hypothetical average time assuming uncongested conditions in all transport links used to access job locations. In addition to the overall effect, indicators are calculated for the effect on users of private and public transport separately.

4. Map analysis

The identification of patterns in the spatial distribution of some of the indicators defined above, together with knowledge about the study area, gives insights on the relationships between those indicators and demographic and socio-economic variables, which are estimated in the next section. Fig.3 shows the differences between the position of each district in the ranks of commuting distance and private transport accessibility in each year of analysis. The indicator of private transport accessibility is used because its value is higher than the indicator of public transport accessibility in all districts in both years, and so it represents the maximum potential accessibility in each district. The map represents the extent to which the actual destinations of the population in each neighbourhood differ from their potential destinations. Fig.4 and Fig.5 show the effects of travel mode and congestion respectively. These maps focus on the area around Lisbon, as the effects are generally small in the peripheral areas.

The differences in the rank of the districts in terms of commuting distance and accessibility have a wide range, in some cases over 6000 in absolute number (which is 40% and 30% of the number of districts in 1991 and 2001 respectively). In general, Lisbon has small differences, the surrounding suburban areas have negative differences, and the semi-rural areas at the edge of the metropolitan area have positive differences. From 1991 to 2001, the area with negative differences has also extended further away from Lisbon. There are exceptions to these patterns, within Lisbon (with values higher in the eastern part of the city) and among the different access corridors to Lisbon (with values higher in the northeast corridor). The levels of economic deprivation in both areas tend to be higher than average.

The effect of modal choice is higher in the eastern part of Lisbon and along all access corridors to Lisbon except the west corridor, whose population also have the highest qualification levels in the country. The effect generally decreased from 1991 to 2001. The effect of congestion in 1991 is restricted to the areas around three of the access corridors, but in 2001 it is also visible in the south corridor and in the hinterland of the northwest corridor. A few districts in East Lisbon are also affected.

The comparison of the maps shows no visible relationship between the distributions of these three factors behind the gap between commuting time and accessibility: the inconsistency between commuting distance and accessibility and the effects of modal choice and congestion on commuting time. However, some areas are at disadvantage in terms of the three factors, including areas with traditionally high levels of economic deprivation, such as East Lisbon.

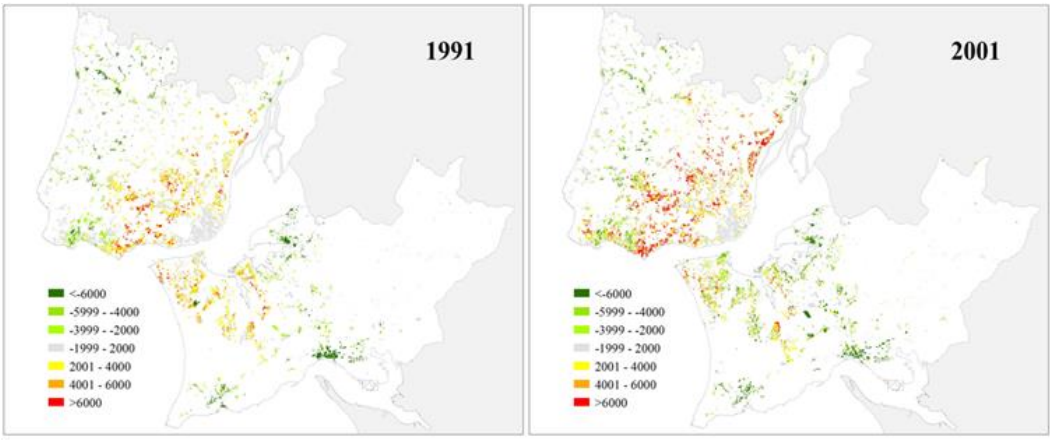

Figure 3. Evolution of the private and public transport networks in the Lisbon metropolitan area

