Urban transport, pedestrian mobility and social justice

A GIS analysis of the case of the Lisbon Metropolitan Area

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Declaration

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Abstract

Urban transport projects redistribute accessibility and environmental quality across the city, potentially creating disadvantages for some social groups. This thesis investigates whether these effects are cumulative or compensatory in the case of the Lisbon Metropolitan Area, analysing inequalities in the light of competing principles of social justice. The novelty of this research lies in the interpretation of local environmental effects as factors restraining the mobility of pedestrians. We propose a series of GIS-based indicators, including community severance and noise exposure of pedestrians on the way to work and walking around their neighbourhoods. We found that projects giving priority to private transport have a disproportionate effect on the pedestrian environment of the elderly and low-qualified populations.

The analysis addresses two of the most pressing issues in transport equity analysis. The first is the spatial heterogeneity in patterns of inequality. We estimate relationships between socio-economic variables and indicators of the local effects of transport using alternative comparison areas, defined in terms of centrality and commuting destinations. We found that the social distribution of those effects is sensitive to location and spatial scale. The second issue is the nature of the processes leading to inequalities. We show that accessibility and pedestrian mobility have an influence on neighbourhood socio-economic recomposition and on patterns of settlement in newly developed areas.

We also analyse the implications of integrating distributive concerns in transport planning. In the design of the optimal route alignment for a new road, these concerns may increase aggregate community severance costs. In the application of traffic restriction policies, there are trade-offs between the welfare of different groups of concern in terms of time to work and pedestrian exposure to noise. In both cases, the achievement of equity may not be compatible with the party-political interests of the policy-maker.

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'What is coming from there? You have three guesses'.

He said: 'Well, a car!'

I said: 'No, take your second guess.'

He looked and said: 'A vehicle.'

I said: 'No, and now you have your last chance.'

And he answered, angry with me: 'An automobile.'

I still wonder when he will realize that what was coming was a person, inside a metal case, and that there is no reason whatsoever for that person in the role of a car driver to have priority over us standing on the sidewalk.

Eduardo A. Vasconcellos, *Urban Transport, Environment and Equity* (2001)

Chapter 1

The socio-spatial dimensions of transport equity

Mobility is the possibility of moving from one place to another. In contemporary cities, levels of mobility depend largely on car ownership and use. This aspect tends to put some groups at disadvantage, due to physiological, social or economic factors. In fact, there is evidence that some sections of the population travel less frequently and cover less distance than average. These include the elderly [Mollenkopf *et al.* 2004, 2005], low-income populations [Hine and Mitchell 2003] and racial minorities [Batelle 2000, Rajé 2004]. However, differences in levels of mobility do not fully explain existing social inequalities in levels of accessibility, that is, in the ease of reaching particular places within the city using a given transport mode. This is because disparities in accessibility levels depend on the spatial distributions of the different groups, employment and transport infrastructure. Inequalities in the distribution of accessibility have therefore a spatial dimension, in the cases where there is a relationship between the levels of accessibility of the different neighbourhoods and their social composition.

The finding of inequalities in levels of accessibility is often discussed in terms of social justice, with implications in transport and urban planning. The argument is that the distribution of accessibility is inequitable if it is systematically disadvantageous for groups that are already at disadvantage in the distribution of other resources, such as income, employment or political power. The confounding factor in this assessment is that urban transport projects are in fact responsible for the redistribution of a bundle of goods among the different areas of the city, including not only levels of accessibility but also local environmental costs. The interpretation of the inequalities in terms of social justice then depends on whether the disadvantages in the distribution of both effects are cumulative or compensatory and on the relationships between the two distributive processes over time. These processes include biased political decisions and adjustments of the housing market to neighbourhood changes linked to transport projects.

Whilst we have some knowledge on the relationships between the distributive outcomes and processes of different dimensions of accessibility (such as accessibility to jobs and to urban facilities) and different dimensions of environmental quality (such as air pollution and noise), relatively little research has focused on the relationships between the two types of effects. More importantly, there is a lack of knowledge on the role of pedestrian mobility as an additional distributive concern and on its relationships with the distribution of both accessibility and environmental quality. In fact, walking can be a means to reach nearby places or to access public transport and so pedestrian mobility is a condition or a complement to accessibility. The quality of mobility for pedestrians also depends on environmental factors, especially when we consider walking as an activity with its own value. While the social groups mentioned above are at a potential disadvantage due to higher reliance on walking, this disadvantage has a spatial dimension, if the areas where these groups walk also have lower levels of pedestrian mobility.

The objective of this thesis is to contribute to the investigation of the social and spatial dimensions of the transport equity problem, by incorporating the distribution of positive and negative local effects in the same empirical framework. The hypothesis is that the two distributive processes depend on the same causes: differences in the level and nature of mobility and decisions that individuals make over space. The main novelty of the project is to consider the role of pedestrian mobility on those two factors. This involves:

a) The study of the relationships between inequalities in pedestrian mobility and inequalities derived from different levels of access to private and public transport.

b) The widening of the set of relevant geographic factors to include not only the choice of residence location but also the choice of daily destinations. These affect the way that individuals fulfil the accessibility potential of the places where they live and the levels of exposure to pollution that they face during the day, as pedestrians.

The work focuses on the changes in the transport system of the Lisbon Metropolitan Area in the period between the last two population censuses (1991-2001). The combination of unprecedented changes in the road network with urban fragmentation and population ageing in this period has raised questions about the adequacy of the transport improvements for meeting the needs of elderly and low-qualified populations. The effects of those changes are assessed in this thesis by comparing the social distribution of several indicators of mobility in 1991 and 2001. These indicators assess dimensions of mobility that are positively or negatively affected by road infrastructure and traffic, including accessibility to jobs and to urban facilities and aspects of pedestrian mobility such as community severance and exposures to noise for pedestrians walking around their neighbourhood or on the way to work.

The hypothesis is that the priority given to the expansion and improvement of the private transport system contributed to the deterioration of pedestrian mobility in areas with elderly and low-qualified populations, without increasing the realized accessibility of these populations, due to their relatively high reliance on public transport or walking and to the increased dispersion of jobs and urban facilities.

The empirical analysis addresses some of the issues that arise when analysing transport inequalities in terms of social justice. While justice is a contested notion, options chosen in empirical studies in this field rely on presuppositions that explicitly or implicitly endorse certain views on social justice. The present study intends to assess the implications of holding competing notions of social and spatial equity. This assessment includes the comparison of alternative definitions of the sub-set of areas within the metropolitan area on which we assess inequalities; the test of different hypotheses regarding the processes that led to inequalities; and the analysis of the implications of holding different levels of priority to vulnerable classes and different valuations of pedestrian mobility when designing transport projects and policies.

This chapter introduces the main questions analysed throughout the thesis. Section 1.1 reviews the existing knowledge in the field of socio-spatial transport disadvantage and the way that these results are inseparable from the methodological approaches used and from certain presuppositions regarding the role of social justice. Section 1.2 points out some reasons for the necessity of including changes in pedestrian mobility as a distributive concern in transport planning. Section 1.3 analyses the relevance of a transport equity study in the Lisbon Metropolitan Area. Finally, Section 1.4 explains how the present study integrates within the existing body of knowledge, by stating the intended contribution, research questions and general methods.

1.1. The role of transport in social exclusion and environmental inequality

The spatial dimensions of the redistributive effects of urban transport have been subject of extensive research in the last decade, including independent studies conducted by academics and projects commissioned by government or groups of activists. The aim of these studies is to test empirically the existence of links between the location of age groups, socio-economic classes or ethnic groups and the spatial distribution of the positive and negative effects of road transport. The existing literature can be broadly divided into studies on the relationships between transport, accessibility and social exclusion and studies on the patterns of inequality in the exposure to local environmental effects.

Existing knowledge and unanswered questions

Accessibility is one of the main distributive concerns in urban transport planning, since transport disadvantage may reinforce processes of social exclusion of some social groups. Generally, the lack of accessibility to the places where urban opportunities are located contributes to the lack of participation of those groups in economic and social activities [SEU 2003, Hine 2003, Lucas 2004, Lucas and Stanley 2009]. This is especially the case when public transport is slow, unreliable or non-existent. Despite the fact that deprived populations tend to have higher rates of public transport use, there is evidence that the areas where they live have in many cases lower public transport accessibility than average [Pennycook *et al.* 2001, Cebollada 2009]. This situation is explained by the general disinvestment in public transport serving disadvantaged areas and to the priority to radial public transport services connecting suburbs with major centres, but not with other suburbs and minor centres.

A case of special concern is accessibility to jobs. In fact, the employment outcomes of underprivileged groups are in part explained by the distance to the areas where job opportunities are located, especially in dispersed, decentralized metropolises, a phenomenon known in the literature as the ‘spatial mismatch hypothesis’ [Kain 1968]. Empirical evidence suggests the existence of social inequalities in the distribution of job accessibility, even after accounting for occupational differences [Cervero *et al.* 1999, Stoll *et al.* 2000]. It is difficult, however, to pinpoint causality in the mechanisms leading to those inequalities [Gobillon *et al.* 2007]. The problem is related with transport, since job accessibility depends not only on proximity to jobs but also on modal choice. This fact may be associated with inequalities in accessibility that do not appear when accessing inequalities based on job proximity [Wang 2003, Ong and Miller 2005]. The decentralization of employment then affects disproportionately the employment prospects of some social groups, due to higher reliance on public transport. Although most of the evidence on this issue comes from North American cities, the process of decentralization of employment is increasingly relevant in Europe.

Other studies have analysed social differences in accessibility to urban facilities and services. There is evidence for example that deprived groups and racial minorities tend to live in places with lower accessibility to public parks [Wolch *et al.* 2005, Omer 2006, Boone *et al.* 2009, Jones *et al.* 2009]. There is also a growing literature analysing the problem of lack of accessibility to food shops [Clarke *et al.* 2002, Guy *et al.* 2004, Smoyer-Tomic *et al.* 2006, Lee and Lim 2009]. These studies show that "food deserts" are usually areas with lower car ownership rates, or in other words, the population who relies on walking tend to live in areas where the number of food shops at walking distance is relatively scarce. Lack of car or reliance on public transport may also have an effect on levels of accessibility to health facilities [Lovett *et al.* 2002, Martin *et al.* 2008].

A parallel strand of literature has focused on the inequalities in the distribution of the environmental costs of the transport system. The question is usually analysed with reference to the concept of environmental equity, the principle that disadvantaged groups should not be disproportionately exposed to environmental costs and risks [Bryant 1995]. In most empirical studies, a link was found between social deprivation and exposure to road traffic air pollution [Brainard *et al.* 2002, Mitchell and Dorling 2003, Buzzelli and Jerrett 2004, Pearce *et al.* 2006, Havard *et al.* 2009] and between deprivation and exposure to noise [Brainard *et al.* 2003, Hoffmann *et al.* 2003]. Although the hypothesis of environmental disadvantage of income-deprived populations has been confirmed in several countries [Braubach and Fairburn 2010, Deguen and Zmirou-Navier 2010], the generalization of the results should be approached with caution. For example, King and Stedman (2000) and Pye *et al.* (2001) found significantly different types of associations between air pollution and social-economic status in different cities, using the same method of analysis. In addition, if accounting for control variables such as population density, associations between air pollution and deprivation can be negative [McLeod *et al*. 2000], or become irrelevant [Green *et al.* 2004]. On the other hand, the link between air pollution and racial minorities seems more stable across different countries [Brainard *et al.* 2002, Pearce *et al.* 2006, Grineski *et al.* 2007].

While the environmental justice concept has been mainly applied to socio-economic and racial divides, recent debate has drawn attention to the relationships between age and local environmental quality [Day 2010]. However, the hypothesis of the transport-based environmental disadvantage of elderly population has not been confirmed, with studies finding that age is not significant [Brainard *et al.* 2002, 2003] or that young children are more affected, while the elderly are less affected by road pollution [Mitchell and Dorling 2003].

The main point of contention in the academic debate of transport inequality is the fact that the findings of empirical studies are highly dependent on the methodological options taken. Most of the studies in this field rely on geographic information systems (GIS) to overlay maps of transport effects and socio-economic variables at census unit level. The results are then analysed by estimating statistical relationships occurring within a city or urban area. However, there are a series of possible options regarding the definition and estimation of transport's effects, the definition of groups of concern, and the assessment of statistical associations between both. The choice of different methodological options may originate different results for the same scenario, both in the case of accessibility and environmental quality (see respectively Neutens *et al.* 2010 and Jacobson *et al.* 2005).

The utility of empirical analysis in informing public policy is especially controversial in the cases when the definition of research questions and methods are bound to assumptions regarding the role of social justice in transport policy. The distribution of accessibility and environmental quality among the different groups has a direct effect on the welfare of individuals and is in part determined by society, through the actions of the policy-maker. According to the concept of Miller (1976), these two conditions place the distribution of those "goods" in the realm of social justice. The effects of transport can indeed be analysed in terms of territorial justice (the distribution of beneficial and noxious facilities in space) [Harvey 1973]. The conceptualization of environmental justice has also drawn from broader theories of distributive and procedural justice [Wenz 1988, Low and Gleeson 1998]. However, the translation of empirical results into statements on the justice or injustice of the inequalities is fraught with the problem that changes in the transport system involve the distribution of multiple intangible "goods" and that competing principles of justice may apply to the distributive outcomes and to the processes that led to those outcomes. We discuss these aspects in the next three sub-sections.

The object of distribution

Studies of transport equity have traditionally focused on the distribution of “physical units” of the effects of transport (accessibility or pollution). The consideration of these effects as objects of social distribution depends however on the extent to which the specific indicators used in the analysis depend directly on transport planning, and on the extent to which they measure changes in the welfare of the individuals living in each neighbourhood. The adoption of a geographic perspective poses some limitations, as the use of areal data assumes that neighbourhoods are internally homogeneous and that patterns of inequality originate only from the relationships between the spatial distribution of the effects of transport effects and the socio-economic characteristics of the population living in each neighbourhood. However, these relationships may not capture the way that transport meets the preferences or needs for accessibility and environmental quality of that population. These preferences and needs depend on a series of population characteristics, such as the level and type of employment, daily destinations and levels and nature of mobility.

A crucial distinction is that between potential accessibility (the possibility of moving from one’s neighbourhood and reach other places) and 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 suitability of the travel modes used to reach them. The construction of new transport infrastructure may not improve the realized accessibility in the areas served, if residents rely on travel modes that are not available in the new link. This may create paradoxical patterns at the aggregate level. For example, low-income groups and racial minorities may travel longer distances to access places of work than other groups, while living in areas with higher levels of private transport accessibility [Grengs 2010] or they may spend longer times on the journey to work while travelling shorter distances [Wang 2001, 2003]. In general, gains in accessibility from new roads tend to favour private transport users, as the design of bus routes is seldom compatible with the use of motorways, especially in areas close to city centres. The restructuring of city-wide public transport networks may also have a detrimental effect on areas populated by the elderly and by families without car, when bus routes are changed in order to underpin the development in the train or underground networks [Wu and Hine 2003]. Finally, the relationship between potential and realized accessibility depends on the quality of the transport available, in particular on levels of congestion and, in the case of public transport, also on the availability and frequency of the services.

On the other hand, the analysis of environmental equity is prone to the "ecological fallacy", a term defining the fact that associations detected for a population may not be valid at the level of individuals [Robinson 1950]. In fact, the levels of exposure to pollution and the associated health effects for an individual do not depend only on emissions or concentrations at his place of residence, but also on personal characteristics and on his degree of exposure as he moves across different parts of the city within the day. Ideally, the estimation of pollution exposures should refer to the population who is directly affected, but in most cases, there is no available data on the characteristics of the individuals most exposed to roadside pollution, such as pedestrians, cyclists or open-air workers. As such, most environmental equity studies use pollution concentrations as a proxy for exposures, together with the assumption that exposure occurs in people's homes. This approach is limited by the fact that a large number of the cities' residents are away from home during daytime, when pollution levels are higher, since road traffic levels are also higher. The assessment of social inequalities and the existence of cumulative effects for some groups may then be dependent on distinctions such as daytime *vs.* night time pollution, exposure at home *vs.* exposure at the workplace and indoor *vs.* outdoor exposure. For example, Houston *et al.* (2004) found that race and socio-economic status relate to both outdoor and indoor exposure to road pollution, while Su *et al.* (2011) confirmed the hypothesis that the patterns of social disadvantage to air pollution also apply when considering individuals' leisure time in public parks.

Distributive outcomes

The second major problem in the study of equity issues in urban transport is the ambiguity in the judgement of the distributive patterns found. This judgment is implicit in the definition of the groups amongst whom the distribution of accessibility or environmental quality is measured, and in the operational definition of equity used to assess that distribution. The definition of groups of concern is usually justified referring to values such as racial non-discrimination [Bullard *et al.* 1997, 2004] or more generally, by the need to protect vulnerable groups [Delbosc and Currie 2011]. This is based on the argument that those who are most affected by the lack of accessibility or environmental quality are the ones who need them the most. These include low-income populations (who are more sensitive to transport costs when accessing low wage jobs) and the elderly (for whom mobility and environmental quality are an integral part of physical and social health). The choice over the methods used to measure equity is more problematic, as different concepts of social justice may apply, regarding the extent to which society should consider equality or departures from equality by favouring certain groups. The political relevance of statistical relationships between the distribution of benefits and costs and the location of the groups of concern is questioned by authors such as Perhac (1999), for whom society should provide minimum standards for all, regardless of their socio-economic characteristics.

In general, judgements on the justice of distributive outcomes have not been explicitly included as a part of quantitative assessments of urban transport policies. The exception is the European Union's Spartacus project [CEC DG XII 1998], which evaluated future transport and land use scenarios in three European cities using parameters measuring societal perspectives on equity. The project found that the use of alternative concepts of distributive justice to assess the distribution of exposure to air pollution and noise across different groups implies different levels of priority for alternative policy options, even when assessing justice as a single dimension within a large set of indicators for the economic, social and environmental outcomes. However, the project only developed equity indicators for the case of exposure to pollution, evaluating accessibility issues in terms of city averages.

The judgement of the distributive outcomes of transport planning depends on the comparison of inequalities in the distribution of different impacts across different groups. Studies in a variety of urban areas have rejected the hypothesis of multiple disadvantage when disaggregating accessibility by type of destination [Witten *et al.* 2003, Scott and Horner 2004, Tsou *et al.* 2005, Macintyre *et al.* 2008]. This result may be explained by the fact that differences in the spatial distribution of each type of urban opportunities ensure that groups of concern are not at disadvantage in terms of access of some of these opportunities. However, this conclusion does not rule out the fact that insufficiencies in public transport may pose a limitation to the accessibility of some groups, as most of the available studies considered only network distance. On the other hands, the hypothesis of multiple environmental disadvantage seems to depend on the specificities of each urban area. For example, Kruize *et al.* (2007) found that low-income groups in Rotterdam are at a disadvantage in the joint distribution of a set of environmental "goods" and "bads" related with transport, such as air pollution, noise, and accessibility to parks. On the other hand, the results of a series of studies in Birmingham revealed different patterns of disadvantage affecting different groups in the distribution of those three items [Brainard *et al.* (2002, 2003), Jones *et al.* 2009].

The integration of the distribution of accessibility and environmental quality in the same empirical framework depends on assumptions about the way they compensate each other. One view is to notice that roads are polluting infrastructure used directly by people and thus the travel behaviour of the population living in some neighbourhoods or using some travel modes is "responsible" for the imposition of costs on other groups or in other areas. We can then overlay the spatial distributions of road users, pollution and social groups. Studies using this approach [Stevenson *et al.* 1998, Mitchell and Dorling 2003, Kingham *et al.* 2007] have concluded that deprivation is associated with both a higher share of external costs from road use and a lower level of "responsibility". This type of analysis usually assumes that car ownership and car use are correlated and that cars are responsible for higher emissions per road user than buses. However, the relationship between income and vehicle emissions at household level is not linear. This is what is known in the literature as the household Kuznets curve hypothesis: richer households own more vehicles and drive more but poorer households use higher polluting vintages [Kahn 1998].

Finally, there are questions regarding the definition of the areas over which we estimate the inequalities. Some authors have argued that if these areas are not selected carefully, inequalities may simply reflect variations in confounding factors among the different neighbourhoods [Mitchell and Walker 2007, p.461]. In fact, empirical applications have shown that associations between socio-economic variables and levels of accessibility or pollution are not stable across space, varying with urbanization levels and other factors that influence the locations of population and transport infrastructure [Mennis and Jordan 2005, Maroko *et al.* 2009, Roorda *et al.* 2010]. Associations may also occur at different spatial scales. This is because they depend on forces that are active only at those scales: the scale of policy-maker's decisions on the location of transport infrastructure (*i.e.*, administrative areas) and the scale considered by households in their residence location and commuting choices.

Distributive processes

Most transport equity studies have focused on the ex-post evaluation of distributive outcomes, using cross-sectional data. However, the identification of a correlation between socio-economic variables and accessibility or environmental quality does not imply a cause-effect relationship. The assessment of transport inequalities in terms of social justice and the development of responses to correct those inequalities need therefore to consider a temporal dimension and model the processes behind the distribution of benefits and costs among social groups. This involves the establishment of links between the location of roads and people. This is a complex task, as it is difficult to disentangle the role of political procedures, market dynamics, changes in urban land use and demographic and economic trends. Many theories have been offered but they have yet to provide conclusive evidence [Liu 2001, chap.2].

The classification of inequalities as unjust seems more consensual when their emergence can be linked to specific procedures of the policy-maker. This may be the case when decisions on the location of transport infrastructure are influenced by the power of lobbies or by the policy maker's own interests in terms of political gain or bias towards specific groups – what Feitelson (2001) calls "malicious siting". This may lead to disadvantages for low-income groups or racial minorities, due to their lower potential for voicing demands through the political process [Hamilton 1993, 1995]. While there is some empirical work on the influence of political aspects in the allocation of regional transport investment and in the location of point sources of pollution, the case of urban transport is still under-researched.

The spatial distribution of social groups may also adjust over time to the distribution of accessibility or environmental quality. The residential sorting of the most desirable areas according to ability to pay depends however on the balance between preferences and housing and commuting costs, on the efficiency of the housing market in the capitalization of neighbourhood attributes and on the available set of levels of accessibility and pedestrian mobility among the neighbourhoods in the city. While historically, levels of accessibility were higher in city centres, where environmental quality was usually lower due to the concentration of activities and road traffic, recent tendencies such as the decentralization of facilities and jobs may contribute to the creation of multiple disadvantages, as there are differences among suburban areas according to their distance to motorway junctions or railway stations and to their distances to the actual infrastructure. Higher-income groups may then move to the suburban areas with higher environmental quality and easy access to centres of employment [Gorz 1980]. Therefore, transport-based inequality does not depend solely on transport planning but also on urban planning and on business relocation decisions.

Even in the cases where it is possible to assess correctly the processes leading to inequalities, we are still left with the question of how to incorporate equity concerns in the planning of new infrastructure and in the design of traffic policies. This can be achieved by estimating equity indices [Martín *et al.* 2010] or by attaching distributional weights to different social groups in the framework of cost-benefit analysis [Mayeres 2001, Suryo *et al.* 2007, Ramjerdi *et al.* 2008]. There is a need, however, for more systematic research on the existence of feasible alternatives, trade-offs between the distribution of multiple impacts among various groups and trade-offs between the objectives of equity and efficiency.

1.2. Pedestrian mobility as a component of transport equity

While the purpose of transport planning is to facilitate mobility, there are possible conflicts between the mobility provided by motorised transport and the mobility of pedestrians. For Ivan Illich (1974), improvements in one type of mobility imply the deterioration of the other. As we will see in this section, the construction of new transport infrastructure and increases in traffic flows tend to affect negatively the mobility of pedestrians. The redistribution of welfare from pedestrians to the users of the transport system may contribute to a potential disadvantage for the elderly, due to higher vulnerability to losses in pedestrian mobility; and for low-income populations, due to higher reliance on walking [Manaugh and El-Geneidy 2011]. In addition, the areas affected by those losses may have disproportionately high numbers of pedestrians belonging to those groups. The study of these potential social and spatial inequalities is relevant to the transport equity problem, as they are closely related to the patterns of accessibility and environmental inequality described in the last section.

Pedestrian mobility is a crucial factor for intra or inter-neighbourhood accessibility, as walking is usually the fastest and most convenient mode for short-distance trips, to access local facilities. The accessibility of jobs and urban facilities at the metropolitan level also depends on pedestrian mobility, as public transport commuting involves walking, to access bus stops or train stations, or to interchange between different modes or services. On the other hand, walking around one's neighbourhood can also be pursued as an activity with its own value. The benefits of walking are becoming increasingly relevant for urban transport planning in developed countries, given current demographic, social and cultural trends such as population ageing and shifts towards healthier lifestyles. The freedom of "walking around and looking around" has long been regarded as an essential component of the quality of life in urban settings [Buchanan and Crowther 1963, Appleyard and Lintell 1972]. The rise in the number of elderly people has increased the policy relevance of this component, as there is a close association between walking and factors such as general health, independence and life satisfaction within this group [Schaie 2003, Mollenkopf *et al.* 2004]. The priority to the needs of pedestrians in road and street design can also contribute to reduce social exclusion along gender and racial lines [Garcia-Ramon *et al.* 2004].

Given the need for promoting walking within the overall objectives of transport and urban planning, it is important to consider the impact that interventions on the transport system affect the level and the quality of pedestrian mobility. In general, the presence of transport infrastructure and heavy traffic is a major deterrent to walking. There is evidence that exposure to road traffic is linked to a lower probability of walking, both to access places and for physical exercise [Giles-Corti and Donovan 2002, Eyler 2003]. Road traffic also influences pedestrians' behaviour while walking [Hine 1996]. Both factors have a social dimension, as the effect of road traffic on the reduction of physical exercise seems to be more salient among deprived groups [Giles-Corti and Donovon 2002]. Perceptions about the walking environment and about its relationships with road traffic levels also depend on gender and age [Sharples and Fletcher 2000].

Community severance is the most significant impact of transport infrastructure on pedestrian mobility. The construction of motorway and rail lines often carries changes in the street network linking different neighbourhoods, separating communities and increasing the isolation of some neighbourhoods. Road traffic itself can also act as a "dynamic barrier" to the mobility of local populations [Guo *et al.* 2001]. Community severance has effects on pedestrian mobility in terms of time to reach places, as the population of one neighbourhood may have to walk longer distances to access other neighbourhoods or urban facilities. There is also evidence that the barrier-effect of transport infrastructure has psychological effects on local residents, with implications on the number of inter-neighbourhood trips and community interaction [Clark *et al.* 1991, Bradbury *et al.* 2007].

The growth of road traffic is also responsible for the increase in pedestrian accident risk, a problem with special incidence in elderly people, since the risk of fatality increases with age [Leaf and Preusser 1999]. The redistributive effects of road traffic on pedestrian safety have been analysed regarding socio-economic or racial aspects, although usually within specific age groups, such as children. Some of these studies use spatial data and relate the probability of accidents with the characteristics of the area where the children live. Patterns of inequality are often related to mobility disadvantages, as children from families who lack access to cars tend to walk more and have less access to safe play areas, such as parks [Abdalla *et al.* 1997, Petch and Henson 2000]. The probability of accidents in all age groups also tends to relate with income-deprivation, since less affluent areas tend to be crossed by longer lengths of road and higher traffic flows [Graham *et al.* 2005, Loukaitou-Sideris *et al.* 2007, Wier *et al.* 2009].

Transport infrastructure and traffic also influences the quality of mobility of pedestrians by decreasing the amenity value of walking, due to changes in the environmental conditions along pedestrian routes [Humpel *et al.* 2004]. According to Taylor (2003), "the experience of road traffic is the most salient aspect of people's experience of the external urban environment". Examples of these environmental changes include the visual blight associated with road infrastructure or cars [Wright and Curtis 2002] and the overall (negative) sensory experience of walking along busy roads [Sheller and Urry 2000]. Several authors have also drawn attention to psycho-sociological factors such as the perception of cars as an alien element to the routes used by pedestrians [Wright and Curtis 2005] and the unequal power relationships between drivers inside cars and pedestrians outside of them [Urry 2002].

Noise is another environmental 'bad' with a particularly marked effect on pedestrian mobility. Due to its intrusive nature, noise pollution is a deterrent to walking and restricts pedestrian options in terms of routes. In particular, roadside noise has been linked to reduced walking levels and to the long terms health effects of reduced pedestrian mobility [Balfour and Kaplan 2002, Ogilvie *et al.* 2008]. Exposure to noise has also a direct effect on the psychological wellbeing and levels of awareness of pedestrians when walking [Korte and Grant 1980] and on the levels of social interaction with other pedestrians [Appleyard 1981].

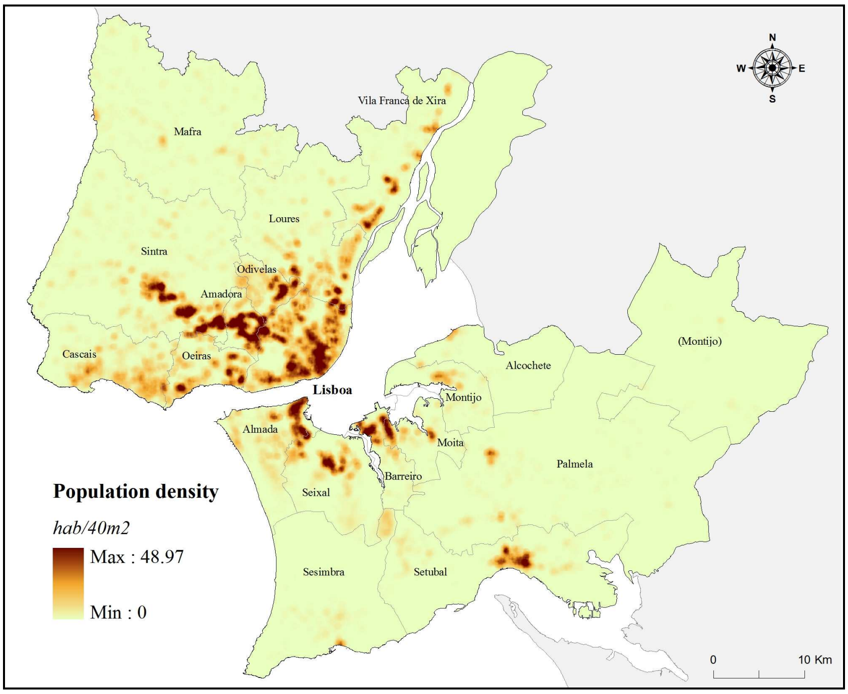
Similar considerations apply for the effects of air pollution on pedestrian mobility [Marshall *et al.* 2009]. In this case there is also empirical evidence that levels of exposure depend on patterns of daily mobility. The comparison of the results of the studies of Chan *et al.* (2003) and Zhao *et al.* (2004) is particularly revealing: measurements in the same urban setting (Guangzhou) show significant inequalities in the exposure to air pollution between pedestrians and users of other travel modes and between pedestrians walking in different parts of the metropolitan area. There is also a social dimension to this problem, as mobility patterns have socio-economic determinants. For example, Brajer and Hall (1992) found that individual levels of exposure are directly related to time spent outdoors (including walking time and time spent on the journey to work), which is then related to ethnicity and socio-economic status.

In conclusion, pedestrian mobility not only plays an important role as a component of accessibility but is also related with environmental factors. This is because the level and quality of pedestrian mobility depends on the environmental quality of the areas crossed and because the choice over these areas determines the overall level of daily exposure to pollution for an individual. There is therefore an overlap between the spatial dimensions of disadvantages in the distribution of pedestrian mobility, accessibility and environmental quality. The study of the spatial distribution of pedestrian mobility has been largely overlooked in project assessment studies and in academic or activist-led transport equity studies. There is growing evidence that dimensions of pedestrian mobility related with urban planning (such as the local availability of pedestrian destinations [Cerin *et al.* 2007, Marshall *et al.* 2009] and levels of “walkability” of local streets [Greenberg and Renne 2005]) relate with socio-economic variables (such as income deprivation and proportion of racial minorities). Nevertheless, apart from the case of pedestrian risk, there is still little knowledge on the extent to which pedestrian mobility is restricted by transport infrastructure and road traffic in the different neighbourhoods, both in terms of barriers to access destinations and in terms of exposure to air pollution and noise.

1.3. The case of the Lisbon Metropolitan Area

The Lisbon Metropolitan Area (AML) provides an interesting case for the study of the redistributive aspects of urban transport, due to the combination of unprecedented changes in the transport system with tendencies for population ageing and urban fragmentation in the period between the last two population censuses (1991 to 2001). This combination has raised questions about the adequacy of the transport improvements for meeting the specific needs of some groups, such as the elderly, and about the equity in the distribution of the overall benefits and costs of the transport projects.

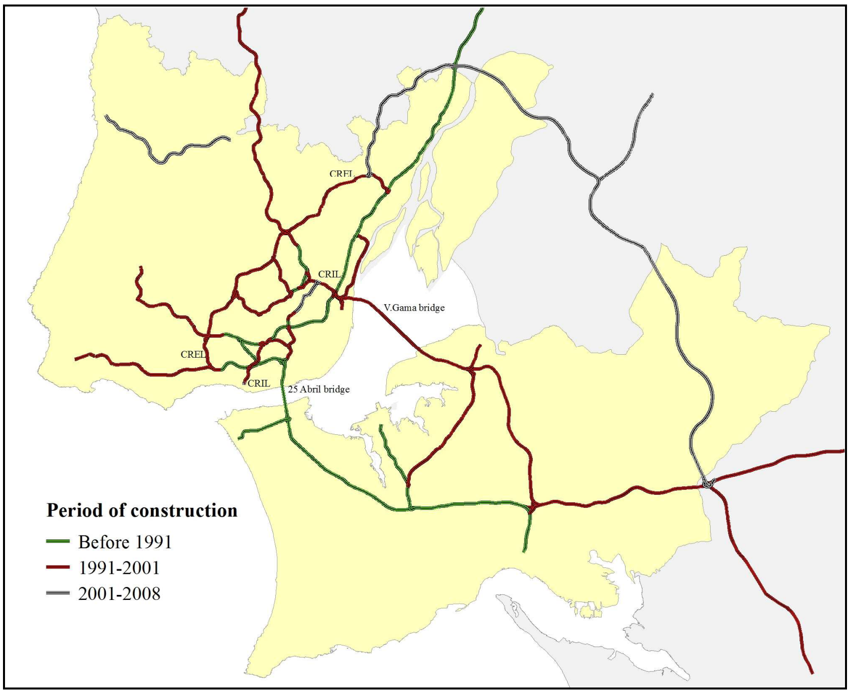
Map 1.1: The Lisbon Metropolitan Area in 2001: Municipalities and population density



Source: Estimated from 2001 census data [INE d2001b] (See Appendix 1).

The AML is the main urban agglomeration in Portugal, with a population of 2 661 850 in 2001, of which 564 657 lived in the city of Lisbon. This metropolitan area of 2 935 km^2 is centred around Lisbon and extends over 18 municipalities in the north and south banks of the River *Tejo* **[Map 1.1]**. The level of urbanization is highly variable, as the metropolitan space includes old provincial towns, new urban developments dispersed along transport corridors, and many semi-rural areas. The most important development in the metropolitan transport system occurred in the 1990s, with an expansion of the motorway and dual carriageway network from 128.4 km to 376.4 km **[Map 1.2]**. The set of projects completed in this period includes a new bridge (*Ponte Vasco da Gama*), the Lisbon Outer Ring Road (*CREL*), several sections of the Lisbon Inner Ring Road (*CRIL*), and a series of radial roads branching from the *CRIL*.

Map 1.2: Motorways and dual carriageways, by period of construction



Source: Modelled transport network (See Appendix 4).

The expansion of the road infrastructure has not led to substantial improvements in the performance of the metropolitan transport system. In particular, road congestion has worsened and affects traffic not only at the major entrances to Lisbon but in the whole length of some roads, including the links built during the period concerned. The most striking example of road congestion is the IC19, the only road linking Lisbon with a series of cities and towns in the west, and which former President Jorge Sampaio has called "a daily tragedy"[1]. The average time to work has decreased slightly from 1991 to 2001, but it is still the highest of the group of cities of comparable dimension included in the European Union's Urban Audit database, despite the fact that the share of journeys to work by car in Lisbon shows a marked tendency to converge to average European values **[Table 1.1]**. The inadequacy of the road transport system to serve the populations' travel needs arises from the fact that the share of

[1] *Diário de Notícias*, 05-05-2005, "Na Estrada, a culpa é sempre dos outros" (On the road, it is always somebody else's fault). On a series of initiatives aiming at raising awareness for road safety problems, the president travelled by bus a distance of 13 km in the IC19 at rush-hour, spending 50 minutes.

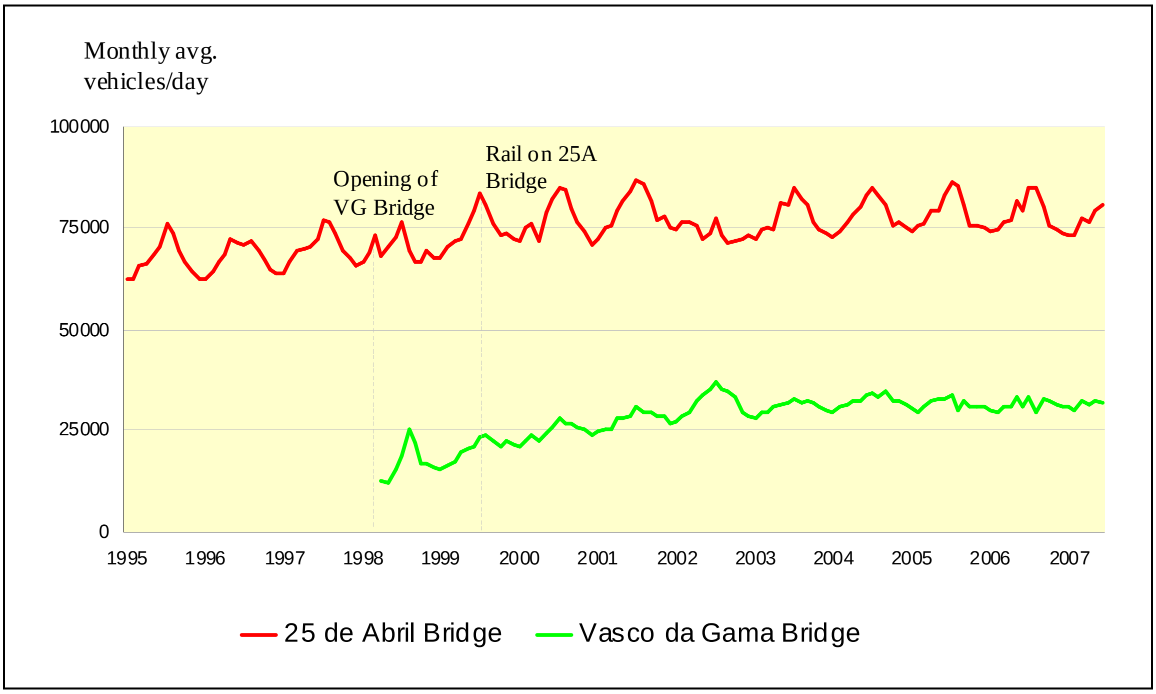
private transport commuters has systematically outgrown the capacity of the road infrastructure. In fact, while the number of people working or studying in Lisbon decreased 7% between 1991 and 2001 [INE d1991d, d2001d], the number of cars entering Lisbon grew 45% [CML-DPPE 1995a, CML-DMPU 2004a]. The increase has occurred in all major access corridors, with no evident correlation with the increase in road capacity or with the availability of alternatives. In particular, traffic levels on the old bridge did not show any signs of decreasing following either the opening of the new bridge in 1998 or the introduction of rail services on the lower platform of the old bridge in 1999 **[Figure 1.1]**.

Table 1.1: Urban indicators: Comparison between Lisbon and similar European cities

City		Share of journeys to work by car (metropolitan area)			Time to work minutes (metropolitan area)		NO_2 µg//m³ (city annual avg.)		PM_{10} µg//m³ (city annual avg.)	
		1991	*2001*	*91→01*	*1991*	*2001*	*2001*	*2004*	*2001*	*2004*
Lisbon		23.4	39.3	15.9%	43.0	40.6	22.5	28	28.2	31.9
	Max.	76.8	82.1	9.4%	33	38.0	56.4	61.4	66.7	58.1
Others	Avg.	53.5	56.1	2%	24.8	26.1	30.9	31.4	27.5	28
	Min.	28.6	36	-4.1%	18.0	19.6	12.2	17.0	16.4	13.9
# cities		14	24	12	13	24	33	36	26	36
Rank of Lisbon		14	21	1	1	1	27	23	10	10

Source: Urban Audit Database [EU d2004]. Cities within the 500 000- 1000 000 population range

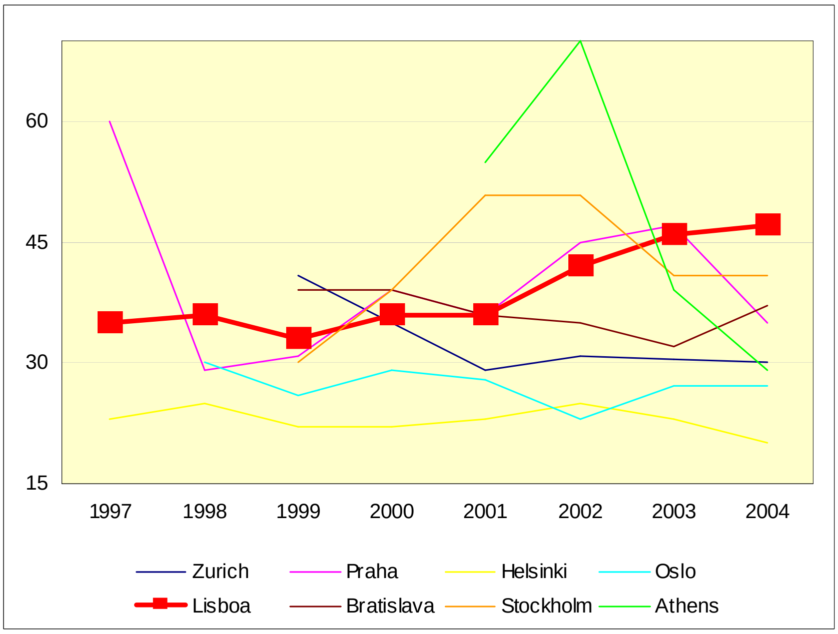
Figure 1.1: Evolution of traffic levels on the two *Tejo* bridges



Source: Traffic Levels Database [IEP d1990-2004, Estradas de Portugal d2005-2007]. Direction South→Lisbon

The fast growth in the use of private transport has also led to an aggravation of the environmental negative effects of the system. During 2004, all the roadside monitoring stations in the AML registered values above the daily standard for PM_{10} concentrations in more than 35 days (annual standard) [CCR-LVT 2006]. Overall, the concentrations of this and other air pollutants have shown a tendency to increase since the late 1990s and are now higher than the average of cities of comparable dimension **[Figure 1.2]**, increasing the concern about their effects in terms of public health. For example, it was estimated that exposure to air pollution reduces life expectancy by an average of six months for people living or working in the surroundings of Avenida da Liberdade, one of Lisbon's main arteries [Nicolau 2009]. There is however great variability in pollution indices across the metropolitan area, especially when comparing areas at roadside and areas far from roads and when comparing Lisbon or surrounding cities with the semi-rural municipalities.[2]. The city of Lisbon is also the most affected by road noise pollution, with an estimated 50% of the population exposed to noise levels higher than 65 db(A) [Valadas *et al.* 1999].