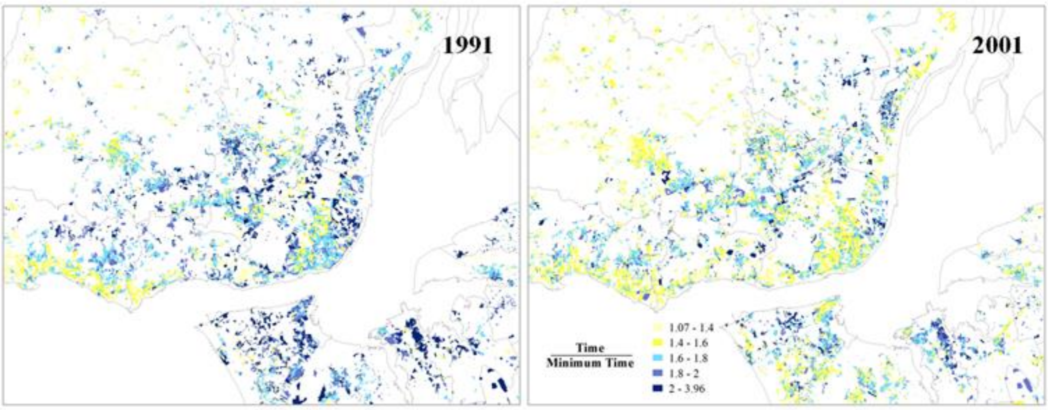

Figure 4. Effect of modal choice on commuting time

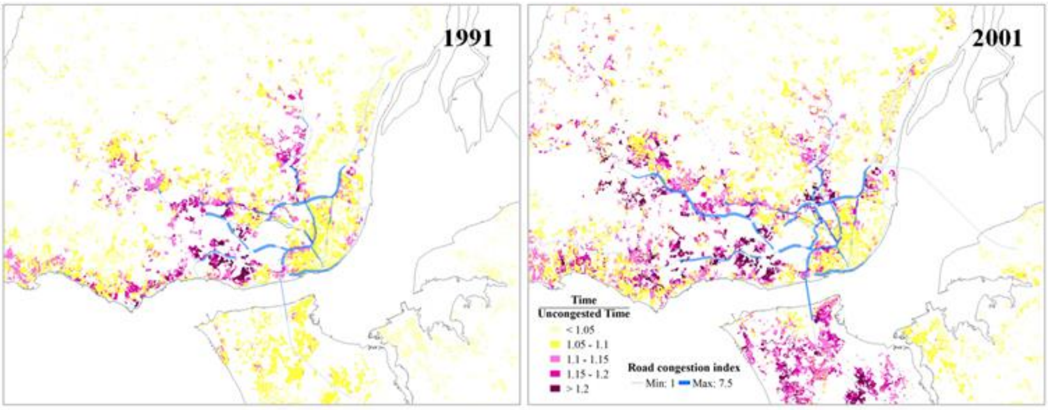

Figure 5. Effect of congestion on commuting time

5. Regression analysis

This section reports the results of regression models explaining indicators of accessibility and commuting outcomes with socio-economic variables. It should be noticed that the dependent variables are theoretically related. It is expected that groups with higher accessibility have shorter commuting distances and times, and so the coefficients of the respective variables should have opposite signs in the models of accessibility and of commuting distances and times. To some extent, the coefficients of the effect of modal choice and congestion should have opposite signs, if we assume that private transport users travel faster than public transport users (which is the case in the Lisbon metropolitan area) but are also more affected by congestion (as workers using fixed-infrastructure public transport or walking to work are not affected).

The focus of the analysis that follows is on the exceptions to these anticipated patterns, furthering the analysis of the differences between average commuting distance and accessibility and of the conflicting effects of modal choice and congestion that were illustrated in the map analysis of the previous section.

5.1 Potential accessibility

Table 1 shows the regressions of indicators of job accessibility, including private and public transport accessibility, the ratio between these indicators, and the number of jobs within walking distance. The goodness of fit is relatively satisfactory (roughly between 0.4 and 0.5 for the 1991 models and between 0.35 and 0.45 for the 2001 models).