Figure 1.2: Evolution of PM10 concentrations at representative traffic monitoring stations



Source: EU Airbase [EEA 2006]. Monitoring station in Lisbon: Entrecampos (major junction in the city centre)

The policy priority to the construction of new road transport infrastructure has not seen a parallel in the improvement of conditions for pedestrians and has in fact contributed to the

[2] In 2008, average PM_{10} concentrations ranged from to 21.3 µg//m3 (Fernando Pó background monitoring station, located in a rural area in the South Bank) to 41.1 µg//m3 Avenida da Liberdade). [APA d1992-2008].

deterioration of the walking environment, not only due to increased air pollution and noise but also because of the encroachment of cars on pedestrian space. Lisbon is a notoriously dangerous and unpleasant city for walking, as in many areas (including newly developed areas) kerbs tend to be in a poor state of repair or are simply non-existent. The fast increase of car ownership and use and the imbalance between parking supply and demand has also forced car drivers to park on pavements and footways. High traffic levels also contribute to a high incidence of pedestrian accidents. Although the number of pedestrian victims of road accidents has been decreasing steadily since the mid 1990s due to road safety campaigns at the national level, Portugal is still the country with the highest rate of pedestrian fatalities in Western Europe [UNECE d2008]. The case of Lisbon is especially serious, as pedestrians account for 21.2% of the total number of road fatalities, comparing with a national average of 13.3% [DGV 2007a, 2007b].

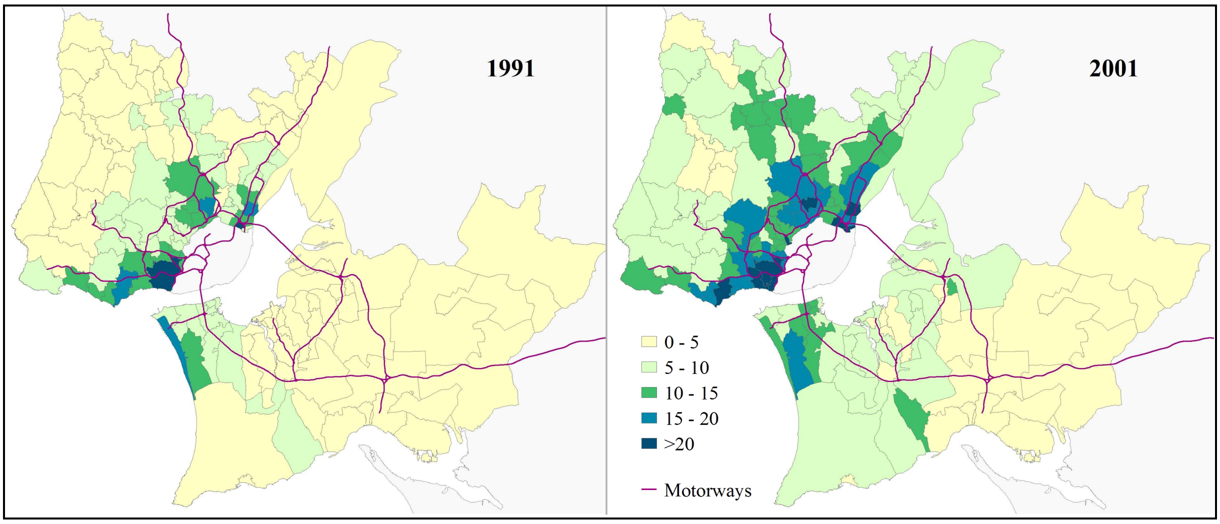
A further negative effect of the construction of new road infrastructure crossing densely populated areas is that some areas have become locked between this infrastructure and other barriers to pedestrian mobility. This is especially the case of some areas at the fringe of Lisbon, where several neighbourhoods are isolated from surrounding neighbourhoods, due to the barriers posed by motorways, the Lisbon Inner Ring Road and industrial or vacant land **[Figure 1.3]**. These areas are geographically close to Lisbon and to the new transport arteries. However, the realized accessibility of the local populations has probably not improved, in the cases where households are dependent on public transport. This is because these areas are not served by the rail and underground network and (due to the "lock" effect) have only a limited number of exits for public road transport, which become easily congested at peak times[3]. On the other hand, realized accessibility has probably improved for the people living in areas located further from Lisbon, which in fact saw an increase on the percentage of workers and students commuting to Lisbon by private transport **[Map 1.3]**.

[3] See for example *Público* 04-05-2005, "Utentes do IC19 alertam para trânsito nas freguesias" (IC19 users alert for local traffic).

Figure 1.3: Example of "locked" neighbourhood

Source: Google Maps © 2011 Google-Imagery ©2001 TerraMetrics

Map 1.3: Proportion of workers and students commuting by private transport to Lisbon



Note: Estimated from INE (d1991d, d2001d).

The improvements in the public transport system were also modest, when comparing with the case of private transport. The most significant change in the period concerned was the set of projects completed as a part of the regeneration of the eastern part of Lisbon, in the context of the 1998 World Exhibition. This area is now connected to the Lisbon city centre by an underground line and is served by a major transport interface at *Oriente*, becoming the neighbourhood with better public transport accessibility in Lisbon [CML-DMPU 2004a, figs.

138, 141-144]. Paradoxically, this area, having been settled by relatively young and affluent households, has also the highest rate of car ownership in Lisbon and the highest share of trips to work by private transport [*Ibid*., figs. 30, 35]. Apart from the new rail line linking the two banks of the River *Tejo*, public transport improvements in the metropolitan area occurred mostly through the integration of different modes and through the development of new interfaces. However, there was also a drastic reduction of rail services in some areas, with a number of stations closing in the rural parts of the South Bank, increasing the asymmetries between these areas (and their relatively old and less affluent populations) and the rest of the metropolitan area, especially regarding access to employment and urban facilities.

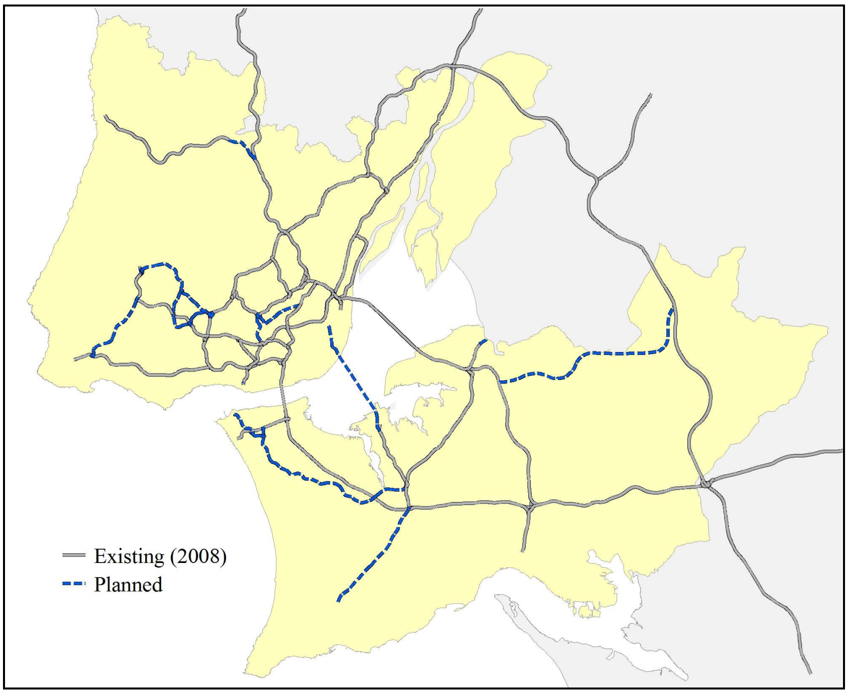
The growing asymmetries between the mobility allowed by walking, private vehicles and public transport do not derive only from changes in transport but also from changes in urban land use, including the fast urbanization of the hinterlands of suburban municipalities. This urbanization has been in many cases haphazard, originating a discontinuous urban form, with large parts of vacant or agricultural land between small clusters of densely built-up and populated areas. Many of the new neighbourhoods have easy access to the private transport network but are isolated from other areas, which cannot be reached either by foot or by public transport, since the majority of the bus routes link the new neighbourhoods with Lisbon or other cities but not with each other.

At the same time, the AML has been following the general demographic trend in Portugal, whose population is ageing at one of the fastest rates in Europe. Elderly people now form the majority of the population in the most isolated semi-rural areas and in the central parts of the cities. This last phenomenon is particularly marked in Lisbon, where in 2001 the share of the population over 65 was 23%, a value 10% higher than in the rest of the metropolitan space [INE d2001b]. The spatial asymmetries described above are therefore linked to an increased disadvantage for the elderly, as they are disproportionately affected by the losses in accessibility following the closure of transport links in the semi-rural areas and the losses in environmental quality and pedestrian mobility associated with the growth in road traffic levels in the city centres. These disadvantages are cumulative to the fact that, as in other urban areas in the world, the elderly in the AML make few trips by car and are more dependent on public transport and walking. Furthermore, there is a socio-economic divide within the elderly, with socio-economically disadvantaged individuals relying on private transport to a much lesser extent than more affluent individuals [CML-DMPU 2004a, p.58].

On the other hand, the recent application of transport policies aimed at restricting car use, such as area-wide traffic restriction, has increased pedestrian mobility and had an inter-generational redistributive effect from the young to the old, since the neighbourhoods targeted are located in the older, central parts of the cities. However, plans for the extension of the areas closed to road traffic or for the introduction of road pricing at the entrances of Lisbon have been systematically postponed, due to their socio-political infeasibility. Further research is needed to investigate whether the redistributive effect of these policies compensate for losses in the efficiency of the road transport system.

The next couple of decades will see further structural changes in the transport system of the AML, including a third bridge and an additional expansion of the road network, from the existing 444.2 km to 578.2 km **[Map 1.4]**. Travel patterns and levels of pollution in the metropolitan area will also be affected by the construction of national-level transport infrastructure, such as the High Speed Rail and the new international airport. These projects have been subject to intense public discussion, as alternative locations for routes and terminals will carry different redistributive effects between the future users of the infrastructure and the populations subject to their negative impacts. Simulation studies also point to a continuation of the demographic trends [INE 2004a] and urban dynamics [Silva 2002] described above. For these reasons, it has become increasingly relevant to acquire an understanding of the redistributive effects of past practices in transport planning.

Map 1.4: Planned motorways and dual carriageways



Source: Modelled transport network

1.4. Situating the thesis

Objectives and motivations

The objective of the present research is to provide an empirical assessment of the ways through which transport planning affects different social groups, in order to test the hypothesis that inequalities in the social distribution of the different effects from transport reinforce each other. The answer to this question has implications on the allocation of public investment for new transport projects and on the application of traffic policies. This is because the distribution of multiple effects raises more questions than the case of a single effect, as it may not be consistent with society's preferences regarding the relative value of each effect for each group affected and regarding the degree of substitution between inequalities in the distribution of the different effects. The issue is also relevant for the assessment of the socio-political feasibility of projects and policies, as the affected populations will object if they perceive systematic inequality in the distribution of their positive and negative effects, which may hamper their implementation.

The thesis aims to be at the confluence of the two strands of the literature reviewed in this chapter: the study of the spatial dimension of the relationships between accessibility disadvantage and social exclusion and the study of environmental inequality patterns. We consider that accessibility and environmental quality are components of a wide concept of mobility, which includes not only the possibility of reaching different distant places by public or private transport, but also the possibility of walking around one's neighbourhood or walk to bus stops or railway stations in a safe and clean environment. Spatial inequalities in the levels of potential accessibility may not correspond to social inequalities in realized accessibility, as these depend on the choice of daily destinations and the adequacy of the available transport options at each neighbourhood to meet the mobility needs of local populations. In the same vein, spatial inequalities in pollution concentrations may not correspond to social inequalities in pollution exposures, as patterns of mobility determine the degree to which individuals are exposed to environmental nuisances during the day. We assume that individuals are most vulnerable to these nuisances when walking along or crossing roads and when using public transport, for example when changing modes of transport or while waiting at bus stops.

Changes in transport then have redistributive effects between people living or working in different areas of the city and using different modes to travel between these areas. The central hypothesis of the thesis is that the priority to road transport infrastructure tends to increase the accessibility of people who use private transport and live in regenerated areas in the cities or in newly-developed areas in the outer suburbs. People who rely on public transport or on walking and live in declining areas in the city centres, nearer suburbs or peripheral areas tend to suffer the negative effects of transport. The improvements in the road transport infrastructure facilitate the dispersion of employment and urban facilities, increasing the problems of these populations in accessing jobs and urban facilities. In addition, the expansion of the road infrastructure and the increase of road traffic create barriers to pedestrian mobility and increase exposures to pollution for individuals walking in their neighbourhood or during the journey to work by public transport. The intent of our analysis is to prove that these spatial changes correspond to social inequalities. The political relevance of these inequalities depends on the confirmation of patterns of multiple disadvantage, on the definition of comparison areas and on the existence of links between changes in the attributes of the different neighbourhoods and changes in the social structure of their population.

These questions are assessed for the case of the Lisbon Metropolitan Area, as the main hypothesis fits with the densification of the road network at the fringe of the main centre and with the process of urban fragmentation occurring in the period concerned. However, the motivation for this work is to assess transport priorities in the framework of trends common to the majority of European cities, including population ageing, vulnerability to macroeconomic cycles and influx of immigrants. These tendencies have increased the need to take into account the needs of vulnerable groups (such as the elderly, income-deprived classes, and racial minorities) when designing transport projects and to attend to the geographical context in which those needs arise. Furthermore, cultural trends, such as the shift towards healthier lifestyles, have increased the relevance of walking as an activity with its own value. For these reasons, the priority given in the past to private transport must be balanced in the future with concerns for pedestrian mobility and public transport. In particular, the decision of construction of new roads must consider its impacts on the level and quality of mobility of the groups mentioned, while policies must be designed to deal with the negative effects of traffic.

The study is directed at two main academic audiences. The first is the group of social scientists in various fields researching the spatial inequalities in the distribution of the local effects of transport. Our main aim is to draw attention to points of contact between the work of researchers studying inequalities in the provision of transport and in the distribution of pollution. We introduce pedestrian mobility as an additional object of distribution, which captures some of the concerns included in the more general concepts of accessibility and environmental quality, but whose social distribution have specific understandings in terms of social justice and policy implications, in face of its relevance for the classes at disadvantage. Another intended contribution is to address some of the issues that have been subject to discussion in this field and remain without definitive answers, such as the spatial variability of patterns of inequality, the processes leading to inequalities, and the integration of equity concerns in actual transport planning.

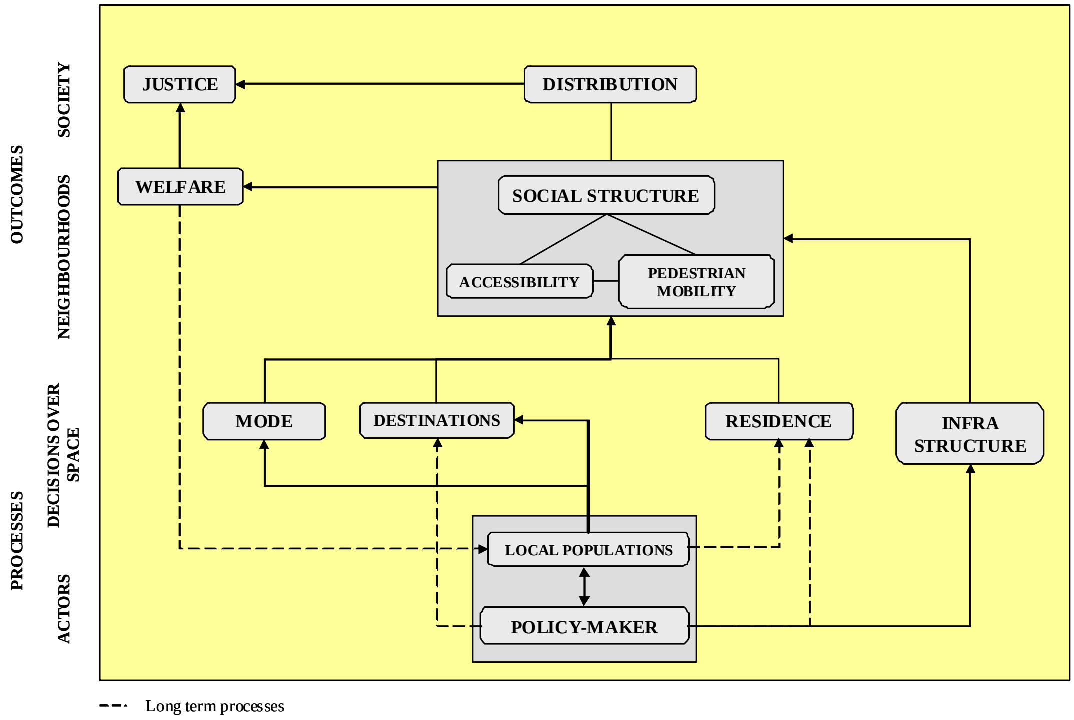
Our second aimed audience are researchers developing quantitative indicators for assessing pedestrian mobility. One of the intended contributions is to add solutions to the relative scarcity of operational concepts of mobility applied to the needs of vulnerable or disadvantaged groups. In fact, some authors have pointed out that the indicators currently used by policy-makers present several inconsistencies with the experiences and perceptions of some groups such as the elderly [Metz 2000, Titheridge *et al.* 2009]. A second contribution is to look at dimensions of pedestrian mobility that are directly affected by road infrastructure and traffic, and whose distributive effects are seldom analysed quantitatively. While the effect of pollution in the mobility of pedestrians has been measured by experiments in several cities and compared with the effect of other travel modes, there is no evidence on the social unbalance in the distribution of those effects for the whole set of projects implemented within a city in a certain period. The effects on community severance are also studied within most transport appraisal projects but in practice, the design of road or rail routes that separate two communities tends to be subject to *ad-hoc* political decisions and based on qualitative assessments. This kind of decisions is generally subject to criticism, due to a perceived lack of transparency, and can benefit from the development of quantitative indicators.

The findings of the study may also be of interest for policy-makers, by adding to the discussion on the social interest and political feasibility of proposed future transport projects in European cities. They might also benefit groups of activists, by suggesting practical tools and providing evidence that can be used to demand transparency and accountability from the policy-maker. A final motivation is to provide elements that may be useful for the population of the AML, by building an “atlas of mobility” for the metropolitan area and by exposing the relations between transport and social disadvantage, as empirical evidence on patterns of transport-based inequality in this area is very scarce.

Questions and methods

Figure 1.4 presents the conceptualization of the problems studied in this work. We consider that the policy-maker decides on the location of transport infrastructure and individuals decide on travel destinations and modes (walking and private or public transport). The policy-maker can influence the individuals' travel decisions by implementing traffic policies but individuals or groups can also influence policies by voting or protesting. The construction of new infrastructure and changes in traffic levels affect the accessibility and pedestrian mobility at the neighbourhood level, with impacts on the welfare of the local populations. At any given time, the spatial distribution of accessibility and pedestrian mobility may be statistically associated with the neighbourhoods' social structure, originating inequalities at the scale of the metropolitan area or in some of its subsets. The social evaluation of transport policies takes into consideration the effects on the welfare of the population in each neighbourhood and judgements on the overall distribution of different kinds of effects across different social groups. In the long term, changes in accessibility and pedestrian mobility may change the neighbourhoods' social structure, through household relocation. The extent of this effect depends on changes in land use, which depend on policies regarding the development of new residential land and creation of new centres of employment.

Figure 1.4: Framework of analysis



The five research questions orientating the study analyse separate sections of the set of relationships described above. These questions are analysed throughout the next four chapters and their conclusions are synthesized and set in a wider context in the concluding chapter.

Research question 1: For which dimensions of accessibility and pedestrian mobility can we find social inequalities?

This question is covered in Chapter 2, where we define indicators of several dimensions of accessibility and pedestrian mobility and analyse their relationships with the main vectors of socio-economic differentiation in the study area. We compare the patterns occurring in 1991 and 2001, in order to assess the effect of the expansion of road infrastructure in this period. The analysis in each year focus on the various links between the location of transport infrastructure and the welfare of individuals, as the policy relevance of social inequalities and the feasibility of possible solutions is different for each of those links. We first study the factors affecting the realization of potential job accessibility in each neighbourhood (such as transport provision, modal choice and congestion) and the redundancy of considering accessibility to urban facilities as an object of distribution additional to job accessibility. We also add to existing literature on the distribution of local mobility by looking at the dimensions of pedestrian mobility that are affected by motorised transport, including community severance, exposure to noise for pedestrians walking around their neighbourhoods and exposure to noise for pedestrians on the way to work.

Research question 2: Do inequalities depend on the areas of comparison?

The identification of inequalities using statistical relationships between socio-economic variables and indicators of the local benefits and costs of transport is bound to the specific set of areas included in the estimation. In Chapter 3, we assume that those relationships vary in space and can be estimated at each place, including data from other places weighted by their proximity. The application of this method in the transport equity field usually assumes that proximity is measured in geographic space. We argue that the variability of statistical relationships in urban areas can also be measured along variables defining the similarity of the different places in terms of their functional role within the metropolitan area or in terms of people’s perceptions about their degree of comparability in the distribution of the effects of transport. Alternative assumptions on the variables defining neighbourhood similarity originate relationships in different locations and at different spatial scales. We estimate regressions weighted in the space defined by those variables, in order to assess the variability in the associations between socio-economic factors and three indicators of mobility: time to work and pedestrian exposures to noise on the way to work and around the neighbourhood. The analysis addresses the changes in the variability of those associations occurring in the period 1991-2001, in order to assess the effects of transport policies in this period in the geographic delimitation of the areas in which social inequalities are found.

Research question 3: Are changes in the neighbourhoods' social structure related to changes in the transport system and in urban land use?

This question is developed in Chapter 4 and contributes to the analysis of the processes behind transport inequalities, by assessing the role of mobility in neighbourhood recomposition. While there is evidence on the influence of accessibility on the spatial sorting of the different social groups, the influence of pedestrian mobility is little understood. We assess this influence separately for the central part of the metropolitan area and for the suburban region, considering the changes linked to the transport projects implemented in the period 1991-2001 in the area of study. We first use logistic regression to test whether changes in mobility explain the probability of a neighbourhood to have significant household relocation. In a second stage, we use canonical correlation analysis to assess the relationships between changes in indicators of mobility and changes in socio-economic variables within the set of areas with significant household relocation, controlling for changes in other neighbourhood attributes. In a separate section, we study the influence of changes in land use on the distribution of mobility, by analysing the social patterns of location in newly developed areas in each municipality. We compare new and old areas and estimate relationships between socio-economic variables and indicators of accessibility and pedestrian mobility within the set of new areas.

Research question 4: What are the implications on transport policy of attending to the distribution of different impacts among different groups of concern?

This question is the object of analysis in the first two empirical sections of Chapter 5. The objective is to contribute to the literature on the methods for the integration of equity concerns in transport planning. We study the sensitivity of the social evaluation of individual projects and policies to alternative assumptions both on the distribution of positive and negative effects and on the valuation of those effects. We analyse this question using as case studies two proposals for policy intervention in the Lisbon Metropolitan Area. In the first case study, we determine the sensitivity of the optimal route alignment for a new road to different judgements on the monetary value of community severance and on its distribution across populations with different socio-economic status. In the second case study, dealing with traffic transport policies, we analyse the trade-offs between judgments on the relative value of changes in time to work and pedestrian exposure to noise and judgments on the distribution of both types of changes among populations with different ages and socio-economic status.

> **Research question 5:** Is the assessment of transport projects based on distributional concerns compatible with the assessment made by a policy-maker who attends to party-political interests?

This question is treated in the last empirical section of Chapter 5 and is analysed in the contect of the two case studies described above. We explore the implications on the assessment of transport projects of holding different assumptions about the level and type of political bias, considered in terms of the degree of priority attached to changes affecting populations with certain political characteristics. We then compare the different "politically optimal" solutions with the "socially optimal" solutions obtained using different judgments on distributional issues.

The approach followed in the analysis of these questions is essentially geographical, as we consider changes in the urban transport system in terms of their effects on the conditions that local populations face and on their responses to it. We assume that the construction of transport infrastructure and the application of traffic policies in a given neighbourhood are explained by the geographic and social characteristics of that neighbourhood. In the same vein, the households' decisions about residence location and transport are also based on the characteristics of their neighbourhoods and on the way the neighbourhoods are linked with the destinations they need to access. The type of transport changes and redistributive effects examined in our work are therefore the ones that fit into this geographical approach. Economical aspects such as the relationships between travel cost and travel decisions or the financing of the project costs through the tax system are not included in the quantitative analysis.

Our method is based on the integration of several datasets in a GIS (geographic information system) and on the construction of private, public and pedestrian transport network models for 1991 and 2001. These models are used to estimate indicators of several dimensions of accessibility and pedestrian mobility at the local level, which are then related with socio-economic variables and other information in the four empirical chapters. One of the novelties of our approach is to assess patterns of inequality at two moments in time, using the same definition of groups of concern and indicators of mobility. Empirical studies in transport and environmental equity so far have relied on analyses at only one moment in time.

The development of the GIS faced with the problem of lack of availability of detailed data for a series of variables for the required moments in time, including employment, road traffic levels and noise levels. We estimate these variables through models relating information such as the location of jobs and companies, commuting flows and land use data. The sources of data and the options taken in these models are described in a series of appendices at the end of the thesis.

Chapter 2

The social distribution of mobility

The objectives of this chapter are to analyse the spatial distribution of multiple dimensions of accessibility and pedestrian mobility in the Lisbon Metropolitan Area in 1991 and 2001 and to assess social patterns in the way that changes in the transport system affect those dimensions. We consider that these patterns arise due to differences in residence location, daily destinations and travel modes associated with each group. The aim is to measure the extent to which the spatial distribution of the transport infrastructure and levels of provision of public transport generate inequalities above those implied by differences in incomes, skills, preferences and other factors that affect the individual choices in the housing, job and transport markets. As such, we compare the effects of transport on the levels of accessibility and pedestrian mobility of different groups, for a given spatial distribution of people, jobs and urban facilities assessed at two moments in time.

More specifically, the analysis intends to contribute to the study of two questions in academic research. The first question is the existence of social disadvantages in the levels of provision of transport at each location, after controlling for the geographic mismatch between jobs and the location of some groups. We address this question by comparing relationships between socio-economic variables, the gap between potential and realized accessibility to places of work, the relative accessibility provided by the public and private transport systems in each location and the relative efficiency of each system at each location, when comparing with other locations. We also test whether the social distribution of levels of accessibility to urban facilities is independent of the distribution of accessibility to centres of employment and of the travel modes used. The aim of the analysis is to complement existing research on the mismatch between private transport accessibility and the public transport needs of different populations [Kwok and Yeh 2004, Kawabata and Shen 2006, Kawabata 2009]. Our intended contribution is to compare the effect of modal choice and congestion as factors behind the gap between potential and realized accessibility and to incorporate the role of pedestrian mobility on the analysis of both effects, by considering walking as a part of private and public transport trips and as an option to access nearby destinations.

The second question is the existence of social disadvantages in the distribution of the impacts of urban transport in the level and quality of pedestrian mobility across different neighbourhoods in the city. While the spatial distribution of pedestrian mobility has been studied in regard to the local availability of pedestrian destinations [Cerin *et al*. 2007, Marshall *et al*. 2009, Witten *et al*. 2011] and perceptions of neighbourhood "walkability" [Greenberg and Renne 2005], there is no evidence on the spatial variability of the effects of motorized transport on pedestrian mobility within an urban area. We assess the existence of cumulative disadvantages for socio-economic groups, by estimating relationships between socio-economic variables and three indicators of pedestrian mobility. Disadvantages in pedestrian mobility that depend on differences in residence location are assessed by the effects of transport infrastructure and traffic levels on community severance and on exposures to noise of pedestrians when walking around the neighbourhood to access nearby destinations or for exercise. Disadvantages that depend on differences in daily destinations and travel modes are assessed by levels of pedestrian exposure to noise on the way to work. We assume that the areas around each place of work have different levels of noise pollution, while workers walking to work or walking to and waiting at public transport stops and stations are more exposed to noise that workers commuting by private transport.

Besides addressing the two questions above, the chapter also intends to give an overall view of the distributive effects of the projects implemented in the period of concern in the Lisbon Metropolitan Area, providing clues as to which of the considered links between transport, accessibility and pedestrian mobility are significant in terms of social inequality, thus becoming potentially policy-relevant. This assessment is useful in the selection of hypothesis to test in subsequent chapters. This is because only some of the indicators mapped in this chapter will be theoretically relevant or empirically significant when estimating their relationships with the neighbourhoods' social structure using different areas of comparison [Chapter 3], changes in the social structure and in land use [Chapter 4] and options and party-political context at the moment of planning [Chapter 5].

The analysis is conducted at the level of the enumeration district (ED), as this is the smallest area for which demographic and socio-economic data is available, from the 1991 and 2001 Portuguese Population and Housing Census. However, to take into account variations in land use within each district, the indicators of accessibility and pedestrian mobility are assessed for a series of points representing all different contiguous areas of residential land inside each district, and then averaged for the district according to the estimated spatial distribution of the population [Appendix 1]. The calculations use GIS network models for the private, public and pedestrian transport systems in 1991 and 2001 [Appendix 4 and 5].

The census data is first reduced to a small set of structured variables, by means of factor analysis [Section 2.1]. We then compare the spatial distribution of these variables with indicators of accessibility [Section 2.2] and pedestrian mobility [Section 2.3]. Due to differences in the statistical distribution of each indicator, the analysis uses a variety of exploratory methods to assess social patterns of distribution. In the case of accessibility to places of work, we compare correlations between socio-economic variables and various dimensions and components of accessibility. The lack of accessibility to urban facilities is mostly a rural *vs.* urban problem, and so we analyse correlations in different partitions of the data, thus controlling for the effect of geographic factors. The case of community severance is analysed through logistic regression, as the problem affects only a small set of districts in the study area. Pedestrian exposures to noise also do not show strong overall relationships with socio-economic variables and so the analysis focuses on the socio-economic profile of the populations affected by different levels of exposure. The analysis of map overlays complements the numerical analysis in all cases, in order to highlight the areas within the metropolitan area with the most striking examples of transport-related disadvantage. The full set of maps of the estimated indicators can be found in Appendix 9. As the indicators used in this chapter support the empirical analysis in the other chapters in the thesis, we also discuss their theoretical implications and a series of caveats in Section 2.4.

2.1. Vectors of social differentiation

In order to identify the main vectors of social differentiation within the Lisbon Metropolitan Area, we synthesise the social structure of the neighbourhoods in 1991 and 2001 through a factor analysis of census data[4]. Factor analysis reduces a multivariate dataset to a smaller set of underlying but unobservable variables, which describe what is in common among the original variables. Although the interpretation of the factors is subjective, factor analysis and the closely related principal component analysis are commonly used in the study of transport inequalities, as they minimize methodological problems related to variable selection and multicollinearity [Buzzelli and Jerrett 2004, Grineski *et al.* 2007]. This is because this technique defines a structured set of variables that have more power than individual variables in explaining the spatial distribution of the local effects of transport. In fact, individual variables are in many cases imperfect proxies for variables of interest that are not available to the researcher, or are redundant due to high correlations with other variables.

The census data available at the enumeration district level has information on individuals, families, dwellings and buildings. We calculate a series of variables from the raw data, a selection of 16 is then used in the factor analysis[5]. The observations corresponding to each district are weighted by its population, to account for the fact that there is considerable variation in the population of districts in different parts of the study area. The analysis used the 1991 and 2001 and pooled datasets. The factors identified in all three data sets have a very similar composition, which means that the variables behind the social differentiation between neighbourhoods are similar in years. The results shown in this section and the ones used in subsequent analysis are the ones for the pooled dataset.

The estimation used the principal components method, in which factors are uncorrelated

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[4] The Portuguese National Statistics Office has published similar studies of the 1991 and 2001 census data [INE 1999, INE 2004b]. We do not use the results of these studies, since the analysis includes variables related to transport, such as time to work, which we consider in the present study as dependent variables explained by the social structure of the neighbourhoods.

[5] The initial set of variables used all data available at ED level. Some variables such as the unemployment rate were excluded due to their low variability. Other variables, such as employment in agriculture and the proportion of young people were excluded due to distortions arising from their inclusion alongside other variables constructed using the same denominator [Johnston 1978, p. 268]. Finally, population density was not included due to its high correlation with total population, which is used in our model to weight observations.

linear combinations of the initial variables that account for as much of the variance in the data set as possible. The factors can be characterized by their loadings, that is, the correlations with the initial variables. Five factors were extracted, using the rule of retaining those whose eigenvalues are higher than one [Kaiser 1958][6]. The analysis also produces values for each observation on the space of the factors, called factor scores. These are obtained using the regression method, which takes into account both factor loadings and correlations among initial variables and produces standardized scores. Factor scores are standardized variables with zero mean and unit standard deviation.

Table 2.1 presents the factor loadings. In order to increase the differentiation of the factors, we create a rotated factor matrix, using the Orthogonal Varimax method, which minimizes the number of variables with high loadings on each factor. The five factors extracted explain 67.5% of the variance in the sample. The Kaiser-Meyer-Olkin measure of sampling adequacy is 0.76, which suggests that the correlation matrix is appropriate for factoring. The values of the communalities of each variable are also acceptable[7]. In the next paragraphs, we characterize the extracted factors by analysing the respective loadings. As we mentioned, the interpretation of the results of factor analyses is subjective, and so the distinctions between factors are not always clear. Therefore, we judged necessary to complement the interpretation of the factors using information not included in the factorization model, including census variables that were only available as categorical data, or at higher levels of aggregation (*freguesia*)[8]. This information can be statistically related to the factor scores, shedding light on the distinctiveness of each factor[9].

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[6] The eigenvalue of a factor is an indicator of the amount of the data set variance explained by that factor. It is measured by the sum of squares of the correlations between the factor and each of the initial variables. An eigenvalue above one means that the factors contain more information than that provided by a single variable

[7] The communality of a variable represents the proportion of its variance shared with the other variables via the common factors. As a rule of thumb, only variables with a communality value above 0.5 are usually retained.

[8] *Freguesias* (civil parishes) are Portugal's smallest administrative units, below the level of municipalities.

[9] We only report the cases where the additional variable is highly correlated to one factor and not with the others. The full set of available variables can be found in the references given in the text.

Table 2.1: Factor analysis of census variables (1991 & 2001)

	Factor 1 Age	**Factor 2** Qualif.	**Factor 3** Urbaniz.	**Factor 4** Inf.Setts.	**Factor 5** Migration	*Comm.*
% of variance	24.5%	20.4%	8.6%	7.5%	6.5%	
INDIVIDUALS						
Men (% of adults)	-0.27	-0.19	-0.30	0.09	0.63	0.61
Elderly	0.90	0.02	-0.16	-0.03	-0.15	0.85
No/Lowest qualification	0.34	-0.67	-0.45	0.06	0.04	0.77
Graduates	0.13	0.80	0.34	-0.07	0.04	0.78
Employment/Population	-0.47	0.20	0.39	-0.30	0.39	0.65
Employment in services	0.28	0.51	0.48	-0.20	-0.14	0.63
FAMILIES						
1-2 members	0.86	-0.03	0.19	-0.08	0.14	0.81
With children (<15yrs old)	-0.84	-0.03	-0.02	0.23	-0.10	0.77
DWELLINGS						
Households per dwelling	0.30	0.07	0.11	0.17	0.67	0.58
Informal	-0.06	-0.02	0.00	0.84	0.08	0.72
With facilities	-0.02	0.17	0.19	-0.79	-0.11	0.69
Large (>5 rooms)	-0.06	0.83	-0.17	-0.04	-0.06	0.73
Owned	-0.49	0.46	-0.03	-0.21	0.18	0.53
BUILDINGS						
Dwellings per building	-0.25	0.10	0.73	-0.06	-0.06	0.61
More than 40 yrs old	0.73	-0.04	-0.08	0.16	0.00	0.56
Exclusively residential	-0.12	-0.04	-0.70	0.05	-0.02	0.51

Note: All variables are expressed as ratios. Households per dwelling and dwellings per building are percentages of maximum values in each year. The variable for dwellings with facilities is an average of the proportion of dwellings with water, electricity, toilet and sewerage facilities.

Factor 1 is the main vector of social differentiation in the study area, accounting for 24.5% of the variance in the data set. This factor is related to ageing and lack of renovation, having high factor loadings on the percentage of elderly people and older buildings. These characteristics are also associated with high proportions of families with one or two members and families without children.

Factor 2 explains 20.4% of the variance and is related to qualification levels. This factor is associated positively with the proportion of graduates in the adult population and the proportion of population working in the services sector, and is associated negatively with the proportion of population with no qualifications or with the lowest qualifications (primary school). This factor is also related with the proportion of the largest dwellings and dwellings owned by the occupiers, thus suggesting a relatively high standard of living. This is confirmed by the fact that the spatial distribution of the values for this factor is related to additional variables such as the share of skilled workers and the values of rents and mortgage payments (variables available as categorical data) [INE 1999, 2004b].

Factor 3 accounts for 8.6% of the total variance and has high factor loadings on variables measuring the level of urbanization within the study area: the number of dwellings per building[10] and employment in services (positive correlations) and the proportion of building that are exclusively residential (negative correlation). It is important to notice the differences between this factor and Factor 2. The two most important variables in the composition of Factor 3 (dwellings per building and residential buildings) have negligible relationships with Factor 2 (and with the other four factors). While the correlations of both factors with the two qualification variables have the same sign, their magnitude is higher for Factor 2, especially for the case of the percentage of graduates. In addition, Factor 3 does not show any relationship either with the percentage of largest dwellings or with the set of auxiliary variables that define standard of living, which are in both cases related to Factor 2. In sum, while Factor 2 shows a clear set of relationships with qualifications and related socio-economic status, Factor 3 seems to be specific to urban structure.

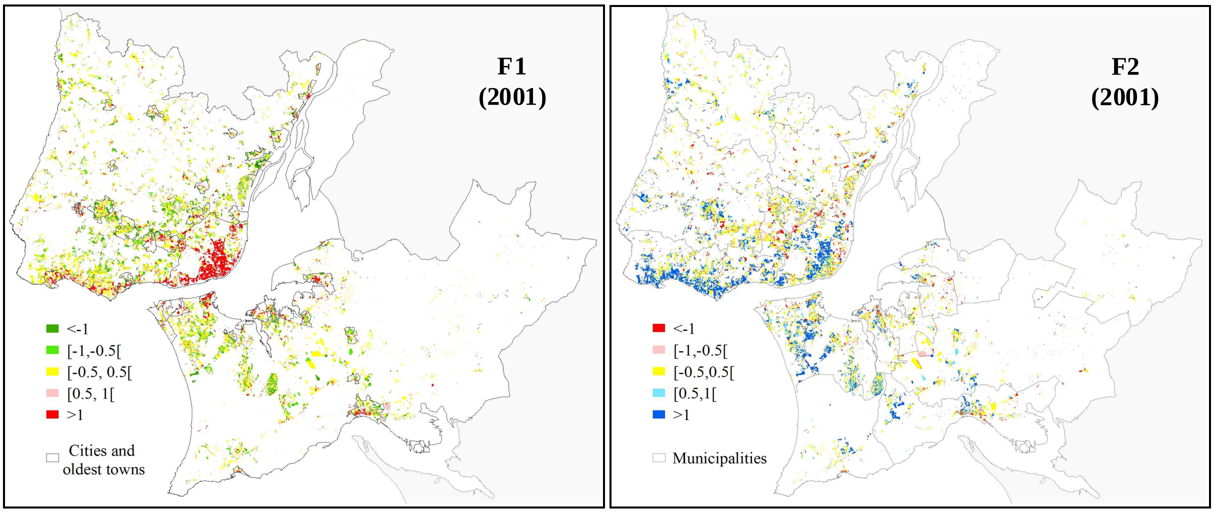
Factor 4 accounts for 7.5% of the variance and is a measure of housing deprivation, with high positive loading on the percentage of informal dwellings and high negative loading on the proportion of dwellings with basic facilities. The mapping of the districts with high values for this factor in 1991 reveals that they correspond mostly to the clusters of informal settlements (slums) existing in the Metropolitan Area, as given by the information produced by some municipalities at the time of the 1993 inventory done in the framework of the Special Rehousing Programme (PER). The factor loadings are also consistent with the socio-economic characterization of informal settlements in the metropolitan area, namely regarding lower than average employment rates and the combination of large families but small dwellings [Costa *et al.* 1999, sect. 1.1]. Factor 4 is therefore an indicator of poverty and economic and social exclusion. Furthermore, high values occur in areas with high percentage of foreign-born population, especially Africans, as given by categorical data available for 2001 [INE 2004b] and data for administrative areas [INE d1991c, d2001c].

Finally, Factor 5 explains 6.5% of the variance and is linked to the proportion of

[10] The number of dwellings per building is also a more accurate characterization of the urban structure in the AML than building density (due to the prevalence of high-rise buildings) and population density (because there are a large number of vacant buildings in the central parts of the cities and in the urbanizations in costal areas).

dwellings shared by more than one family household and by the proportion of males within the population of working age (20-65). Although the proportion of shared dwellings is not correlated with the proportion of households with one or two members, according to National Statistics reports [INE 1999, INE 2004b], that variable is correlated with the proportion of single-individual households (variable not available at the enumeration district level for the present study). The distribution of this factor across administrative areas shows that it tends to be higher in areas with relatively high proportions of people of non-European origin (especially from Brazil) and people who moved to those areas in the last 5 years, and is lower in areas with high proportions of people born in the area where they currently live. Factor 5 is then related to migration, characterized by the single individuals, usually males and of foreign nationality, sharing dwellings and having recently moved to the present area of residence.

Map 2.1: Age (F1) and Qualifications (F2) factor scores in 2001



Apart from the level of urbanization, all factors are relevant for a transport equity analysis, as they define social groups that, based on the results of previous literature, have considerably different mobility needs, levels of access to other resources and restrictions in their choices in the housing and transport markets. In particular, we are interested in investigating the role of the two major factors of social differentiation in the metropolitan area (age and qualification) in the spatial distribution of accessibility and pedestrian mobility. The distribution of the two main factors is represented in the maps above. Elderly populations tend to concentrate in the central parts of cities and towns, while the distribution of populations with different qualifications is based on the corridors of access to Lisbon[11] and, within each

[11] There are four major transport corridors to Lisbon in the North Bank, following the radial urban development shown by **Map 1.1** in Chapter 1: Northeast (V.F. Xira), North (Loures), Northwest (Sintra) and West (Cascais).

municipality, on distances to those corridors. The level of urbanization is treated in subsequent analysis as a control variable, accounting for differences between the urban, suburban and semi-rural areas in the AML. In the next two sections, we relate the spatial distribution of the factors in each year of analysis to the performance of the metropolitan transport system in terms of accessibility and pedestrian mobility.

2.2. The distribution of accessibility

In urban settings, accessibility can be defined as the ease with which opportunities may be reached from a given location and by means of a particular transport system [Morris *et al.* 1979]. The estimation of levels or changes in accessibility is often used in the assessment of the performance of the transport system and of its relationships with urban land use. However, the concept is also central to the evaluation of the equity of the system, that is, the way that the transport system fulfils the needs of all individuals regardless of their socio-economic characteristics. The empirical assessment of inequalities is usually based on the relationship between the distribution of places of residence of the different socio-economic groups and the variability in indicators of accessibility across the city. In the case of accessibility to jobs, these indicators usually take into account the attractiveness of all possible destinations in terms of job opportunities, inversely weighted by the travel time to reach them. In the case of accessibility to urban facilities, the focus tends to be the range of opportunities available, expressed either as the time to the nearest facility or the number of facilities attainable within a given time.

While these methods assess inequalities based on the accessibility potential of each neighbourhood, a growing number of studies have been stressing the necessity to shift the focus to the constraints faced by the individuals to the realization of the accessibility potential of the neighbourhood where they live. In fact, 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. We can then have a mismatch between the type of accessibility provided by each place and the modes of transport used by the population, especially in the cases of low-income households and racial minorities [Shen 1998, Hess 2005, Grengs 2010]. Furthermore, the extent of this mismatch may vary considerably within an urban area [Kwok and Yeh 2004, Kawabata 2009]. This phenomenon tends to be more visible in cities with employment dispersion, low population densities and orientation towards car travel [Kawabata and Shen 2006]. While these are traditional features of North American cities, they are increasingly relevant in Europe, due to tendencies for suburbanization and decentralization of employment, and in the AML in particular, where there are still numerous semi-rural areas available for urban expansion relatively near to the metropolitan centre.

The analysis in this section intends to add to this body of research, by comparing differences in the relative accessibility of public and private transport at each location with differences in the efficiency of each transport mode relative to other locations, in terms of travel time and effects of congestion. In the case of accessibility to jobs, developed in the first two sub-sections, those two differences are studied among other factors affecting the gap between potential and realized accessibility that do not depend directly on levels of transport provision at each place, but instead on the individuals' choices regarding residence, employment and transport. These include the distance travelled and the proportion of commuters using public transport and walking. In the case of accessibility to urban facilities, developed in the last sub-section, we investigate whether social differences in the accessibility to urban facilities are independent of differences in the accessibility to centres of employment and of the travel mode used.

The comparison of accessibility levels by different transport modes requires a detailed modelling of network travel times. In most of the studies on relative accessibility, car and bus times do not include congestion and public transport times are derived from schedules. However, the incorporation of more realistic hypothesis about public transport time may increase considerably the estimated accessibility gap between public and private transport [Benenson *et al.* 2010]. There are also socio-economic differences in the time restrictions to accessibility, such as the necessity of scheduling and trip chaining [Dong *et al.* 2006] and the variation of the availability and frequency of public transport services and levels of congestion throughout the day [Weber and Kwan 2002]. To attend to these issues, we model the walking sections of the private and public transport trips. In addition, we only consider public transport options that allow passengers to arrive at and return from the place of work or urban facilities within the relevant periods of the day, in line with assumptions regarding starting and finishing time of jobs and opening time of facilities as described in Appendix 3.

The gap between potential and realized accessibility to places of work

In this section, we assess relationships between socio-economic variables and indicators of accessibility. We define potential accessibility as a measure of the centrality of each enumeration district in relation to major centres of employment, when using the private or public transport network under normal conditions. Realized accessibility is the average time to work of the district's population, based on data on commuting trips by motorized transport to major centres of employment and walking trips to nearby destinations. In this indicator, we consider the actual conditions of the transport networks, including congestion.

The assessment of potential accessibility uses a gravity measure [Hansen 1959], which defines the accessibility of a place as the sum of the number of opportunities (in our case, number of jobs) at a series of destinations, weighted by an impedance function measuring the separation between the two places. The negative exponential form of the impedance function is more appropriate at the urban scale, comparing with the power function, which usually works better at regional scale [Fotheringham and O'Kelly 1989, p. 11-13]. We define the indicator for two travel modes (private and public transport) and divide the day in peak and off-peak periods [Appendix 3]. Potential accessibility in the district *i* by mode *m* is then the sum of the number of jobs *E* at each destination *j* starting at each period *p*, weighted by a negative function of travel times *t* to access that destination using that travel mode in that period[12]. The parameter β in the impedance functions defines the steepness of the decay of accessibility with travel time. We use the value β=0.05, 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, chap.5][13].

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

The set of destinations represents major centres of employment and includes 207 and 240 points in 1991 and 2001 respectively [Appendix 2.1]. This set was constructed considering employment levels at the municipality level by sector of activity, which were disaggregated using data on the number of employees of companies registered at each *freguesia* by sector. A series of ancillary information was then used to identify precise locations in each *freguesia* for the employment in each sector. The level of employment in all sectors is then aggregated for each of these locations. The set includes places outside the AML, as there are important commuting flows from some peripheral areas in the metropolitan areas to nearby municipalities. The percentage of jobs starting at each period in each destination uses data from a 1998 mobility survey at the municipality level [DGTT and INE d1998].

Travel times take into account a series of conditions influencing the crossing times for each link in the network [Appendix 4.2 and 5.1]. In the case of the private transport and bus

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[12] We exclude from the analysis the cases where public transport is not attainable within a reasonable walking distance, taken as 1600m [Ayvalik and Khisty 2002].

[13] The estimation used the 1991 and 2001 pooled dataset of commuting flows [INE d1991d, d2001d]. While tests showed that the choice of a particular value in the interval [0.1-2] does not influence subsequent analysis, our approach is limited by the fact that spatial interaction in a heterogeneous urban area like the AML is a non-

network models, these comprise the speed limits for each type of road and location, proportion of drivers above speed limit, levels of road hierarchy, road quality, slopes and intersections. In the case of other public transport, crossing times are based on the speeds inferred from the 1991 and 2001 schedules. The estimation of optimal routes for the users of private transport includes walking time from parking areas to final destinations in the case of centres of employment in major urban areas where street parking is limited. The optimal routes for users of public transport include walking time between origins and destinations and bus stops or stations, waiting time and interchange time [Appendix 4.3 and 5.2].

We define the average time to work[14] of the population living in a given district *i* as the weighted average of travel times to each destination at each period of the day and by each transport mode. In the formula below, the first part respects motorized modes, with $t_{i,j,m,p}$ being the times to destination *j* during period *p* by mode *m* (private or public transport) and $F_{i,j,m,p}$ the corresponding proportions of flows in the total number of workers living in the district. The second part respects workers walking to work, with $t_{i,k}$ the walking time to destination *k* and $W_{i,k,,p}$ the proportion of all workers walking to that destination in period *p*.

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

The estimation of commuting flows for each travel mode and period are described in detail in Appendix 2.4 and 3. We use data from the 1991 and 2001 Census Commuting Database at the *freguesia* level to derive the proportion of workers walking to work. The destinations of these trips are a set of points inside and around each district [See Section 2.3 and Appendix 2.3]. We then use census data at the ED level to split trips by motorized transport into intra and inter-municipality trips and into private and public transport trips. The inter-municipality trips are then disaggregated into municipalities, using data from the commuting database. Intra and inter-municipality trips are finally assigned to the same set of points used in the estimation of potential accessibility, according to its estimated number of jobs starting at each period of the day.

The travel times used in the calculation of this indicator include the effect of congestion, which depends on road traffic levels and compositions. These are modelled by assigning trips to work and other personal trips to the respective optimal routes calculated using theoretical crossing times (based only on the characteristics of the road) and by modelling freight

stationary process and so the model would produce different estimates in different subsets.

[14] Time to work is a variable available in the population census but only at the *freguesia* level.

transport, other work-related trips, bus traffic and traffic crossing the AML. The procedures are described in Appendix 6. The resulting passenger car units are then compared with road capacity and finally used to reduce the crossing times of cars and buses in the affected links [Appendices 4.2 C and 5.1 A].

Table 2.2 shows the correlations between the five socio-economic factor scores found in the previous section, potential accessibility, average time to work and average commuting distance. The calculation of this last variable uses the same formula as time to work, adapted for distances. Urbanization levels (*F3*) and elderly populations (*F1*) are positively associated with private and public transport accessibility and negatively associated with time to work and commuting distance, which is explained by the high values of those factors in the central part of the metropolitan area (Lisbon). *F2* (Qualifications) shares the same relationships with accessibility and time to work as *F1* and *F3*, but relates positively with commuting distance. This result dismisses the hypothesis that the inequality in times to work among qualification groups is due to different levels of geographic matching between people and jobs. Despite a reduction in the association of qualifications with accessibility, the associations of *F2* with commuting distance and time to work have also strengthen from 1991 to 2001.

Table 2.2: Correlations between socio-economic factors, accessibility and commuting

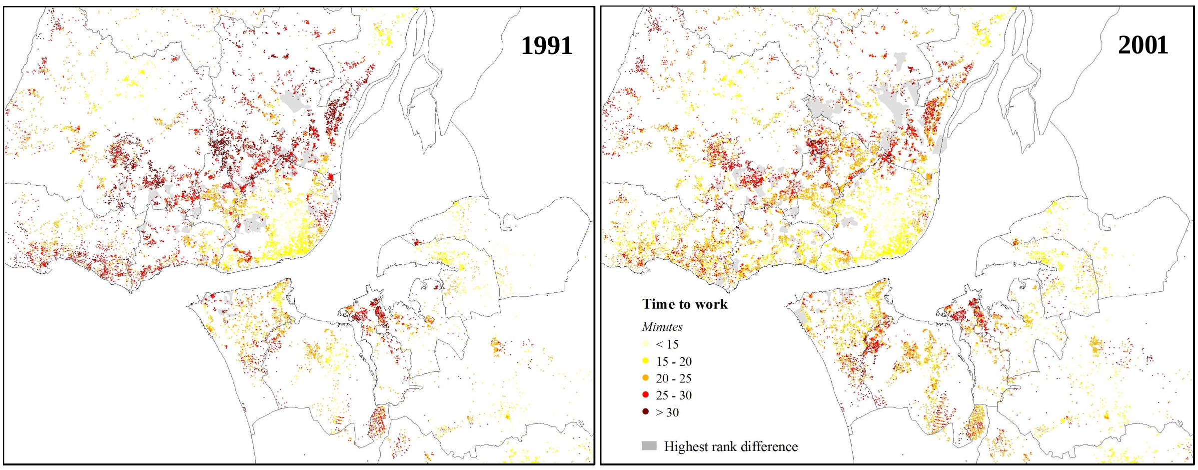
	Private tr. accessibility		**Public tr. accessibility**		**Time to work**		**Commuting distance**	
Year	*1991*	*2001*	*1991*	*2001*	*1991*	*2001*	*1991*	*2001*
F1	0.47	0.40	0.59	0.52	-0.42	-0.33	-0.64	-0.65
F2	0.19	0.17	0.20	0.16	-0.26	-0.40	0.08	0.15
F3	0.39	0.37	0.37	0.32	-0.09	-0.16	-0.12	-0.07
F4	0.08	0.16	0.06	0.15	*0.00*	-0.02	-0.16	-0.20
F5	-0.06	-0.07	-0.07	-0.06	0.04	0.03	0.07	0.15

Notes: Pearson correlations. N (1991)=14747, N(2001)=20836. All values significant at 1% except where italic.

We can visualise the social dimension in the gap between potential and realized accessibility by mapping its spatial distribution [**Map 2.2**]. Although there was a general reduction in time to work from 1991 to 2001, its distribution in both years shows the same pattern based on the position of centrality and commuting to Lisbon. Times to work are lower in Lisbon, increase in the surrounding areas, decrease in the areas less dependent on commuting to Lisbon and then increase in the peripheral regions. However, there are exceptions to that pattern, which we can confirm by looking at the areas where the gap between time to work and accessibility to jobs is most evident in each year. We selected the districts where the difference between their positions in the time to work and private transport accessibility ranks is a number higher than half the total number of districts[15]. Although Lisbon concentrates the major centres of employment, some of those districts are located in this city, especially in deprived neighbourhoods in the east. The situation has improved, due to the redevelopment of the areas around the new transport terminal at Lisboa Oriente. However, some parts in eastern Lisbon remain inside the group of areas of concern in 2001. Outside Lisbon, the areas with the highest accessibility gap are located mainly in the Northeast corridor, despite the fact that this was the only access corridor to Lisbon that in 1991 had access to both motorways and railways. There was also an increase in the number of areas located in the Northwest corridor from 1991 to 2001, which is also striking, as a new motorway was completed during that period and the frequency of rail services increased considerably.

Overall, areas at similar distances to Lisbon and with similar proportions of workers commuting to Lisbon show very different times to work, with an opposition between the areas mentioned above and the West corridor, which has the highest proportions of qualified populations. The table in **Figure 2.1** confirms the incidence of the accessibility gap in areas with less-affluent populations (as shown by the negative average of *F2* and the positive average of *F4* (Informal Settlements). The scatter plot also shows that the accessibility gap tends to occur in areas that are more urbanized and have less-qualified populations, while the few areas where the population has high qualifications are located in less urbanized regions.

Map 2.2: Time to work and the gap between potential and realized accessibility

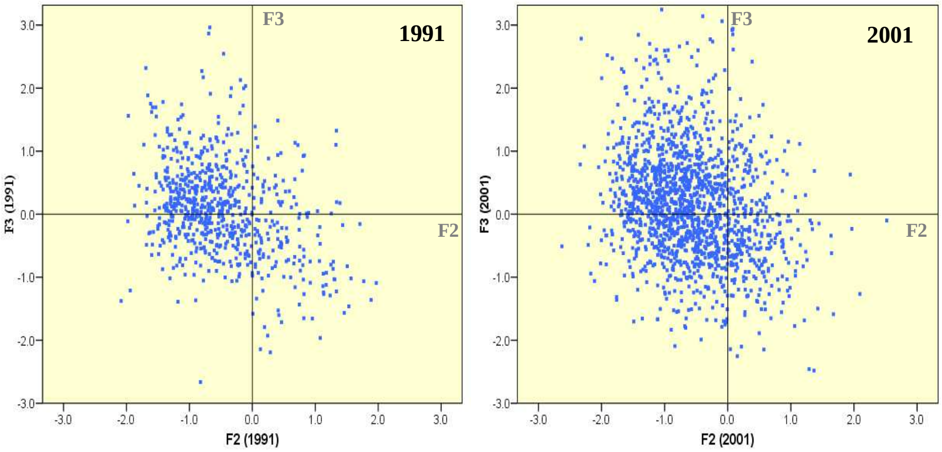


[15] We use the indicator of private transport accessibility because its value is higher than the public transport accessibility in all EDs and in both years and so, it represents the maximum potential accessibility in each ED.

Figure 2.1: Characterization of areas with highest accessibility gap

Population-weighted averages

	1991	*2001*
F1	-0.52	-0.40
F2	-0.59	-0.71
F3	0.28	0.69
F4	0.44	0.45
F5	-0.05	-0.07



The effects of modal choice and congestion

We now look at measures of the gap between the potential and realized accessibility of each place considering the destinations chosen by its population. We analyse separately the effect of modal choice (the ratio between actual average time to work and the average time using the fastest transport mode available to access each destination) and the effect of congestion (the ratio between actual average time and the average time under uncongested conditions). Both effects depend on the proportion of the population using each mode and on the relative efficiency of each mode for accessing the destinations chosen. To isolate from the former, we compare inequalities in the two effects for all commuters in each ED and for the users of each travel mode separately. We then compare both with the ratio of public to private transport accessibility, which gives the general relative efficiency of each mode, independently of the specific destinations chosen by its population. Finally, it is relevant to consider the role of differences in proportions of workers walking to work as a mitigation factor of potential inequalities caused by poor public transport or congestion. We suppose that walking is the fastest mode to access nearby destinations and is unaffected by congestion.

Table 2.3 shows the correlations between the socio-economic factors and the indicators presented in the last paragraph. While the general effect of modal choice relates negatively with *F2* (Qualifications) in both years, there is only a mild correlation when considering the effect on public transport users only. The correlation of *F2* with the ratio of public to private transport accessibility is also low. The inequality in the effect of modal choice seems to come therefore from the association between *F2* and the percentage of workers commuting by public transport, taking into account that private transport is the fastest mode for the vast majority of the estimated optimal routes from enumeration districts to destinations. The importance of the choice between public *vs.* private transport is especially relevant when we look at the fact that *F2* is negatively correlated with the percentage of workers walking to work (who are not at disadvantage in the access of their destinations). The factors *F1* and *F3* do not show strong correlations with the effect of modal choice and confirm that the advantage of elderly populations and urbanized areas in terms of public transport accessibility found in the previous sub-section is also valid in relative terms, when comparing with private transport accessibility. The effect of congestion is positively associated with qualifications and urbanization levels. However, the association with qualifications is weaker (and has decreased in the period concerned) when we separate the effect for users of private and public transport. This is because districts with higher qualifications also tend to have lower proportions of workers walking to work, who are not affected by congestion.

Table 2.3: Correlations between socio-economic factors, relative accessibility and modal choice

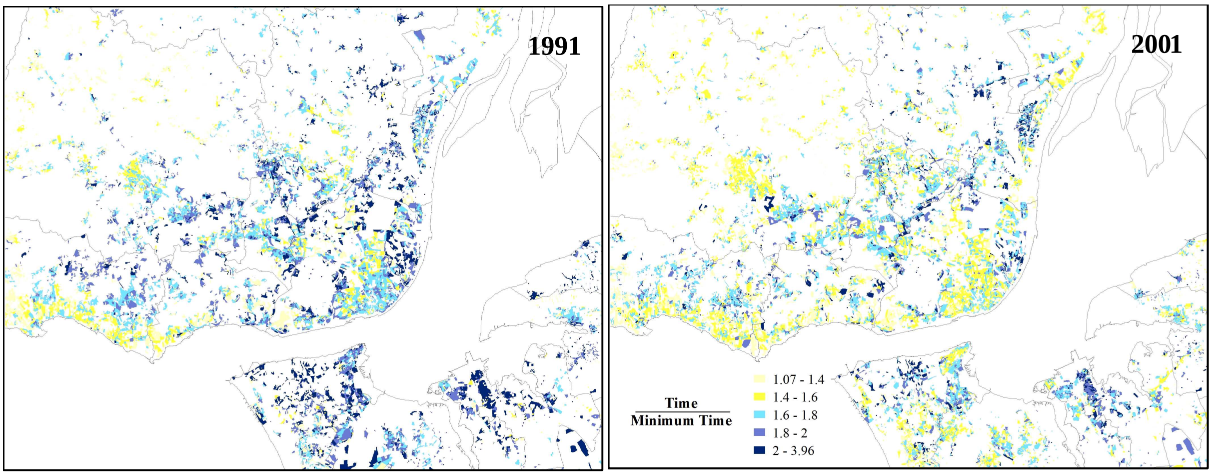
	Effect of modal choice				**Ratio pub.-priv. tr. accessibility**		**Modal choice**			
	All workers		Public transport				% Public transport		% Walk	
year	*1991*	*2001*	*1991*	*2001*	*1991*	*2001*	*1991*	*2001*	*1991*	*2001*
F1	-0.05	0.05	0.01	-0.04	0.56	0.51	*0.01*	0.17	0.31	0.32
F2	-0.49	-0.56	-0.07	0.05	0.16	0.09	-0.35	-0.44	-0.31	-0.42
F3	-0.14	-0.09	-0.24	-0.19	0.40	0.33	0.19	0.20	-0.06	0.08
F4	0.16	0.14	0.13	0.05	*0.00*	0.11	0.08	0.13	0.07	0.10
F5	*-0.01*	-0.04	*0.00*	0.01	-0.07	-0.06	*-0.01*	-0.03	*0.00*	*0.01*

	Effect of congestion					
	All workers		Public transport		Private transport	
year	*1991*	*2001*	*1991*	*2001*	*1991*	*2001*
F1	-0.07	-0.17	0.02	-0.05	0.05	*0.01*
F2	0.40	0.44	0.18	0.12	0.20	0.13
F3	0.33	0.22	0.31	0.16	0.38	0.31
F4	-0.09	-0.09	-0.08	-0.06	-0.03	*0.00*
F5	*0.00*	-0.02	-0.02	-0.06	0.03	-0.03

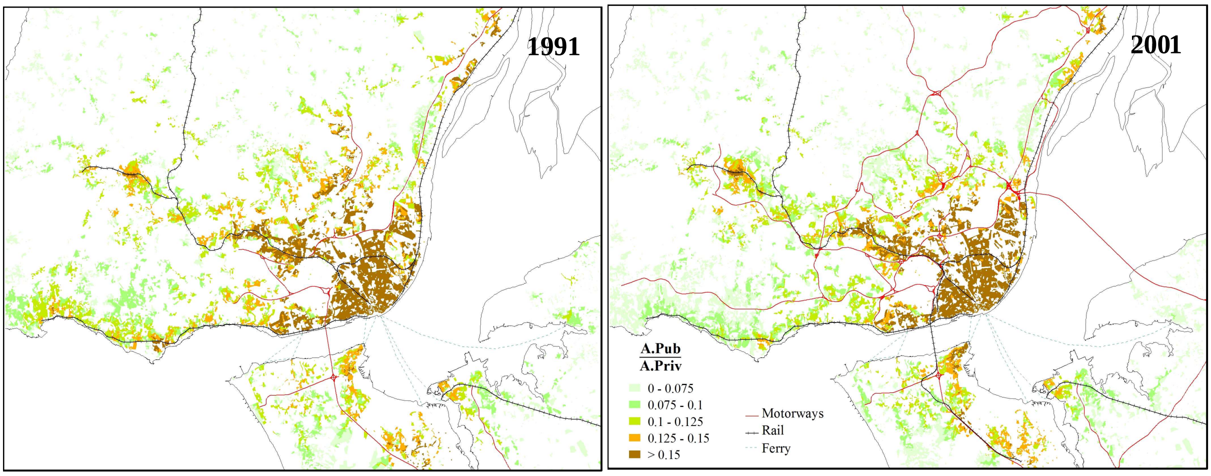
Notes: Pearson correlations. N(1991)=14747, N(2001)=20836. All values significant at 1% except where italic.

The comparison of **Map 2.3** and **Map 2.4** suggests that the general decrease in the effect of modal choice may be due to the increase of the share of private transport usage, as the ratio of public to private accessibility in most districts has not increased. Some of the areas where the effect of modal choice is more relevant have poor public transport relative accessibility, such as the Northeast corridor and the central peninsula in the South Bank. These are areas where rail services are relatively inefficient [CML-DPPE 1995b, p.55] and where urban expansion has favoured areas near to the motorway but far from rail stations. In the second case, public transport accessibility is also affected by long interchanges by walking, as the only direct connection with Lisbon is by ferry. Other areas have good public transport relative accessibility, such as the new neighbourhoods in east Lisbon, where public transport is the fastest option to the centre but where workers tend to use private transport, as was mentioned in Chapter 1 (p.21). In the remaining cases, the effect of modal choice seems to be related with the share of public transport, such as in the municipalities of Amadora and Almada, which have the highest rates of public transport usage in the AML [INE d2001d]. In both years, there are also patterns at smaller scales (within the same corridor or municipality), as the effect is especially felt in areas far from railways but near motorways. These areas tend to be rural and with less-qualified populations.

Map 2.3: Effect of modal choice on time to work

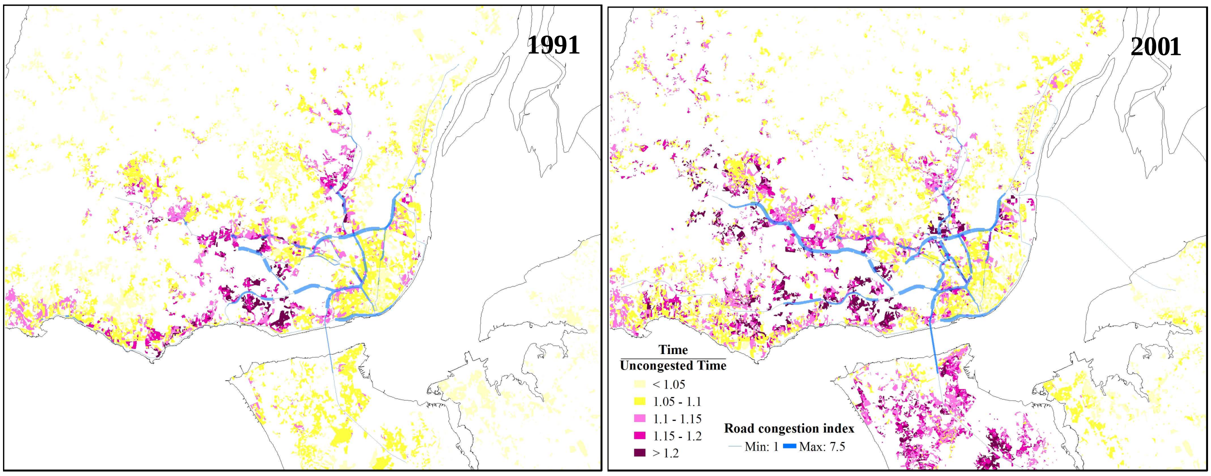


Map 2.4: Ratio of public-private job accessibility



The maps of the effect of congestion **[Map 2.5]** shows that this effect has generally deteriorated and has spread to the hinterland of the Northwest and West corridors and the South Bank, despite the construction of new road links and the widening of public transport options. This pattern explains the decrease in the correlations of the effect with *F3*. Overall, the imbalance between more and less affluent regions in the effect of modal choice has a mirror image in the imbalance in congestion, with the exception of the Northwest corridor, which shows high values for both effects. We can also see that the accessibility gap identified for the Northeast corridor in the previous sub-section is not due to the effect of congestion but only to poor relative public transport accessibility, as this is the only corridor that does not show high levels of congestion. High congestion indices are also observed in areas near some rail lines (which are not affected by congestion) and in areas served by roads with moderate congestion indexes (such as the IC15 motorway in the West corridor), which is in both cases explained by the high proportion of workers using car and bus transport instead of rail.

Map 2.5: Effect of congestion on time to work



The results of this sub-section show that inequalities in the gap between potential and realized accessibility are not necessarily due to a mismatch between the relative provision of private and public transport and the specific needs of the populations served, or to disadvantages for the users of each mode in relation with other locations. Relationships between time to work and socio-economic variables depend largely on differences in the proportion of workers using private transport, which derive from larger-scale economic and social differences that affect the individual choices.

Accessibility to urban facilities

The adequacy of the metropolitan transport system to provide for non-work trips is a dimension of accessibility that is increasingly important in some parts of the AML, due to the high and increasing proportions of elderly populations, who need to access on a regular basis urban facilities such as health centres, public institutions, parks, public libraries or sport facilities. Policies to improve accessibility to urban facilities are not necessarily consistent with policies directed at the overall accessibility at the metropolitan level, since they must attend to the number and distribution of facilities in each municipality and to the provision of public transport services in routes that may not coincide with major commuting routes. Time constraints are also more relevant than in the case of access to jobs, because access to facilities is needed throughout the day and often requires trip chaining, as individuals tend to visit more than one facility in a typical "run errands" day. Levels of accessibility to facilities then depend on the availability, frequency and reliability of public transport at non-peak times. The inclusion of accessibility to facilities in the present study aims at finding whether inequalities in this dimension of accessibility should be included as a distinct component of transport equity or if they are fully captured by inequalities in accessibility to centres.

The analysis considers two types of facilities: health centres and tax departments [Appendix 2.2]. These facilities were chosen since they are not located in the same places within each municipality. The location of tax departments is an indicator of the location of a series of facilities available in the traditional administrative centres. The location of health facilities is usually in less central, more residential areas. Other advantages in the use of these pair of facilities are the facts that their spatial distribution is relatively sparse as to require the use of motorised transport and that most of the adult population needs to access them on a regular basis, as the services provided are independent of individual preferences. The analysis assumes that the location of facilities is given and that transport policy is the only potential policy lever to address accessibility inequalities, due to limitations on the resources needed to multiply the number of facilities in dispersed, semi-rural areas.

We integrate access to both facilities in a single index, in order to capture the effect of trip chaining, which is especially relevant in the cases when people living in semi-rural areas need to access nearby cities and then access different locations within the city. The indicators we use are then the minimum time spent in a round trip from home to a health centre and a tax department, either by private or public transport. We assume that the set of choices in each

ED is restricted to the facilities inside each municipality and that facilities are homogeneous, providing the same services. A final aspect to notice is that access times are usually dependent on scheduled arrangements of the institution visited. In order to include the effects of variations in the level of public transport services throughout the day, we consider that the first facility is visited at peak time while travel between facilities and the trip back home occurs at off-peak time.

Table 2.4 shows the extent to which the social distribution of time to facilities is independent of the distribution of accessibility to centres and the extent to which the distribution of public transport time to facilities is independent from the distribution of private transport time. We distinguish between patterns at the metropolitan level and within the subsets of urban municipalities and municipalities with both urban and rural areas. Predictably, time to facilities is negatively correlated with urbanization levels (*F3*) in both years and in the three subsets. Elderly populations (*F1*) tend to have better access to urban facilities, but that advantage is less evident in semi-rural areas. The strength of all correlations is reduced when we control for the effect of general accessibility to centres. However, in the semi-rural municipalities, time to facilities correlates negatively with qualifications (*F2*), an effect that is independent of accessibility to centres. The relationships for public transport time when controlled for private transport time and the relationships for the ratio of public and private transport time are weak in all cases.

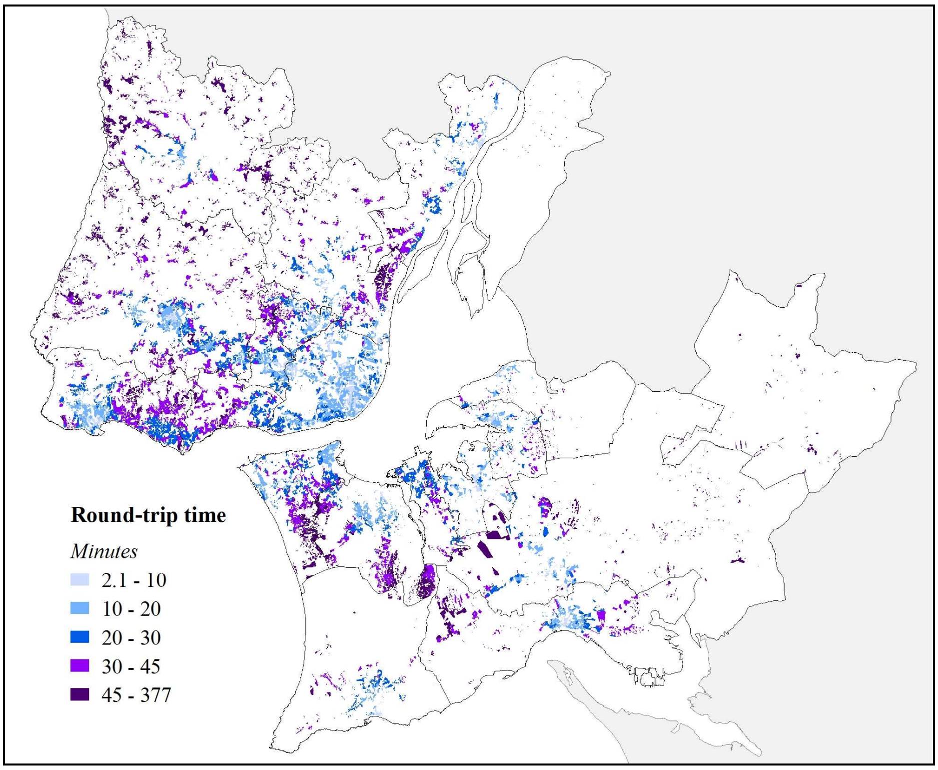
Table 2.4: Correlations between socio-economic factors and time to urban facilities

		Private tr. time to facilities				**Public tr. time to facilities**				**Ratio public-private tr.time to facilities**	
Control variable				Private tr. access. jobs		Public tr. access. jobs		Private tr. time to facilities			
year		*1991*	*2001*	*1991*	*2001*	*1991*	*2001*	*1991*	*2001*	*1991*	*2001*
AML	F1	-0.31	-0.29	-0.21	-0.19	-0.10	-0.10	-0.07	-0.09	-0.08	-0.10
	F2	-0.12	-0.08	-0.06	-0.05	-0.02	*0.00*	*0.01*	0.07	0.04	0.10
	F3	-0.34	-0.35	-0.21	-0.20	0.20	-0.20	-0.15	-0.13	-0.11	-0.10
Urban municipalities	F1	-0.34	-0.40	-0.24	-0.29	-0.15	-0.19	-0.14	-0.14	-0.14	-0.12
	F2	0.03	0.10	0.12	0.16	0.16	0.22	0.04	0.12	0.04	0.11
	F3	-0.37	-0.38	-0.25	-0.25	-0.18	-0.20	-0.12	-0.14	-0.10	-0.09
Semi-rural municipalities	F1	-0.19	-0.11	-0.16	-0.15	-0.18	-0.11	0.05	-0.04	0.08	*-0.01*
	F2	-0.23	-0.25	-0.27	-0.28	-0.25	-0.22	*0.00*	0.06	0.06	0.10
	F3	-0.30	-0.29	-0.21	-0.17	-0.15	-0.11	-0.19	-0.14	-0.08	-0.07

Notes: Pearson correlations. N(1991)=14744, N(2001)=20833. All values significant at 1% except where italic. Correlations with F4 and F5 are not shown due to low significance.

Map 2.6 presents the distribution of the public transport time to facilities in 2001, which is similar to the distribution in 1991 (see p.264 in appendix). The distribution is more variable than in the case of accessibility to jobs, having several extreme values, mostly in the rural areas of the South Bank. The influence of position in relation to main commuting corridors is also less marked, as patterns occur mostly at the municipality level, with the peripheral areas in each municipality having higher times than the areas around the municipal capitals and other cities and towns. However, these differences vary among the group of semi-rural municipalities and seem to relate less with the distribution of facilities inside each municipality than with the scarcity of off-peak transport services in specific areas. This factor is especially relevant in the northwestern municipality (Mafra), where afternoon public transport regularly connect villages with major cities but not always with the nearest town, where the nearest facility is likely to be located. It is also relevant in the industrial areas in the central area in the South Bank, where public transport is limited to the starting and ending times of work in the biggest factories. The absence of a correlation between socio-economic factors and public transport time to facilities when controlled for private transport time may therefore hide relationships occurring inside each municipality.

Map 2.6: Public transport time to facilities in 2001



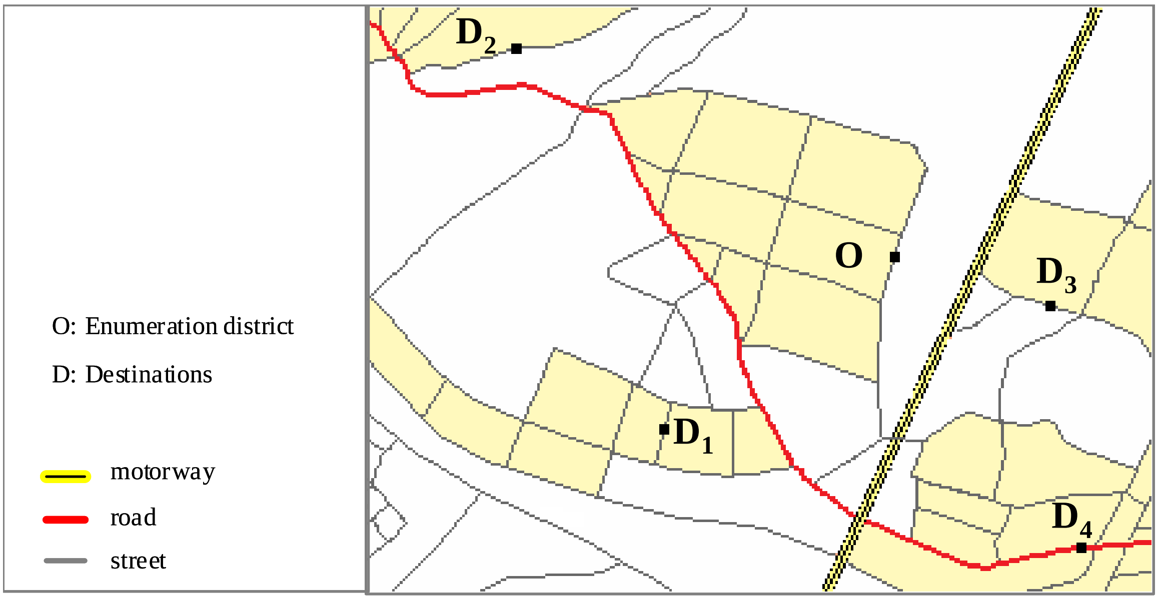
2.3. The distribution of pedestrian mobility

The quantification of changes in the mobility of pedestrians has been slowly making its way into transport project assessment, especially in the cases of large infrastructure constructed inside highly urbanized areas. However, the use of these measures has been confined to the specific projects being assessed, leaving a gap of knowledge regarding the effects of past practices in the distribution of changes in pedestrian mobility across the metropolitan area and regarding the possible social patterns in this distribution. The development of GIS-based measures of pedestrian mobility of "walkability" at the neighbourhood level is however an expanding research field [Leslie *et al.* 2007, Achuthan *et al.* 2007, Iacono *et al.* 2010]. These measures have been integrated in the study of several distributive issues in transport planning, such as the accessibility to jobs or to public transport by socially disadvantaged groups [Jones *et al.* 2005] and the special mobility needs of the elderly [Mackett *et al.* 2008]. Indicators of pedestrian mobility have also been integrated in the study of related issues like the probability of walking [Manaugh and El-Geneidy 2011], choices among public transport services [Guo and Ferreira Jr. 2008] and the hedonic modelling of house prices [Lake *et al.* 2000, Song and Knaap 2003].

The study of intra-urban spatial variations in levels of pedestrian mobility has predominantly focused on the local availability of pedestrian destinations [Cerin *et al.* 2007, Marshall *et al.* 2009, Witten *et al.* 2011]. There is less evidence on the spatial differences in the quality of pedestrian mobility and on the extent to which this mobility is restricted by road traffic. This issue was only partially covered by Greenberg and Renne (2005), who used a sample of self-reported measures of neighbourhood walkability. The objective of this section is to study this issue using objective measures of pedestrian mobility estimated using GIS methods and covering the metropolitan area. We consider that pedestrian mobility concerns are less about the extent of the opportunities found at each destination or the time required reach destinations than about the characteristics of the trip itself. We focus on the effects of transport infrastructure and motorized traffic on the quality of pedestrian trips. These effects include community severance and the environmental "disamenity" of walking, as measured by exposure to noise by pedestrians walking around the neighbourhood (to access particular locations, meet people, or as exercise) or as a part of the journey to work.

We consider that pedestrians walk from the representative points of each enumeration district (*O*) to a set of nearby destinations (*D*) [**Figure 2.2**]. In the case of exposure to noise on the way to work, pedestrians also walk to/from car parks or public transport stops. The location of pedestrian destinations is different in 1991 and 2001 and is obtained by a sampling process described in Appendix 2.3A. This process ensures that each point *O* has between 4 and 12 possible destinations. All destinations are located at a maximum distance of 800m. In the calculation of the pedestrian mobility indicators, we assume that the general attractiveness of each destination is measured by the population living nearby (estimated by assigning all the population in the AML to its nearest point in the set of all pedestrian destinations). For each representative point in each district, the attractiveness of each destination is then corrected by a factor depending on distance [Appendix 2.4]. The result is interpreted in the sections that follow both as the potential of that destination for population interaction and as a proxy for the location of local jobs.

Figure 2.2: Spatial framework for the assessment of pedestrian mobility



Community severance

The definition of transport-related community severance depends on one's understanding of what is a "community". However, we can broadly describe it as the reduction in the interaction potential between different parts of a city or town, due to the construction of linear transport infrastructure, such as roads or railways. Community severance is a dimension of pedestrian mobility in the sense that it restricts the possibility of accessing destinations in other communities on foot. Several countries have produced guidelines for the assessment of community severance, which usually focus on the need for pedestrian crossings or on the way that populations are separated from services and facilities located on the other side of new transport links. In this study, we translate the concept of community severance into a measure based on a more literal interpretation of separation between local populations, as we consider that pedestrian destinations are places where population interact.

We construct three alternative indicators, based on alternative definitions of what constitutes a barrier to the movement of people between different communities [Appendix 2.3 B]. In the first version, the set of barriers includes only restricted-access transport infrastructure, such as railways, motorways, dual carriageways and respective access roads. In these cases, pedestrians can only cross to the other side of the infrastructure through a number of footbridges or underpasses. We assume that infrastructure is a barrier to the movement of pedestrians even when these facilities are present, due to the intimidation effect of the infrastructure and traffic at high speeds. In a second, wider, definition of transport barriers, we add a number of multi-lane roads, where the number of pedestrian crossings is limited. In a third indicator, we also include barriers posed by industrial sites. This accounts for the fact that in some large industrial estates, access to pedestrians is prohibited, while in other cases there is a "disamenity" effect of walking through areas that are non-residential and visually unappealing. In all versions, we define the community severance indicator in a given district as the proportion of the population-interaction potential in that district's set of destinations that cannot be reached on the street network unless crossing a barrier. This means that in the example in **Figure 2.2**, the destinations D_3 and D_4 are labelled as "unattainable" for the population living in point O.

Community severance does not follow a normal statistical distribution, as it affects only a small set of districts in the study area. The variable of interest is then the probability of a district being affected by the problem. We use logistic regression to model the relationship between the five socio-economic factors and the logged odds ratio of a district being above a given threshold for the community severance indicator. The model is applied for the three versions of the indicator and for two different threshold values: 0.25 and 0.75. We model only the case of 2001, as the number of barriers in 1991 is relatively small. While the models are significant in all cases, it should be noticed that logistic regression is used here as a descriptive measure only and not as an explanatory model, as it omits potentially relevant explanatory variables, such as patterns of land use. **Table 2.5** shows the change in the odds ratios for a unit change in the socio-economic factors. These values are obtained by taking the exponential of the regression coefficients.

Table 2.5: Logistic regression of community severance (2001)

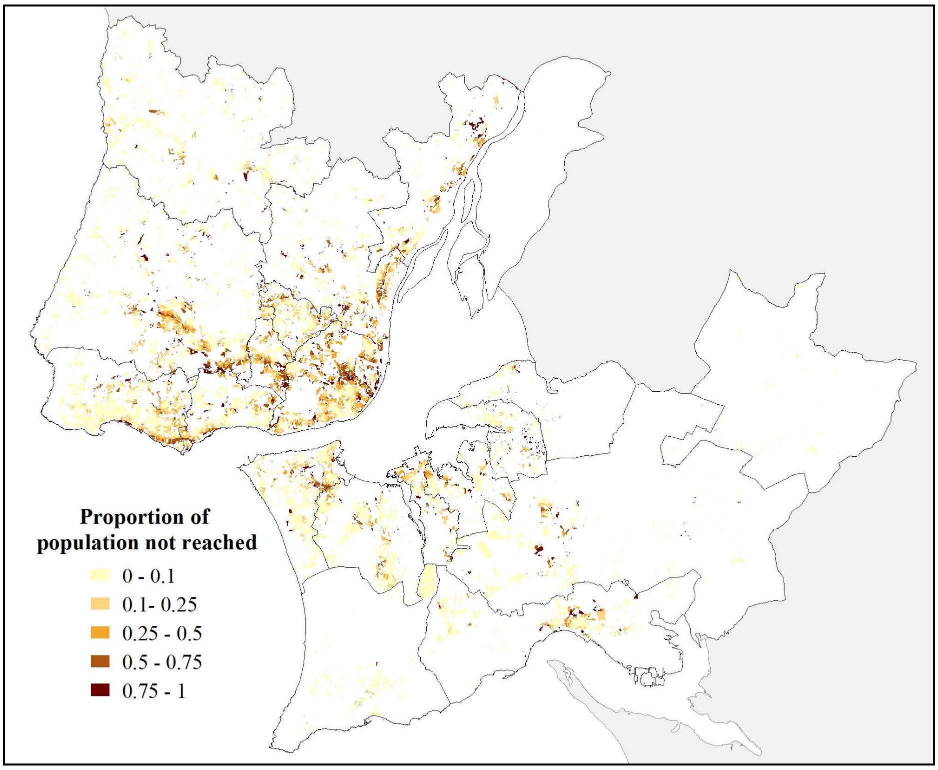
Barriers	Transport (motorways and railways only)		Transport (all)		Transport and industry	
Indicator	*>0.25*	*>0.75*	*>0.25*	*>0.75*	*>0.25*	*>0.75*
F1	1.16^{**}	1.03	1.27^{**}	1.20^{*}	1.11^{**}	1.03
F2	1.00	0.59^{**}	1.20^{**}	0.79^{**}	1.00	0.67^{**}
F3	1.01	0.44^{**}	1.38^{**}	0.79^{*}	1.18^{**}	0.90^{*}
F4	1.14^{**}	1.24^{**}	1.13^{**}	1.28^{**}	1.19^{**}	1.32^{**}
F5	0.99	0.86	0.97^{**}	0.94	0.99	1.01
# Cases	2334	211	3253	369	5303	964
χ likelihood ratio (df=5)	38.6 (p<0.001)	68.8 (p<0.001)	278.9 (p<0.001)	37.6 (p<0.001)	190.3 (p<0.001)	203.2 (p<0.001)

Note: N=20859. Significance (Wald test): * 1%, ** 5%

For the group of the most severely affected districts (indicator above 0.75), *F4* (Informal Settlements) has the highest positive impact on the odds ratio, especially as we include a wider set of barriers in the definition, while *F2* (Qualifications) has a negative effect (change in the odds ratio lower than unity). The impact of *F4* is due to the typical location of slums areas in the most undesirable parts of each municipality. The negative impact of *F2* is also consistent with the hypothesis stated in Chapter 1 that there is a sorting of neighbourhoods to the different socio-economic classes according to their ability to pay for avoiding local disamenities (p.11). However, when we include the group of districts with moderate severance indices (indicator above 0.25), the positive effect of *F4* become less visible, while the negative effect of *F2* disappears or become positive (in the case of the indicator for all transport barriers). While the socio-economic sorting of areas probably operates at very small scales, the analysis of the spatial distribution of the indicator **[Map 2.7]** shows that there are variations between the different corridors of access to Lisbon. In fact, the problem is more acute in the two corridors that we identified previously as the ones at highest disadvantage in terms of realization of accessibility potential. These are the Northeast corridor, where motorway and railway run parallel, and the Northwest corridor, where population density is high and population is distributed equally between both sides of motorway and rail.