Table 1. Regressions of job accessibility

Dependent variable	**Private transport job accessibility**		**Public transport job accessibility**		**Ratio public-private transport accessibility**		**Jobs within walking distance**	
Year	**1991**	**2001**	**1991**	**2001**	**1991**	**2001**	**1991**	**2001**
Male (%adults)	-0.600**	-0.142	-1.372**	-0.431	-0.791**	-0.300*	-3.267**	-1.487**
Young (% pop. 20-65)	-0.123	0.639**	-0.445**	0.871**	-0.332**	0.268**	-0.498*	0.917**
No/lowest qualification	0.452**	0.095*	0.270*	-0.335**	-0.202**	-0.457**	-1.257**	-2.138**
Graduates	1.429**	0.996**	1.813**	1.305**	0.393**	0.322**	0.821**	0.988**
Employment: agriculture	-3.856**	-3.598**	-6.840**	-7.679**	-3.103**	-4.258**	-8.134**	-8.971**
Employment: industry	-1.210**	-1.401**	-1.869**	-2.315**	-0.693**	-0.975**	-2.966**	-2.848**
Families with children	-0.112**	-0.144**	-0.635**	-0.753**	-0.547**	-0.634**	-2.423**	-2.132**
Families per dwelling	1.026**	0.519**	1.865**	1.059**	0.875**	0.559**	3.742**	1.921**
Population per room	-0.540**	-0.370**	-0.903**	-0.900**	-0.383**	-0.562**	-1.980**	-1.673**
Informal dwellings	0.900**	1.053**	1.717**	1.966**	0.864**	0.979**	3.040**	3.045**
Without basic facilities	0.267*	-0.370*	-0.519*	-1.651**	-0.847**	-1.396**	-1.112*	-2.807**
Large dwellings	-0.044	-0.194**	-0.087*	-0.335**	-0.044*	-0.157**	-0.227**	-0.537**
Owned dwellings	-0.454**	-0.528**	-0.841**	-1.075**	-0.408**	-0.576**	-1.281**	-1.368**
Constant	11.502**	12.076**	9.668**	10.361**	-1.867**	-1.731**	8.658**	9.716**
R2	0.436	0.401	0.528	0.455	0.458	0.352	0.507	0.428

Notes: Dependent variables are expressed in natural logarithms. N (1991)=14729; N (2001)=20777

The most interesting result is the one obtained for the proportion of individuals with low qualifications. The coefficient of this variable is positive in the models of private and public transport accessibility in 1991, but in 2001 the coefficient in the second model is negative. In addition, in both years, the coefficients in the models of relative public transport accessibility and the number of jobs within walking distance are negative. This means that low-qualified individuals tend to live in areas poorly served in public transport, when comparing with private transport, and in areas with poor walking access to jobs. The disadvantage of these populations has also grown as shown by the increase in absolute number of the coefficients in the models of relative public transport accessibility and walking accessibility.

In 1991, the proportion of dwellings without basic facilities has a positive coefficient in the model of private transport accessibility but a negative coefficient in the model of public transport accessibility. In 2001, both coefficients are negative. In contrast, the coefficients of the proportion of young adults in both models became positive.

As expected, the signs of the other coefficients are generally the same in the four regressions. The sign of the proportion of graduates is positive in all models and the signs of the proportion of workers in the agricultural and industrial sectors, families with children, large and owned dwellings, and population per room are negative. It is interesting to compare variables which are alternative indicators of some socio-economic or demographic condition. For example, indicators of housing deprivation have opposite signs: the signs of the proportion of dwellings without facilities (a characteristic of slum areas) are negative in almost all cases but the signs of the proportion of informal dwellings (incident in slums but also in some rural and seaside parts of the metropolitan area) are positive. The sign of the proportion of families per dwelling (indicator of shared housing) is positive but the sign of the proportion of males in the adult population (indicator of recently arrived migrants) is negative.

5.2. Commuting distance and time

Table 2 shows the regressions of average commuting distance and time and of average commuting time of private transport and public transport users in each district. The goodness of fit is considerably smaller in the models of commuting time, comparing with the models of commuting distance and accessibility.

In 1991 the proportion of young adults is associated with lower accessibility and longer commuting distances, but in 2001 that group is associated with longer commuting distances, despite living in places with high accessibility, comparing with other groups. The opposite happens for the population living in large dwellings and in dwellings without facilities in both years. These variables are associated with lower accessibility but with shorter commuting distances. These results suggest that from 1991 to 2001 the actual destinations of the young population no longer correspond to the levels of accessibility their residential areas provide, while the populations living in large dwellings and dwellings without facilities tend to work nearer to home than expected.

There are also differences between the signs of variables in the models of commuting distance and time. The populations with low qualifications and living in informal dwellings are negatively associated with commuting distance but not significantly (in 1991) or positively associated (2001) with commuting time, despite the fact that the commuting times of private transport users in these groups have a negative coefficient. Conversely, the influence of employment in the agricultural and industrial sectors on commuting distance is positive and the influence on commuting time is insignificant or negative, despite the fact that the commuting times of public transport users have a positive coefficient. These results suggest that for these groups, modal choice offsets the effect of advantages or disadvantages of living close to jobs.

The coefficient of the graduate population in the models of commuting time is negative, despite being positive or insignificant in the models of the commuting time of public transport users, pointing out to the dominance of time savings in private transport trips in the determination of the average commuting times of this group.

Table 2. Regressions of commuting distance and time

Dependent variable	**Commuting distance**		**Commuting time**		**Commuting time (private transport)**		**Commuting time (public transport)**	
Year	1991	2001	1991	2001	1991	2001	1991	2001
Male (%adults)	1.492**	0.474**	0.791**	0.093*	0.772**	0.210**	0.763**	0.234**
Young (% pop. 20-65)	0.890**	0.382**	0.297**	0.234**	0.180**	-0.208**	0.230**	-0.200**
No/lowest qualification	-0.586**	-0.651**	0.005	0.064**	-0.126**	-0.091**	0.011	0.037
Graduates	-0.191**	-0.333**	-0.884**	-0.710**	-0.069	-0.252**	0.156**	-0.040
Employment: agriculture	0.784**	1.157**	-0.476**	0.074	-0.119*	0.170**	0.229**	0.641**
Employment: industry	0.533**	0.749**	-0.199**	0.029	-0.171**	0.089**	0.000	0.235**
Families with children	0.530**	0.619**	0.324**	0.239**	0.203**	0.168**	0.309**	0.261**
Families per dwelling	-1.353**	-0.679**	-0.436**	-0.154**	-0.502**	-0.218**	-0.607**	-0.390**
Population per room	0.144*	0.174**	0.067	0.028	0.174**	0.121**	0.186**	0.203**
Informal dwellings	-0.393**	-0.547**	-0.003	0.094*	-0.127*	-0.161**	-0.264**	-0.279**
Without basic facilities	-0.778**	-0.549**	-0.084	-0.168**	-0.094	-0.100	0.118*	0.125
Large dwellings	-0.165**	-0.047**	-0.162**	-0.105**	-0.115**	-0.041**	-0.063**	-0.004
Owned dwellings	0.605**	0.686**	0.109**	0.134**	0.202**	0.239**	0.232**	0.316**
Constant	8.726**	8.571**	3.140**	3.087**	2.629**	2.574**	3.339**	3.374**
R2	0.491	0.490	0.273	0.335	0.171	0.228	0.270	0.321

Notes: Dependent variables are expressed in natural logarithms. N (1991)=14729; N (2001)=20777

5.3. Effect of modal choice

Table 3 shows the results of the regressions of the effect of modal choice. By definition, these effects depend on the relative efficiency of the modes used by the population when comparing with the fastest modes available in each district, and on the proportion of the population not using the fastest mode. In the study area, private transport is faster in the large majority of the routes, which means that the effects of modal choice depend on the efficiency of public transport relative to private transport and on the share of public transport users. The share of walking trips is also relevant, as walking is in many cases the fastest mode, due to the incorporation of time penalties in private and public transport trips accounting for walking to car parking areas, stations and bus stops and for waiting and interchange. The regressions of the effect of modal choice should then be interpreted alongside the ones of the ratio between public and private transport accessibility (Table 1) and of modal choice (Table 3).

Table 3. Regressions of the effect of modal choice on commuting time

Dependent variable	**Public transport (share)**		**Walk (share)**		**Effect of modal choice on commuting time**		**Effect of modal choice on commuting time (public transport)**	
Year	*1991*	*2001*	*1991*	*2001*	*1991*	*2001*	*1991*	*2001*
Male (%adults)	0.170*	-0.438**	-1.260**	-0.950**	0.019	-0.119**	-0.150**	-0.023
Young (% pop. 20-65)	0.220**	1.222**	-0.231**	0.493**	0.117**	0.443**	0.022	0.083**
No/lowest qualification	0.081	0.135**	-0.447**	-0.274**	0.131**	0.155**	0.155**	0.157**
Graduates	-2.376**	-1.705**	-3.016**	-1.835**	-0.817**	-0.459**	0.131**	0.205**
Employment: agriculture	-2.052**	-1.501**	0.681**	0.905**	-0.357**	-0.096**	0.391**	0.540**
Employment: industry	-0.621**	-0.639**	0.251**	0.179**	-0.028*	-0.060**	0.147**	0.112**
Families with children	0.170**	-0.048	-0.542**	-0.522**	0.122**	0.071**	0.075**	0.062**
Families per dwelling	0.202**	0.396**	0.821**	0.777**	0.067**	0.064**	0.054**	-0.051**
Population per room	-0.310**	-0.427**	-0.218**	-0.306**	-0.106**	-0.093**	-0.022	0.053**
Informal dwellings	0.599**	0.923**	0.186**	0.214**	0.124**	0.256**	-0.095**	-0.078**
Without basic facilities	-0.418**	-0.797**	-0.007	0.413**	0.009	-0.068	0.236**	0.330**
Large dwellings	-0.261**	-0.291**	-0.009	-0.053**	-0.047**	-0.064**	0.067**	0.040**
Owned dwellings	-0.231**	-0.345**	-0.235**	-0.446**	-0.093**	-0.105**	-0.022**	-0.000
Constant	-0.641**	-0.717**	-1.211**	-1.386**	0.508**	0.509**	0.720**	0.784**
R2	0.418	0.412	0.322	0.370	0.393	0.408	0.132	0.097