While the influence of *F3* (Urbanization) on community severance is positive when considering the wider set of affected areas, it is negative for the set of the most affected areas (indicator above 0.75). This is because the effect of the barriers in proportional terms is naturally higher in rural communities, due to lower population interaction potentials. In addition, areas with numerous mobility barriers tend to be located outside major centres and especially in the suburbs at the fringe of Lisbon, as a result of the densification of the motorway network along and crossing major commuting areas in the North Bank **[Map 2.7]**. The most affected areas are the ones around the Lisbon ring road (CRIL), which are also constrained by other transport infrastructure and industrial areas. The problem does not affect the South Bank, however, as the low population densities allowed the construction of motorways far from existing population concentrations. For both threshold levels, the factor score for elderly populations (*F1*) has a positive effect on community severance, especially in the case of the indicator that considers all transport barriers, as these populations have high relative concentrations in Lisbon and in major centres, where the density of roads is higher but where motorways and large industrial sites are relatively rare.

Map 2.7: Community severance in 2001 (Barriers: transport and industry)



These results suggest that the relationships between community severance and socio-economic variables are more relevant when we focus on the most severe cases of severance. The need to attend to the distributive effects of new transport infrastructure is then especially relevant in the cases of routes crossing areas that have already other barriers to pedestrian mobility. In addition, the analysis of those effects must consider existing patterns of land use and future changes. This is especially the case when routes cross through mixed residential-industrial areas, creating multiple barriers to pedestrian mobility. It is also relevant in the case of semi-rural communities, which may be geographically far from other communities on the same side of the new links and where the impact of severance with communities on the other side would be proportionally more damaging to levels of pedestrian mobility than in other cases.

Environmental quality

As we mentioned in the introductory chapter, the quality of mobility for pedestrians depends on the number and level of environmental nuisances in the routes chosen, a significant part of which being effects of motorised transport. In this study, we focus on the specific case of pedestrian exposures to noise[16]. We consider that exposures depends on the individuals' patterns of daily mobility, as they need to access different areas at different times of the day, which are associated with different noise levels. We assume that those needs depend on employment condition, and so distinguish for each neighbourhood the exposures for the employed population and the exposures for the remaining population **[Table 2.6]**.

Table 2.6: Exposure to transport noise of a neighbourhood's population

Employment status	Means of transport	Exposure to noise as pedestrian	Exposure route
Not employed	Walk	Around the neighbourhood	Fastest routes to nearby destinations
Employed	Walk		
	Public transport	Waiting at stops or stations	Fastest route to places of work
		Walking to/between stops or stations	
	Private transport	Walking to car parks	

The exposure to noise of the population that is not employed is based on the fastest walking route from home (one of the enumeration district's representative points) to the corresponding set of pedestrian destinations. We define the indicator of "exposure to noise around the neighbourhood" for a given district *i* as the sum for all destinations *k* of the length-averaged noise levels on the pedestrian routes to each destination ($N_{i,k}$) multiplied by the probability that pedestrians choose that destination. This probability is the proportion of that

[16] We analyse this case because the noise propagation patterns are less complex to model than those of air pollution. We must bear in mind, however, that differences in the spatial distribution of noise and air pollution may originate different socio-economic patterns of inequality in the same urban area [Brainard *et al*. 2002, 2003].

destination's population-interaction potential for that ED *($P_{i,k}$)* and the total population-interaction potential of the ED ($\Sigma_k P_{ik}$)). We assume that pedestrians do not consider destinations on the opposite side of the transport barriers defined in the previous sections, in order to assure that the exposure to noise and community severance indicators provide measures of separate dimensions of pedestrian mobility. We also assume the number of pedestrian trips is constant throughout the day and as such the noise exposures $N_{i,k}$ are a weighted average of exposures at peak and off-peak times, where the weights are the number of hours in each period (see p.216).

$$Nar_i = \sum_k \frac{P_{i,k}}{\sum_k P_{i,k}} * N_{i,k}$$

The exposure to noise of the employed population depends on the mode of transport used and is based on the pedestrian sections of the fastest routes to work using each mode, obtained in the estimation of accessibility indicators (p.44)[17]. We define the indicator of "exposure to noise on the way to work" for a district's population (Nwk_i) as the weighted average of the exposures for workers travelling to each destination at each period of the day by each transport mode. In the formula below, $F_{i,j,m,p}$ and $W_{i,k,p}$ are the proportions of all workers in district *i* that start work during period *p* at location *j* and travel by motorized mode *m* (private or public transport) and the proportions of workers starting work during the same period *p* at location *k* accessed by walking. $N_{i,j,m,p}$ are the exposures to noise in the pedestrian sections of the journey to work by motorised mode, while $N_{i,k,p}$ are the length-weighted average of noise exposures in the routes taken by workers walking to work.

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

We use the same disaggregation of commuting data as in the calculation of average time to work. Workers walking to work access the same destinations as the population walking around the neighbourhood, as defined previously. The daily exposure to noise of users of motorized mode *m* starting work during period *p* and ending at the corresponding period *p'* is then given by the equivalent exposure level[18] of the exposures in all pedestrian sections of the

[17] We focus on the exposure to noise of individuals on the walking sections on their journey to work and not while inside vehicles. Levels of exposure inside vehicles tend to be comparable in cars and buses and slightly higher in trains and in the underground [Bugliarello *et al.* 1976, Chs. 6, 10].

[18] Equivalent exposure level is the noise level that, over a defined period, contains the same amount of acoustic energy as the actual varying noise.

return trip to work. In the formula below, $T_{i,j,m,p}$ and $T_{j,i,m,p'}$ are the total walking times in the journey from district *i* to location *j* using mode *m* during periods *p* and *p'* respectively. $N_{i,j,m,p}$ and $N_{j,i,m,p'}$ are the length-averaged noise levels in the pedestrian routes used (or the noise level at the stop or station, in the case of waiting time).

$$N_{i,j,m,p} = 10 * \log_{10}\left[T_{i,j,m,p} * 10^{\frac{N_{i,j,m,p}}{10}} + T_{j,i,m,p'} * 10^{\frac{N_{j,i,m,p'}}{10}} \right]$$

In the case of private transport, the pedestrian sections are the walking time between car parks and places of work[19], while in the case of public transport, those sections are the times walking from home or place of work to stops or stations or when interchanging to different modes or services. We include the waiting time at all stops, as the usual noise loudness and duration of exposure at bus stops and train or underground stations tends to exceed standards [Gershon *et al.* 2006]. In the AML, levels of exposure to noise while waiting at bus stops are probably above similar cities, due to the location of a large number of stops along major transport arteries, both in Lisbon and in the surrounding areas [**Figure 2.3**]. There is also evidence that noise levels at the Lisbon underground stations at the time of arrival, stop and departure of trains is higher than any other underground systems in the world [Davis and Zubkoff 1964, results reproduced in Bugliarello *et al.* 1976, p.89].

Figure 2.3: Examples of bus stops in the Lisbon Metropolitan Area

Sources: http://www.aca-m.org, http://a-sul.blogspot.com, htttp://cidadaniaresponsavel.wordpress.com

The estimation of exposures uses peak and off-peak noise levels surfaces modelled for 1991 and 2001. Appendix 7 presents in detail the methodological procedures used. We estimate noise levels for each link of the motorway, road and rail networks, based on the

[19] In the routes accessing destinations where car parking is not modelled, we assume that the exposure to noise is an average of the background noise at origin and destination (see p.248).

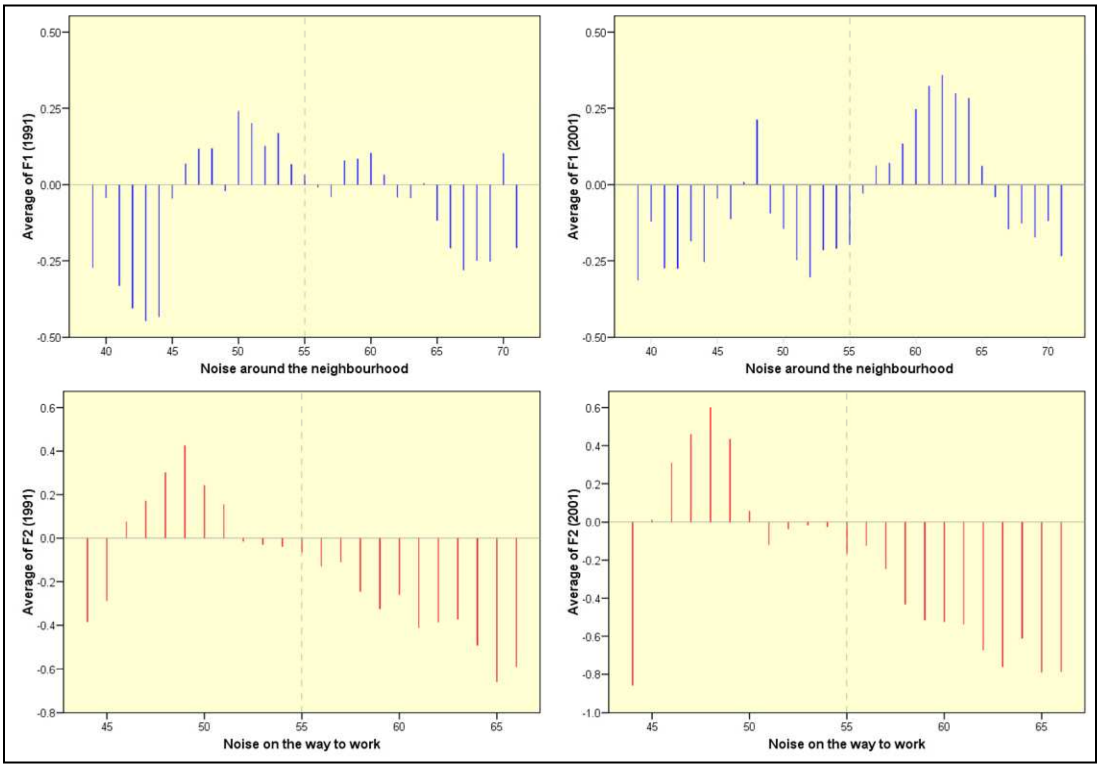
characteristics of the link and on the estimated traffic levels, composition and speeds in each year. Information is also included on industrial noise and flight paths, extracted from available noise maps for recent years. The noise levels at these sources are then used to estimate levels for a 40m grid of points, based on formulas on noise propagation from each source and using several geographic datasets representing local conditions. Noise levels at railway and underground stations are modelled separately.

The maps of the two indicators [**Map 2.8** and **Map 2.9]** show their singularities in terms of absolute values and variability. The exposures to noise around the neighbourhood are higher and less variable than values found in the transport equity literature based on exposures at home. This is because the construction of the indicator implies that people in all districts in given area visit with the highest probability some of the noisiest points in that area, as more populated places will tend to have higher noise levels. On the other hand, exposures to noise on the way to work are lower than exposures around the neighbourhood, as they incorporate the share of the population that is not exposed to noise (the cases of private transport commuters who travel to destinations where there is no need to walk from parking spaces to the place of work). Finally, the distributions of both indicators show different overall patterns from the indicator of community severance, as they depend not only on the location of the infrastructure but also on traffic levels.

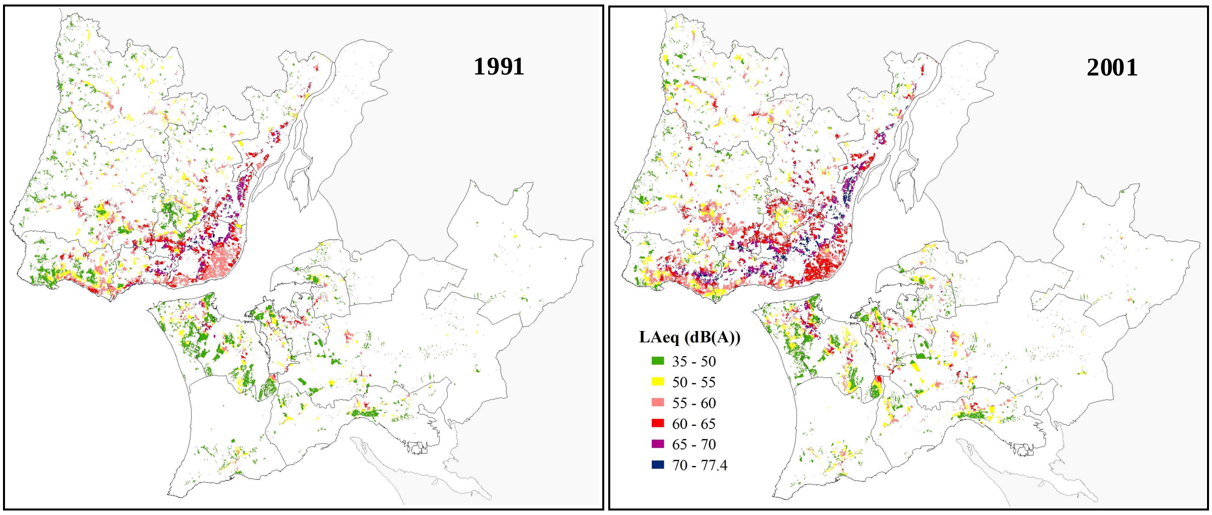
Figure 2.4 shows the population-weighted averages of socio-economic factor scores for each class of noise exposure. The top part of the figure shows that in the period concerned there was a structural change in the distribution of exposures around the neighbourhood among age groups (*F1*). In fact, apart from the most extreme exposure levels, which remain associated with negative values of *F1*, the average value of *F1* for noise exposures above standards (taken as 55 dB(A)) has increased substantially. **Map 2.8** suggests that this change may be linked to the increase of noise levels in the city of Lisbon, municipal capitals and other consolidated urban areas, where the population is older than average. Exposures have increased in most areas, with values above standards spreading to a large number of areas in the outer municipalities the South Bank. Spatial differences in 2001 occur mostly at the level of the municipality, as the areas with the highest exposure are the outer parts of Lisbon and the parts of adjacent municipalities that are closer to Lisbon or to major transport infrastructure. The situation is especially acute in the Northeast corridor, which is formed by a long and narrow strip of residential land sided by national-level road and rail infrastructure, along flight paths and beside the major industrial corridor in the metropolitan area. Exposures are also especially high in some of the new developments in less dense areas, which have few pedestrian destinations, accessible only by using busy roads crossing vacant areas.

The distribution of exposures on the way to work according to qualification levels (bottom part of **Figure 2.4)** has remained unchanged from 1991 to 2001, showing an almost perfect separation between above-average qualifications in areas above standards and below-average qualifications in areas below standards. The exception to this pattern occurs in the areas with the smallest noise exposures, which correspond to isolated areas in rural municipalities [**Map 2.9]**. These regions tend to have populations with relatively low qualification levels**.** Overall, the spatial distribution of this indicator follows patterns based on levels of commuting to Lisbon by public transport, as destinations in Lisbon have the highest noise levels and as such, waiting at bus stops on the return trip will contribute to higher daily exposures. The socio-economic dimension underneath this pattern is similar to the case of the gap between potential and realized accessibility (and to a lesser extent, to the case of noise around the neighbourhood). Areas in the Northwest and Northeast corridors, which have relatively less-qualified populations, tend to have the highest number of districts with exposures above standard, while more affluent areas in the West corridor have lower exposures for comparable proportion of workers commuting to Lisbon by all transport modes.

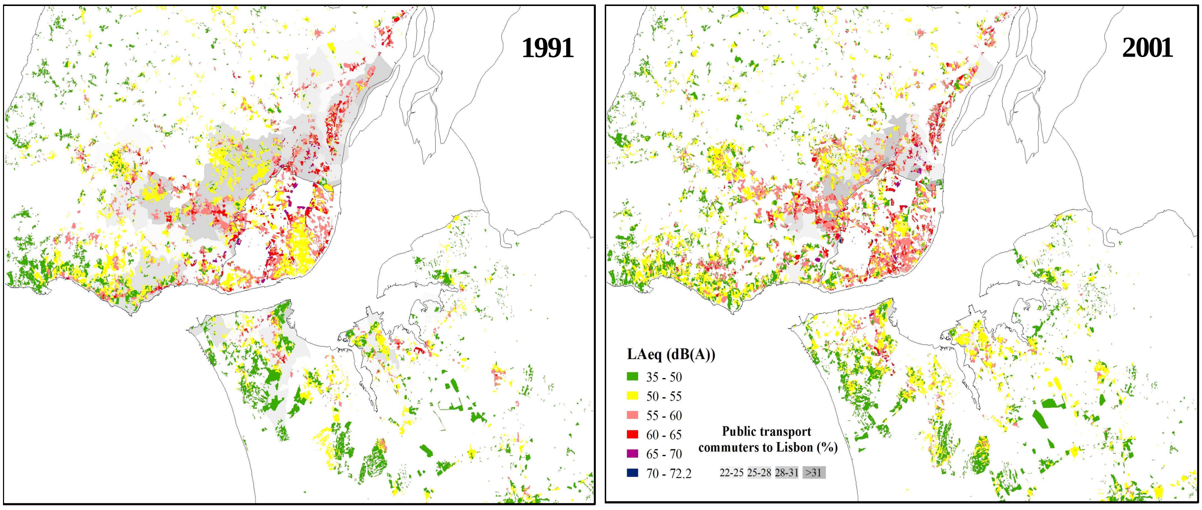
Figure 2.4: Pedestrian noise exposures and socio-economic factor scores in 2001



Map 2.8: Exposure to noise of pedestrians walking around the neighbourhood

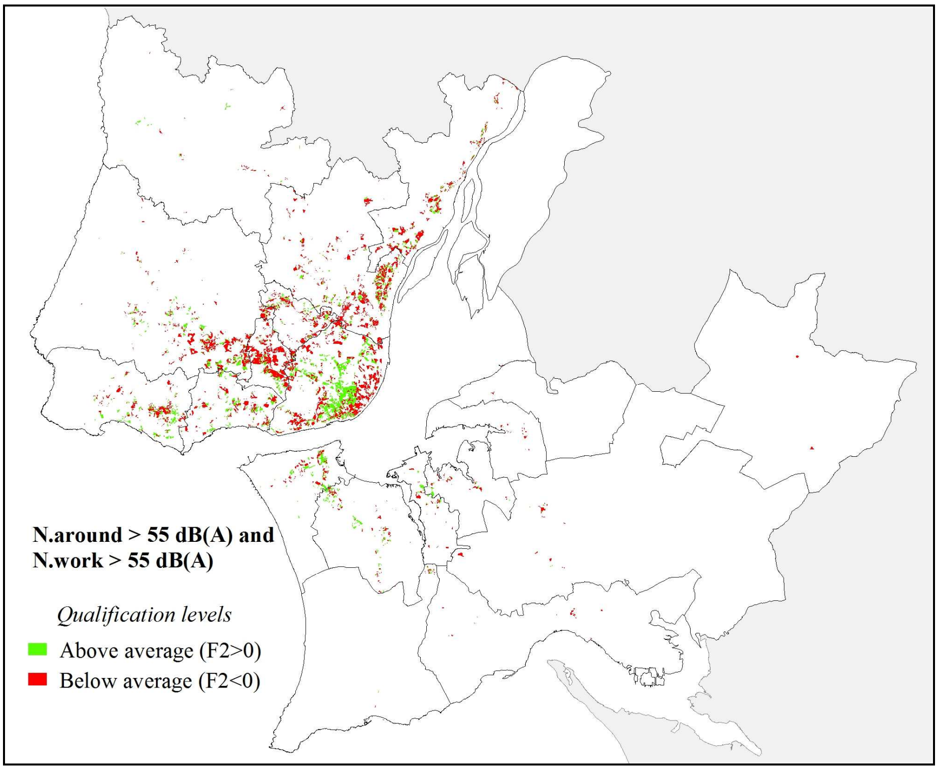


Map 2.9: Exposure to noise of pedestrians on the way to work



Although the distribution of noise exposures around the neighbourhood according to qualification levels does not show a discernable statistical structure at the level of the metropolitan area, patterns emerge when we map the areas that exceed standards of both exposures around the neighbourhood and exposures on the way to work. The situation in 2001 is presented in **Map 2.10**, which shows that areas with exposures above standards and with qualifications higher than average are limited to the central part of Lisbon, while the large majority of the other areas above standards have qualifications lower than average.

Map 2.10: Noise above standards and qualification levels



As a conclusion, the results of this sub-section show that the effects of the construction of transport infrastructure on the two indicators of exposure to noise contribute to the emergence of inequalities at different scales. The projects have intensified the differences between exposures of noise around the neighbourhood among areas in the same municipality, with effects on exposures of elderly populations. On the other hand, the projects have not reduced the differences between exposures of noise on the way to work among different corridors of access to Lisbon and qualification groups.

2.4. Methodological considerations

This section discusses some of the limitations and possible extensions to the analysis in the preceding sections, namely regarding the geo-demographic classification of the enumeration districts and the construction and interpretation of the indicators of accessibility and pedestrian mobility.

A problem common to most transport equity studies is that results are sensitive to the specification of the unit of analysis, which comprises the choices over the level of data aggregation and over the borders dividing the units. This is known in the literature as the Modifiable Areal Unit Problem (MAUP) [Openshaw 1984]. In fact, the interpretation of census districts as socio-economic units may create distortions in the assessment of relationships between socio-economic groups and levels of accessibility or pedestrian mobility, due to the internal heterogeneity of the districts and to the fact that residential segregation leads to the concentration of some groups in specific sections of each district. In fact, evidence shows that aggregation issues affect the social distribution of pollution concentrations [Sui 1999, Baden *et al* 2007] and the estimation of levels of pedestrian mobility [Hewko 2002]. While these distortions are minimal in each district, they are potentially amplified at the metropolitan level, because enumeration districts do not always have similar population and compactness, with differences in our case between Lisbon and the rest of the metropolitan area.

The factorization of socio-economic data may also hide relevant detail, such as the socio-economic differentiation within the aged population and the age structure of different socio-economic classes. Furthermore, due to the unavailability of data at the enumeration district level, the analysis does not incorporate racial differentiation. As we saw in Section 2.1, the values of Factors 4 and 5 are related with the proportions of some national or racial minorities at higher levels of data aggregation, but this relationship may not hold at the level of the enumeration district. Race may therefore be an independent factor of social differentiation, with specific relationships with levels of accessibility or pedestrian mobility. The results of studies in the AML show that in areas where minorities are more numerous and there are high levels of racial segregation, the specific locations occupied by those groups have serious insufficiencies in terms of access to public transport and local mobility [Cachado 2008].

There is also some ambiguity in the identification of classes of concern in terms of cut-off values of the factor scores obtained (opposing for example age or qualifications above and below the mean). In fact, transport-related disadvantages may affect especially the classes in the middle [Havard *et al.* 2009]. Alternatives to our approach could be to use a multiple-class structure [Brainard *et al.* 2003] or to analyse social indices alongside their individual components [King and Stedman 2000, Pye *et al.* 2001]. However, these approaches would bring a level of complexity that could obscure the focus of our analysis, which is the determination of patterns in the distribution of multiple effects of transport.

The unavailability of individual data also limits the construction of some of our indicators. The estimation of accessibility levels assumes that trips are only assessed in terms of time. However, beside less tangible costs such as convenience and comfort, accessibility also depends on monetary costs, including the relative cost between car and public transport or between different public transport companies and the additional costs of using more than one company. In the case of the AML, this issue is especially relevant in the South Bank where the integration of public transport services has started only recently. The estimated levels of public transport accessibility in this area may then overestimate accessibility as felt by the population. In general, it is difficult to make an economic interpretation of accessibility measures based on times or gravity potentials, as they do not include the preferences of the households and their available or perceived choice sets, in terms of destinations and available transport. Possible solutions to integrate the utility of each destination in the analysis of job accessibility include the consideration of wages or competition for jobs at each destination [Van Wee *et al.* 2001, Wang 2003] and the measurement of accessibility as a proportion of jobs attainable for the population of each district according to its socio-professional group [Cervero *et al.* 1999]. However, in our case, while it is possible to disaggregate employment by sector of activity at each destination, the available census data only provides a simple 3-sector classification for the population living in each district.

The relevance of exogenous factors of cost is also an issue in the estimation of levels of pedestrian mobility. In fact, the times, effort and pleasure associated with walking depend on topography and on the characteristics of the streets, especially when pedestrians share the same space with cars in narrow streets, such as in most of the old neighbourhoods in Lisbon, or in cases where parked cars occupy the space for pedestrians, which happens throughout the metropolitan area. It is also important to consider the way that people perceive the deterioration of pedestrian mobility. Perceptions of “near” or “connected” in heterogeneous urban regions such as the AML depend of administrative borders, historical factors and levels of socio-economic and racial segregation. The interpretation of the maximum walking distances used to construct the set of pedestrian destinations (800m) also depends on whether we consider that value as "usual" (average) walking distances or as a standard that should not be exceeded. We can also presume that populations in less urbanized areas are more receptive to walk longer distances in order to assess services or population centres. In that case, the value used for the definition of pedestrian destinations should not be uniform throughout the study area. The ambiguity in the assignment of parameters in the measurement of mobility is also felt in the case of community severance, which depends on judgements on the way that available crossings facilitate or not the movement of people between the two sides of a road or railway. For example, Clark *et al.* (1991) propose a mitigation factor for community severance representing the number and acceptability of crossing points.

We should also question the rationale of understanding noise as a 'bad' restricting pedestrian mobility. Generally, noise annoyance has effects in terms of health and quality of life [Dratva *et al.* 2010], which may condition people's propensity to walk or attitudes towards walking, perhaps to a higher degree than other environmental aspects such as air pollution, since noise is a more perceivable nuisance. However, subjective assessments of individual annoyance do not depend only on levels of exposure but also on individual characteristics and on the physical and social environment. The empirical evidence on the link between noise levels and annoyance is mixed, being validated by some studies [Sato *et al.* 1999, Michaud *et al.* 2008], but rejected by others [Heinonen-Guzejev *et al.* 2000, Paunović *et al.* 2009]. While the general idea is that noise annoyance is higher at home and at night-time, as noise stands out against a lower level of background noise, results from some studies in the UK have shown that levels of annoyance are not related to the distance between home or workplace to a road [Williams and McCrae 1995]. The results of an experiment in Italy also suggest that personal assessments of noise levels correlate well with actual noise levels when individuals are travelling in the city, but not when individuals are at home or at work [Orlando *et al.* 1994]. It is nevertheless difficult to generalize the results of studies of noise annoyance, as they depend on the characteristics of the city analysed and on the environmental (and economic) conditions at the time of the survey.

There are also certain caveats in the inclusion of noise levels in quantitative studies. In fact, the effect of halving the acoustic power of a sound source is only a 3 dB (A) reduction on the noise level, which is scarcely noticeable to most people. There are also differences in levels of perception of different noise sources, with noise from trains perceived as less annoying than noise of equal loudness from cars, with the difference corresponding to an effect of 5 dB(A) [Miedema and Oudshoorn 2001]. In general, annoyance depends on a variety of physical characteristics of the noise itself, such as intensity, duration and frequency. The noise measure used in this study (the equivalent sound level) could then be complemented with quantile-based measures (such as L_{10}) and with measures of fluctuations of noise or the number of noise events from different sources. Extensions of our analysis can also benefit from ongoing research on the construction of qualitative noise maps for Lisbon, which incorporate people's perceptions and the sound attributes of different noise sources [Boubezari and Bento Coelho 2004].

A final issue regards the question of whether to consider the overall statistical distribution of noise levels or to focus only on "unacceptable" levels. Although some previous studies follow this last approach [Gunier *et al.* 2003 and Green *et al.* 2004], the definition of these standards is not consensual. For example, according to the current legal framework in Portugal[20], noise mitigation plans should be implemented when noise levels in an area exceed standards defined for each time of day and type of land use. The law distinguishes between the daytime standard of 55 db (A) equivalent continuous sound level for "sensitive zones" (such as residential areas or hospitals) and 65 dB(A) for other areas. However, these values are higher than the values proposed by the WHO (1999), which suggests that 50 dB(A) is the annoyance limit for outdoor activities (such as walking).

[20] Noise General Regulation, Decree-Law 9/2007, of 17 January

Conclusions

This chapter compared the social distribution of several dimensions of accessibility and pedestrian mobility in the Lisbon Metropolitan Area. The focus was on the inequalities caused by the insufficiency of the transport supply in face of the individuals' accessibility needs at each neighbourhood and on inequalities in the distribution of the effects of transport on pedestrian mobility. We found that because elderly populations tend to live in central areas, they have relatively good accessibility to urban facilities but they are also affected by community severance and pedestrian exposure to noise. Less-qualified populations tend to have longer times to work, but this may be solely due to higher rates of public transport usage and not to geographic disadvantages, as these populations travel shorter distances and are less affected by congestion. In addition, their areas of residence are not at disadvantage in the provision of public transport, either when comparing with private transport in the same areas or with public transport in other areas. On the other hand, the areas where the effects of transport on community severance and pedestrian exposure to noise are more acute tend to have less-qualified populations. Finally, the results point out to the relevance of considering urbanization level as a control variable and to the modest explanatory power of other socio-economic variables, expect in the case of community severance, where the location of informal settlements is the most relevant variable.

The analysis of the evolution of the various indicators allows some generalization to other urban areas facing the same context of fast expansion in the motorway network and increase in private transport commuting. The maps in this chapter show that these two factors contribute to the deterioration of pedestrian mobility both in areas in the historical centres (where road traffic increases) and at the fringes of the main city in the metropolitan area (which are crossed by the new roads). However, in these areas the population usually tends to rely on walking and on public transport, since these are the most efficient means of transport or because the population lacks access to cars, due to high proportions of elderly and low-qualified populations. The integration of pedestrian mobility as an equity issue in transport planning should attend therefore to the existence of cumulative disadvantages derived from social patterns of residence location and private transport use in the areas where new roads do not bring accessibility benefits, but where pedestrian mobility is negatively affected.

The map analysis also suggests that inequality patterns do not occur necessarily at the scale of the metropolitan area and may vary among its different regions. The spatial distribution of indicators related to the journey to work (such as the effect of modal choice and congestion and the level of noise exposure) creates inequalities between the different corridors of access to Lisbon, that is, between areas at similar distances to Lisbon and with similar proportions of workers commuting to Lisbon. However, the distribution of other indicators, such as community severance, exposures to noise around the neighbourhood and accessibility to local facilities creates patterns within the same corridor of access or within each municipality. We develop this issue in the following chapter, by estimating statistical models to explain the distribution of accessibility and pedestrian mobility taking into account the spatial variability of their relationships with socio-economic factors.

Chapter 3

Spatial non-stationarity in transport inequality

The recognition of the policy relevance of social inequalities presupposes the acceptance of certain principles of social justice. However, justice is a value-laden concept and can have as many definitions as the situations in which it is used or the political agendas of the individuals using it. While equality can be simply defined as a uniform distribution, principles of justice (or equity) tend to be justifications for deviating from equality. According to authors such as Young (1990) and Elster (1992), these justifications are not universal but contextual, as in practice, different goods are distributed following different principles, by different institutions and at particular times and places. This debate has also reached the fields of transport and environmental research, where it is often argued that social justice should not be equated with the achievement of perfect equality in the distribution of benefits and costs among social groups, but instead with the correction of specific inequalities that emerged in the light of specific processes [Cutter 1995, Feitelson 2002].

As transport is an activity with effects over space, the evaluation of its distributive outcomes must consider the specific geographic context in which these outcomes appear and in particular the set of areas among which the effects are distributed. Transport equity studies have examined patterns occurring in cities, metropolitan areas or wider regions. However, the borders of these areas do not always correspond to discontinuities in terms of the forces affecting the location of transport infrastructure and the spatial distribution of the population. When those forces operate over a wider area, there are distortions arising from not including all the relevant areas in the analysis ("edge effects"). When they operate at a smaller scale, the analysis may hide relevant detail, due to the multiple distributive patterns that arise when the processes behind those patterns are non-stationary in space, that is, vary among the different parts of the study area. The search for statistical associations between socio-economic variables and indicators of the effects of transport must then consider the specific locations and the scale[21] where they might occur. The interpretation of those associations as injustices

[21] We use the term "scale" in this chapter with the meaning of "scale of analysis" (the set of observations included in each model, also known as "scope of analysis"), not with the meaning of "scale of resolution" (the

will then depend on the priority one assigns to the achievement of equality along different socio-economic lines, in specific locations and at specific scales. The correction of the spatial inequalities found will also depend on the degree to which they overlap with administrative units and on the access of the governments of these units to the relevant policy instruments.

The spatial variability in the relationships between the effects of transport and socio-economic factors has attracted growing interest in recent years. Among the methods used to analyse this question, geographic weighted regression (GWR) is the one that provides a higher degree of flexibility. GWR assumes that relationships are specific to each place and can be estimated by using the data for all other places in the study area weighted by their proximity. This approach was used to analyse the distribution of effects of transport such as job accessibility [Lloyd and Shuttleworth 2005] and pollution [Gilbert and Chakraborty 2011]. This research has however focused on the spatial variability within broad regions. The analysis in this chapter intends to build on this research, by adapting the GWR method to the study of the spatial variability within an urban area. We assume that relationships between transport and socio-economic variables are specific to all places sharing certain geographic attributes. We then estimate a separate regression for each place, using the data for all places weighted by their distances measured not in geographic space but in the space defined by those attributes.

The hypothesis is that in urban contexts, and especially in heterogeneous metropolitan areas such as the AML, households and policy-makers make decisions over space by comparing neighbourhoods according to their functional role in the metropolitan space. This role is assessed by factors such as the position of the neighbourhoods in relation to the main centres or by the commuting possibilities that those neighbourhoods offer. The relationships between the effects of transport and the social groups affected may then vary with the local relevance of those factors, as they have a variable influence in the location of population and transport infrastructure. In addition, individuals may also assess the fairness of transport policies by comparing the conditions of neighbourhoods that they believe have similar functional roles or where the population has similar needs for the different goods distributed by transport. In other words, they construct "communities of justice" defining the set of areas among which they consider that the policy-maker should redistribute the effects of transport. For these reasons, it is possible to derive different inequality patterns from the same scenario,

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spatial unit at which those observations were measured).

depending on which we consider to be the attributes defining comparable areas.

This chapter will assess the influence of the definition of different comparison spaces in the relationships between socio-economic variables and the effects of urban transport on different dimensions of mobility of the local populations. The analysis aims at answering the hypotheses that emerged in the map analysis in Chapter 2, which suggested the existence of local patterns that do not correspond to the numerical relationships estimated at the global (metropolitan) level. We focus on three of the indicators defined in that chapter: time to work [Section 3.2], pedestrian exposure to noise on the way to work [Section 3.3] and exposure to noise of pedestrians walking around the neighbourhood [Section 3.4]. In a first section [Section 3.1], we briefly describe the methods used in previous research and present our model formulation and the interpretation of spatial non-heterogeneity in transport inequality in terms of communities of justice. The results are interpreted jointly in Section 3.5, where we discuss the limitations posed to policy intervention by the existence of inequalities in different locations and at different scales.

3.1. Spatial non-stationarity and "communities of justice"

The concept of spatial non-stationarity describes the variation of a statistical relationship estimated in different places. This is one of a quartet of inter-related issues affecting spatial analysis, together with spatial autocorrelation, the Modifiable Areal Unit Problem and the ecological fallacy. While the denominations of the latter two issues hint at the presence of a problem that needs to be fixed, the cases of spatial non-stationarity and autocorrelation pose different questions, as we may consider them as the object of study itself. In this chapter, we are concerned about the hypothesis of non-stationarity in the relationships between transport and the location of social groups, although as we will see below, some methods to analyse this question also address spatial autocorrelation. Spatial non-stationarity is especially relevant in relationships measured in large or heterogeneous regions. In the case of the processes leading to transport inequality, the relationships between the variables of concern depend for example on contextual factors that influence both the transport and land use policies applied at each place and the individuals' preferences and choices in the housing and transport markets. There are usually spatial variations on the parameters and on the performance of a given model in explaining relationships between transport and socio-economic variables. This detail can only be captured by models where parameters are allowed to vary with location. The research on transport inequalities has profited from recent developments on the methods for tackling this issue, including the formulation of models and the design of specific statistical software.

We can address spatial non-stationarity by estimating separate regressions on different partitions of the data, possibly related across more than one scale. For example, multilevel models estimate relationships at the level of individuals and places aggregated at different levels. These models have been used in the analysis of inequalities in accessibility [Kwan and Weber 2008, Shuttleworth and Gould 2010] and transport pollution [McLeod *et al.* 2000, Briggs *et al.* 2008]. They assume, however, that the processes analysed are discontinuous at the borders between areal units, a hypothesis that collides with the fact that most spatial processes are unbounded [Leung 1987]. An alternative is to assume that model parameters follow trends across space (spatial expansion models). This approach was used by Roorda *et al.* (2010) and Morency *et al.* (2011) to show that individuals in vulnerable groups (elderly and low-income groups) tend to make less trips and travel shorter distances, but that mobility limitations are found only in suburban areas. The hypothesis also seems to apply to measures of accessibility to specific destinations such as food shops [Páez *et al.* 2010]. Although this method is less rigid than estimations on data partitions, it still presupposes a pre-determined, explicit and regular structure for the variability of the processes modelled.

Geographically weighted regression (GWR) [Brunsdon *et al.* 1996, Fotheringham *et al.* 2002] is a solution to model the cases where we have no clear assumptions about the scale at which non-stationary processes operate or about the trends they follow over space. This method assumes that there is a continuous surface of regression parameters across the study. A separate regression is estimated at each place, using all data points weighted by a decreasing function of their distance to that place. The method is flexible in the definition of hypothesis about the type of variability, as it relies on user-defined options regarding the number of data points included in each regression and the specification of the weight function. GWR has been applied to show the non-stationary character of social differences in commuting times [Lloyd and Shuttleworth 2005] and in the health risks of pollution exposure [Gilbert and Chakraborty 2011]. Similar results were found for relationships that depend on processes similar to the location of transport infrastructure, such as the location of point sources of pollution [Mennis and Jordan 2005]. These studies tend to focus on very broad areas (such as countries or USA states). However, their hypotheses may also apply within an urban area. For example, Maroko *et al.* 2009 and Tooke *et al.* 2010 have found significant spatial variability in levels of accessibility to green space in an urban area, although the role of transport in assuring accessibility was not included in their analyses.

Our contribution to this debate is to study the spatial variability in transport inequalities in the case of a metropolitan area. Urban space is not usually perceived as isotropic and continuous and as such, the non-stationarity in statistical relationships is not necessarily linked to geographic location. In fact, the associations between the effects of transport and the social structure of each neighbourhood depend on the set of alternative places considered by households when searching for residences, and on the places considered by the policy-maker when deciding on the location of transport infrastructure[22]. The assumption implicit in the GWR method is that the degree to which a given place is an alternative for another place depends on the geographic locations of both. If weights are a decreasing function of distance, in practice, each local regression measures the relationships occurring in the areas around a given place. However, households and policy-makers usually consider a broad set of places located in different parts of the metropolitan area but having similar characteristics, for

[22] In the case of the distribution of job accessibility, it also depends on the set of alternatives considered by

example in terms of centrality or available transport options. The exploratory analysis in the previous chapter suggests that, in the case of the AML, the associations between socio-economic variables and indicators of accessibility and pedestrian mobility depend on the position of each area relative to the major centre (Lisbon) and on the location of transport corridors allowing commuting to that centre. The spatial variability of transport inequalities may then be relative not to distances in geographic space but to differences in attributes related to the functional role of each area, as these are the attributes limiting the options and shaping the perceptions of the actors behind the processes leading to the inequalities.

There remains the question, however, of which of the many attributes of a place define a type of variability in patterns of inequality that is important in terms of social justice. We argue that associations between socio-economic variables and accessibility or pedestrian mobility are politically relevant when they occur in subsets of the metropolitan region that correspond to individuals' judgements of the set of comparable areas in the distribution of the effects of urban transport. These areas correspond to what Dobson (1998, pt.3) calls "communities of justice", that is, the group of individuals one judge to be entitled to receive justice as part of public policy. This concept is especially relevant in the case of policies that affect different neighbourhoods in an urban area. Some authors suggest for example that public perceptions of equity in issues such as environmental policy are based on the individuals' delimitation of a community of justice that they believe is attached to each policy [Dietz and Atkinson 2005]. We assume that in urban contexts, this delimitation is less based on geographic proximity than on the perceived similarity between places.

In our analysis, we measure the spatial variability in regression parameters within the space defined by variables that describe the membership of each place in a certain community of justice. The higher the similarity between two enumeration districts in terms of these variables, the higher they are judged to be comparable and included in the same community of justice. While in the global model and in the GWR model, the comparison spaces for each place are respectively the metropolitan area and the area around each place, in our case, we consider different possibilities for the comparison spaces in the distribution of each particular effect of transport. We study the distribution of time to work and pedestrians' exposure to noise on the way to work and when walking around their neighbourhood. The alternative comparison spaces are defined by the variables listed in **Table 3.1**. The rationale for using

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businesses when locating their facilities.

these variables as a base to compare inter-neighbourhood differences in each effect is discussed at the beginning of the sections presenting the model results. For ease of interpretation, we organize the variables in four groups. Group A includes the measures of potential job accessibility obtained in Chapter 2. Variables in Group B are also indicators of centrality, but are more specific than the variables in Group A, measuring the position of each place in relation to the main centre of the metropolitan area. The variables in the other groups are indirect measures of the need for transport of the population in each place[23], including employment rate and structure (Group C) and daily destinations (Group D).

Table 3.1: Dissimilarity variables

Group	Variable	Description
A: Accessibility	*APriv*	Private transport job accessibility
	APub	Public transport job accessibility
B: Centrality	*TimLis*	Time to Lisbon on the private transport network
	DisLis	Distance to Lisbon on the private transport network
	GeoLis	Straight line distance to Lisbon
C: Employment	*Emp*	Employment rate
	Emp23	Employment in industry and services (% of population)
D: Commuting	*ComMot*	Commuting by motorized transport (% of population)
	ComInt	Commuting to other municipality (% of population)
	ComLis	Commuting to Lisbon (% of population)
	ComDis	Average commuting distance
	*ComLis**	Commuting to Lisbon (% of employed)

Note: Times and distances are relative to the point in Lisbon with the highest density of jobs (Saldanha/Picoas).