Notes: Dependent variables are expressed in natural logarithms. N (1991)=14729; N (2001)=20777

The variables showing a positive association with the effect of modal choice are also positively associated with the share of public transport. The effect is reinforced by a negative association with relative public transport accessibility (in the case of the proportions of individuals with low qualifications, young adults (in 1991) and families with children), or occur despite a positive association with relative public transport accessibility (in the case of the proportions of young adults (in 2001), families per dwelling and informal dwellings). It should be noticed that in the case of informal dwellings, the overall effect of modal choice is positive, despite being negative for public transport users. This suggests that a relatively high share of public transport users offsets the lower time losses for public transport users, when comparing with private transport users. The time losses may also occur because workers walk to access jobs located far from home, instead of using motorised transport. This hypothesis may be valid if we consider that informal dwellings are found in slum areas and that public transport costs influence travel decisions in the populations in these areas (Cachado, 2008).

The variables with a negative association with the effect of modal choice are also negatively associated with the share of public transport. This is the case of graduates, workers in the agricultural and industrial sectors, large and owned dwellings, dwellings with no facilities, proportion of males in the adult population, and population per room. In general, the effect occurs despite a negative association with relative public transport accessibility, but in the case of the graduate population, the association with relative public transport accessibility is positive. Nevertheless, the association of graduates with the effect on public transport users is positive. This effect is offset by the low proportion of public transport users in this population. In the case of workers in the agricultural and industrial sectors, the positive effect on public transport users is offset by the lower proportion of both public transport users and by the relatively high proportion of workers walking to work.

5.4. Effect of congestion

Table 4 shows the results of the regressions of the effect of congestion. Prior expectations are that the effect is higher for the variables negatively associated with the shares of walking (which is not affected by congestion) and public transport (as railway and underground users are also unaffected).

Table 4. Regressions of the effect of congestion on commuting time

Dependent variable	**Effect of congestion**		**Effect of congestion (Private transport)**		**Effect of congestion (Public transport)**	
Year	*1991*	*2001*	*1991*	*2001*	*1991*	*2001*
Male (%adults)	0.077**	0.046**	0.107**	0.016	0.061**	0.016
Young (% pop. 20-65)	0.036**	-0.022*	0.056**	0.064**	0.030**	0.013
No/lowest qualification	-0.029**	-0.031**	-0.097**	-0.077**	-0.043**	-0.053**
Graduates	0.183**	0.129**	0.113**	0.049**	-0.016	-0.055**
Employment: agriculture	-0.135**	-0.156**	-0.347**	-0.460**	-0.308**	-0.325**
Employment: industry	-0.071**	-0.041**	-0.189**	-0.169**	-0.100**	-0.080**
Families with children	-0.005	-0.001	-0.049**	-0.022**	-0.016**	-0.025**
Families per dwelling	-0.005	-0.074**	0.080**	-0.015	0.018*	-0.059**
Population per room	-0.006	0.014*	-0.045**	-0.031	-0.025**	-0.006
Informal dwellings	0.023*	-0.016	0.131**	0.123**	0.058**	0.057**
Without basic facilities	-0.006	-0.048**	-0.006	-0.106**	-0.037*	-0.126**
Large dwellings	-0.011**	-0.001	-0.055**	-0.049**	-0.007**	0.002
Owned dwellings	0.016**	0.044**	0.002	0.008*	-0.004	0.013**
Constant	0.044**	0.118**	0.128**	0.290**	0.103**	0.185**
R2	0.309	0.316	0.253	0.163	0.247	0.126

Notes: Dependent variables are expressed in natural logarithms. N (1991)=14729; N (2001)=20777

Most of the variables with a positive coefficient in the model of the effect of congestion do have a negative association with the share of public transport users and workers walking to work. These variables include the population per room and the proportions of graduates, owned dwellings and males (in 2001). In the case of the graduate population, the effect on public transport trips is negative, but in the case of other variables, the effect is positive for both public and private trips. In 1991, the proportions of young people and males in the adult population had a positive association with the share of public transport, but users of this mode were more affected by congestion than average. Areas with informal dwellings had a positive association with walking, but that association is offset by the congestion affecting both private and public transport users.