We should note some advantages of this formulation when comparing with alternatives. Spatial variability could be inferred, for example, by modelling regression parameters as functions of dissimilarity variables, using interaction terms or more complex formulations. However, this method imposes a rigid structure to the variability of the relationships. Besides being more flexible, regressions weighted in attribute space also correct for spatial autocorrelation. This issue tends to affect transport equity studies, as census variables and indicators of transport's effects usually assume similar values in nearby places, leading to biased and unreliable parameter estimates [Buzzelli and Jerrett 2004, Havard *et al.* 2009, Chakraborty 2009]. The use of GWR reduces this effect [Fotheringham *et al.* 2002, pt.5], but

[23] We assume that higher employment rates and higher proportions of employment in industry and services imply higher need for job accessibility. The proportion of commuters using motorized transport is an indicator of the need to access destinations that cannot be reached on foot.

in our case would introduce another distortion. Because geographically weighted regressions are estimated in the areas around each place, the variations in our indicators of time and noise exposure on the way to work would not take into account differences in the populations' daily destinations, as this variable is only available at a level higher than the enumeration district. This problem is partially solved in our model, as regressions include places located in different parts of the metropolitan area, thus accounting for variations in destinations.

Model formulation

The models presented in the next three sections explain the spatial distribution of three indicators of effects of urban transport (time to work and pedestrian exposure to noise on the way to work and when walking around the neighbourhood) as a function of the five socio-economic factors obtained in Chapter 2. We consider that in each year, the regression parameters vary in the space defined by one or two of the dissimilarity variables defined above[24]. The model is then formed by a set of local regressions, one for each enumeration district. In the regression for district i, y_i is the dependent variable, x_{ik} are the explanatory variables and b_0 and b_k are respectively the intercept and the regression parameters. These parameters are a function of S_i, the value(s) of the dissimilarity variable(s). The regressions are linear, as it was found in preliminary analysis that non-linear transformations of dependent or independent variables tend to produce poorer models. As the explanatory variables are factor scores, which are standardised and largely uncorrelated, multicollinearity is also not an issue. The specification of the error terms ε_i follows the assumptions of the standard linear regression models: independence and identical distribution of the residuals, which have zero mean and constant variance.

$$y_i = b_0(S_i) + \sum_k b_k(S_i) x_{i,k} + \varepsilon_i$$

The estimation of the regression for each district includes data for all districts weighted by a decreasing function of their dissimilarity with the first district[25]. In the case of a single dissimilarity variable, the dissimilarity is simply the difference in the values of that variable in

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[24] We analyse only pairs of variables that are not significantly correlated, thus providing two distinctive axes along which we can assess the character of each place.

[25] The vector of parameters for the regression at district *i* is estimated as $b=[X^T W(i) X]^{-1} X^T W(i) Y$, where W(i) is a diagonal matrix whose elements in the main diagonal give the weights assigned to each district in the data set. See Fotheringham *et al.* (2002, chap.2.7) for the derivation of this formula.

the two districts. For example, when the variable is private transport accessibility, the regression for a district includes all districts with the same level of accessibility. Districts with different accessibility levels are only partly included, weighted by the difference in accessibility between the two districts. Districts with very different accessibility levels will have a weight close to zero and are virtually excluded from the estimation. In the case of pairs of dissimilarity variables, we define the dissimilarity between two districts as the Euclidian distance in the bi-dimensional space formed by the standardized values of the two variables. The standardized values are obtained by ranking observations. We assume that weights decrease according to a Gaussian function. The weight of district j in the regression for district i is given by the function below, where d_{ij} is the dissimilarity between the two districts.

$$w_{ij}=exp[-(d_{ij}/b)^2]$$

This function depends on a positive parameter b called the bandwidth. The lower the bandwidth, the steeper is the decay of the weights with distance. This parameter can be assigned a-priori or estimated by minimizing indices of the models' goodness of fit. In our case, the value of the bandwidth is the one that minimizes the Akaike Information Criteria (AIC), an index that takes into account the estimated standard deviation of the error term and the number of degrees of freedom in the model (which depend on the value of the bandwidth). Details of this procedure can be found in Hurvich *et al.* (1998). The estimation used the GWR3 software developed at the University of Newcastle upon Tyne, which can be easily adapted to locations defined in non-geographical space while still using the Cartesian system.

In the analysis that follows, we explore the different types of information provided by these models. We analyse the explanatory power of the models (that is, the sets of local regressions) estimated using different dissimilarity variables, and compare them with the global model (which uses unweighted data) and with the GWR model (where weights are based on geographic distances). Each local regression within a model is independent of the others (since it uses a specific set of weights) and yields separate parameter estimates and regression diagnostics, including measures of goodness of fit. We study the trends of these estimates according to the values of the dissimilarity variable. For selected models, we study the statistical and spatial distribution of the estimates in more detail[26]. Finally, we test the hypothesis of the spatial variability of regression parameters, using Monte Carlo experiments.

[26] We analyse only the two models with the lowest index of spatial autocorrelation in the residuals. The distribution of parameters in other models is described by a series of charts and maps in Appendix 10.

3.2. Modelling time to work

Being calculated with observed commuting data, our indicator of average time to work can be understood as the time required for the workers living in a neighbourhood to reach the options chosen out of the available choice set of destinations and travel modes. One can argue that differences in time to work would be equitable if similar choice sets correspond to similar times, regardless of the actual destinations or travel modes chosen. The variables in Groups A and B in **Table 3.1** would then be the base to judge the distribution of times to work. The use of private transport accessibility or the position in relation with Lisbon corresponds to the view that times should not depend on differences in destinations, modal choices and the relative accessibility provided by public and private transport at each neighbourhood. The use of private and public transport accessibility as a bi-dimensional dissimilarity variable is analogous, but controls for differences in relative accessibility. A different point of view is that similar origins for the journey to work should have similar average times. This similarity can be assessed by the population's employment rate and structure (Group C). A third possibility is to consider that similar choices of destinations (Group D) should have similar times, regardless of the choice of travel mode.

This section compares the relationships between time to work and socio-economic factor scores using the alternative comparison spaces proposed above. The case of the percentage of workers commuting to other municipality is also combined with accessibility and with time to Lisbon, forming bi-dimensional comparison spaces (See note 24). We discuss the results obtained for the three most important socio-economic factors: Age (*F1*), Qualifications (*F2*) and Urbanization (*F3*). The results for the remaining two factors found in Chapter 2 (*F4* (Informal Settlements) and *F5* (Migration)) are not shown, as their parameters tend to be insignificant or show a low degree of variability in most of the models.

The results are synthesized in **Table 3.2**. For each year, each line in the table represents the model estimation based on one comparison space, which is formed by one or two dissimilarity variables. This estimation is composed of a set of regressions, centred at each enumeration district. The first two lines give the results of the global model[27] and of the GWR model. The goodness of fit of each model is given by the overall coefficient of determination (R^2). This is a modified version of the usual R^2, based on a comparison between the observed

[27] The results of the global model are detailed in Appendix 10.

values of the dependent variable and the prediction values coming from the different local regressions.[28] As mentioned in the last section, the local regressions in each model produce separate parameter estimates and coefficients of determination, which can be matched with the values of the dissimilarity variable at the district where the regression is centred. For each year, the second group of columns then gives the Pearson correlations of the dissimilarity variable with the regression R^2 and with the parameters of the three most important explanatory variables.

Table 3.2: Regressions of time to work: Goodness of fit and parameter summary

		1991					2001				
	Comparison space	**Overall R^2**	**Correlations with dissimilarity variable**				**Overall R^2**	**Correlations with dissimilarity variable**			
			R^2	F1	F2	F3		R^2	F1	F2	F3
	Global	0.16					0.18				
	GWR	0.65					0.54				
A	APriv	0.38	0.92	0.09	-0.76	-0.70	0.31	0.89	-0.41	-0.59	-0.05
	(APriv, APub)	0.45					0.36				
B	TimLis	0.42	-0.73	0.86	0.73	0.53	0.34	-0.71	0.43	0.53	0.03
	DisLis	0.46	-0.71	0.72	0.56	0.38	0.38	-0.62	0.47	0.47	0.20
	GeoLis	0.48	-0.61	0.80	0.63	0.28	0.39	-0.64	0.54	0.61	0.09
C	Emp	0.18	0.48	-0.47	-0.91	0.38	0.20	0.50	0.77	-0.91	-0.46
	Emp23	0.19	0.66	-0.62	-0.90	0.48	0.20	0.38	0.82	-0.87	-0.31
D	ComMot	0.33	0.88	-0.96	-0.98	0.83	0.22	0.03	0.85	-0.85	0.68
	ComInt	0.44	0.24	-0.29	-0.64	-0.67	0.32	-0.29	0.56	-0.69	0.18
	ComLis	0.46	0.80	-0.82	-0.95	0.30	0.33	0.89	-0.74	-0.93	0.49
	ComDis	0.37	-0.82	-0.78	0.27	0.92	0.31	-0.39	0.95	-0.56	0.35
	ComLis*	0.51	0.77	-0.50	-0.83	-0.18	0.39	0.83	-0.33	-0.61	0.19
	(APriv, ComInt)	0.63					0.44				
	(TimLis, ComInt)	0.62					0.43				

The ranking of the overall R^2 is similar in both years. All models show a better goodness of fit than the global model, which suggests that the relationships estimated by the latter cancel out the roles that socio-economic factors play in explaining time to work in different subsets of the metropolitan space. The GWR has the highest coefficient of determination of all models. This is because this model estimates regressions based on the areas around each district, where daily destinations do not vary due to data limitations, as explained in the

[28] The most accurate method to compare the goodness of fit of different models is the AKAIKE index, since it incorporates information on the number of degrees of freedom of the model. We show the R^2 because it has a more intuitive interpretation and because the ranking of the models in each year is identical for the two indices.

previous section (p.78-79). In these areas, differences in time to work depend solely on differences in modal choice, which are more directly influenced by socio-economic factors, comparing with the choice of destinations. The models presented in the two last lines, with comparison spaces formed by pairs of dissimilarity variables, have higher explanatory power than the models using the same variables in isolation. This is not accountable only by the difference in the number of degrees of freedom, as the models using pairs of variables also have a better AKAIKE index (not shown). In general, models for comparison spaces based on the geographic or functional relationship of the neighbourhoods with Lisbon tend to have a better fit than other models.

When looking at the trends of the local R^2 across the values of the dissimilarity variable in each model, we see that regressions tend to fit better as we move towards Lisbon, more accessible locations and areas with higher proportions of commuters to Lisbon. In most cases, this occurs alongside an increasing negative influence of age and qualifications. These trends do not account, however, for the fluctuations of the parameters in different intervals of the dissimilarity variable. In this and the next sections, we select two cases to analyse in more detail. In this section, we focus on the comparison spaces based on potential accessibility and on proportion of people commuting to another municipality. **Figure 3.1** and **Figure 3.2** plot the regression coefficients against the values of these variables.

The regression parameter of the qualifications factor (*F2*) is negative for most values of private transport potential accessibility **[Figure 3.1]**. In other words, when comparing with other areas with similar potential accessibility, the populations in areas with higher qualifications tend to have shorter times to work. The effect is especially relevant in the third quartile of the distribution of accessibility. This interval corresponds to the areas that do not have the highest concentrations of employment but are the most accessible to these. As we move from these areas to the employment centres themselves or to less accessibility areas, the negative influence of qualification becomes less marked. However, the increase in the qualifications parameter as we move towards less accessible areas has became less steep from 1991 to 2001. This suggests that the advantages of more qualified populations in average time to work have extended to less central parts of the metropolitan area. In particular, the relationship occurring in the most peripheral areas between higher qualification levels and longer times to work in 1991 changed sign in 2001. The fluctuations of the age and urbanization parameters have also reduced considerably in the period of concern. In 2001, the influence of these factors on time to work was negative and relatively stable across the metropolitan area.

We find a similar evolution in the case of the models comparing areas with similar commuting patterns, assessed by the proportion of people commuting to another municipality **[Figure 3.2]**. The relationships for all variables are more stable in 2001 than in 1991 and the negative influence of qualification has increased for almost all levels of inter-municipal commuting. In both years, longer times to work tend to be associated with younger populations, lower qualification levels and less urbanized areas. The only interval where the associations do not follow the general trends of each parameter is the second quartile of inter-municipal commuting, where in 1991 the age parameter is positive and the negative association of time to work with qualifications is considerably lower than in other areas. This exception does not occur in 2001. There was also a change in the variation of the age parameter in the set of areas with higher inter-municipal commuting (two last quartiles), with the parameter increasing with commuting in 2001.

A word should be said regarding the magnitude of the parameters. As the explanatory variables are standardized factor scores, the value of -2.5 obtained for the qualifications parameter in the areas with highest percentages of inter-municipality commuting **[Figure 3.2]** means that the expected average time to work increases 2.5 minutes for every standard deviation from the average qualification levels in the metropolitan area. Given that times to work refer to one-way trips and that there is an average of 90 workers per district in those areas, workers in a district with qualifications one deviation below average spend an aggregate daily excess of 15 hours travelling, comparing with workers in a district with qualifications one deviation above average and similar rates of inter-municipal commuting.

Figure 3.1: Regressions of time to work in (*APriv)* space

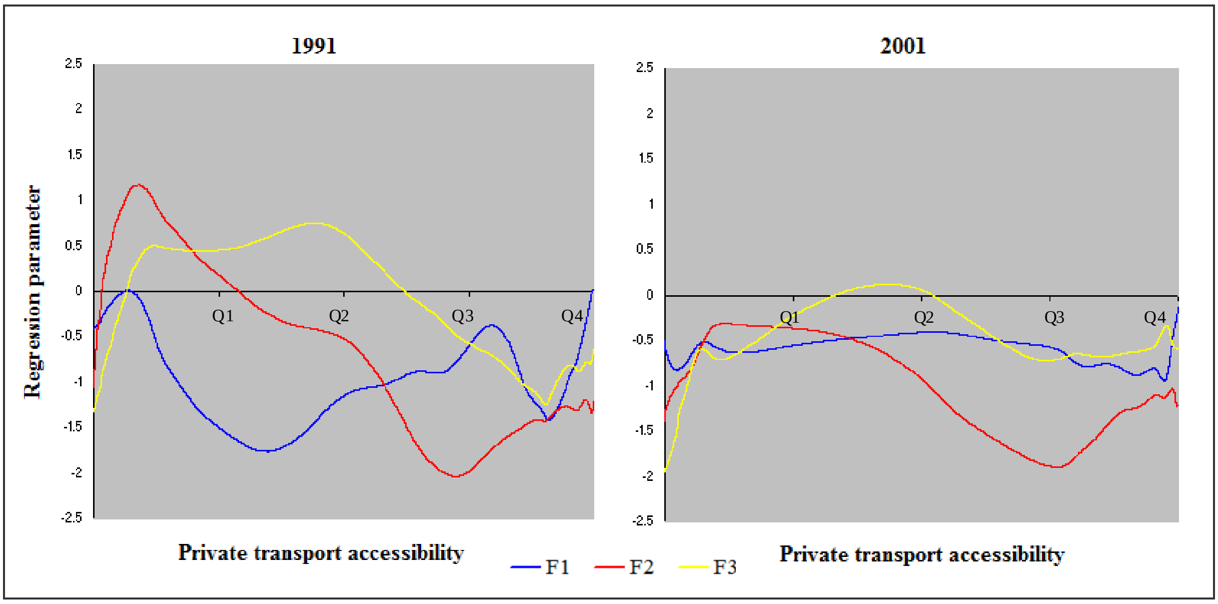
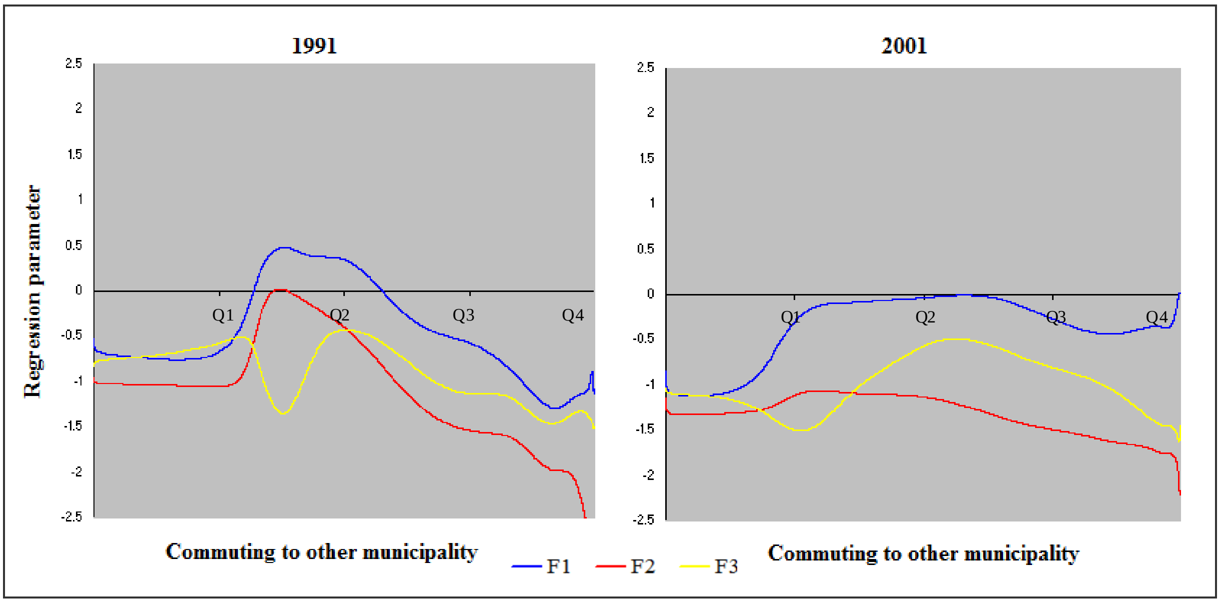


Figure 3.2: Regressions of time to work in (*ComInt)* space



Another way to assess the role of accessibility and inter-municipal commuting in the variability of relationships between time to work and socio-economic factors is to map the spatial distribution of the parameters of the local regressions in the model estimated in the bi-dimensional comparison space formed by those two variables. **Map 3.1** shows the distribution of the *F2* parameter for this model. The highest negative values for this parameter occur in the first suburban ring around Lisbon, which correspond roughly to the third quartile of accessibility and to the last quartile of inter-municipal commuting in **Figure 3.1** and **Figure 3.2** respectively. However, the negative influence of qualification levels has extended towards the areas around that ring from 1991 to 2001. In addition, there was a decrease of the parameter in some of the most peripheral regions in the metropolitan area, including the Northwest (Mafra) municipality and the outer municipalities in the South Bank. There are areas in the lowest quartile of accessibility but where commuting to Lisbon has increased considerably in the period concerned. The two most important geographic foci of transport disadvantage in 2001 are therefore the areas surrounding Lisbon and some of the peripheral areas[29]. The differences in the policy implications of these two cases are discussed later in this chapter.

The statistical distribution of the parameter estimates of this model is presented in **Figure 3.3**, which shows box plots of the four quartiles of the estimates' distribution. The results for *F4* and *F5* are also included for reference purposes. All parameters have lower variability in 2001, especially the qualifications (*F2*) and the urbanization (*F3*) parameters. Only a small minority of districts show positive values for the *F2* and *F3* estimates in 2001. We can also see the decreased variability of coefficients when comparing in each year the standard error of the coefficients estimated in all local regressions (s_{loc}) with the standard error of the coefficients in the global regression model (s_{glo}). Although the theoretical statistical distribution of s_{loc} is an unknown, the hypothesis of non-stationarity of the local coefficients can be formally tested using simulation techniques such as the Monte Carlo test. In the case of locally weighted regressions, a possible test is to compare the position of the observed s_{loc} in a rank list of values obtained re-estimating the model with a large number of different random rearrangements of data in space [Brunsdon *et al.* 1996]. The *p* values listed in the table are the resulting probabilities of obtaining the observed s_{loc} given the null hypothesis that the process is stationary. In this case, these probabilities tend to zero, suggesting that the parameter variability obtained by the model is the result of a non-stationary process.

[29] The interpretation of this map should take into consideration that areas with similar estimates have so because they are similar in terms of accessibility or inter-municipal commuting and as such have similar comparison spaces. However, models estimated in locations with different comparison spaces may yield the same estimate. The reader is directed to the indicator maps in Appendix 9 to identify the areas that were directly compared.

Map 3.1: Regressions of time to work in (*APriv*, *ComInt*) space: F2 parameter

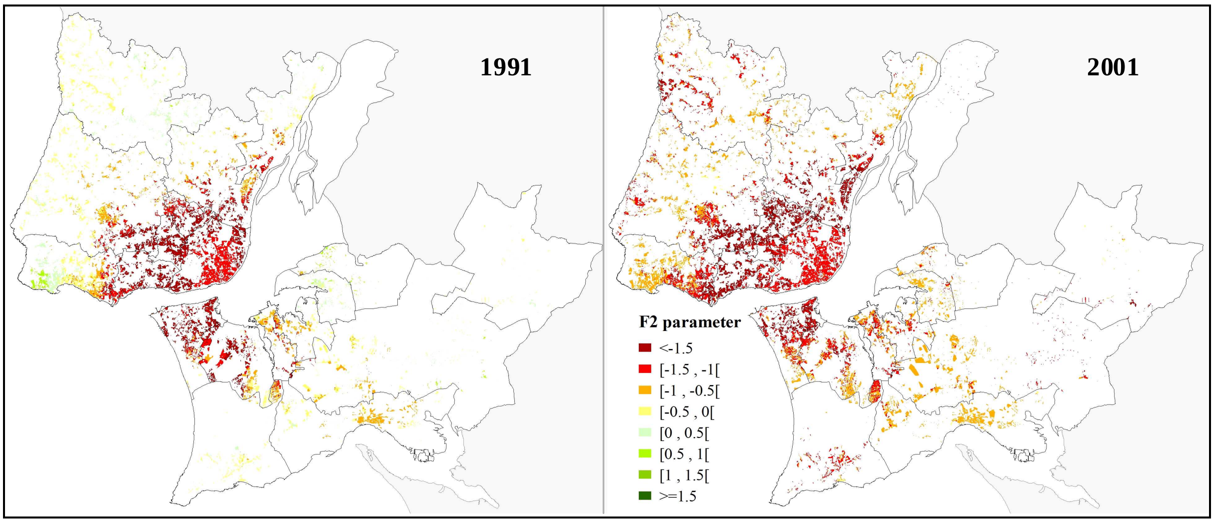
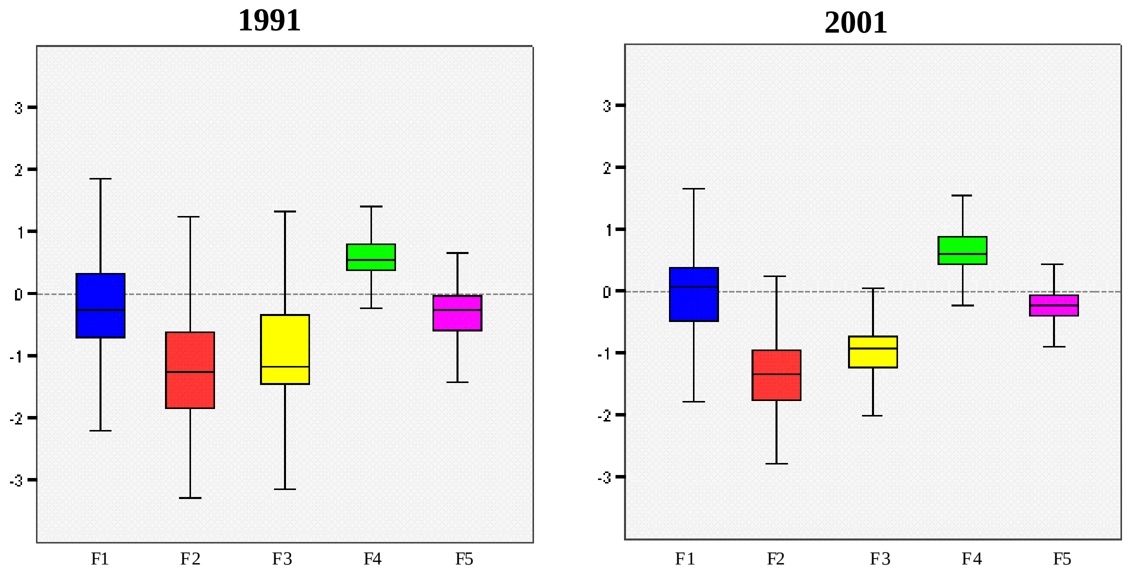


Figure 3.3: Box plots of regressions of time to work in (*APriv*, *ComInt*) space



	1991 F1	1991 F2	1991 F3	1991 F4	1991 F5	2001 F1	2001 F2	2001 F3	2001 F4	2001 F5
S_{loc}	1.98	0.85	1.06	0.68	0.53	1.38	0.51	0.52	0.61	0.30
S_{glo}	0.04	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.02
p	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

In general, the three main socio-economic factors show the expected signs for all comparison spaces and in almost all the local models estimated in each space, with higher times to work being associated with younger, less-qualified populations and less urbanized areas. These results confirm the exploratory analysis of the previous chapter, but include level of information that was previously absent, which is the geographic delimitation of the areas where the effect of qualification is more discernible in both years. The most important point to retain is the fact that the patterns of disadvantage for less qualified populations have shown a tendency to extend to further areas, where the advantage of the older populations has also decreased. This may be related to the construction of new transport infrastructure and to the urbanization of some semi-rural areas, which allowed for a widening of the commuting possibilities in these areas. The higher proportion of commuters to other municipalities amplifies the differences in time to work that are due to different levels of car usage, comparing with the original case when most workers travel to nearby destinations. The changes in the regression parameters in these areas will then reflect changes in daily destinations and the fact that less-qualified and older populations have lower rates of car usage.

3.3. Modelling pedestrian exposure to noise on the way to work

Exposure to noise is one of the costs of the journey to work, together with other factors such as time, monetary expenditures and accident risk. We can then apply to the spatial differences in noise exposures the same comparison spaces that we used for the case of time to work. Similar choice sets (as measured by potential accessibility or position in relation with Lisbon), similar origins (in terms of employment) or similar choices (of destinations) should then be associated with similar noise exposures. However, to the list of dissimilarity variables in **Table 3.1**, we also add in this case the values of time to work (*Tim*). This corresponds to the view that the environmental cost of the journey to work is comparable only across areas sharing similar time costs, or more generally, that the judgement of the equity in the distribution of environmental costs is conditional on the distribution of times to work.

Table 3.3 shows the results of the models relating noise on the way to work to socio-economic factors. The ranking of the models according to the overall coefficient of determination is similar to the ranking of models for time to work studied in the last section. All locally weighted models have a better fit than the global model. The GWR and the bi-dimensional comparison spaces have the highest coefficient of determination, while the model where time to work itself defines the comparison space for noise exposures is one of the models with less explanatory power. Unlike the previous section, models based on the variables in Group A (potential accessibility) tend to be have higher goodness of fit than variables in Group B (position relative to Lisbon).

The distribution of the goodness of fit of the local regressions in each model also follows similar trends to the ones found in the last section, with the correlations between the local R^2 and the dissimilarity variables having the same sign as in the case of time to work. However, these correlations are generally lower in 1991 and higher in 2001, comparing with the previous case. In both years, the local regression parameters show a clearer relationship with the values of the dissimilarity variables. In fact, in some cases, the values of the parameter estimates follow an almost linear trend, with correlations close to one in absolute value. In almost all models, the values of the three parameters decrease as we move towards areas that are more accessible, closer to Lisbon and where commuting is more relevant. The trends of the age parameter, however, become less noticeable in 2001.

Table 3.3: Regressions of noise on the way to work: Goodness of fit and parameter summary

	Comparison space	1991					2001				
		Overall R^2	Correlations with dissimilarity variable				Overall R^2	Correlations with dissimilarity variable			
			R^2	F1	F2	F3		R^2	F1	F2	F3
	Global	0.09					0.20				
	GWR	0.53					0.55				
A	APriv	0.37	0.84	-0.72	-0.90	-0.94	0.49	0.93	-0.40	-0.90	-0.84
A	(APriv, APub)	0.42					0.52				
B	TimLis	0.40	-0.65	0.80	0.94	0.78	0.48	-0.93	0.48	0.94	0.70
B	DisLis	0.36	-0.66	0.54	0.93	0.76	0.47	-0.90	0.37	0.93	0.78
B	GeoLis	0.35	-0.55	0.72	0.91	0.77	0.44	-0.76	0.56	0.93	0.74
C	Emp	0.10	0.41	-0.66	-0.81	-0.62	0.23	0.10	0.81	-0.92	-0.72
C	Emp23	0.15	0.11	-0.81	-0.88	-0.45	0.23	0.37	0.37	-0.95	-0.63
D	ComMot	0.19	0.78	-0.78	-0.92	-0.47	0.23	0.20	0.05	-0.95	-0.76
D	ComInt	0.15	0.80	0.59	-0.95	-0.94	0.31	0.38	0.16	-0.94	-0.92
D	ComLis	0.36	0.87	-0.94	-0.94	-0.95	0.45	0.98	0.27	-0.88	-0.87
D	ComDis	0.16	0.90	-0.71	-0.20	0.66	0.35	-0.15	-0.07	0.24	-0.77
D	ComLis*	0.41	0.74	-0.54	-0.82	-0.91	0.50	0.93	-0.24	-0.81	-0.79
	(APriv, ComInt)	0.45					0.53				
	(TimLis, ComInt)	0.46					0.51				
	Tim	0.19	-0.76	-0.85	-0.44	-0.37	0.28	-0.94	-0.98	-0.65	-0.06

Figure 3.4 presents the distribution of the parameter estimates for different times to Lisbon. The quasi-linear overall trend pointed above becomes unstable only in the areas at longest times from Lisbon. There was also a shift on the curve of the qualifications parameters towards lower values and a flattening of the age and urbanization curves from 1991 to 2001. The qualifications parameter is always negative, while the age and urbanization parameters are negative only in the first quartile of distribution of time to Lisbon. This interval corresponds roughly to the city of Lisbon itself. This exception to the general pattern suggests the specificity of social differences in residence location and commuting in Lisbon. Unlike other municipalities, elderly populations and individuals living in areas with lower levels of urbanization tend to have higher average exposures to noise on the way to work. However, these associations are less marked in 2001 and, in the case of the age parameter, have changed sign in the areas at the shortest distances (that is, the areas around the major centre in Lisbon).

Figure 3.5 shows the patterns obtained when the dissimilarity variable is the proportion of inter-municipality commuting. We should note that this variable is not correlated with times to Lisbon, as areas with low inter-municipality commuting include both Lisbon and peripheral regions. There are also significant inter-municipal commuting flows with destinations other than Lisbon, such as flows from less to more urban municipalities in the South Bank. The figure shows that the qualifications parameter is always negative and follows a decreasing and quasi-linear trend with inter-municipal commuting. The age parameter is always positive, unlike the model using time to Lisbon as dissimilarity variable, where it was negative in some intervals of this variable. There was also a decrease in the variability of this parameter from 1991 to 2001. The urbanization parameter is only negative in a small interval of values in both years, but unlike the case in the previous figure, this interval does not correspond to Lisbon, but to the areas with highest inter-municipal commuting.

Figure 3.4: Regressions of noise on the way to work in (*TimLis*) space

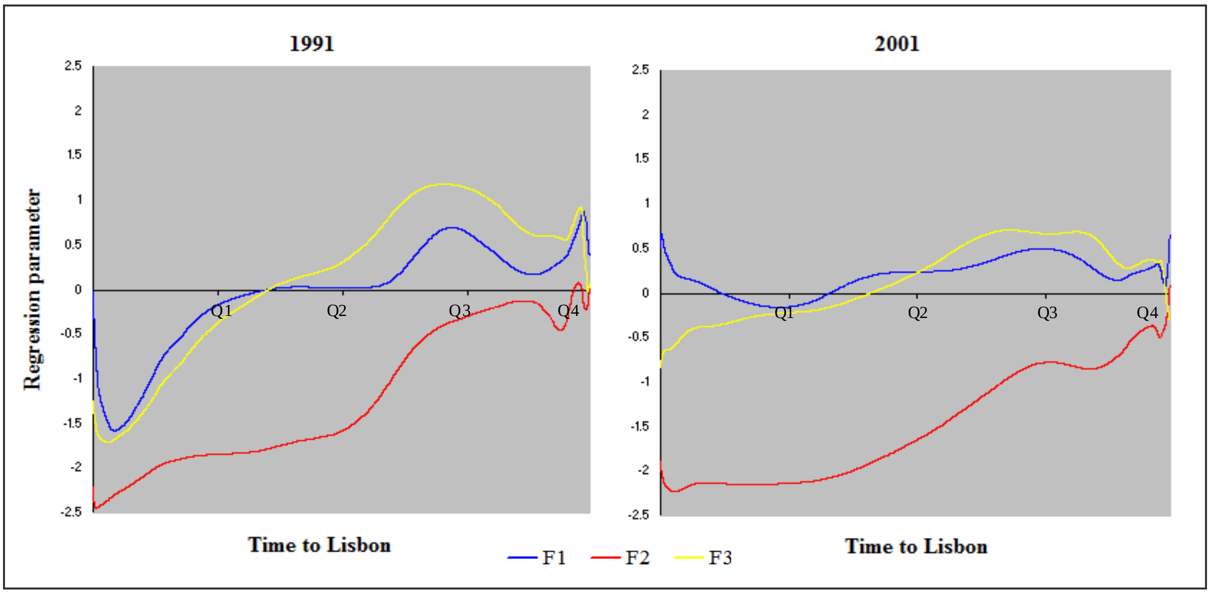
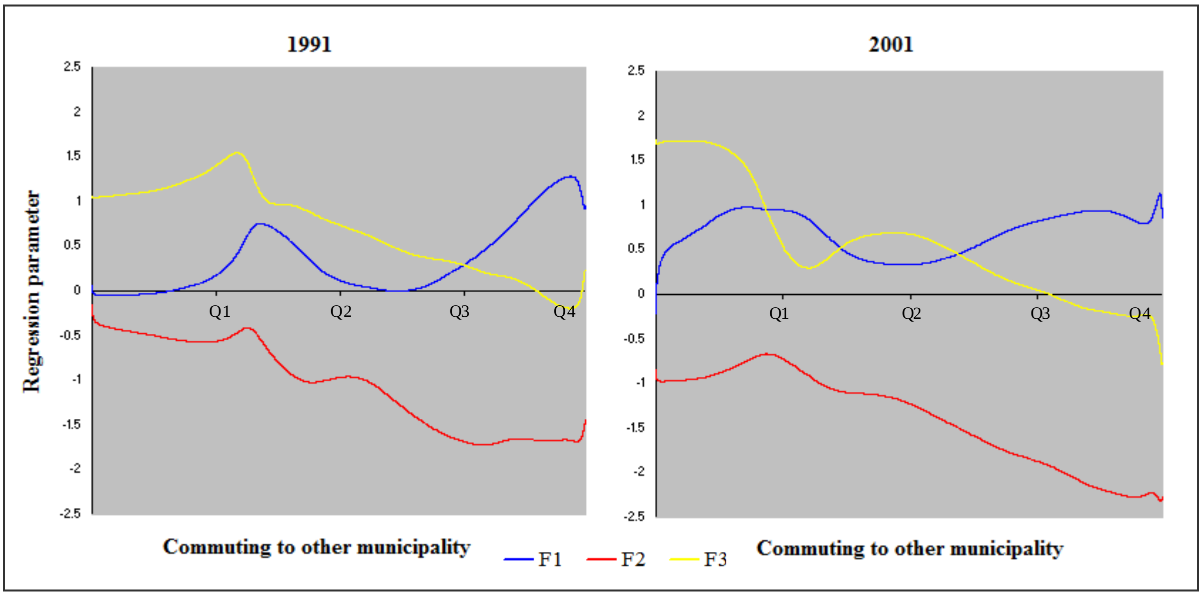


Figure 3.5: Regressions of noise on the way to work in *(ComInt)* space



Map 3.2 shows the spatial distribution of the qualifications parameter for the model using the bi-dimensional comparison space formed by times to Lisbon and inter-municipal commuting. The most striking difference in relation with the case of the previous section is that inequalities are as visible in the suburban areas around Lisbon as in the city of Lisbon itself. As in the case of times to work, there was also a geographical extension of the influence of the qualifications in noise exposures. However, the increase in the influence of qualifications in the outer areas in the Northwest and in the east municipalities in the South Bank is not as marked as in the previous case. These are the regions with the lowest noise exposures in the metropolitan area (See p.269). Some of the most isolated districts in these regions have a positive regression parameter in both years, although the number of these districts has decreased considerably from 1991 to 2001.

The statistical distribution of the parameters obtained for this model **[Figure 3.6]** reveals that all parameters are less variable in 2001, although in the case of the qualifications parameter, they still have a high level of variability. However, the range of positive values for this parameter has reduced considerable. It is also visible that the age parameter is only negative in a minority of districts in 2001. Although the parameter for urbanization levels were seen in **Figure 3.5** to be positive for most values of inter-municipality commuting, the box plot of the parameter estimates suggests that its distribution is centred on zero, when inter-municipality commuting is combined with times to Lisbon. Except for the case of *F4* and *F5* parameters, all parameters are significantly non-stationary, as shown by the *p* values of the Monte Carlo simulation test.

Map 3.2: Regressions of noise on the way to work in *(TimLis, ComInt)* space: F2 parameter

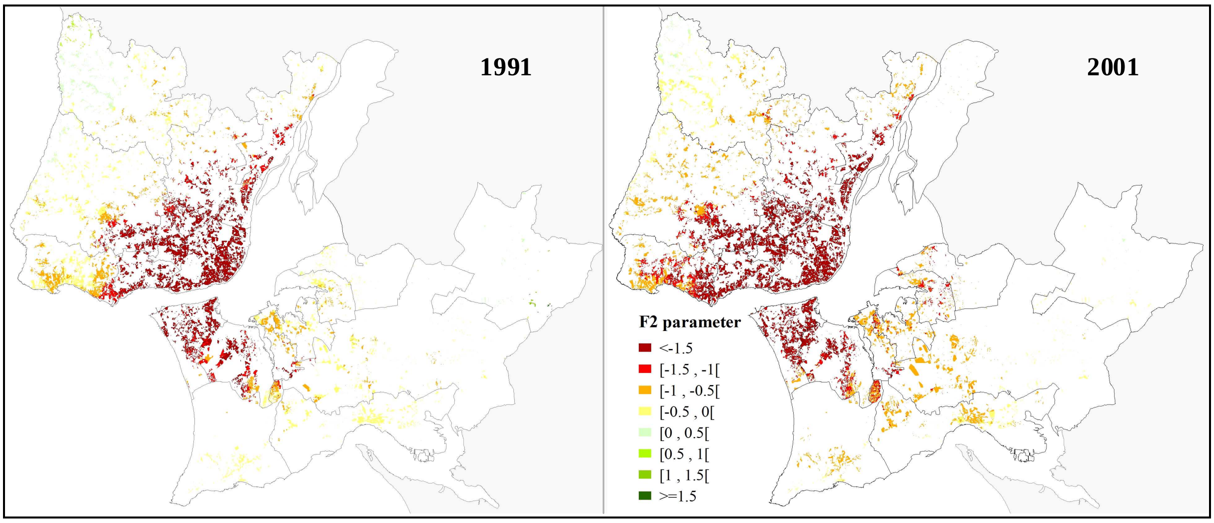
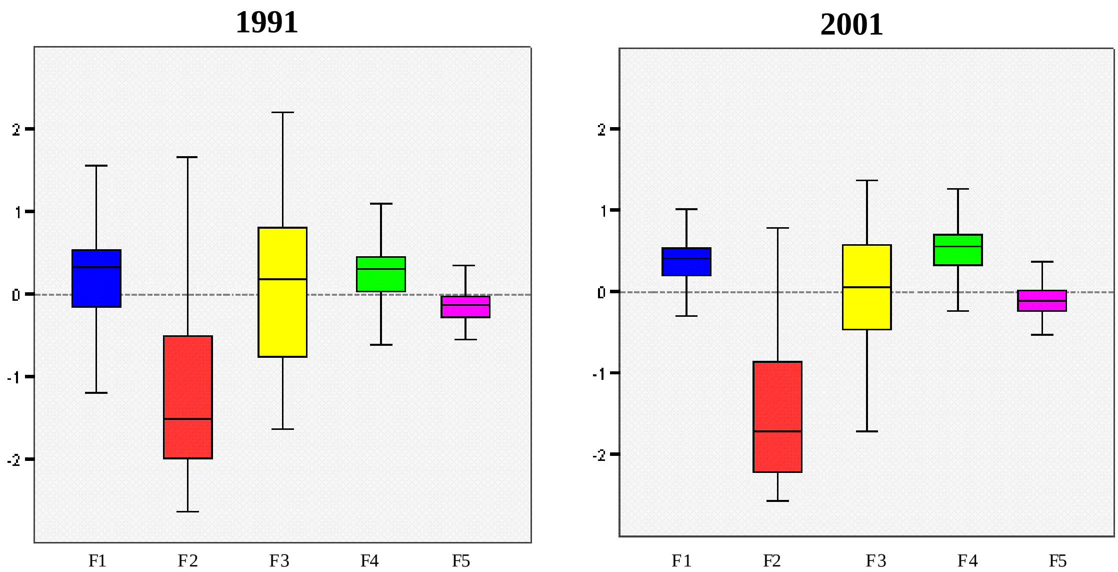


Figure 3.6: Box plots of regressions of noise on the way to work in *(TimLis, ComInt)* space



S_{loc}	0.74	0.91	1.56	0.40	0.28	0.45	0.82	1.26	0.33	0.25
S_{glo}	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.02
p	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00

The results of this section show that differences in qualification levels tend to explain differences in noise exposures to a greater degree than age or urbanization. In general, higher qualifications are associated with lower exposures, especially in areas closer to Lisbon and with higher needs for commuting. The disadvantage for low qualified populations is more regular in space in 2001, extending to neighbourhoods that are more distant to Lisbon. Older populations and populations in more urbanized areas also tend to be at disadvantage, with the extent of this disadvantage also showing a tendency to stabilize across space. As in the case of time to work, these changes may be related to the effects of the investment in road infrastructure and urbanization in regions relatively distant to Lisbon. This has lead to an approximation between the commuting potential of those regions and of the inner suburbs. The social differences in daily destinations and travel modes of the populations in the different neighbourhood in the outer suburbs may then replicate the differences existing in the inner suburbs. As we are assuming that exposures depend on noise levels at daily destinations and on the travel mode used to reach them, the inequalities in noise exposures in the two regions will then tend to converge.

3.4. Modelling pedestrian exposure to noise around the neighbourhood

The definition and interpretation of comparison spaces for the assessment of differences in exposure levels of pedestrians walking around the neighbourhood is different from the cases of times and noise exposures on the way to work. This is because the indicator of noise exposure around the neighbourhood does not depend on commuting choices, namely the choices regarding daily destinations and travel modes. The employment structure and the variables in Group D of **Table 3.1** are therefore not relevant in the definition of comparison spaces.