Some variables with a negative influence on congestion are positively associated with the share of public transport users and workers walking to work (the case of young people and families per dwelling in 2001) or only with the share of public transport (the case of low qualifications). In the case of young people, the overall effect of congestion occurs despite both private and public transport users being more affected by the problem than average, which may be explained by the relatively high share of walking to work.

The other variables with a negative influence in congestion (agricultural and industrial sectors, dwellings with no facilities and large dwellings) are negatively associated with the share of public transport users. These variables have a positive association with the share of walking, except in the case of large dwellings. All variables have a negative influence in the effect of congestion of both private and public transport trips.

5.5. Synthesis

The comparison of the four results tables highlights some of the factors behind social differences in commuting time. Low-qualified individuals tend to live in places with low relative accessibility by public transport and poor walking access to jobs and in 2001, also in places with low absolute accessibility by public transport. Despite the lack of accessibility, low qualifications are a negative predictor of commuting distances in areas with high proportions of low-qualified individuals. This result is not explained by a higher share of walk trips to work, comparing with other areas, but by smaller distances travelled by motorized mode. However, while travelling shorter distances, low-qualified populations are positively associated with commuting times, overall and considering only public transport trips. The effect of modal choice is a combination of the relatively high share of public transport trips and of the inefficiency of these trips when comparing with public transport trips in other areas. There is no evidence that this inefficiency is due to congestion.

The disadvantages of the young population are linked to different factors, changing over time. In 1991, areas with high proportions of this group had lower accessibility and higher commuting distances than average. This was compounded by the effects of modal choice and congestion, leading to high commuting times. In 2001, young populations had higher accessibility but still travelled longer distances and spent longer times commuting, despite a positive association with walking and negative associations with both private and public transport commuting time. These factors are offset by the positive association with the share of public transport. This association also grew from 1991 to 2001.

The other disadvantages in commuting time are linked to low potential accessibility, compounded with the effect of congestion (in the case of areas with owned dwellings and with higher proportion of males) or the effect of modal choice (in the case of families with children). The populations living in informal dwellings have higher accessibility but are not at an advantage in terms of commuting time due to a relatively high share of public transport users. The population living in dwellings with no facilities and the workers in the agricultural and industrial sectors have lower accessibility but are not at disadvantage in commuting time, due to the lower incidence of congestion and in the case of the last two variables, also due to a relatively high share of private transport and walking.

The advantages of the graduate population are linked to higher accessibility and with the relatively high proportion of private transport users, which offset the effects of congestion, while the advantages of individuals in shared dwellings are linked to higher accessibility, which offset the effects of high proportions of public transport users. Populations living in large dwellings and in dwellings with no facilities have lower accessibility but are at an advantage due to lower effects of both modal choice and congestion.

6. Conclusions and directions for further research

Inequalities in the distribution of accessibility are increasingly relevant for transport policy, as evidence grows of their role in processes of social exclusion, particularly given trends for the decentralization of employment in many cities. Previous literature has studied a series of mismatches leading to those inequalities, including those between residences and jobs, between the travel modes available and feasible in each location, and between the time constraints in accessing jobs and the availability of public transport services throughout the day. The main contribution of this paper was to bring together these different strands of the literature by decomposing the factors behind social differences in commuting time. The analysis compared models explaining indicators of accessibility and commuting outcomes with demographic and socio-economic variables. Walking trips to work or as a part of private and public transport trips were incorporated in the modelling of commuting trips.

The results suggest that some groups traditionally at disadvantage in the job market (such as young adults and low-qualified individuals) are also at disadvantage in terms of commuting times. However, the implications for transport policy depend on the factors creating those disadvantages. Some of these factors are related to poor provision of public transport. These include for example the differences between the public and private transport time to access the destinations where individuals actually travel, and the differences between the private or public transport efficiency for trips starting in different areas of the city. Both factors have an impact on the disadvantages of low-qualified individuals in terms of commuting time. The effect of congestion can also be addressed by transport policy, with a possible impact on reducing the disadvantage of young adults. Other factors, such as the mismatch between the actual and potential workplaces of the population living in some areas, and the share of private transport, which are behind the disadvantages of other groups, depend on large scale economic and social differences that affect household decisions.

Some of the economic and social aspects of residence and employment location and travel mode choice can however be included in the measurement of accessibility, for example, by considering wages or competition for jobs at each destination (Shen, 1998; Van Wee and Hagoort and Annema, 2001; Wang, 2003). Current efforts to refine indicators of accessibility will also provide further knowledge about the way that transport meets the preferences and needs of different groups. For example, the assumption that travel time is a "bad" is starting to be questioned (Jain and Lyons 2008).