One possible view is to consider that there is a universal right to local environmental quality. The comparison space for judging the equity of the distribution of noise exposures would then be the whole metropolitan area. A more pragmatic view is to allow for trade-offs between the right for environmental quality and the efficiency and equity in the distribution of other goods and “bads” associated with urban transport. One can argue that noise levels should be equalized across the set of areas that allow for the same overall levels of accessibility for the populations in the metropolitan area and in the rest of the country. For example, areas with the same level of potential accessibility, at the same time or distance to Lisbon or with lower times to work, have in theory an equal probability of being crossed by transport infrastructure providing access to the main centres of employment. This is therefore the rationale used when we consider the variables in groups A and B of **Table 3.1** and time to work as dissimilarity variables judging inequalities in the distribution of noise exposures of pedestrians walking around their neighbourhoods. The employment rate (Group C) is relevant because it measures differences in the need for walking of the population in each neighbourhood. The higher the proportion of individuals not employed, the higher the probability that they walk to places around their home during the day.

Table 3.4 gives the results of the models of noise exposures around the neighbourhood, using alternative comparison spaces. As in the previous sections, all the models weighted in attribute space have better goodness of fit than the global model, but lower than the model weighted in geographic space (GWR). It should be noticed that unlike the previous cases, the performance of the GWR is not due to distortions caused by data limitations, as all the variables used to build the indicator of pedestrian exposures to noise around the neighbourhood vary at the enumeration district level. The models using the employment rate and times to work as dissimilarity variables have the least explanatory power of all models apart from the global model.

The trends in the local coefficients of determination and parameter estimates are less obvious than in the previous sections. The regressions fit better as we move towards more accessible areas and areas with lower times to work. In the first case, this occurs alongside an increasing negative influence of the age and urbanization parameters. In the second case, the improvement of the model fit occurs alongside an increasing influence of the qualifications parameter. The trends in the model parameters for comparison spaces based on times and distances to Lisbon have the same nature (but are less noticeable) as the trends in the model that uses accessibility, with the age and urbanization parameters being lower in the places closer to Lisbon

Table 3.4: Regressions of noise around the neighbourhood: Goodness of fit and parameter summary

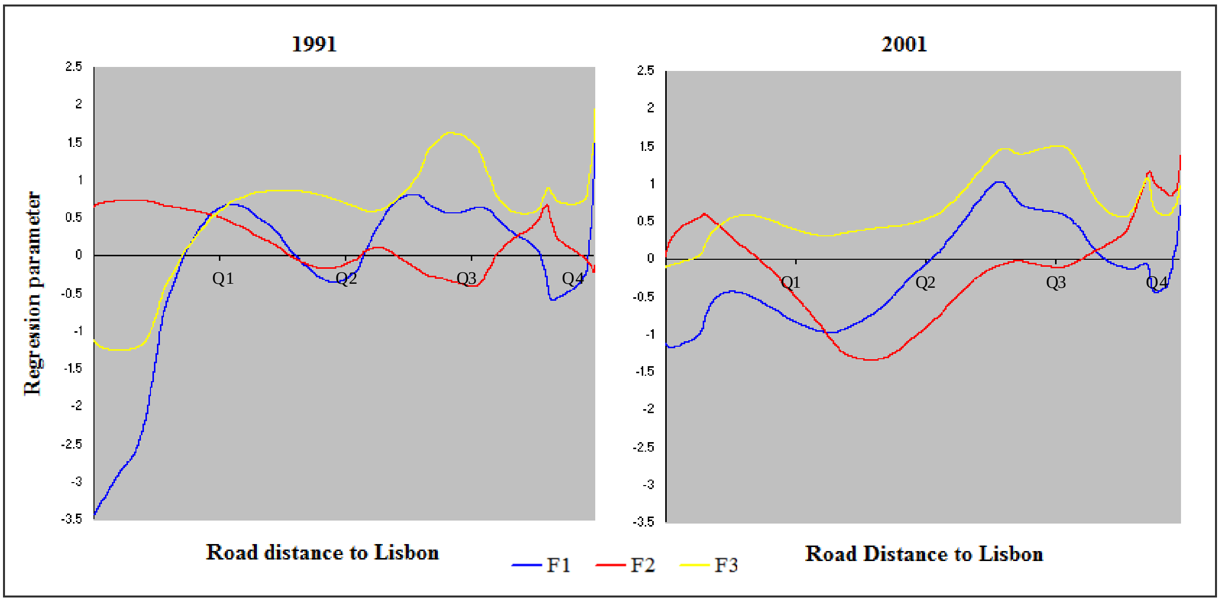
	Comparison space	**1991**					**2001**				
		Overall R^2	**Correlations with dissimilarity variable**				**Overall R^2**	**Correlations with dissimilarity variable**			
			R^2	F1	F2	F3		R^2	F1	F2	F3
	Global	0.05					0.08				
	GWR	0.51					0.54				
A	APriv	0.26	0.52	-0.75	-0.14	-0.92	0.41	0.48	-0.80	-0.23	-0.74
	TimLis	0.29	-0.24	0.75	0.24	0.74	0.36	-0.40	0.75	0.45	0.69
B	DisLis	0.25	-0.18	0.44	-0.30	0.61	0.33	0.02	0.61	0.43	0.60
	GeoLis	0.24	-0.09	0.62	-0.30	0.72	0.27	0.14	0.70	0.37	0.65
C	Emp	0.06	0.21	-0.59	-0.55	0.67	0.09	0.27	-0.55	-0.27	0.16
	Tim	0.09	-0.89	-0.10	-0.86	-0.07	0.13	-0.51	-0.92	-0.93	0.22

The irregularity in the spatial patterns followed by the regression parameters is especially visible in the case of the comparison space defined by the road distance to Lisbon **[Figure 3.7]**. In fact, noise exposures are negatively associated with age both in the closest and in the most distant areas to Lisbon. The association in the regions close to Lisbon has extended geographically from 1991 to 2001, but has reduced considerably in the areas where it was already present in 1991. In these areas, the urbanization parameter has also become positive. The location of the associations with the age parameter can be seen in **Map 3.3**. The borders of the areas with the highest negative values in 1991 corresponded almost exactly to the Lisbon municipal borders. The associations decreased in the residential areas around the centre, which in 2001 have similar estimates as the suburban areas around, where the parameter changed from positive to negative.

There are also important changes in the spatial patterns of distribution of noise exposures according to qualification levels. **[Figure 3.7, Map 3.4]**. The range of the F2 parameter in 1991 is small and there are no intervals in the dissimilarity variable where disadvantage is especially evident, either for the more or less qualified populations. This is not the case in 2001, where the second quartile of distribution of road distances to Lisbon defines a negative peak for the parameter estimates. The map shows that this interval corresponds to the hinterlands of the suburban municipalities surrounding Lisbon, both in the North and the South Banks. These are the areas where the motorway network has expanded the most during the period concerned (See **Map 1.2** in Chapter 1).

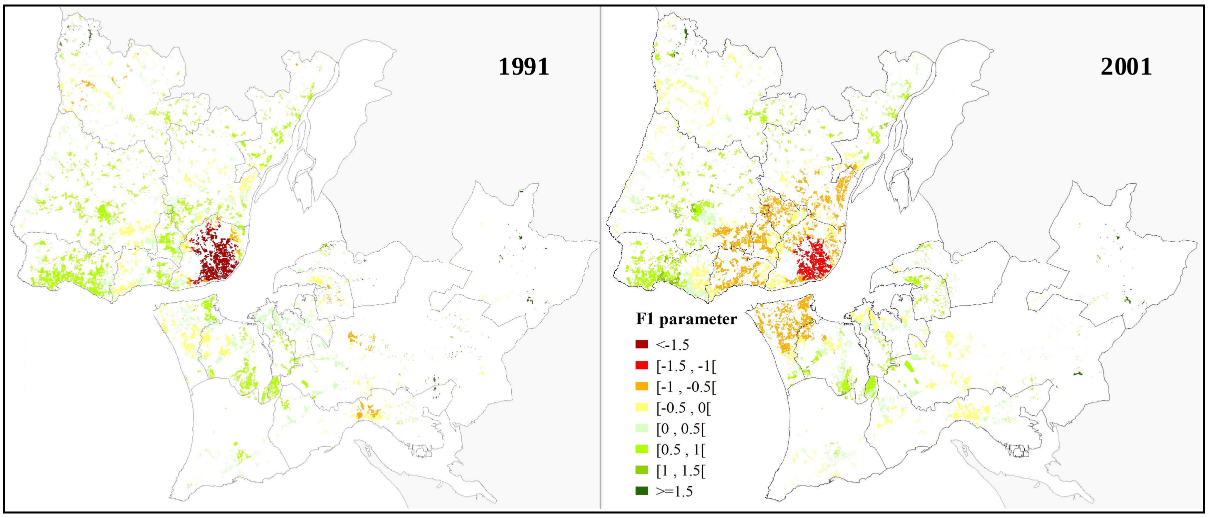
The box plots of the statistical distribution of the five parameters **[Figure 3.8]** show that although the mean value of the qualifications parameter is close to zero in both years, from 1991 and 2001 its distribution became more dispersed and skewed, while the distribution of the age parameter became less dispersed and more skewed. The urbanization parameter is positive in almost all cases[30]. The Monte Carlo simulation results prove the significance of the non-stationarity hypothesis for the three main factors.

Figure 3.7: Regressions of noise around the neighbourhood in (*DisLis*) space



[30] The few negative values obtained in 1991 are classified as "extreme values" and not shown in the box plot.

Map 3.3: Regressions of noise around the neighbourhood in *(DisLis)* space: F1 parameter



Map 3.4: Regressions of noise around the neighbourhood in (*DisLis*) space: F2 parameters

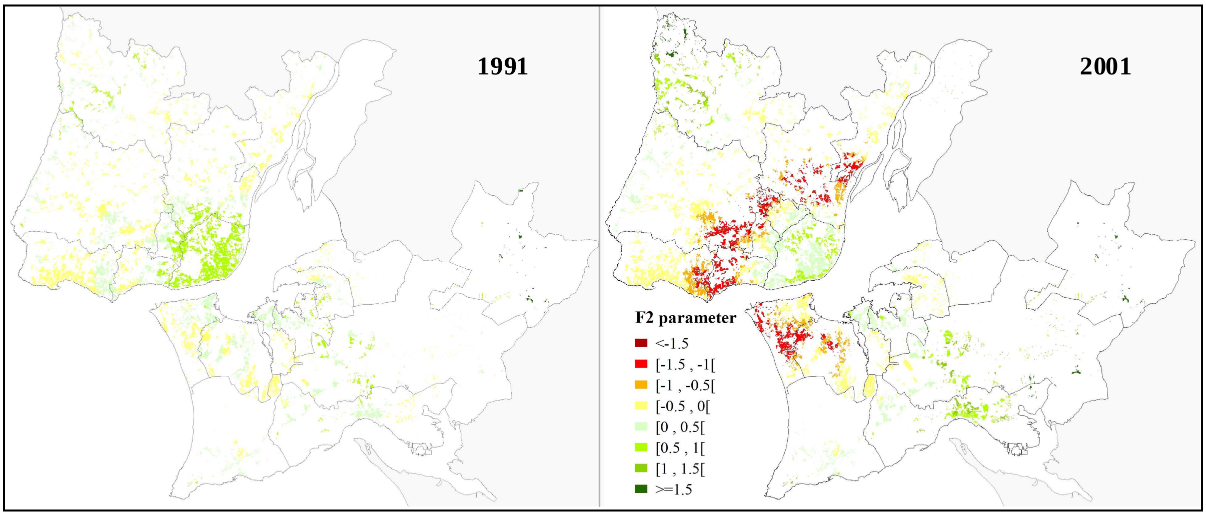
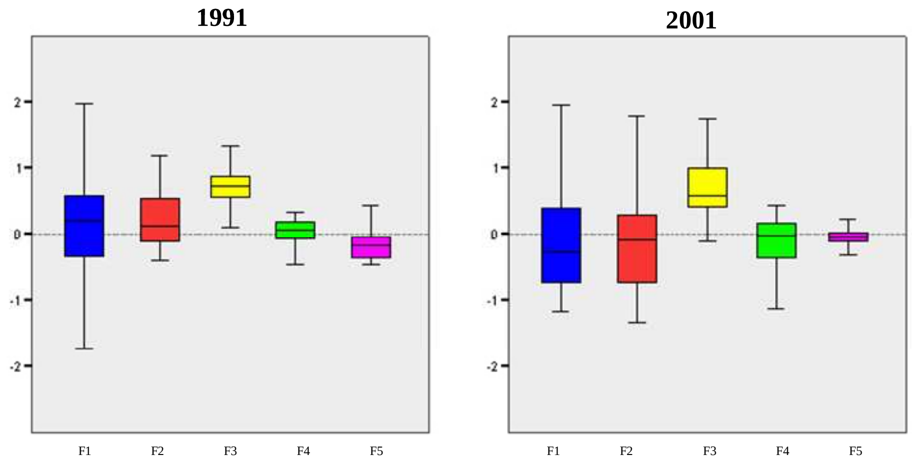


Figure 3.8: Box plots of regressions of noise around the neighbourhood in (*DisLis*) space

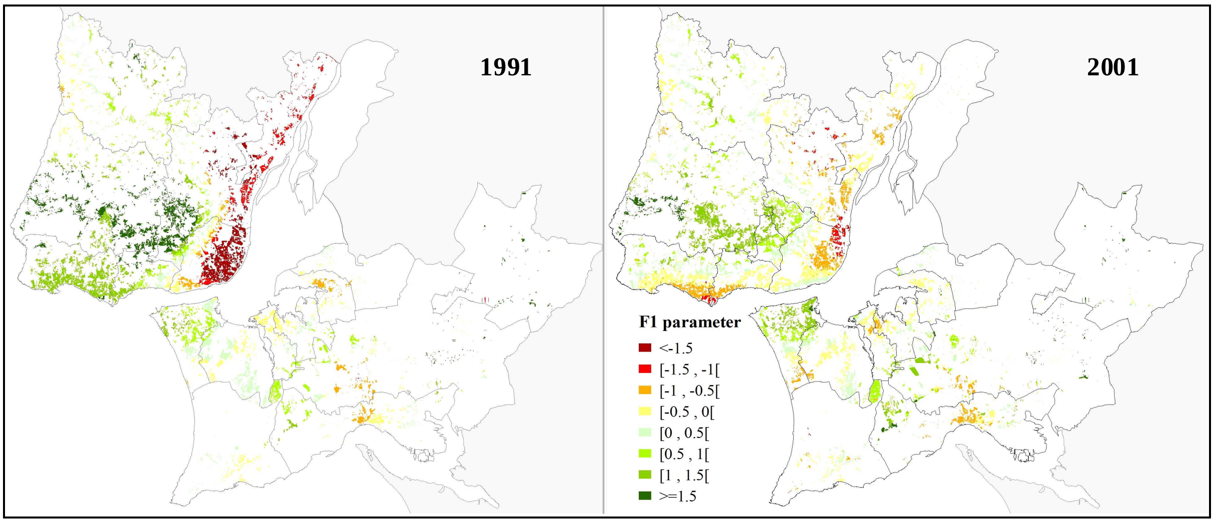


	1991 F1	1991 F2	1991 F3	1991 F4	1991 F5	2001 F1	2001 F2	2001 F3	2001 F4	2001 F5
s_{loc}	1.09	0.66	1.47	0.28	0.17	0.88	0.92	1.59	0.42	0.14
S_{glo}	0.06	0.06	0.07	0.05	0.05	0.05	0.05	0.05	0.06	0.04
p	0.00	0.00	0.00	0.06	0.28	0.00	0.00	0.00	0.00	0.15

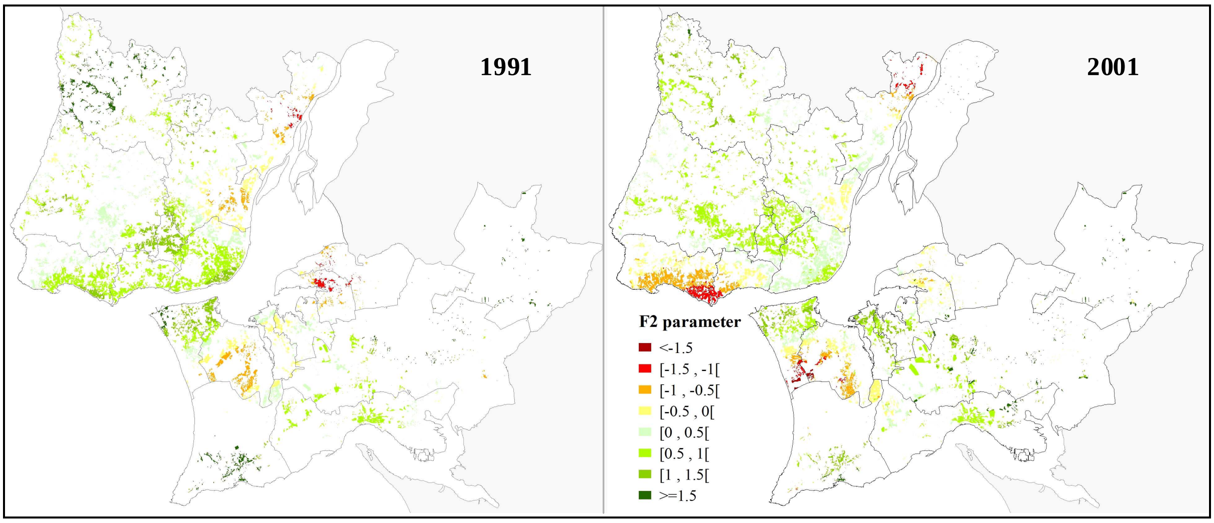
It is interesting to compare the results above with the ones obtained with the GWR estimation, where regressions in each district weight other districts based on geographic distance. **Map 3.5** shows the distribution of the age parameter for this model. As in the previous case, the highest parameter estimates in 1991 are located in the Lisbon municipality. However, in the present case there is also a clear opposition between the negative estimates found in the Northeast corridor and the positive estimates found in the Northwest and West corridors. This means that although the regressions in the GWR estimation are, in practice, based on areas around each district, the estimates tend to follow patterns that correspond to the main corridors of access to Lisbon. Similar patterns occur in 2001, although the differences between corridors become less marked, as the estimates decreased in absolute values in most districts in the metropolitan area. The relationships in Lisbon also became more localised around the east part of the city, a result that is different from the previous model, where relationships in 2001 were stronger in the central part [**Map 3.4]**. In addition, the changes in the signs of the parameters in some regions (West corridor and South bank) are the opposite from the changes shown in the previous model.

The comparison between **Map 3.6** and **Map 3.4** shows that there are also differences in the qualification parameter estimates in the two models. In 1991, the GWR model follows similar patterns as the model using distances to Lisbon but the absolute value of the parameters tends to be higher. In addition, the changes from 1991 to 2001 are limited to a small number of areas, unlike the previous case, where there was a structural change in the spatial distribution of the estimates in the suburban areas. Only two zones are “inequality hotspots” using both comparison spaces, in the West corridor and in the two municipalities in the South Bank. In other words, in these areas, lower qualifications are associated with higher noise exposures, either when comparing each district with other districts at the same distance to Lisbon or when comparing with the surrounding districts.

Map 3.5: GWR of noise around the neighbourhood: F1 parameter



Map 3.6: GWR of noise around the neighbourhood: F2 parameter



In conclusion, the spatial variability of the distribution of exposure to noise for pedestrians walking around the neighbourhood does not follow the same patterns as the distribution of time and noise exposures on the way to work. This is mainly because the first indicator does not take into account social differences in daily destinations and travel modes. Nevertheless, like the other indicators, the distribution of exposures in the city of Lisbon represents a singular case, with different patterns from the rest of the metropolitan area. Older populations are associated with lower exposures within Lisbon, although this relationships has became weaker from 1991 to 2001. Throughout the metropolitan area, but especially in the suburban areas, the disadvantage of less qualified populations has increased. The extent of this disadvantage depends, however, on the subset of areas we compare directly. We described the differences between the comparison space based on the areas around each district, using GWR, and the comparison space based on road distance to Lisbon. The maps in Appendix 10 show that the GWR differs from all other models. The singularity of the GWR in the models of noise around the neighbourhood is in contrast with the cases of time to work and noise exposures on the way to work, where the differences between the GWR and the other models are smaller.

3.5. Theories of local justice and the policy implications of inequality

The models in this chapter assessed the spatial variability of relationships between the characteristics of the population living in each place and the degree to which transport affects their mobility. This section discusses some of the policy implications of the inequalities implicit in the relationships found. In a first sub-section, we focus on different perspectives regarding the assignment of priorities to inequalities found in different parts of the metropolitan area, and describe some of the differences between the types of policies required to address those inequalities. In a second sub-section, we discuss the implications of the differences between the spatial scales at which inequalities occur and the scale of application of available policy instruments.

Location

The first question raised by the existence of different types of inequalities in different areas is which of these inequalities deserves policy attention. For example, in 2001 we may attach a different level of priority to the disadvantages in time to work for less qualified populations in the suburban areas around Lisbon and to the disadvantages for the same group in the peripheral areas Northwest municipality **[Map 3.1]**. Within the suburban areas, we may also attach different priorities to the disadvantages in time to work and to the disadvantages in pedestrian exposure to noise around the neighbourhood **[Map 3.4]**.

One possible way to rank the priority of the distributive outcomes in each part of the metropolitan area is to consider that the variables defining the similarity between different places also define the relevance of the inequalities found. For example, the relevance of commuting for the population in one neighbourhood (assessed by one of the variables in Group D of **Table 3.1**) measures the need for transport and for job accessibility of that population. In the empirical models in this chapter, we compared neighbourhoods with similar levels of need. We can also consider that inequalities are more relevant when they occur within the sets of neighbourhood with higher levels of need. The focus of policy intervention would then be the fulfilment of needs of the people at disadvantage in those areas. This means that, in the case of the patterns of **Map 3.1**, given the lower need for transport in the peripheral areas, the satisfaction of unfulfilled needs in this region would be attached a lower level priority than in the case of suburban areas.

The assessment of the distributive patterns using several comparison spaces may also provide a guideline on the necessity of policy intervention. We can attach a higher level of priority to inequalities that appear regardless of the comparison space used. This is for example the case of the inequalities in the average time to work of populations with different qualifications in suburban regions. The patterns of inequality in the distribution of noise exposures around the neighbourhood in these regions is more sensitive to the definition of the comparison spaces and would then be attached a lower level of priority.

The level of priority of the inequalities arising in one region may also depend on whether there are cumulative disadvantages for one group in the distribution of the different effects of transport. For example, if we overlay the charts or maps obtained for the same comparison spaces in the regressions of the three dependent variables analysed in this chapter (See Appendix 10), we can see that in the suburban areas closer to Lisbon, less qualified populations are at disadvantage in the distribution of all three effects in both years. On the other hand, in distant suburbs, the disadvantage of those populations in terms of time and noise on the way to work is compensated in 1991 by lower exposures to noise when walking around the neighbourhood. However, in 2001, these areas were also at disadvantage in terms of this item. If we consider that the main equity concern of public policy is the existence of cumulative disadvantages, these changes mean that the social inequalities in the outer suburbs have in 2001 the same level of priority as the inequalities in areas closer to Lisbon.

Regardless of their relative priority, the methods for dealing with inequalities arising in different parts of the metropolitan area are necessarily different, as the nature of the unfulfilled mobility needs depends on the geographic context in which those needs arise. In suburban areas, the improvement of times to work for the populations at disadvantage would involve the provision of public transport or policies tackling congestion, while the improvement of environmental quality of walking trips would involve car traffic restriction in the busiest areas, such as city centres. In semi-rural regions, the inequalities are more purely geographical, as the populations at disadvantage are the ones who live in villages away from the local centres of employment (the municipality capitals) and from the places giving direct access to the main metropolitan centres. Given the dispersion of the population in these areas and the lack of economic viability for the extension of the bus routes in this area, the improvement of accessibility in these areas would involve either the construction of further road infrastructure or the provision of subsidies to households with special accessibility needs. The improvement of pedestrian mobility in these areas is also different from the case of suburban areas, as the main points of concern are not the environment conditions in the central areas of towns but the conditions along pedestrian routes that share the same space as national roads with heavy traffic.

Scale

The social, economic and political processes that lead to social inequalities in the distribution of the benefits and costs of urban transport operate at a given spatial scale, that is, affect only a number of places. The exact delimitation of the set of these places is unknown, as the processes change over time and affect each place to a different degree. In practice, when discussing spatial inequalities, different actors will refer to different scales to approximate the "real" scale at which the relevant processes operate. Kurtz (2003) distinguishes for example between the analytical, regulation, and contestation scales, associated respectively to the role of the researcher, policy-maker and groups of activists. We are concerned with the degree of overlap between the scales implicit in the models analysed in this chapter and the limits of the administrative areas at different levels. The models estimate relationships in the sets of places that are judged to be comparable in the distribution of the benefit and cost from urban transport, that is, the areas belonging to the same "community of justice". The focus of analysis was therefore the delimitation of the "recipients of justice", which may not correspond to the delimitation of the "dispensers of justice", that is, the political structures that decide on the location of transport infrastructure and the regulation of traffic.

The scales of analysis in our models are implicit in the specification of the local regressions. In fact, the estimation of statistical relationships between the variables of concern uses a specific sub-set of data in each local regression and every observation is assigned a probability of membership in this sub-set, which is defined by the particular weight structure adopted. The estimation of the model with endogenous determination of weights assumes the existence of an "optimal" partition of the data into fuzzy subsets that apply to each regression. The weights that define this partition in our models are the ones that minimize a measure of the models' goodness of fit (the AKAIKE index). The size of the subsets of data included in each regression can then be interpreted as an indicator of the scale of adjustment between spatial differences in the dependent variables and in the socio-economic factors. This is the scale of operation of the processes that influence the sorting of the different social groups according to the characteristics of the places and the processes that influence the adoption of transport policies by the policy-maker according to the characteristics of the populations affected. The consideration of alternative values for the weighting structure would correspond to different scales of analysis and different assumptions to the scale of operation of those processes.

Within the weighting structure adopted, the scale of analysis is determined by the value of a single parameter – the bandwidth. The models of time to work in 2001 where the comparison spaces are private transport accessibility and the proportion of inter-municipal commuting have bandwidths of 13500 and 0.02 respectively. This implies that the districts with an accessibility index 33000 superior or inferior and the districts with percentages of inter-municipal commuting 5% superior or inferior to a given district will only have a 1% degree of inclusion in the regression centred at that district. In practice, in the model where weights are based on differences between districts in terms of the two variables, the regressions estimated in the majority of the places in suburban areas around Lisbon will share approximately the same data. However, in most of the peripheral areas, the regressions centred at each district tend to be restricted to neighbouring areas, as accessibility and commuting variables in these regions are more variable than in suburban areas. The consideration of comparison spaces based on spatial attributes implies therefore different scales of analysis when translated in geographic space.

With the exception of the patterns occurring within the borders of Lisbon municipality, the spatial distribution of the regression parameters obtained with the different comparison spaces suggests that the scale of the relevant processes does not correspond to the scale of the jurisdictions that hold effective power and responsibility over transport issues in the AML (the central and the municipal governments). The existing structures at an intermediate level, including the recently created Lisbon Metropolitan Transport Authority have limited scope for intervention, due to the lack of financing and power and to problems in the coordination of the interests of each municipality[31]. The results of this chapter suggest that the distribution of the benefits and costs of transport follows patterns that spread over the set of suburban municipalities around Lisbon. The need to correct those inequalities is an argument in favour for the increase of the power and means available to supra-municipal institutions, as the

[31] Silva (2002) describes the limitations of the two institutions at regional level (the Commission for Regional Development and Land Use Planning of the Lisbon and Tejo Valley (CCR-LVT) and the Association of the Municipalities in the AML. See also "Autoridade Metropolitana de Transportes de Lisboa sem "poder e dinheiro" (Metropolitan Transport Authority without power or money), *O Primeiro de Janeiro*, 20-08-2010.

emergence of these inequalities also depends on the dynamics of residence location and commuting patterns that operate at a supra-municipal scale. At the same time, the formulation of transport and urban policies needed to address those inequalities requires the definition of plans and strategies at a scale lower than the national level. The same arguments can be used to support social and political claims for proceeding with abandoned plans for a territorial reorganization of the Portuguese administrative system.

There remains the question of whether the instruments to address transport-based inequalities are available at each scale. The provision of better public transport may decrease the disadvantage in time to work of the populations with lower qualifications living in the suburban areas, especially in the second commuting ring from Lisbon, where the existing transport infrastructure is insufficient to satisfy the growing need for commuting to the central part of the AML. However, policy intervention on the public transport system is usually limited to the definition of broad strategies implemented by the state-owned companies managing the public transport infrastructure and to the financing of private companies providing bus services. The effectiveness of these strategies for dealing with the inequalities shown in this chapter is restricted by the fact that these inequalities extend over the different transport corridors, while the extent of operation of most bus companies consists of only a pair of municipalities in each corridor. As with the institutions defining transport policy, there is also a trend in the AML for the integration of strategies and resources of the different bus companies, such as the recent creation of the association of public transport operators (OTLIS). However, private operators cannot attach the same priority to equity issues as policy-makers. The recently announced privatization of all suburban train lines in Lisbon will also contribute to the loss of influence of government institutions in defining equity goals at the intended scale.

Traffic restriction policies can also promote equity, by improving the environmental quality of some neighbourhoods. These measures are usually applied at the municipal scale, as they require a level of detail that is only compatible with urban plans and enforcement structures specific to each municipality. If the policies applied in a given municipality follow criteria of equality based only on the comparison of the neighbourhoods within that municipality, then the definition of the areas of application of the policy will depend on the location of the groups considered to be at disadvantage. However, the effect on the distribution of noise exposures based on larger comparison spaces is indeterminate, given that the reorganization of traffic will affect the noise levels in places outside that municipality.

There are also effects on the times to work and noise exposures on way to work of workers living in other municipalities and commuting to the areas in which traffic restriction is applied. We study these aspects in more detail in Chapter 5.

The effects of transport policies on the redistribution of welfare among the different social groups depend therefore on the scale of application of those policies. Given the limitations on the instruments available at each administrative scale, the achievement of equity may require the application of a combination of policies. This involves the formulation of 'policy packages', where different instruments address disadvantages of different groups of concern at different scales. This is a complex endeavour, as the interrelationships between these effects depend on the institutional context, the time scale of each measure and the dynamic effects over both the equity and sustainability of the transport system (See for example Feitelson *et al.* 2001).

Conclusions and further considerations

There is usually a high degree of spatial variability in the patterns of transport inequality, as the statistical relationships between socio-economic variables and indicators of the local benefits and costs of transport are not uniform throughout space, varying with the context of each region. In this chapter, we tested the effect of using alternative definitions of the sub-set of places within the metropolitan area that are included in the estimation of those relationships. We found that inequalities in the distribution of times to work and exposures to noise of pedestrians on the way to work do not follow the same spatial patterns as inequalities in the distribution of exposures to noise of pedestrians walking around the neighbourhood. The differences regard both the locations and the scales at which inequalities are more evident. The effects of the expansion of the motorway network on the distribution of the indicators are also different. In the case of time to work, there was a tendency from 1991 to 2001 for the geographic extension of the regions where less-qualified populations are at disadvantage, from inner to outer suburbs. The most noticeable trend in the case of exposures to noise around the neighbourhood was the intensification or reversal of the type of disadvantage in the inner suburbs. There was also a reduction of the advantage of older populations in terms of both indicators of pedestrian exposure to noise in central areas.

These results prove that the hypothesis of spatial variability in the distribution of the effects of transport, which until now was tested mostly over broad regions, also applies in the case of metropolitan areas. The measurement of this variability depends however, on assumptions regarding the processes that lead to the adjustments between the different social groups and the conditions of each neighbourhood. The assumption that these processes operate within sets of areas with similar values for a given attribute leads to the identification of inequalities in certain locations and at certain scales that may be different from the inequalities obtained using another attribute. More generally, the analysis in this chapter has added to the idea that there are multiple perspectives to the assessment of social inequalities in the distribution of local benefits and costs associated with changes in the transport system and that these perspectives are often implicit in the statistical methods used.

These conclusions must take into consideration a series of caveats of the models used. We assumed that spatial non-stationarity is a feature of the dataset. However, some of the variation captured by the parameter estimates may derive from the insufficiency of the set of independent variables in explaining differences in the dependent variables. This may be due to omitted variables, model misspecification or measurement errors in dependent and independent variables (as they are both combinations of other data). The use of more detailed socio-economic data or the inclusion of further variables (such as income levels, socio-professional status and population density) could dismiss the hypothesis of non-stationarity of some of the parameters. There are therefore limitations on the extrapolation of the results found, as procedures for the statistical inference of models using weighted regressions are still developing. The test of spatial non-stationarity using Monte Carlo randomization distributions is an imperfect solution, as these distributions refer specifically to the data sets tested in each model [Leung *et al.* 2000]. Although in our particular case the models' residuals do not show any relevant spatial pattern, in general it is difficult to disentangle the effects of spatial non-stationarity, spatial autocorrelation and the errors implicit in the definition of dependent and independent variables. In this regard, the use of alternative definitions for the axis along which spatial variability is measured provides an advantage over the measurement of variability only on geographic space, as there is a smaller probability that the variability arose from chance or from insufficiencies of the model in all the different alternatives.

The model can also be improved by adopting local variants of procedures that we treated as global. We assumed that the rate of decay of the weighting function is constant across the study area, although this function can vary spatially, for example, by adopting a weighting system that assigns a gentler bandwidth in regions where data is sparser. We also assumed that the variance of the error term is constant in space. It is possible to address both problems by using other formulations, such as the error variance heterogeneity model developed by Páez *et al.* (2002). We can also use local procedures in the definition and measurement of the explanatory variables, as the results of the factorization of census variables into principal components can vary in space and as such, can be estimated locally [Lloyd 2010].

Finally, we should bear in mind that the regressions in each model represent equilibrium relationships between the location of social groups and indicators of mobility at given moments in time, but do not explain the specific processes leading to these relationships. The analysis in this chapter provides a guideline for the definition and the interpretation of these relationships, but does not imply that they are product of an adjustment process of individuals to conditions existing in the different neighbourhoods. The relationships between changes in the transport system, the neighbourhoods' social structure and patterns of urban land use are important components in the study of that hypothesis and will be analysed in the next chapter.

Chapter 4

Transport and neighbourhood change

Measures to address social inequalities have only a temporary effect, if the forces leading to those inequalities continue to operate. In general, it is difficult to identify the causal mechanisms leading to inequalities that are related to social differences in residence location, due to the lack of detailed data on the different variables of concern over a suitable length of time. In the case of the distribution of locally unwanted land uses, such as polluting infrastructure, the problem can be framed in terms of what came first to the affected areas, whether the infrastructure or the low-income populations or racial minorities [Been 1994, Liu 1997, Talih and Fricker 2002]. The case of urban transport is more difficult to assess, as the distribution of its local costs depends not only on the location of infrastructure but also on traffic levels, which vary over time. In addition, people may move close to the infrastructure because of the benefits they derive from it in terms of accessibility. The study of transport inequalities must then consider the determinants of residence location and analyse whether changes in the transport system induce household relocation and eventually lead to an adjustment between the spatial distributions of social groups and of the local benefits and costs of the system.

In the classic model of a monocentric city, households trade commuting costs and housing space. Income classes are then sorted according to the distance to the centre, depending on the relationship between the income elasticities of the demand for land and commuting costs [Alonso 1964, Mills 1967, Muth 1969]. The problem becomes more complex when we consider that accessibility is only one out of several geographic attributes valued by the individuals. This question is often approached using the local public goods model known as the “Tiebout model” [Tiebout 1956], which assumes that differences in the quality of local amenities or public services are capitalized in local taxes, housing prices or rents. Income classes are then sorted among neighbourhoods, depending on differences in the preferences and ability to pay of each class and on the available choice set of attributes of the neighbourhoods in each specific city. This choice set may be homogeneous in terms of some of these attributes, possibly leading to cumulative advantages for some groups. For example, empirical studies show that residential relocation may reproduce or reinforce inequalities in the distribution of several types of accessibility, including access to main centres and to urban facilities [Hesse and Scheiner 2009]. The extent to which this outcome also applies to the joint distribution of accessibility and environmental quality depends on the structure of each city. While in monocentric cities, environment quality tends to decrease with proximity to the centre; in dispersed and polycentric cities the two attributes may be positively correlated. These differences may explain why in some cities there is a balance between the advantages of different groups in the distribution of the two attributes, while in others there are cumulative disadvantages for the low-income groups [Reginster and Goffette-Nagot 2005].

Pedestrian mobility may also play a role in the spatial sorting of social groups. Evidence in several cities shows that pedestrian mobility is indeed capitalized in house prices, when assessed by walking distance to local facilities [Bateman *et al.* 2001, Cortright 2009], quality of walking access to public transport [Goetz *et al.* 2010, Duncan 2011] or general street "walkability" [Matthews and Turnbull 2007, Diao and Ferreira Jr. 2010]. However, the valuation of the negative effects of motorized transport on pedestrian mobility has been studied only indirectly. For example, Song and Knaap (2003) include in their hedonic study of house prices a variable measuring inter-community walking access (which depends implicitly on the presence of transport infrastructure acting as a barrier), while Orford (1999) includes traffic levels and noise levels in the streets around each property, but without establishing the link to pedestrian mobility.

Two other questions that lack definitive evidence are whether preferences for pedestrian mobility depend on income or other socio-economic variables, and whether these preferences are strong enough to incite household relocation. Levine and Frank (2007) found that preferences for living in a "walkable" neighbourhood are indeed associated with a greater desire for change in the characteristics of one's neighbourhood than preferences for auto-oriented neighbourhoods; although the preferences over the two types of neighbourhood are uncorrelated with income. The provision of public transport in conjunction with the improvement of pedestrian access also tends to have a stronger effect on neighbourhood gentrification than the provision of public transport next to "park and ride" facilities [Khan 2007]. On the other hand, the comparison of the results of Bhat and Guo (2007) and Pinjari *et al.* (2007) using the same data set shows that the effect of walkability on residence location depends on the set of land use variables that are included in the same model.

The objective of this chapter is to test if changes in the transport system of the AML in the period 1991-2001 lead to an adjustment of the spatial distribution of the different socio-demographic groups to the distribution of different dimensions of mobility. This adjustment can be assessed by looking at aggregate effects on the neighbourhoods' social structure. Our main contribution to the existing literature is to identify the role of aspects of pedestrian mobility that are negatively affected by motorized traffic, when considered alongside changes in accessibility and in other neighbourhood attributes. Those aspects include community severance and exposure to noise for pedestrians walking around their neighbourhoods.

We also look at two specific issues. The first is the variability in the effects of different dimensions of mobility in neighbourhood social recomposition in different parts of the urban area. Differences in the effects of mobility on household location in city centres and in inner and outer suburbs have been identified both in the case of accessibility [Hesse and Scheiner 2009] and general pedestrian mobility [Song and Quercia 2008], but have not been tested for the case of the indicators of pedestrian mobility mentioned above. The second issue is the effect of the development of new urban land in the social distribution of levels of mobility. The housing market in new areas is usually more effective than in other areas in capitalizing mobility or other neighbourhood attributes. This allows for a more effective overall sorting of households according to levels of accessibility and pedestrian mobility, if there are differences between the set of new and old areas or within the set of new areas.

We then analyse patterns occurring in separate sub-sets of the metropolitan area. In the first two sections, we focus on the set of areas where there is higher evidence of household relocation in the period of concern. The analysis in the preceding chapters has shown that inequalities in the distribution of mobility occur especially within Lisbon and in the surrounding suburban areas. These regions are analysed in parallel, in Sections 4.2 and 4.3, using variables defined in Section 4.1. In both cases, the analysis is divided in two stages. First, we use logistic regression to model the probability of a district to belong to the set of areas with high relocation. We then use canonical correlation analysis to assess the relationships occurring within that set of areas between changes in indicators of mobility and other neighbourhood attributes, and changes in demographic, socio-economic and housing variables. In Section 4.3, we work with a different sub-set of the data, focusing on the group of newly developed urban areas. We assess patterns occurring in each municipality, by comparing the mean values of socio-economic variables and mobility indicators in new and old areas and analysing the correlations between those variables inside the set of new areas. As in previous chapters, we discuss the results in a final section, framing the empirical findings in terms of wider processes affecting the social distribution of mobility.

4.1 Measuring neighbourhood change: social and spatial variables

The starting point for this chapter is the hypothesis that the social structure of the neighbourhoods in an urban area depends on changes in mobility and in other neighbourhood attributes, as these changes may induce household relocation among neighbourhoods in the city. Inter-neighbourhood differences in those attributes at a given moment also influence the residence location decisions of households migrating from outside the urban area. Ideally, the study of these links requires data at the household level. However, the results of surveys on housing satisfaction or household relocation covering large areas are usually only available to academic research at an aggregate level. Census data provide the second-best solution, although the use of this data also faces limitations derived from the aggregation of household data into areal units that are not always internally heterogeneous. In addition, the changes in the social structure of the population in each neighbourhood that are captured by data at the level of the census unit do not necessarily reflect household relocation, but can be due to demographic or economic changes within the population who did not moved.

One possible method to minimize these problems is to focus the analysis on the set of areas where household relocation is more significant. In our case, the data on the number of households that relocated from other areas can be inferred from the information published in INE (2004b), which provides categorical data at the enumeration district level on the proportion of households that were living in another administrative area (*freguesia*) five years before the census date. The areas with higher evidence of relocation are identified as the ones where more than 20% of the population have relocated[32]. The districts that correspond to newly developed land are not included and are analysed separately in Section 4.3. The first part of the next two sections models the probability of a district to belong to the set of areas with higher evidence of relocation. The models give us an understanding of the determinants of neighbourhood recomposition. The dependent variable accounts mainly for the relocation of households who move to dwellings previously occupied by households who moved to other neighbourhoods, but it also includes the relocation of households who moved to dwellings that were previously vacant or had non-residential uses.

[32] The set of districts with relocation above 20% provides more explicative models than those obtained with the other two alternatives provided by the data. The set of districts with relocation above 40% is too small, while the set above 10% is much less variable than the set above 20% in terms of changes in the census variables.

The separation between the two processes is made clear in the second part of the analysis, which looks at the particular changes within the set of areas with high relocation, isolating changes in the social structure from changes in the total population and in the characteristics of the housing stock. In this analysis, we do not use the factor scores obtained in Chapter 2, but revert to the original variables calculated from the census data. Although factors are composite variables correlated with a series of individual variables, changes in mobility and in other neighbourhood attributes may affect differently changes in the individual variables, even when they are correlated at one given moment. **Table 4.1** lists the variables tested. All variables express changes occurring in the period 1991-2001 and refer to enumeration districts.

Table 4.1: Social variables: population and housing characteristics

Individuals
Population
Men (% of adults)
Elderly (%)
Average age
No/Lowest qualification (%)
Graduates (%)
Employment/Population
Employment in agriculture (%)
Employment in industry (%)
Employment in services (%)

Families
1-2 members (%)
Average family size
With children (<15yrs old) (%)

Dwellings
Households per dwelling
Vacant (%)
Informal (%)
With facilities (%)
Small (1-2 rooms) (%)
Large (>5 rooms) (%)
Owned (%)

Buildings
Dwellings per building
Old (>40 years old) (%)
New (<10 years old) (%)
Exclusively residential (%)
Exclusively non-residential (%)

The probability of neighbourhood recomposition and the changes in the population and housing characteristics are related with a series of variables defining changes in neighbourhood attributes **[Table 4.2]**. We include variables that define characteristics of the places and are independent of the commuting decisions of the population living in each ED. Therefore, we only consider some of the indicators of accessibility and pedestrian mobility indicators presented in Chapter 2, excluding for example time to work and noise on the way to work. We also include additional indicators of accessibility and pedestrian mobility and a group of other neighbourhood attributes. All variables express changes in the period 1991-2001, except for the “historical areas” dummy variable.

Table 4.2: Spatial variables: mobility and other neighbourhood attributes

Accessibility
Job accessibility (private/public tr.)
Time to urban facilities (private/public tr.)
Time to Lisbon CBD (private/public tr.)
Time to nearest motorway junction (private tr.)
Time to nearest rail/metro station (private tr./bus/walk)
Congestion index (private transport.)