The results of the map and regression analysis in this paper are consistent with those of surveys of individual travel behaviour in the study area, which found for example, that Lisbon is the only part of the metropolitan area where low-income individuals have high mobility and accessibility (Pritchard and Moura and Silva and Martinez 2014). Nevertheless, the reliance on geographic units tends to introduce distortions in the analysis (Robinson, 1950; Openshaw, 1984), which also apply in the estimation of proximity to jobs and commuting time (Boussauw and Neutens and Witlox, 2010). The consideration of variations within census units or travel analysis zones is an important direction in the study of distributive issues in accessibility. A first step has been taken by Grengs (2012), who refined accessibility measures with household-level data, assuming that households within the units of analysis experience either private or public transport accessibility, not a combination of the two. The use of detailed data may also contribute to increased knowledge about how households respond to changes in accessibility (for example, by relocating or changing destinations and travel modes), possibly reinforcing existing inequalities (Hesse and Scheiner, 2009).

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References

Benenson I., Martens K, Rofé Y (2010) "Measuring the gap between car and transit accessibility: Estimating access using a high-resolution transit network geographic information system" *Transportation Research Record* **2144**, 28-35.

Boussauw K, Neutens T, Witlox F (2012) "Relationship between spatial proximity and travel-to-work distance: the effect of the compact city" *Regional Studies* **46**(6), 687-706.

Cachado R d'A (2008) "Acessibilidades limitadas no espaço metropolitano: o caso dos Hindus da Quinta da Vitória (Limited accessibility in the metropolitan space: the case of the Hindu community of Quinta da Vitória)", *VI Congresso Português de Sociologia*, Lisbon. Available from www.aps.pt/vicongresso/pdfs/95.pdf. Accessed 27th July 2014. In Portuguese.

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.

De Rango K (2001) "Can commutes be used to test the spatial mismatch hypothesis?" *Urban Studies* **38**(9), 1521–1529.

DGTT (Direcção-Geral dos Transportes Terrestres) (Directorate-General of Land Transport) and INE (Instituto Nacional de Estatística) (National Statistics Institute) (1998). *Inquerito à mobilidade na AML 1998* (Mobility survey of the population of the AML 1988), DGTT and INE, Lisbon. In Portuguese.

Dong X, Ben-Akiva M E, Bowman J L, Walker J L (2006) "Moving from trip-based to activity-based measures of accessibility" *Transportation Research A* **40**(2), 163-180.

European Commission (no date) *Travel time to major cities: A global map of accessibility*. Available from http://bioval.jrc.ec.europa.eu/products/gam/sources.htm. Accessed 27th July 2014.

Fan Y, Guthrie A, Levinson D. (2012) "Impact of rail implementation on labor market accessibility: a transportation equity perspective" *Journal of Transport and Land Use* **5**(3), 28-39.

Foth N, Manaugh K, El-Geneidy A M (2013) "Towards equitable transit: examining transit accessibility and social need in Toronto, 1996-2006" *Journal of Transport Geography* **29**, 1-10.

Fotheringham A S, O'Kelly M E (1989) *Spatial interaction models: formulations and applications*, Kluwer Academic, Dordrecht.

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.

Gobillon L, Selod H (2014) "Spatial mismatch, poverty, and vulnerable populations" in M M Fischer, P Nijkamp (eds.) *Handbook of regional science*, Springer, Berlin: 93-107.

Grengs J (2010) "Job accessibility and the modal mismatch in Detroit" *Journal of Transport Geography* **18**(1), 42-54.

Handy S, Niemeier D (1997) "Measuring accessibility: an exploration of issues and alternatives" *Environment and Planning A* **29**(7), 1175-1194.

Hansen W G (1959) "How accessibility shapes land use" *Journal of the American Institute of Planners* **25**(2), 73-76.

Hess D B (2005) "Access to employment for adults in poverty in the Buffalo-Niagara Region" *Urban Studies* **42**(7), 1177-1200.

Hine J (Ed.) (2003) "Social exclusion and transport systems" (Special Issue) *Transport Policy* **10**(4).

Hu L (2014) "Changing job access of the poor: effects of spatial and socioeconomic transformations in Chicago, 1990-2010" *Urban Studies* **51**(4), 675-692.

Jain J, Lyons G (2008) "The gift of travel time" *Journal of Transport Geography* **16**(2), 81-89.