Pedestrian mobility
Community Severance (industrial)
Community Severance (motorway)
Exposure to noise around the neighbourhood

Other neighbourhood attributes
Historical areas (Dummy)
Jobs
Shops
Greenery (urban parks)
Greenery (forests)
Car parking
Slums

The list of accessibility indicators includes private and public transport job accessibility and time to urban facilities, which are defined in Chapter 2 (p.43, 51-52). The indicator of time to urban facilities is included because it can be understood as a measure of accessibility to local centres or municipal capitals, as these are the places that concentrate those facilities. The times to the Lisbon central business district (Saldanha/Picoas) and to the nearest access to the transport network (motorway junction or rail or underground stations) capture additional dimensions of accessibility by private and public transport, while the congestion index captures concerns specific to private transport users. The congestion index is the ratio of job accessibility estimated with uncongested and congested network times. It is therefore a measure of the way that the congestion in the whole network affects the population in each neighbourhood. The index is assumed to be exogenous in each neighbourhood, that is, independent on the characteristics of the population and their levels of car usage. This is because the index is affected mostly by levels of traffic in the motorways and roads that link the neighbourhood with the major centres, and not by traffic in local streets.

The list of pedestrian mobility variables includes the indicator of pedestrian exposure to noise around the neighbourhood and two indices of community severance, accounting for different types of barriers to inter-neighbourhood access: industrial sites and motorways. The construction of these indicators is given in Chapter 2 (p.55-56, 59-60). We also tested an indicator of the number of pedestrian accidents in the roads and streets around each district, which was found to be insignificant in all models.

The set of spatial variables is complemented with seven other indicators measuring neighbourhood attributes. We include a dummy variable for the areas in the historical centres of towns and cities, to account for the specificity of the housing markets and of the urban and social environment in those areas. The location of these areas was extracted from AML (d2001). The number of local jobs is given by the number of residents in each enumeration district who walk to work [Appendix 2.4]. The construction of the other five variables is based on the hypothesis that people experience their neighbourhoods when walking. The assumptions, data and methods used are detailed in Appendix 2.3C. Accessibility to shops is measured by the number of shops that can be reached within 500m from the district's representative points [Appendix 1], measured on the street network. Accessibility to green space is the area-weighted number of green spaces within 800m. In Lisbon we consider only urban parks and large leisure and recreation areas. In the suburbs we add a separate indicator for forests and other natural areas. The variable measuring car parking space is the length of the street network within 100m of the representative points, subtracted by the length corresponding to paid parking space. A final variable (*Slums*) captures the influence of the proximity to "problematic" neighbourhoods on the desirability of the areas around them. We hypothesize that the residents in one neighbourhood may not wish to interact on the street with residents of a slum area. The indicator of proximity to slums for a given district is then the total length of the intersection of the set of streets within 800m of the district's representative point and of the slum area, weighted by the slum population.

4.2. Mobility and neighbourhood recomposition I: Lisbon

In this section, we analyse changes in the population living in the neighbourhoods of the Lisbon municipality in the period 1991-2001, focusing on the set of areas containing a large proportion of households who relocated from other areas. In a first stage, we examine the influence of changes in mobility and other neighbourhood attributes in the probability of an area to belong to the set of areas with high relocation. In a second stage, we determine the relationships between changes in neighbourhood attributes and changes in demographic, socio-economic and housing variables within that set of areas.

Geographical determinants of neighbourhood recomposition

Our first objective is to assess the role of changes in accessibility and pedestrian mobility in the probability of neighbourhood recomposition, when included in a model with other variables measuring changes in the geographic attributes of each place. The analysis is conducted at the enumeration district level. As the membership of a district in the set of areas with highest relocation is a dichotomous variable, the question can be assessed using logistic regression. The dependent variable is the logged odds ratio of a district being in that set. The number of districts in the set of high relocation corresponds to 5.3% of the enumeration districts in Lisbon. The explanatory variables are the changes in the variables defining neighbourhood attributes presented in **Table 4.2.** We also tested interaction terms between the changes in commuting severance indicators and in noise exposures. These terms apply when both changes have the same sign, in order to account for cumulative effects of a simultaneous increase or decrease of both aspects[33].

The model presented in the table below is the one that yields the highest goodness of fit such that all variables are significant at 10%. The overall significance and goodness of fit of the model are assessed by the likelihood test and the Nagelkerke R^2 respectively[34]. The significance of each coefficient is based on the Wald statistic, which is the square of the ratio between coefficient and their standard deviation. This statistic can also be used to rank the variables in order of importance. In order to facilitate comparison, the model coefficients (β)

[33] We define the interaction terms as the product of the change in community severance and the absolute value of the change in noise exposure. When changes have the opposite sign, the term is equal to zero.

[34] See Pampel (2000) for significance tests and goodness of fit in logistic regression.

are standardized, with the exception of the "historical areas" dummy variable. The exponential of the coefficients (e^{β}) is then the predicted change in the odds ratio for an increase in the explanatory variable equal to the standard deviation of that variable. We also present the 95% confidence intervals for this value.

Table 4.3: Logistic regression of the probability of neighbourhood recomposition (Lisbon)

	β	**Wald**	**Sig.**	**e^{β}**	**95% C.I.**
Constant	-2.94				
ACCESSIBILITY					
Δ Private tr. job accessibility	0.48	4.02	0.05	1.62	[1.01-2.59]
Δ Public tr. job accessibility	0.24	5.01	0.03	1.27	[1.03-1.57]
Δ Bus time to station	-0.25	6.04	0.01	0.78	[0.64-0.95]
Δ Walking time to station	0.87	5.91	0.02	2.38	[1.18-4.79]
Δ Congestion (Private tr.)	0.91	12.93	<0.001	2.47	[1.51-4.05]
PEDESTRIAN MOBILITY					
Δ Community severance (motorway)	0.65	13.74	<0.001	1.92	[1.36-2.70]
Δ Com.Sev (motorway) * |Δ Noise around|	0.34	3.38	0.07	1.41	[0.98-2.02]
OTHER NEIGHBOURHOOD ATTRIBUTES					
Historical areas (Dummy)	-0.26	6.18	0.01	0.77	[0.63-0.95]
Δ Jobs	-0.18	4.93	0.03	0.84	[0.71-0.98]
Δ Retail	-0.25	5.11	0.02	0.78	[0.63-0.97]
Δ Green (Park)	0.66	26.56	<0.001	1.93	[1.50-2.47]
Δ Parking	-0.57	11.39	<0.001	0.57	[0.41-0.79]
Δ Slums	0.28	7.61	0.01	1.32	[1.08-1.61]

N: 2319 (Yes: 5.3%; No: 94.7%)

Model likelihood test (df=13): χ=158.28 (p<0.001)

Nagelkerke R2: 0.34

The change in urban green areas is the most significant variable in the model, as measured by the Wald statistic. This variable has a positive coefficient, which reflects a particular process occurring in Lisbon in the period concerned: the regeneration of a large section of the east part of the city to build new residential areas and urban parks in an area previously occupied by industrial sites.

Aspects related to car use, such as congestion and parking, are also highly significant. The probability of neighbourhood recomposition is higher for higher increases in congestion and lower increases of parking space. In other words, the neighbourhood's population show stronger propensity to change in areas with lower improvements in those two issues, which are accessory aspects of private transport accessibility, although the probability of change is higher for higher improvements in the index of private job accessibility itself. The significance of changes in parking space is consistent with the results of a survey that found that parking space is the most important reason for dissatisfaction of households regarding their neighbourhood in Lisbon [CML-DMPU 2004b p.126]. There are also differences between different dimensions of public transport accessibility. The lower the improvements in aspects that complement the public transport journey, such as the walking time to station (that is, the higher the variation in that time), the higher the probability of neighbourhood recomposition. On the other hand, the higher the improvements on indicators more closely related with the journey, such as the index of public transport job accessibility, or the bus time to the nearest station, the highest the probability of neighbourhood recomposition.

We should also notice the absence of variables related to changes in the accessibility to specific destinations (such as time to urban facilities and time to the Lisbon CBD), either by private and public transport. Changes in the time to nearest motorway junction and private transport time to the nearest station are also not significant. The first case may be explained by the relatively low density of motorways within Lisbon, comparing with the suburban area, while the second case is explained by the low relevance of “park and ride” commuting.

The significant pedestrian mobility dimensions are the ones related with community severance posed by motorways, both as an individual variable and interacted with the changes in exposure to noise around the neighbourhood. In both cases, the higher the deterioration in the conditions of pedestrian mobility in a neighbourhood, the higher the probability of neighbourhood recomposition. The Wald statistic of the community severance coefficient is the second highest in the model and is higher than the value of the significant accessibility variables, which points out to the relevance of this dimension of mobility in the probability of neighbourhood recomposition. The changes in community severance posed by industrial sites and the changes in noise exposure as an individual variable were found to be insignificant.

The remaining control variables in our list are also significant. The increase in the proximity to slum areas has a positive coefficient, while the change in the number of jobs and shops and the location in historical areas have a negative coefficient. The odds ratio of a district in the historical areas is 0.77, which suggests that there are characteristics specific to those areas that decrease the propensity for household relocation from and to those areas. Characteristics preventing residents moving out are probably the existence of close-knit communities, while characteristics preventing people moving in include the hilly reliefs and high proportions of buildings in poor state of repair.

Social patterns of neighbourhood recomposition

This sub-section analyses the multiple relationships between the changes in the two groups of variables presented in Section 4.1, measuring social and spatial neighbourhood attributes. These relationships are assessed at the enumeration district level and within the set of areas with highest proportion of relocated households. The objective is to explain the overall variance in each group of variables in terms of the overall variance in the other group. The most appropriate procedure to approach this type of problems is canonical correlation analysis. This method is a sequential process that finds pairs of correlated linear combinations of the two groups of variables. These pairs are known as canonical variates and the correlation between them is called canonical correlation. At each stage, the process finds the pair of variates yielding the largest correlation such that they are uncorrelated with the previous pairs of variates. The method captures therefore a series of independent relationships between the two groups of variables. The procedure continues until the obtained variates contain all the co-variation between the two groups of variables, although only a small number of variates are usually needed to represent adequately this co-variation. In our case, the synthesis of the two groups of variables into variates provides an interpretation of the multiple effects of changes in mobility in demographic and socio-economic variables, controlling for changes in other neighbourhood attributes and in population and housing dynamics.

The approach followed was to test a run a series of canonical correlation models using different selections of the variables in both groups[35]. We started with all the variables in each group that have a significant correlation with any single variable in the opposite group. We then re-ran the model without one of these variables and estimated the sum of the proportions of the variance of each group explained by the other group (see note 37). The variable whose removal leads to the highest increase in that sum is definitely excluded. This procedure is applied repeatedly until is no longer possible to improve the model by removing any variable.

Table 4.4 shows the results of the final model, which found three canonical correlations significant at the 1% level[36]. The table on the top left side gives the correlations between the canonical variates. The variates of the group of spatial variables are identified as c_1, c_2 and c_3

[35] The distance to slums (in the spatial group) and the proportion of informal dwellings (in the social group) are never included together in the same model, as they are closely related by definition (See chapter 2, p.38).

[36] The significance test assesses whether, after having extracted one pair of variates, there are any pairs independent of the ones already extracted and having non-zero correlations. See Levine (1977, p.20-21).

and are associated respectively with the variates c'_1, c'_2 and c'_3 in the group of social variables. The correlations between the three pairs are strong, at 0.86, 0.79 and 0.72. The table on the top right side gives measures of redundancy. These measures assess the extent to which the variance in one group is explained by the canonical variates on that group and on the opposite group[37]. The spatial and social variates explain very similar proportions of the variances in the respective group, 64.5% and 64.4% respectively. The spatial variates explain 37.8% of the variance in the group of social variables, while the social variates explain 41.3% of the variance in the group of spatial variables. The interpretation of the variates follows a similar rationale as in factor analysis. We assume that the variates are unobservable latent variables, the nature of which is suggested by their correlations with the original variables. These correlations are known as canonical loadings and are given in the two tables at the bottom. We can also assess the character of each variate by mapping its distribution. **Map 4.1** shows the distribution of the variates of the group of spatial variables.

Table 4.4: Canonical correlation analysis of spatial and social changes (Lisbon)

Canonical correlations

(c_1,c'_1)	(c_2,c'_2)	(c_3,c'_3)
0.86	0.79	0.72

Redundancy measures (%)

	Spatial variates				Social variates			
	c_1	c_2	c_3	Sum	c'_1	c'_2	c'_3	Sum
Spatial	27.6	20.3	16.6	64.5	20.3	12.5	8.5	41.3
Social	11.1	9.3	17.4	37.8	15.1	15.2	34.1	64.4

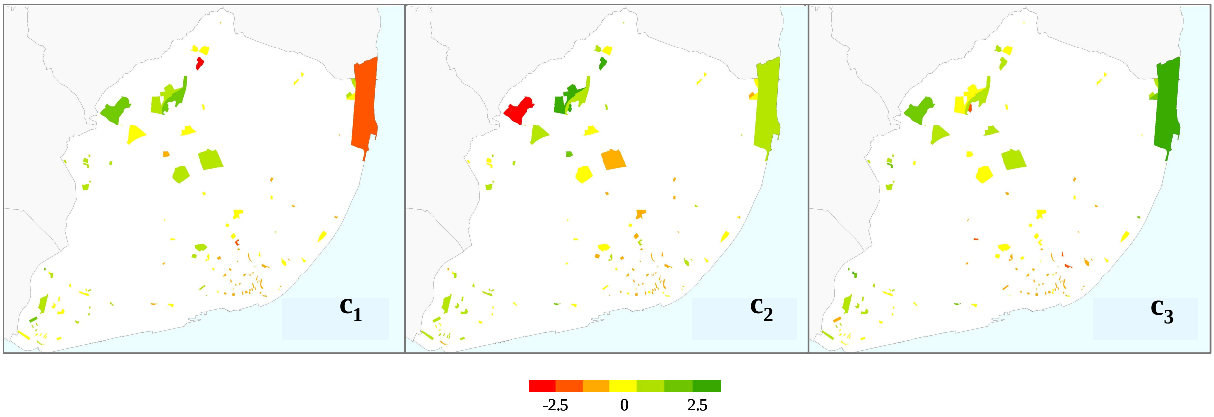
Canonical loadings

Spatial	c_1	c_2	c_3
ACCESSIBILITY			
Δ Private tr. job accessibility	0.14	-0.11	0.71
Δ Public tr. job accessibility	0.44	0.66	-0.22
Δ Congestion (Private tr.)	0.48	0.66	0.23
PEDESTRIAN MOBILITY			
Δ Com.Severance (industrial)	0.77	-0.52	-0.22
Δ Com.Severance (motorway)	0.61	0.38	-0.41
Δ Noise around	0.08	0.04	-0.49
OTHER NEIGHBOURHOOD ATTRIBUTES			
Δ Retail	0.46	0.48	0.41
Δ Green (Park)	-0.77	-0.30	-0.33

Social	c'_1	c'_2	c'_3
INDIVIDUALS			
Δ Population	0.11	0.76	0.19
Δ No/Lowest qualifications	-0.32	-0.16	-0.51
Δ Graduates	-0.04	0.30	0.84
Δ Employment/total pop.	-0.26	0.03	0.65
DWELLINGS/BUILDINGS			
Δ Vacant dwellings	-0.65	-0.57	0.23
Δ Owned dwelling	0.04	0.09	0.79
Δ Small dwellings	-0.61	0.00	-0.50
Δ Large dwellings	0.07	0.07	0.87
Δ Informal dwelling	0.72	0.28	-0.44
Δ New buildings	0.01	0.64	0.30

[37] The proportion of the variance of one group that can be accounted for by a variate from the same group can be estimated by the sum of its squared correlations with each variable, divided by the number of variables. The proportion of the variance explained by the correspondent variate in the opposite group is the product of the proportion above and the squared canonical correlation between the two variates [Stewart and Love 1968].

Map 4.1: Spatial canonical variates (Lisbon)



Note: Variates are standardized and classified by standard deviation

The first variate in the group of spatial variables (c_1) accounts for 11.1% of the variance of the group of social variables, while the corresponding variate in the social group (c'_1) accounts for 20.3% of the variance of the spatial group. The spatial variate is negatively related with the change in green space and positively related with both types of community severance and (to a lesser extent) with changes in public transport job accessibility and congestion. The map shows that this variate assumes the highest positive values in the northwest, at the confluence of the two main Lisbon motorways, which were completed in the period concerned. The negative values occur especially in the east, which accounts for the previously mentioned transformation of derelict industrial sites into residential areas and parks. There are also negative values in the residential areas in the centre, where community severance is not relevant due to the absence of industry or motorways. The social variate is negatively related with the change in the proportions of small dwellings and vacant dwellings and positively related with the change in the proportion of informal dwellings. The association between community severance and changes in informal dwellings is consistent with the results obtained previously, in the model of the probability of a district to be affected by community severance in each year (Chapter 2, p.57).

The second variate in the spatial group (c_2) has positive associations with changes in public transport job accessibility and in the congestion index and negative association with the change in industry-based community severance. The variate in the group of social variables (c'_2) is mainly explained by variables measuring population and housing dynamics, being positively related with the change in population and the proportion of new buildings and negatively related with the change in the proportion of vacant dwellings.

The third pair of variates is explained on the spatial side (*c_3*) by a positive correlation with the change in private transport job accessibility and a negative correlation with the change in the pedestrian mobility variables. The social variate (*c'_3*) accounts for the highest share in the variance of its own group (34.1%), as is strongly associated with several variables. The variate is positively related with the changes in the proportion of graduates, employment-to-population ratio, proportion of owned dwelling and large dwellings and negatively related with the change in the proportion of individuals with the lowest qualifications and in the proportion of small dwellings. This is the most interesting pair of variates from an equity perspective, as it relates combinations of variables defining benefits from transport changes (increase of accessibility and reduction of its negative effects) with variables that are usually considered as proxies for income levels and socio-economic status. The result confirms the hypotheses of simultaneous adjustment between the location of income groups and levels of accessibility and pedestrian mobility, with cumulative advantages for the high-income groups.

It is also worth mentioning the variables that did not fit into the final canonical correlation model. The absence of age variables dismisses the hypothesis that the spatial distribution of age groups tends to adjust to the distribution of the type of mobility they theoretically value the most, with younger people moving to areas with better job accessibility and the elderly moving to areas with better conditions for pedestrians. The lack of evidence on this adjustment may be explained by the correlation between improvements in the two types of mobility. Elderly populations are relatively more concentrated in the central areas, where the spatial variate c_3 has the lowest values, which represent lowest improvements of accessibility and highest deterioration of pedestrian mobility. The double disadvantage of these areas, allied to other factors preventing relocation derived from the location of these areas in the historical centres mean that there is no incentive for younger population to settle in these areas or for the elderly residents to move to other neighbourhoods. The absence of this adjustment process explains the decrease in the advantage of the elderly in pedestrian exposures to noise seen in the previous chapter [**Map 3.3**, **Map 3.5]**.

Some dimensions of public accessibility that contribute to the probability of neighbourhood recomposition, such as the bus and walking times to the nearest station, are also absent from the final canonical correlation model, not having a noticeable relationship with either the total population living in a neighbourhood or the social structure of that population. The recomposition of the neighbourhood's population may then be explained by differences in the preferences of the individuals who moved in and out of the neighbourhood or by the effect of omitted variables related with bus and walking times to stations.

The results provide two conclusions that can apply in other urban settings. First, the spatial sorting of groups with different socio-economic status is more strongly associated with improvements in private transport accessibility than with improvements in public transport accessibility. The latter are only moderately related to an increase in the proportion of graduates, but are strongly related with population and housing dynamics. Improvements in the public transport network serving areas with populations with lower socio-economic status may then have a relatively stable effect on the overall distribution of accessibility levels, as it does not seem to lead to large relocation movements of individuals with higher socio-economic status to those areas. The second conclusion is that the adjustment of socio-economic groups to changes in pedestrian mobility may be explained by changes in accessibility. In our case, the adjustment to changes in pedestrian exposure to noise and community severance suggested by the association between the third pair of variates may be explained by changes in private transport accessibility, which have a stronger correlation with the same spatial variate. The common factor to these two conclusions is that in cities with rapid increases in the motorization rate and car usage, such as Lisbon, private transport accessibility is the main driver of the sorting of socio-economic groups to the different neighbourhoods.

4.3. Mobility changes and neighbourhood recomposition II: Suburbs

The determination of the appropriate scale of analysis is as relevant in the study of the relationships between spatial and social neighbourhood changes as in the analysis of patterns occurring at a moment in time, which was the object of previous chapters. This is due to the differences in the processes affecting those relationships in different parts of heterogeneous metropolitan areas. In fact, households do not consider the whole of the metropolitan area when looking for a house, but just a small set of areas. This leads to the existence of housing sub-markets, whose borders depend on a series of geographic factors such as administrative borders, centrality, accessibility, and in the case of the AML, the natural barrier posed by the Tejo estuary. The relevance of some dimensions of accessibility and pedestrian mobility for the households, and the efficiency of the housing market in the capitalization of differences in mobility may also vary in space.

If in the case of Lisbon, the delimitation of the area of analysis is straightforward, as the municipal borders also define the city limits, in the case of the suburban areas there are many possible alternatives. A geographically weighted approach comparing similar areas as done in Chapter 3 is theoretically possible but of difficult implementation, due to the multiple patterns of interrelationship between indicators of mobility and socio-economic variables. In our analysis, we use a selection of areas based on the relevance of commuting to Lisbon. In a preliminary analysis, this solution revealed to have highest explanatory power than other possibilities, including separate analyses in each municipality, in major cities or in clusters of enumeration districts with similar values for accessibility and pedestrian mobility indicators.

The approach used was to run the logistic regression model in different selections of the data, each including the enumeration districts in an additional administrative area (*freguesia*), ranked in descending order of the proportion of workers commuting to Lisbon. The process started with the administrative areas where more than 50% of the population commutes to Lisbon. The selection chosen was the one yielding the best model (the one with highest goodness of fit such that all variables are significant at 10%). This region contains the administrative areas where more than 43% of the workers commute to Lisbon. The logistic regression model for this region is presented in the first sub-section. The same region is used in the estimation of the canonical correlation model presented in the second part of the analysis, which studies the relationships between social and spatial neighbourhood changes.

Geographical determinants of neighbourhood recomposition

Table 4.5 shows the results of the logistic regression of the probability of a neighbourhood to contain a large proportion of households who relocated from other areas, using as explanatory variables the changes in accessibility, pedestrian mobility and other neighbourhood attributes. The number of enumeration districts in the set with high relocation is smaller than in Lisbon, but represent a higher percentage of the total number of districts (11.9%).

Table 4.5: Logistic regression of the probability of neighbourhood recomposition (Suburbs)

	β	**Wald**	**Sig.**	**e^{β}**	**95% C.I.**
Constant	-1.93				
ACCESSIBILITY					
Δ Private tr. job accessibility	0.38	10.94	<0.001	1.47	[1.17-1.84]
Δ Public tr. job accessibility	0.68	36.07	<0.001	1.96	[1.58-2.45]
Δ Private tr. time to facilities	-0.50	10.25	<0.001	0.61	[0.45-0.83]
Δ Public tr. time to Lisbon	-0.54	3.33	0.07	0.58	[0.33-1.04]
Δ Time to motorway junction	-0.48	3.70	0.05	0.62	[0.38-1.01]
Δ Bus time to station	-0.40	4.16	0.04	0.67	[0.46-0.99]
PEDESTRIAN MOBILITY					
Δ Noise around	0.38	7.82	0.01	1.46	[1.12-1.89]
Δ Community severance (industrial)	0.68	11.88	<0.001	1.98	[1.34-2.91]
Δ Community severance (motorway)	0.35	4.64	0.03	1.42	[1.03-1.96]
OTHER NEIGHBOURHOOD ATTRIBUTES					
Historical areas (Dummy)	-0.82	22.22	<0.001	0.44	[0.31-0.62]
Δ Jobs	1.23	34.58	<0.001	3.42	[2.27-5.16]
Δ Green (Forest)	-0.69	18.36	<0.001	0.50	[0.36-0.69]

N: 1486 (Yes: 11.9%; No: 88.1%)

Model likelihood test (df=12): χ=176.93 (p=<0.001)

Nagelkerke R2: 0.35

The most significant variable is the change in public transport accessibility, as reflected in the Wald statistic. Higher increases in this type of accessibility correspond to higher probability of neighbourhood recomposition. All other variables in the accessibility group show the same pattern: the probability of neighbourhood recomposition is related positively with the size of the improvements in accessibility. These improvements include increases in the job accessibility index and decreases in the time to reach urban facilities, the Lisbon CBD, motorway junctions and rail or underground stations. This pattern differs from the case of Lisbon studied in the previous section, where there was a negative relationship between probability of neighbourhood recomposition and improvements in the case of two accessibility indicators: changes in congestion in the walking time to stations. These variables are insignificant in the present case. The change in car parking space is also insignificant.

Another particularity of the case of the suburban region when comparing with Lisbon is the significance of the time to motorway junctions and of some of the variables related to changes in the accessibility to specific destinations. However, while access to Lisbon is significant for public transport users, access to urban facilities (which is also an indicator of access to local centres) is significant for private transport users. This result may be related to the growth of employment in new centres outside Lisbon and near motorway junctions. These locations have good access by motorways but not by public transport. Access to these centres is therefore more relevant for private transport users, while public transport users place more emphasis on access to traditional centres of employment in Lisbon.

The two types of community severance and the increase in the exposure to noise for pedestrians walking around their neighbourhood are significant and have positive coefficients. The higher the deterioration in these measures of pedestrian mobility, the higher the probability of neighbourhood recomposition. The measure with the highest relevance is the change in the community severance posed by industrial sites. Unlike the case of Lisbon, interaction terms between pairs of measures were found to be irrelevant.

In the group of control variables, the most significant variable is the change in the number of local jobs. This variable has a positive parameter, which means that the higher the increase in the number of jobs, the higher the probability that the population living in the neighbourhood will change. This result contrasts with the case of Lisbon, where the parameter for this variable was negative. The two other significant variables are the increase of green space and the location in the historical areas, both with a negative parameter. The parameter for green space is again different from the one found in Lisbon, although in the present case, the significant variable relates to forests areas and not to urban parks.

Social patterns of neighbourhood recomposition

We now apply the canonical correlation model to the relationships between changes in the spatial and social attributes of the neighbourhoods in the suburban area. The results are presented in **Table 4.6**, which is organized in a similar fashion as **Table 4.4**.

Table 4.6: Canonical correlation analysis of spatial and social changes (Suburbs)

Canonical correlations

(c_1,c'_1)	(c_2,c'_2)	(c_3,c'_3)
0.91	0.75	0.73

Redundancy measures (%)

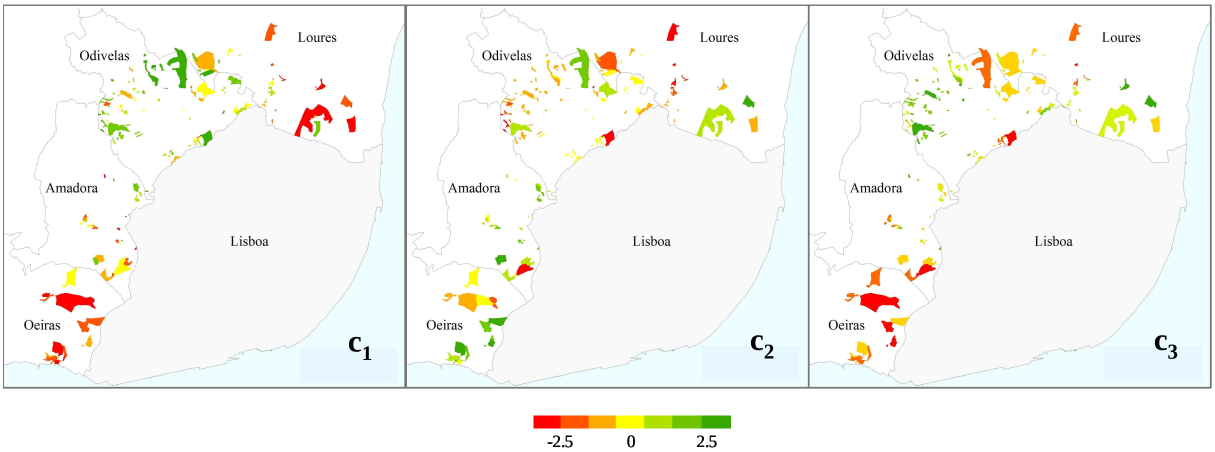
	Spatial variates				Social variates			
	c_1	c_2	c_3	Sum	c'_1	c'_2	c'_3	Sum
Spatial	32.1	20.8	12.9	65.8	26.6	11.7	6.9	45.2
Social	24.1	7.9	7.8	39.8	29.0	14.1	14.4	57.5

Canonical loadings

Spatial	c_1	c_2	c_3
ACCESSIBILITY			
Δ Private tr. job accessibility	0.63	0.25	-0.28
Δ Public tr. job accessibility	0.14	0.87	0.01
Δ Bus time to station	-0.93	-0.23	-0.15
Δ Congestion (Private tr.)	0.06	0.16	-0.72
PEDESTRIAN MOBILITY			
Δ Noise around	0.63	0.23	-0.05
OTHER NEIGHBOURHOOD ATTRIBUTES			
Δ Green (Park)	0.55	-0.50	-0.30
Δ Slums	0.51	-0.50	0.44

Social	c'_1	c'_2	c'_3
INDIVIDUALS/FAMILIES			
Δ Population	0.91	0.28	-0.11
Δ No/Lowest qualifications	-0.29	-0.05	0.55
Δ Graduates	-0.06	0.60	-0.65
Δ Employment/total pop.	0.48	-0.49	-0.01
Δ Family size	-0.48	0.05	-0.52
DWELINGS/BUILDINGS			
Δ Owned dwelling	-0.72	0.24	-0.22
Δ Small dwellings	0.44	-0.62	0.06
Δ Large dwellings	-0.49	-0.09	0.31

Map 4.2: Spatial canonical variates (Suburbs)



Note: Variates are standardized and classified by standard deviation

There is a pair of variates (c_1, c'_1) that is clearly dominant in the model, having a canonical correlation of 0.91. These variates also explain a large part of the variance in their own group and in the opposite group. The spatial variate (c_1) is related with the majority of the variables included in the model, especially with the reduction of the bus time to railway or underground stations, a variable that was absent in the case of Lisbon. As in Lisbon, the changes in private transport job accessibility and in exposures to noise appear in the same variate, but they now have the same sign. The variate then accounts for improvements in accessibility simultaneous with the deterioration of the environmental quality of pedestrian mobility. The variate is also related with the proximity to slum areas and with the increase in urban green space. The social variate (c'_1) is related to suburbanization, including the increase in population and employment-to-population ratio, the decrease in average family size and the renovation of the housing stock resulting in smaller, rented dwellings. In the area of analysis, the process described above occurs mainly in the Odivelas municipality, in the areas around a new motorway (IC22) **[Map 4.2]**. Other characteristics of suburbanization were not found to be related to this or to the other variates, such as the decrease in the number of jobs or the increase in the proportion of younger populations, dwellings per building and proportion of residential buildings. Two of the variables that measure population and housing dynamics (and which were found significant in Lisbon) are also absent from the present model: the changes in the proportions of new buildings and in the proportion of vacant dwellings.

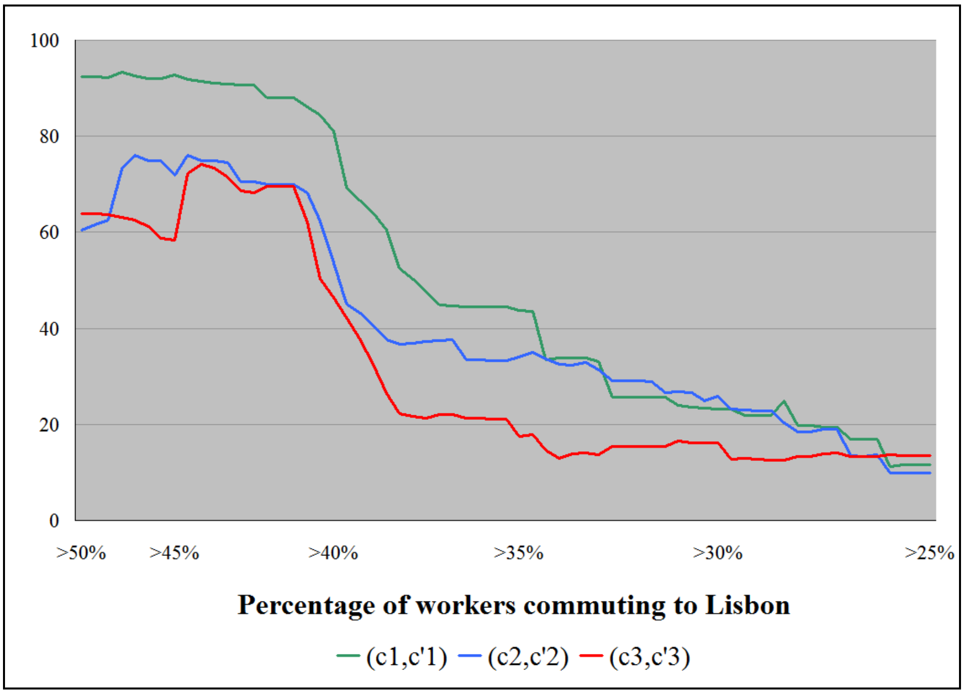
The two variables without strong correlations with the first social variate (c'_1) are the changes in qualification levels, assessed by the proportions of individuals with the lowest and highest qualifications. These variables are related to the other two variates (c'_2 and c'_3). While the canonical correlations of these variates with the corresponding spatial variates are high (0.75 and 0.73 respectively), the redundancy measures of these variates are modest comparing with the first variate, as they represent relationships between a small number of variables in the two groups. The increase in the proportion of the highest qualification levels defines the second social variate (c'_2), together with the decrease in the employment-to-population ratio and in the proportion of small dwellings. These variables are then related, via the spatial variate (c_2), to increases in public transport job accessibility and decreases in green space and in the proximity to slum areas. The third social variate (c'_3) accounts for a more comprehensive shift in the qualification structure of the neighbourhoods, as it integrates changes in the proportion of both lowest and highest qualifications. The variate is also related negatively with family size, a variable that was insignificant in Lisbon. The corresponding spatial variate (c_3) is largely determined by changes in congestion levels.

The association between improvements in public transport accessibility and increases in the proportion of graduates is much clearer than in the case of Lisbon. In fact, in the present case, these are the most important variables in the respective variates (c_2 and c'_2). The association between changes in congestion and qualification levels is also clearer in the present case (via the c_3 and c'_3 variates). The fact that graduates move to areas with the highest increases in congestion may be explained by the influence of other changes that occur in those places. The composition of variate c_3 suggests two of these forces: the decrease in the proximity to slums and the increase of green space. In fact, the lowest values of this variate occur in the Oeiras municipality, around the areas previously occupied by the largest slum area in the country, which was cleared and re-urbanized in the period concerned.

The facts that indicators of community severance are insignificant and that changes in exposure to noise are mainly related to variables unrelated to socio-economic status also suggest that aspects of pedestrian mobility have a secondary role in the sorting of socio-economic groups among neighbourhoods. Although the logistic model found that the deterioration of pedestrian mobility is associated with a higher probability of neighbourhood recomposition, the canonical correlation results show that this change is mainly related to changes in the total population (via the c_1 and c'_1 variates). However, the positive relation between changes in noise exposures and population size may be explained by the effect of a simultaneous reduction of times to the nearest station, which are more strongly related with the spatial variate.

The role of the extracted canonical variates in the explanation of neighbourhood demographic and socio-economic changes is specific to the sub-set of areas included in the analysis, that is, all districts in administrative areas where more than 43% of the workers commute to Lisbon. However, the variates are also relevant when restricting or extending that set to include places more or less dependent on commuting to Lisbon. **Figure 4.1** presents the correlations between the three pairs of canonical variates for regions defined by different thresholds of the proportion of workers commuting to Lisbon. The three variates are highly correlated for regions narrower than the one we used. They are also correlated for wider regions, up to a threshold of 40%, which includes 30 of the 96 administrative areas in the North Bank outside Lisbon. For regions that include additional areas, the three canonical correlations are considerably lower, which means that the associations between the variables they represent no longer hold. The influence of mobility in the patterns of neighbourhood recomposition is therefore dependent on the scale of analysis.

Figure 4.1: Correlations between variates at different spatial scales



4.4. The social structure of new urban settlements

The spatial sorting of social groups does not depend only on differences in their preferences and ability to pay for mobility and other neighbourhood attributes, but also on factors influencing the housing supply, such as the development of new urban areas. The creation of new neighbourhoods extends the set of alternatives available to households in their location decisions. Social inequalities in the distribution of accessibility and pedestrian mobility may increase if on average the new neighbourhoods offer better conditions than existing areas and if they tend to be settled by certain groups. In addition, the capitalization of neighbourhood attributes into housing prices also tends to be more efficient in newly built-up areas, not being affected by market distortions characteristic of others areas, especially in the old parts of cities and towns. If the set of new neighbourhoods is heterogeneous in terms of accessibility and pedestrian mobility, the sorting of social groups within that set may reflect more clearly the social differences in preferences or ability to pay, comparing with existing neighbourhoods. If some groups tend to locate in the areas offering the best conditions, the strength of overall relationships between the distribution of social groups, accessibility and pedestrian mobility will increase.

In this section, we amalyse levels of accessibility and pedestrian mobility and the social structure of the population in areas built-up in the period 1991-2001 in the Metropolitan Area of Lisbon. The identification of these areas makes use of the fact that the development of new urban land leads to a reorganization of the borders of enumeration districts. The districts that correspond to newly built-up areas are the ones that in 1991 were classified as non-residential land in land use maps [e-Geo d1990]. The analysis is disaggregated by municipality, which is the natural scale of analysis, since land use policies are the responsibility of municipal councils. All variables refer to 2001. We focus on the two main socio-economic factors derived in Chapter 2, which synthesize variables measuring age (*F1*) and qualification levels (*F2*) and on four mobility indicators: private and public transport job accessibility (*APriv* and *APub*), public transport time to urban facilities (*TFacPub*) and community severance (*ComSev*). This last indicator takes into account barriers to inter-neighbourhood pedestrian access posed by both transport infrastructure and industrial sites (See Chapter 2, p.56 and Appendix 2.3B). We first compare means of the two factors and mobility indicators in the set of new areas and in the whole municipality. Then, we estimate correlations between the indicators and the qualifications factor inside the set of new areas.

The table below reports the means of mobility indicators and socio-economic factors in the set of newly built up areas in the 18 municipalities. The suburban region defined in the previous section is also included for reference. The first two columns give the number of districts in the set and the proportion they represent in the inhabited area in each municipality. The other columns give the means of mobility indicators and socio-economic factors in 2001, standardized by the means and standard deviations of all inhabited districts in the municipality. Positive/negative values indicate that the mean is higher/lower in new areas than in the whole municipality. Values above/below one indicate whether the difference in the two means is above/below the standard deviation of the values in the whole municipality. The significance tests assess the null hypothesis that the standardized means are equal to zero, that is, the means in new areas are equal to the means in the whole municipality.

Table 4.7: Socio-demographic factors and mobility levels in new areas: (standardized means)

North Bank

	N	% area	F1	F2	APriv	APub	TFacPub	ComSev
Lisboa	138	4.9	-1.55**	-0.16	-0.33**	-0.60**	0.37**	0.42**
Odivelas	58	4.8	-1.36**	1.19**	-0.28**	-0.58**	0.20^{x}	-0.12
Amadora	20	4.3	-1.14**	1.83**	0.48^{x}	-0.37^{x}	0.97**	0.39
Loures	81	3.3	-0.91**	0.65**	-0.01	-0.02	-0.25**	-0.19^{x}
Oeiras	138	10.1	-1.15**	0.11	-0.16^{x}	-0.25**	0.38**	0.23*
Sintra	271	7.6	-0.92**	0.32**	0.17**	0.01	0.03	0.30**
V.F.Xira	65	8.3	-0.95**	1.04**	0.31**	0.11	0.21**	-0.08
Cascais	95	3.4	-1.12**	0.42**	-0.05	-0.03	0.26**	0.00
Mafra	40	4.1	-1.47**	1.70**	0.00	0.04	-0.30*	-0.01
Suburban	155	7.1	-1.06**	1.14**	-0.17**	-0.46**	0.38**	-0.01

South Bank

	N	% area	F1	F2	APriv	APub	TFacPub	ComSev
Almada	134	10.0	-1.08**	0.57**	-0.01	-0.22**	0.44**	0.34*
Barreiro	39	5.3	-1.74**	1.41**	0.87**	-0.21	0.44*	-0.26*
Seixal	173	7.7	-0.91**	0.51**	-0.47**	-0.22**	0.16*	-0.04
Moita	42	5.0	-1.05**	1.23**	0.28	-0.10	-0.19	-0.25*
Alcochete	20	8.8	-1.31**	1.31**	-0.28	0.04	-0.29^{x}	-0.31**
Sesimbra	66	8.7	-0.81**	0.51**	0.48**	0.30*	0.54**	-0.14
Montijo	32	2.8	-1.32**	1.13**	-0.09	-0.24*	-0.32**	-0.37**
Palmela	53	9.9	-1.33**	0.83**	0.26**	0.18^{x}	-0.15^{x}	-0.21**
Setúbal	86	12.4	-1.05**	0.71**	0.51**	-0.15^{x}	0.11	0.30*

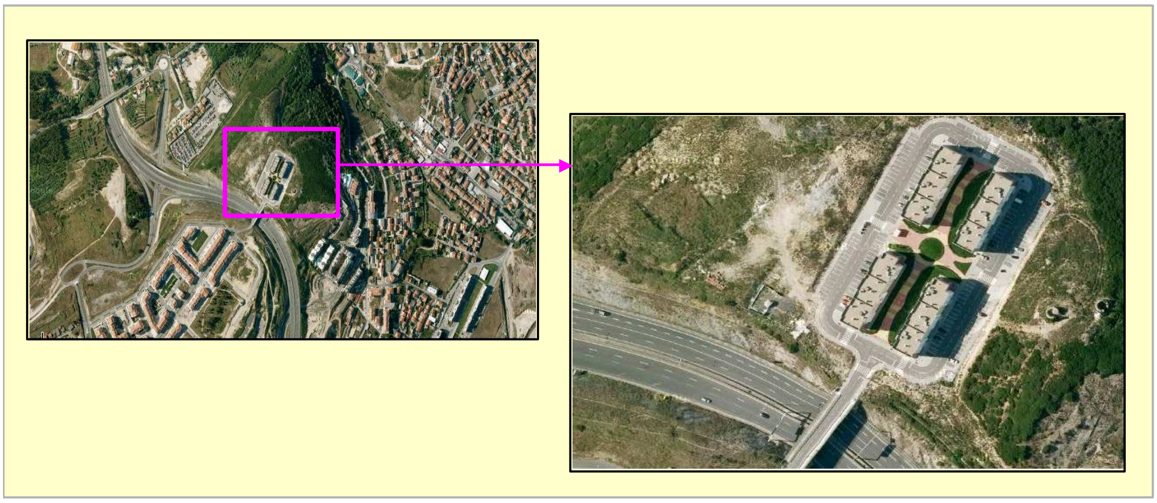
Notes: Significance (t-Student test): **1%, *5%, ^{x}10%. In each bank, municipalities are ordered by the proportion of workers commuting to Lisbon.