Kain J F (1968) "Housing segregation, negro employment and metropolitan decentralization" *Quarterly Journal of Economics* **83**(2), 175-197.

Kawabata M (2003) "Job access and employment among low-skilled autoless workers in US metropolitan areas" *Environment and Planning A* **35**(9), 1651-1668.

Kawabata M (2009) "Spatiotemporal dimensions of modal accessibility disparity in Boston and San Francisco" *Environment and Planning A* **41**(1), 183-198.

Kawabata M, Shen Q (2006) "Job accessibility as an indicator of auto-oriented urban structure: a comparison of Boston and Los Angeles with Tokyo" *Environment and Planning B* **33**(1), 115-130.

Korsu E, Wenglenski S (2010) "Job accessibility, residential segregation and risk of long-term unemployment in the Paris Region" *Urban Studies* **47**(11), 2279-2324.

Kwok R C W, Yeh A G O (2004) "The use of modal accessibility gap as an indicator for sustainable transport development" *Environment and Planning A* **36**(5), 921-936.

Lau J C-Y (2011) "Spatial mismatch and the affordability of public transport for the poor in Singapore’s new towns" *Cities* **28**(3), 230-237.

Lucas K (Ed.) (2004) *Running on empty: transport, social exclusion and environmental justice*, The Policy Press, University of Bristol, Bristol.

Lucas K, Stanley J (Eds.) (2009) "International perspectives on transport and social exclusion" (Special Issue) *Transport Policy* **16**(3).

Manaugh K, El-Geneidy A (2012) "Who benefits from new transportation infrastructure? Using accessibility measure to evaluate social equity in transit provision" in K Geurs, K R Krizek, A Reggiani (eds.) *Accessibility and transport planning: challenges for Europe*, Edward Elgar, London: 211-227.

Matas A, Raymond J-L, Roig J-L (2009) "Car ownership and access to jobs in Spain" *Transportation Research A* **43**(6), 607-617.

Ong P M, Miller D (2005) "Spatial and transportation mismatch in Los Angeles" *Journal of Planning Education and Research* **25**(1), 43-56.

Openshaw S (1984) *The modifiable areal unit problem*, GeoBooks, Norwich.

Ortúzar J de D, Willumsen L G. (2006) *Modelling transport* (3rd Edition), Wiley, Chichester.

Pennycook F, Barrington-Craggs R, Smith D, Bullock S (2001) *Environmental justice: mapping transport and social exclusion in Bradford*. Report for Friends of the Earth. Available from www.foe.co.uk/resource/reports/env_justice_bradford.pdf. Accessed 27th July 2014.

Pritchard J P, Moura F, Silva J A, Martinez L M (2014) "Spatial analysis of transportation-related social exclusion in the Lisbon metropolitan area" *Procedia - Social and Behavioral Sciences* **111**(2014), 440-449.

Reggiani A, Bucci P, Russo G (2011) "Accessibility and impedance forms: empirical applications to the German commuting network" *International Regional Science Review* **34**(2), 230-252.

Robinson W S (1950) "Ecological correlations and the behavior of individuals" *American Sociological Review* **15**(3), 351-357.

Shen Q (1998) "Location characteristics of inner-city neighborhoods and employment accessibility of low-wage workers" *Environment and Planning B* **25**(3), 345-365.

Van Wee B, Hagoort M, Annema J A (2001) "Accessibility measures with competition" *Journal of Transport Geography* **9**(3), 199-208.

Wang J (2001) "Explaining intraurban variations of commuting by job proximity and workers' characteristics" *Environment and Planning B* **28**(2), 169-182.

Wang J (2003) "Job proximity and accessibility for workers of various wage groups" *Urban Geography* **24**(3), 253-271.

Wang E, Song J, Xu T (2011) "From “spatial bond” to “spatial mismatch”: An assessment of changing jobs–housing relationship in Beijing" *Habitat International* **35**(2), 398-409.

Weber J (2003) "Individual accessibility and distance from major employment centers: An examination using space-time measures" *Journal of Geographical Systems* **5**(1), 51-70.

Weber J, Kwan M-P (2002) "Bringing time back in: a study on the influence of travel time variations and facility opening hours on individual accessibility" *The Professional Geographer* **54**(2), 226-240.

Weinberg B (2004) "Testing the spatial mismatch hypothesis using inter-city variations in industrial composition" *Regional Science and Urban Economics* **34**(5), 505-532.

Wu B, Hine J (2003) "A PTAL approach to measuring changes in bus service accessibility" *Transport Policy* **10**(4), 307-320.