The values obtained for the standardized means of F1 (Age) and F2 (Qualification) factors provide strong evidence that newly developed areas are settled by young and qualified populations. In fact, the set of new areas have negative standardized means for the age factor in all 18 municipalities, which indicates that the mean value of this factor in these areas is lower than the mean value in the whole municipality. In the large majority of the cases, the mean of the new areas is one standard deviation below of the municipality mean. All the significant standard means for the qualifications factor are positive, which indicates that the mean of this factor is higher in the set of new areas than in the whole municipality.

While we would expect that new areas have lower levels of private transport accessibility (*APriv*) than other areas, as the main centres of employment are usually located in consolidated urban areas, this is contradicted by the results obtained in some municipalities, especially in the South Bank. These municipalities are served by the newly built second *Tejo* bridge and by the first section of the South Bank ring road (IC 32), which had an effect on the reduction of times of access to Lisbon and led to the urbanization of the areas that are most accessible to the new motorway junctions. On the other hand, the new areas in the majority of the municipalities in both North and South banks are at a disadvantage when it comes to public transport job accessibility (*APub*) and public transport time to urban facilities (*TFacPub*). In most cases, the significant standardized means of the public transport accessibility indicator are negative, while the standardized means of time to facilities are positive.

The standardized mean of the indicator of community severance (*ComSev*) in new areas is positive in densely populated municipalities (Lisboa, Oeiras, Amadora and Sintra in the North Bank; Almada and Setubal in the South Bank) and lower in dispersed, mixed urban and rural municipalities. The results of the first group of municipalities suggest that the development of new urban land in these regions is related with the location of transport infrastructure or industrial sites. This phenomenon increases the fragmentation of the urban space, since the infrastructure separates the new neighbourhood from existing areas. In fact, a close look at the location of the new areas reveals that they tend to follow the locations of motorways and do not integrate with the existing urban space **[Figure 4.2]**. It is also worth noticing that there is an inverse relationship between the values of the standardized means of the community severance indicator and of the qualifications factor across the different municipalities, suggesting that community severance influences the spatial sorting of people with different qualifications between old and new areas.

Figure 4.2: First came the motorway, then the new development



Source: Google Maps © 2011 Google-Imagery ©2001 TerraMetrics

A different way to assess the role of changes in land use in the distribution of mobility is to estimate the associations between indicators of mobility and qualification levels of the population within the set of newly developed areas. **Table 4.8** shows the correlations between the four indicators and the F2 factor (Qualification) in each municipality. **Map 4.3** synthesises the results, classifying the significant correlations in terms of advantages for individuals with higher and lower qualifications. We consider that there is an advantage for individuals with higher qualifications when the correlations of the qualifications factor with private or public transport accessibility are positive or when the correlations with public transport time to urban facilities and with community severance are negative.

In the North Bank, the population with high qualifications tends to settle in the areas providing the best conditions, especially in terms of job accessibility. The significant correlations between the qualification factor and private and public transport job accessibility are positive in almost all cases. The associations with community severance are also favourable to the higher qualified populations in the suburban region and in two of the municipalities (Oeiras and Sintra) that have a high number of newly developed areas and a high community severance mean value, as shown in **Table 4.7** above. In the South Bank, the associations tend to be favourable for low-qualified populations, as all significant correlations between the qualifications factor and private and public job accessibility are negative. In the municipalities where the correlations with job accessibility are significant, the qualifications factor is also positively related with public transport time to urban facilities. The only significant advantage for the high-qualified populations occur in the three central municipalities of the South Bank (Barreiro, Moita and Palmela), where the qualifications factor is negatively correlated with time to urban facilities.

As in the analysis of other issues in this dissertation, these results show the differences in the relationships between mobility and socio-economic factors in different parts of the metropolitan area. While the major differences are between the North and South banks, the location of the municipalities in terms of centrality is also relevant. Evidence of significant relationships is concentrated in central and suburban regions. The peripheral municipalities (Mafra in the North Bank and Alcochete, Sesimbra and Palmela in the South Bank) show weak evidence of relationships between qualification levels and indicators of mobility.

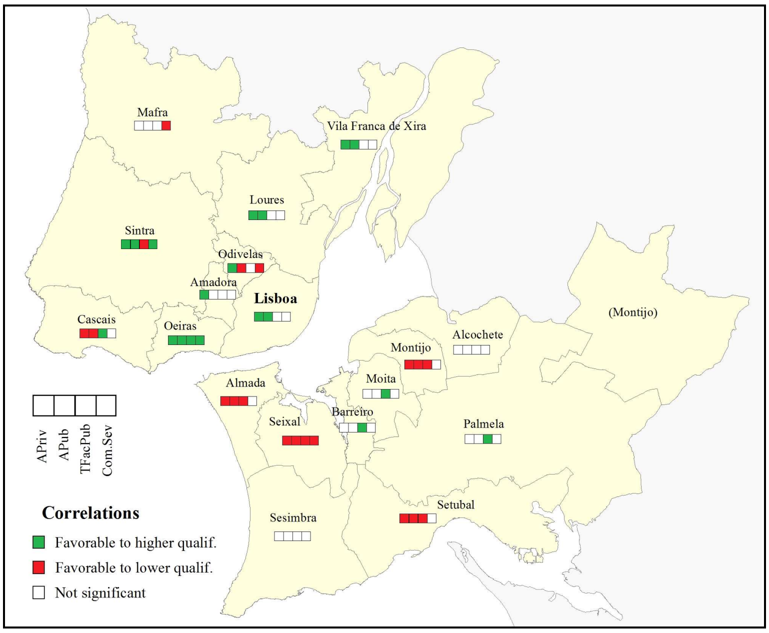
Table 4.8: Correlations between mobility and qualification levels in new areas

	APriv	APub	TFacPub	ComSev
Lisboa	0.22**	0.15^{x}	-0.08	-0.04
Odivelas	0.23^{x}	-0.43**	-0.09	0.37**
Amadora	0.52*	0.36	-0.06	0.02
Loures	0.44**	0.36**	-0.06	0.09
Oeiras	0.16^{x}	0.29**	-0.42**	-0.26**
Sintra	0.17**	0.16**	0.23**	-0.32**
V.F.Xira	0.28*	0.33**	0.02	-0.14
Cascais	-0.28**	-0.28**	-0.24*	0.03
Mafra	-0.04	-0.23	0.07	0.34*
Suburban	0.50**	0.40**	0.01	-0.22**

	APriv	APub	TFacPub	ComSev
Almada	-0.21*	-0.43**	0.36**	0.09
Barreiro	0.25	0.18	-0.29	0.26
Seixal	-0.24**	-0.29**	0.20**	0.20**
Moita	0.20	0.22	-0.40**	0.12
Alcochete	0.11	0.19	-0.17	0.00
Sesimbra	-0.06	-0.11	-0.01	0.00
Montijo	-0.31^{x}	-0.53**	0.41*	-0.02
Palmela	0.04	-0.10	-0.53**	-0.05
Setúbal	-0.25*	-0.25*	0.37**	0.05

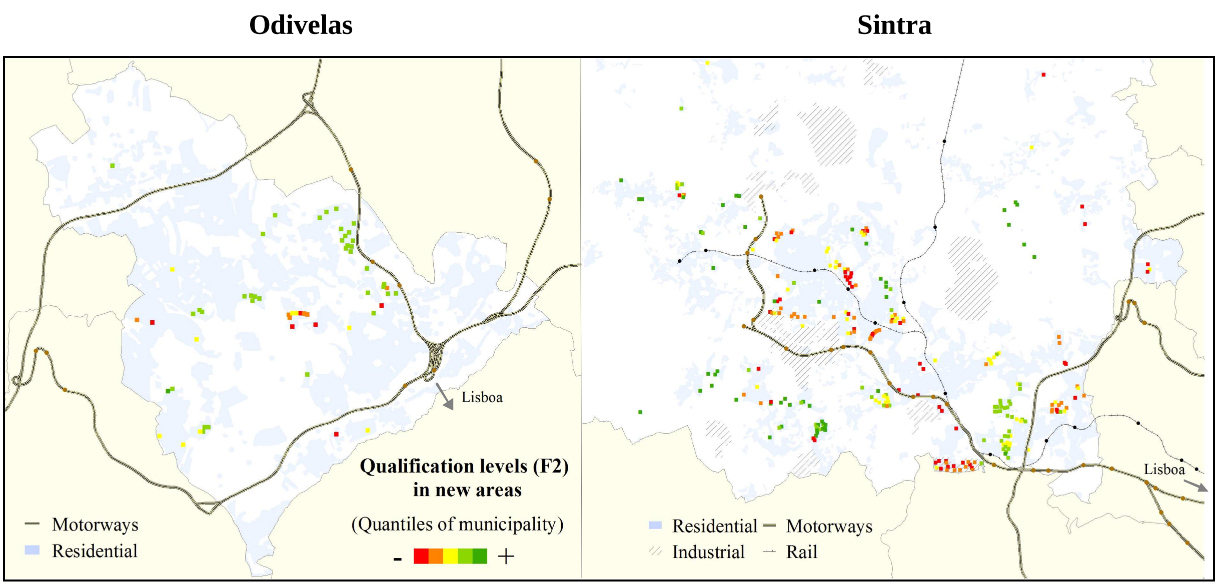
Note: Pearson correlations. Significance: **:1%. , *:5%, $^{x:}$10%

Map 4.3: Spatial differences in relationships between mobility and qualifications in new areas



The cases of the two municipalities showing more complex patterns are illustrated in the map below and suggest the existence of trade-offs between the sorting of the populations with different qualifications among neighbourhood with different characteristics. In the case of Odivelas, there is a concentration of high-qualified populations around the areas near the new motorway junctions, which offer high private transport accessibility. These areas are more affected by community severance and did not benefit from improvements in public transport accessibility. In the case of Sintra, the developments with high concentrations of low qualified population have limited inter-neighbourhood pedestrian mobility, due to their location between motorways and industrial sites. On the other hand, there are high concentrations of high-qualified population in areas with lower population densities, which are not affected by barriers to pedestrian mobility but are farther from the local centres, where urban facilities are located.

Map 4.4: Patterns of settlement in new areas according to qualification levels



To sum up, the results add to the evidence on the importance of private transport accessibility in the spatial sorting of the different groups, comparing with public transport and pedestrian mobility. Younger and more qualified populations are disproportionately represented in the population moving to newly developed areas. The advantages of these areas relative to existing areas are greater when considering private transport accessibility. Within the set of newly developed areas, most of the significant correlations between mobility conditions and qualification levels are also found for the indicator of private transport accessibility, although the sign of the correlation is different in the North and South banks. Public transport accessibility plays a less important role in the choice of residence location between old and new areas and among the new areas. In fact, most of the new areas have worse conditions in terms of public transport than the existing areas. The correlations between qualification levels and public transport accessibility or public transport time to urban facilities are significant in some municipalities but tend to have the same sign and be less strong than the correlations for private transport accessibility. The role of community severance is mixed, as there are differences among municipalities in terms of the conditions in new areas comparing with old areas and in terms of the associations between qualifications and community severance within the new areas.

4.5. The dynamics of transport inequality

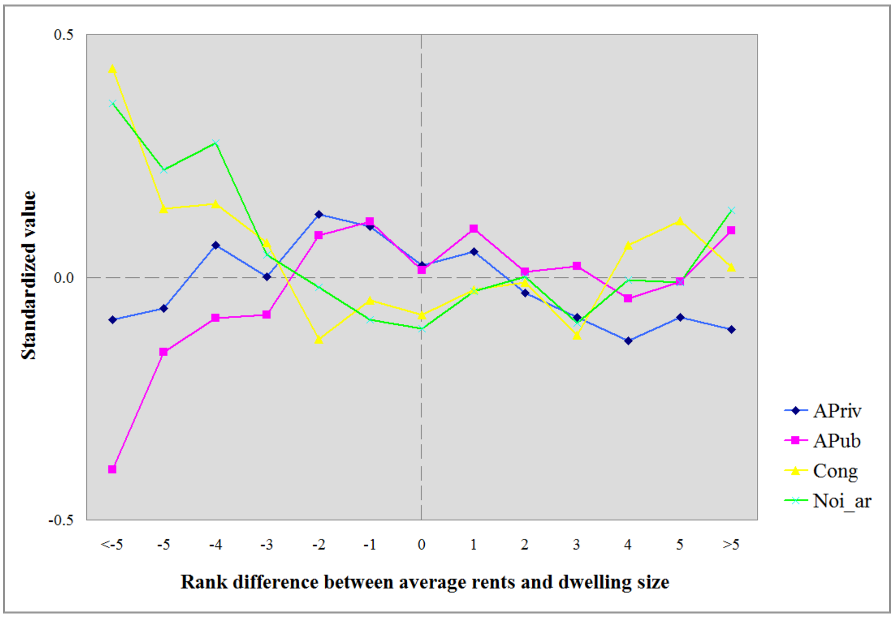
The analysis in this chapter provided some insights on the relationships between issues of mobility and changes in the social structure of the neighbourhoods. The assumption was that households' location decisions are sensitive to those issues. However, causal mechanisms linking the two kinds of changes are not explicit in our models. For example, canonical correlation models do not make assumptions on the nature of dependence between the two groups of variables, which are treated symmetrically. The observed statistical relationships may therefore be explained by factors other than household residence location. In fact, the distribution of accessibility and pedestrian mobility reflects decisions of the policy-maker, who may consider the social characteristics of the populations affected by transport policies. Some authors argue that inequalities in the spatial distribution of noxious infrastructure are product of both biased political decisions and re-adjustments in the population living in the affected neighbourhoods [Richardson *et al.* 2010]. The influence of political factors in transport planning will be treated in the next chapter, but it is pertinent at this stage to discuss the alternative hypothesis, that changes in accessibility and pedestrian mobility influence the distribution of socio-economic groups. We first focus on the role of social differences in preferences and ability to pay in household location decisions and then describe the influence of urban policies on those decisions.

Market processes and household preferences

The identification of market processes leading to the unequal distribution of levels of mobility among different groups is policy relevant, as different perspectives may apply regarding the fairness of those processes. For example, one may consider inequalities as fair if they are the outcome of choices made in pure and perfect markets. However, these characteristics do not necessarily apply to most housing markets. In general, the spatial sorting of social groups among neighbourhoods with different mobility characteristics depends on two conditions: the efficiency of the housing market in valuing those characteristics and the differences among groups in terms of preferences and ability to pay for them.

The hypothesis that the housing market capitalizes changes in neighbourhood attributes has been assessed empirically in cities around the world. In suburban areas, housing prices and rents tend to be positively associated with private and public accessibility, a result also found in the AML [Martinez and Viegas 2009]. However, this association is not always found for other neighbourhood attributes and in the central parts of metropolitan areas, where a variety of factors influence housing supply and demand. The case of Lisbon is illustrated in **Figure 4.3**, which shows the relationship between housing rents and four of our mobility indicators in 2001. The data on average rents per enumeration district was extracted from CML (2009a, part V)[38] and consists of 10 classes ranked in ascending order. We calculate for each district the difference in this rank and the rank of average dwelling size, extracted from the census data and based on classes with the same number of observations as the classes of rents. The chart shows the average of the four indicators for each rank difference. As expected, districts with the lowest rank difference between rents and dwelling size have the highest indices of noise exposure around the neighbourhood (*Noi_ar*) and congestion (*Cong*) and the lowest indices of private and public transport job accessibility (*APriv* and *APub*). Higher rank differences correspond to improvements in these indices only until a certain level, above which the relationships change sign or become weaker. This probably reflects the influence of demand for office space in the areas with the highest concentration of business, explaining the above-average levels of congestion and noise in the areas with the highest rank differences. These relationships suggest that inter-neighbourhood differences in some dimensions of mobility are not always reflected into housing rents.

Figure 4.3: Housing rents and mobility indicators in Lisbon (2001)



[38] The results obtained for the case of housing prices are similar to those obtained for rents.

It is also difficult to assess the relative importance of differences in preferences and ability to pay for each single dimension of mobility in the spatial sorting of social groups. Households may choose neighbourhoods with a given characteristic because of the value they attach to it or simply because it is correlated with another characteristic that they value more. This question is relevant in our case because we found that changes in one dimension of pedestrian mobility (exposure to noise) tend to be correlated with changes in private transport accessibility. In Lisbon, improvements in noise exposures correlate positively with improvements in accessibility, while in the suburbs the correlation is negative. The fact that only the first case is associated with changes in the qualifications structure of the population may or may not be explained by differences in preferences and ability to pay for local environment quality. The results of Arsénio *et al*. (2006) and Martínez and Viegas (2010) confirm the hypothesis of self-selection of residential location choice in Lisbon and in the suburbs respectively: individuals with higher marginal values of local environmental quality tend to live in areas with better environmental conditions. A factor analysis of a survey of household residential preferences has also found that preferences over local environment issues explain the highest part of differences in the sample [CML-DMPU 2004b p.96]. However, this factor includes noise pollution alongside the availability of car parking spaces, which suggests that issues of accessibility contribute to the formation of preferences over local environmental quality.

We also need to consider the time scale of the hypothetical adjustment between levels of accessibility or pedestrian mobility and neighbourhood composition. The housing market may not capitalize immediately changes in neighbourhood attributes. Household relocation decisions are also restricted by imperfect information and moving costs. Usually, relocation is only considered after a minimum threshold of housing dissatisfaction is reached. Therefore, small variations in neighbourhoods' attributes may not lead to neighbourhood social recomposition within a relatively short period. The changes observed within this period may disguise the effect of processes operating at a larger temporal scale, as at a given moment, some neighbourhoods will be at equilibrium and others in transition. In that sense, the restriction of our analysis to the relocation movements in the last five years of the period between censuses may not be a disadvantage, as the majority of the transport projects were implemented in the first five years, allowing for a sufficient time lag in order to observe their effects on the spatial sorting of different groups.

A final aspect is that the indicators of accessibility and pedestrian mobility considered in our analysis measure levels of potential mobility, as they are attributes of places and not of the population living in those places, who realize that potential to different degrees. Individuals may respond to changes in accessibility or pedestrian mobility not by changing their residence location but simply by changing their level of mobility, for example, by changing their daily destinations or travel modes. For example, there is evidence that residence location, employment location and commuting decisions are jointly determined [Van Ommeren 2000], with individuals balancing housing prices, wages and commuting costs. Levels of pedestrian mobility also influence the probability of walking to work and the number of total walking trips [Saelens *et al.* 2003, Rodríguez and Joo 2004]. The spatial sorting of social groups will then depend on differences in their assessment of the "optimal" levels of accessibility and pedestrian mobility, considering their prices (implicit in housing prices) and the utility they derive from them.

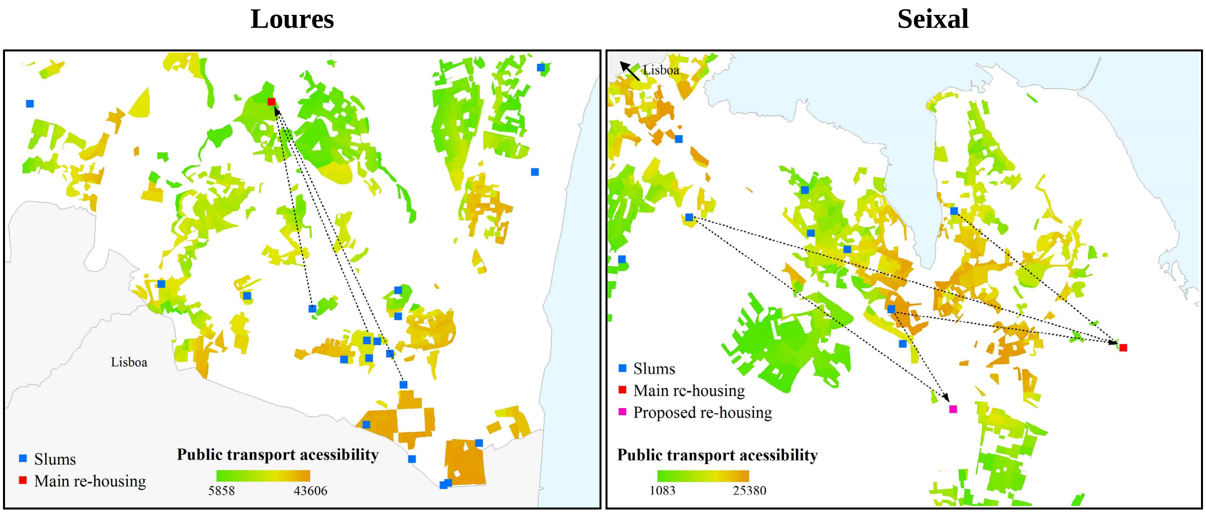
Urban policies

Urban policies often restrict or influence the households location decisions, contributing to the spatial sorting of the different groups. For example, land use policies may reinforce the social patterns of settlement in newly developed areas analysed in Section 3.4. In fact, the separation between "high density" and "low density" residential areas in municipal master plans leads to the homogeneity of the housing built in each area and defines the structural characteristics of the properties that are built on new urban land, including type of building, size of dwellings, gardens and car parking. These factors determine the socio-economic composition of the population who moves to the newly developed areas and may reinforce the social distribution of levels of mobility, if differences in the structural characteristics of the properties correlate with the desirability of the neighbourhoods in terms of accessibility or pedestrian mobility.

The regeneration of run-down areas may have similar effects on the spatial concentration of some social groups and on the distribution of levels of mobility, if the policy involves simultaneous changes in both housing and neighbourhood attributes. For example, in the case of Lisbon, the rehabilitation of several neighbourhoods in the historical areas involved the restoration of old houses and a simultaneous improvement in pedestrian mobility through the implementation of car traffic restriction policies, leading to a significant reduction of the proportion of low-income populations and racial minorities [Salgueiro 1994, p.83, Mendes 2006].

Household relocation may also be the direct effect of urban policies, such as the clearance of slum areas and rehousing of its population. These policies may have an effect on the overall distribution of levels of mobility across the different social classes, as they affect the conditions of the most income-deprived sections of the population. The clearance of a slum area is often related to past or future improvements in the accessibility of those areas, which benefit the populations moving to the cleared areas or who live or move to areas nearby. At the same time, the population of the slum may be rehoused in locations with worse accessibility and pedestrian mobility levels that the slum areas. **Map 4.5** illustrates the effects of slum clearance in two municipalities in the AML. In both cases, rehousing sites are isolated from other population concentrations, thus having lower public transport accessibility and poorer pedestrian mobility than the original locations of the population.

Map 4.5: Location of slums and rehousing sites



Note: Location of slums in 1993 (Data from CET 1992 and CM Seixal 2008). Main rehousing sites only.

Conclusions and further considerations

The main question analysed in this chapter was whether changes in the location of the different social groups are related to changes in the attributes of the different neighbourhoods in a city, comparing the role of several dimensions of accessibility and pedestrian mobility. We saw that private transport is the main driver of neighbourhood recomposition, although there are some differences between the cases of the central region (Lisbon) and the suburban region. In Lisbon, changes in qualification levels are mainly associated with simultaneous changes in private transport job accessibility and in pedestrian mobility; while in the suburbs, public transport job accessibility and congestion are more relevant. In both areas, changes in accessibility or pedestrian mobility do not have a noticeable impact on the distribution of age groups. The development of new urban areas tends to accelerate the overall adjustment process of individuals with different qualification to differences in accessibility levels, as individuals with high qualifications tend to settle in the areas offering better accessibility. The associations between qualifications and pedestrian mobility in newly developed areas are relatively weak.

The main contribution of this analysis to the existing literature was the assessment of the role of pedestrian mobility in neighbourhood recomposition, when included in models controlling for accessibility and changes in other neighbourhood attributes. The change in community severance and exposure to noise for pedestrians are significant in the explanation of the probability of neighbourhood recomposition, while exposure to noise is also related to the change in the qualification levels in the neighbourhoods where that change is more relevant. Another contribution to existing knowledge is the confirmation that the spatial variability in the effects of mobility on household location already tested for other dimensions of mobility also applies in the case of the aspects of pedestrian mobility that are restricted by motorized transport. As pointed above, the role of these aspects in neighbourhood recomposition in Lisbon and in the suburbs differs considerably, while the analysis of the patterns of settlement in newly developed areas also shows differences among municipalities with different levels of centrality. The processes that contribute for the adjustment of social groups to changes in pedestrian mobility then operate in different subsets of the metropolitan area and are felt at different spatial scales. This result confirms the necessity of attending to the spatial scale of public polices that address inequalities in the distribution of pedestrian mobility.

There are some caveats to the analysis that are worth noting. The reliance on area-based data prevents the modelling of households' location decisions as an economic problem, considering the available choice set of neighbourhoods, the price of each neighbourhood attribute (as reflected in housing prices or rents) and the balance between preferences and budget restrictions. In addition, households' location decisions do not depend only on neighbourhood attributes but also on the structural characteristics of the properties available in the market. If these characteristics are not correlated with neighbourhood attributes, they have to be considered as an additional element in the modelling of location decisions. Relocation also depends on the characteristics of the population, including age and personal factors such as life situations, number of workers in the household, lifestyles and general preferences over living in centres or suburbs or over the use of transport modes.

The role of location is in itself complex. Neighbourhood characteristics that were omitted in our models but may be relevant for household location include for example the quality of local schools, crime and natural factors such as climate or slopes. Places are "composite goods" with several characteristics and residence location may be subject to hierarchical choice decisions, the effect of which was not captured in our analysis, which was based on latent variables that are correlated with more than one characteristic. The main question left to answer is therefore whether households choose first a broad area in terms of a given characteristic and then choose a particular neighbourhood within that area based on another characteristic. The analysis of this question would help to disentangle the role of private transport accessibility and pedestrian mobility in the spatial sorting of social groups, as they integrate the same vector of neighbourhood change in both of our canonical correlation models.

The analysis in this chapter provided a further understanding of the distribution of the local benefits and costs of transport in the AML, complementing the analysis of the first two empirical chapters by considering alternative hypotheses for the relationships between temporal changes in the variables of concern. The analysis so far has not considered, however, the implications of holding specific principles of distributive justice in face of the actual alternatives and feasibility constraints available to the policy-maker at the moment of planning new transport infrastructure or designing traffic policies. These aspects will be considered in the following chapter.

Chapter 5

Incorporating equity in transport planning

Empirical studies addressing issues of spatial equity in transport usually assess the distributive outcomes associated with a set of projects implemented in the past. The objects of distribution are the physical units of the effects of those projects, while the principles of distribution are implicit in the specification and interpretation of the results of statistical models. In most cases, the researcher is interested in the hypothesis of disadvantage of certain groups identified as vulnerable or at disadvantage in other spheres. The analysis then compares the distribution of the effects between those groups and the rest of the population. This approach differs from the methods commonly used by policy-makers at the planning stage, which are project-based and as such do not necessarily integrate concerns on broad societal issues such as equity.

Unlike in the study of overall patterns of inequality, the integration of equity in project assessment must make explicit judgements about the distribution of different effects among different groups. There are trade-offs between distributive outcomes, as advantages for one group in the distribution of one effect may compensate disadvantages in the distribution of another. There is also a need to define the extent to which the achievement of one distributive outcome compensates for losses in efficiency, that is, the variation of welfare across the population affected by the project. A positive effect on the welfare of one group may not be socially desirable, if it implies a disproportionate negative effect on the welfare of another group. In sum, project evaluation requires the identification of principles of distribution and their incorporation of these principles into a measure of the social value of the project.

The identification of society's views on distributive justice can be inferred from surveys to the public [Atkinson *et al.* 2000] or from previous choices made by the policy-maker [Brent 1979, Nellthorp and Mackie 2000]. The theoretical implications of using different principles of distributive justice have been extensively discussed in the transport literature [Khisty 1996, Church 2001, Litman 2011], while a growing number of empirical applications have analysed specific transport policies. This literature is briefly reviewed in Section 5.1 of this chapter. In general, equity concerns have been incorporated in project assessment by using inequality indices or by attaching distributional weights to the effects of the project on different social groups within a measure of the overall net benefit of the project.

One common hypothesis of existing work is that project evaluation does not separate social judgements on distributive issues and on welfare valuation[39]. However, transport projects are composite goods, whose components affect individual welfare in different ways and to which society may assign a different "value of use". Project evaluation then depends on judgements regarding the value of those components. The use of money as a common measurement unit allows for a single judgement only, the one implicit in the set of assumptions of the methods used to translate welfare changes into money, which are usually based on the individuals' stated or revealed preferences. The consideration of the implications of using alternative valuation methods is especially relevant for issues of pedestrian mobility, because there is little available evidence on its monetary value and because needs for pedestrian mobility are often unrecognized.

The main objective of this chapter is to add to previous knowledge by analysing the implications on project evaluation of holding different views not only on distribution but also on valuation. This involves testing different assumptions on the trade-offs that have been analysed throughout this thesis: between the welfare of different social groups and between welfare associated with accessibility and with pedestrian mobility. These assumptions respect the degree of attention towards vulnerable groups and the relative value of use of accessibility and pedestrian mobility. We analyse this question for two types of project evaluation: the determination of the optimal alignment of a new road link and the assessment of the social desirability of traffic restriction policies, using as case studies two recent proposals in the Lisbon Metropolitan Area.

In the first case study (Section 5.2), we include community severance as a factor of cost in the choice over the best route alignment for a new road in the west corridor of access to Lisbon. We test alternative assumptions about the value of community severance when compared with the financial cost of the project, and about the aggregation of changes in community severance across areas with populations with different qualification levels. The method used is to find the optimal route for different values of two parameters, one converting community severance into monetary units and another defining distributional

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[39] While evaluation means the comparison of the relative merits of alternative states of affairs, valuation refers to the comparison of different objects in terms of a common unit of measurement.

weights, which are attached to changes in community severance affecting populations with low qualifications.

In the second case study (Section 5.3), we analyse the trade-offs between valuations of changes in time to work and pedestrian exposure to noise and evaluations of the respective redistributive effects, in the context of traffic restriction measures in Lisbon city centre. We test alternative assumptions about the relative value of the two types of changes and about their aggregation across areas with populations with different age structures and qualification levels. The approach is to compute the combinations of three parameters that produce a positive net value for the project. One parameter converts changes in time to work and changes in noise exposures into the same unit and the other two define distributional weights, attached to changes in time to work for populations with low qualifications and to changes in noise exposures for the elderly or for populations with low qualifications.

Our second contribution to existing knowledge is the analysis of the compatibility between the assessment of projects based on distributive criteria and the assessment made by a policy-maker who attends to his own political interests. Empirical studies have proved the influence of political factors in transport policy [Boschken 1998, Castells and Solé-Ollé 2005] and in environment policy [Brooks and Sethi 1997, Earnhart 2004]. These studies tested the existence of political bias by analysing patterns arising from a series of past decisions. We add to this literature by exploring the implications of political bias in the evaluation of individual transport projects. The objective is to compare socially and politically optimal decisions, for different possibilities about the level and nature of political bias. We reassess the two case studies, assuming that distributional weights are attached according to the political characteristics of the populations affected by the project, comparing the results with the ones obtained when weights are attached according to their vulnerability. This topic is developed in Section 5.4.

The goal of the analysis is not to assess in detail all the factors involved in the construction of transport infrastructure and in the evaluation of transport policies, but to assess the effects of holding alternative views on the distribution of different effects on different groups of concern. The genesis of the two projects chosen as case studies is near the last population census (2001). As such, the assessment will refer to a hypothetical moment of decision in 2001, considering the spatial distribution of the population as given by the census data and the future transport network as figured in the national road plan and municipal master plans that were in effect in that year.

5.1. Equity concerns and transport appraisal

In this thesis, we are concerned about issues of equity regarding the relationships between the location of social groups and the spatial distribution of the positive and negative effects of urban transport. A simple way to include these concerns in the appraisal of transport projects is to disaggregate those effects according to the social groups affected. In the case of the local environmental effects, this assessment involves the identification of the areas affected by the project and the estimation of the socio-economic characteristics of its population. These characteristics can then be compared with non-affected areas, with the city average or with the population potentially affected by alternative proposals. This methodology, with roots on the work of Wadden *et al.* (1976), has been widely used since it was adapted to GIS-based data and procedures [Chakraborty *et al.* 1999, Chakraborty 2006]. A similar overlay method can be used to analyse the distribution of other local costs and benefits of the project [Forkenbrock and Sheeley 2004].

The information obtained with these methods can then be analysed alongside efficiency and other evaluation criteria. Equity concerns are often measured through inequality indices, such as the coefficient of variation and the Gini or Theil indices, and used as a criterion to compare different scenarios for a project. These measures can be applied to the distribution of "physical units" of the effects of the project [Martin *et al.* 2010] or to the distribution of changes in the welfare of the affected individuals [Maruyama and Sumalee 2007].

Inequality indices can also be included in the formulation of transport projects and policies, as an objective function or as a constraint in optimization procedures. The analysis can then compare the results obtained with the application of different principles of equity. Santos *et al.* (2008) studied the case of optimal network design, comparing networks that attend to levels of accessibility in low-accessibility areas and networks that attend to the inequality in the distribution of accessibility across all areas or across areas in the same region. Duthie and Waller (2007) approached the same problem using alternative environmental justice measures. Similar methods have been developed for the analysis of other transport policies. For example, Hay (1993) compared the application of different principles of equity in the determination of optimal levels of public transport provision in each area, while Sumalee *et al.* (2005) compared the optimal location for road pricing cordons, when considering efficiency criteria with and without equity constraints.

The limitations of using inequality indices in the assessment of the distribution of the effects of transport projects are that these indices are independent of the magnitude of the effects and of the characteristics of the individuals affected, preventing the analysis of equity concerns that may be attached to these aspects. An alternative is to use measures of the social value of the project, which aggregate the effects across all individuals. We can then address issues of equity by assigning weights to the effects of the project on different social groups. These weights may also depend on the magnitude of the effect, relative to initial levels or to some standard. The problem becomes complex, however, in the cases where there are multiple effects, as they need to be made comparable, by using a common unit of measurement. The assignment of distributional weights is then a subjective process, as it makes assumptions not only about the specification of the weights but also about the quantities to which these weights are attached.

A usual procedure is to assume that individuals are rational decision-makers and that their choices in the market place reveal their preferences. Welfare changes are then measured in monetary units and expressed in terms of willingness to pay for a marginal unit of a market good. A variety of methods has been devised to valuate individual preferences in the case of the several intangible goods redistributed by transport policies [Litman and Doherty 2009]. Welfare changes can then be treated as variations in income and integrated in a "social welfare function" that aggregates the welfare of all individuals measured in monetary units. This is the rationale of cost-benefit analysis, the most common method for project assessment. The social welfare function may integrate distributional weights, which measure society's marginal valuation of the welfare of individuals with different characteristics. The specification of the function usually includes an unknown parameter measuring society's degree of inequality aversion, the implications of which are studied by sensitivity analyses. This approach has been mainly used in the study of the distributive impacts of road pricing policies [Mayeres 2001, Suryo *et al.* 2007, Ramjerdi *et al.* 2008].

The problem of using monetary units is that if we accept that income has a diminishing marginal utility, then willingness to pay will depend not only on individual preferences but also on ability to pay, and the valuation will be biased towards the preferences of individuals with higher income. One solution to this problem is to attach weights to the willingness to pay of each individual, in order to arrive at a more accurate measure of individual welfare. This can be achieved by expressing weights as a decreasing function of relative income levels, corrected by the elasticity of the marginal utility of income [Pearce *et al.* 2006, Ch.15]. Equity concerns or degrees of priority to the welfare of some groups will then be implicit on the extent to which distributional weights go beyond the neutralization of differences in ability to pay [Hau 1987]. An alternative approach is to attach weights not to willingness to pay but to the physical units of the different effects of the transport policy, for example as part of the determination of their monetary values [Dodgson and Topham 1987]. This method allows for the inclusion of separate judgments on the distribution of each effect, while still expressing individual welfare in monetary units.

However, individual preferences may still depend on socio-economic status, even when they are not expressed in monetary terms. Some authors argue that preferences are partly endogenous and determined by the social context, to which individuals adjust [Elster 1983]. In fact, issues of accessibility and local environmental quality are often unrecognized by underprivileged groups [Lucas *et al.* 2001, p.34-35]. Qualification levels and socio-economic status also influence the levels of awareness about the health effects of exposure to roadside pollution and the perceptions that one's community is unduly exposed [Lercher *et al.* 2005]. Attention to these aspects requires valuation methods that are based not on individual preferences but on social judgements on the value of use of the different effects of transport policies. For example, Talen (1998, 2003) suggests a "spatial need index" for measuring the values of accessibility and pedestrian mobility at the local level. Another option is Multi-Criteria Analysis (MCA), which assumes that there are multiple criteria to evaluate a state of affairs. These criteria are assessed by a set of attributes not necessarily expressed in the same units. The most comprehensive application using this method is the Spartacus project [CEC DG XII 1998], which considers equity alongside other objectives in the evaluation of future transport and land use scenarios. Although this field has been expanding in terms of methodology [Thomopoulos *et al.* 2009], the emphasis has been on large-scale transport projects and on distributive issues at a regional scale, not including local issues such as pedestrian mobility.

In this chapter, we add to this discussion by analysing the implications of holding different perspectives both on the distribution of the effects of a project across social groups and on the valuation of those effects. We consider that society has preferences both on the distribution of accessibility and pedestrian mobility and on the relative value of use of both aspects. We then analyse the relationships between the two sets of preferences, drawing from the methods used in the previous literature. We assume that on societal preferences on values of use are expressed in the conversion of "physical units" of accessibility and pedestrian mobility into commensurate scales, while preferences for distribution are expressed as weights assigned to the effects on different groups within measures of the social value of the project.

Our emphasis on the analysis of the implications of alternative valuations is motivated by the fact that there is little consensus on methods to valuate pedestrian mobility, due to difficulties in the definition and measurement of benefits and costs. Pedestrian mobility also tend to be undervalued in transport planning, because it is usually taken for granted by policy-makers [Goodman and Tolley 2003] and because valuation studies do not consider all the relevant economic, social and environment aspects [MacMillen 2010].

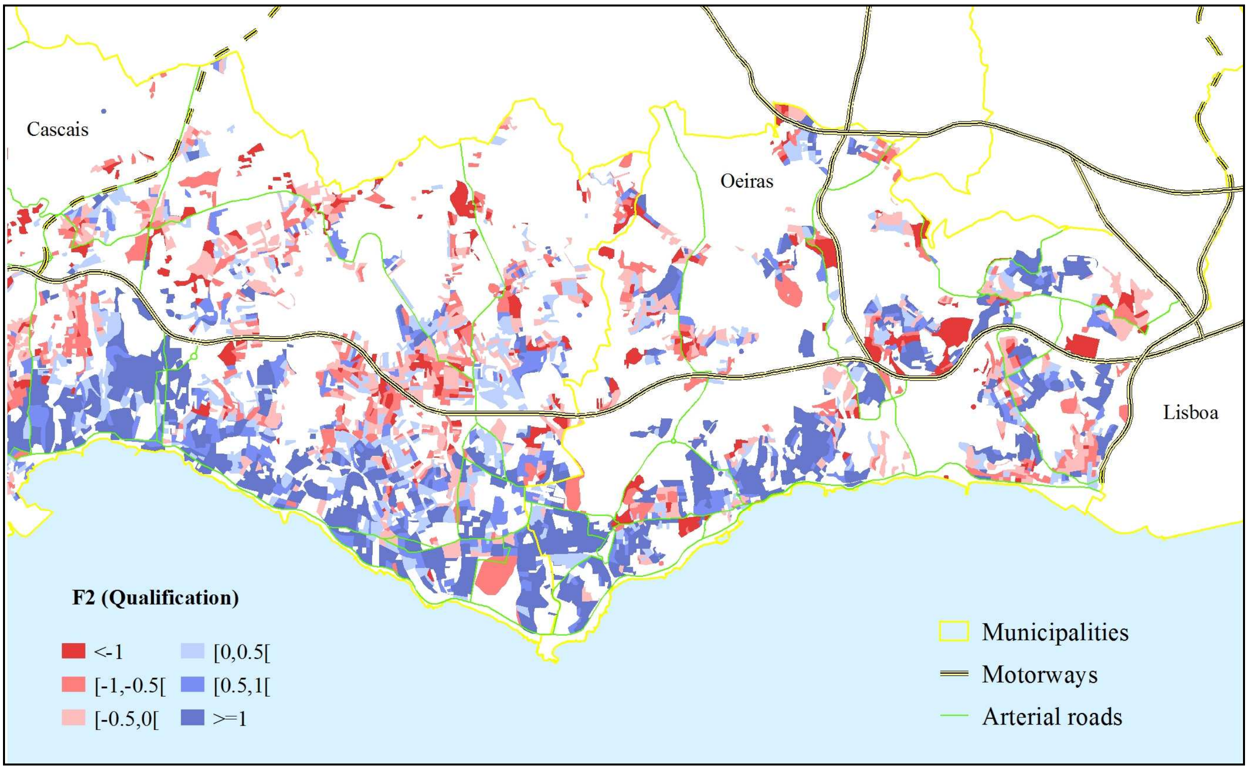
We assess distributive concerns based on the criterion of vulnerability, considering alternative hypothesis about the groups to which we assign the vulnerable status and about the degrees of attention to vulnerability. The concept of vulnerability is implicit in most of the social exclusion and environmental justice literature. Delbosc and Currie (2011) stress for example that the attention to vulnerable groups should have priority over the correction of overall patterns of inequality. While in the case of the distribution of accessibility, the assignment of the vulnerable status to individuals with low-income or low qualification seems consensual [Hine 2003, Lucas and Stanley 2009], the case of pedestrian mobility merits additional comments. The European Charter of Pedestrians' Rights states that "children, the elderly and the disabled have the right to expect towns to be places of easy social contact and not places that aggravate their inherent weakness" [European Parliament 1988, Art.III]. In their study of community severance, Clark *et al.* (1991) defends a broader criterion, based on the interaction of socio-economic, cultural and geographic factors. Vulnerable communities then include not only areas with high proportions of elderly people but also areas with low-income groups and racial minorities, who have special needs and preferences and live in close-knit communities often located in peripheral areas, resulting in a limited choice of destinations they can access on foot. In the analysis that follows, we then consider that populations with low qualifications are vulnerable to the deterioration of both accessibility and pedestrian mobility, while elderly people are vulnerable to the deterioration of pedestrian mobility.

5.2. Road planning

The objective of this section is to study the implications of attending to the social distribution of pedestrian mobility, in terms of the optimal alignment of a new road and of the relationships between efficiency and equity. Efficiency is assessed by the effects on several elements of cost of the projects, while equity is assessed by the distribution of the community severance effects across population with different qualification levels. The case study is a proposal for a new road linking Lisbon with the northern part of the two municipalities to the west (Cascais and Oeiras). This road is a project funded and planned at the municipal level and figures in the municipal master plans of both municipalities as "*Via Longitudinal*" (Longitudinal Road). The purpose is to create a new access corridor to Lisbon, improving the accessibility of an area that lacks a clear network of arterial roads and direct access to Lisbon [**Map 5.1**]**.** The new road will also ease congestion on the existing motorway crossing the middle part of both municipalities and contribute to a more rational distribution of road traffic at the entrance of Lisbon, when used in conjunction with a future arterial road in the western part of this city. One of the objectives of the project is to increase spatial and social equity, as there is a clear socio-economic and accessibility divide between the population in the areas served by the new road and the population in the coastal areas of the two municipalities, who have qualification levels above the metropolitan average and easy access to both motorway and rail services to Lisbon.

The geographic context of the *Via Longitudinal* simplifies the study of the trade-offs between changes in accessibility and pedestrian mobility and the need to attend to more than one group of concern. In fact, given the relatively narrow corridor between the existing motorway and the borders of the two municipalities, and the fact that the new road (not being a limited-access motorway) will be connected to all existing and future transversal links, differences in the road alignment will not have a substantial impact on the distribution of accessibility gains among each area. These gains will depend mainly on levels of private transport use. Furthermore, while the region has a population that is substantially and uniformly younger than the rest of the AML, qualification levels tend to be below average but variable among the different communities. Given these characteristics, the analysis can be conducted considering the deterioration of pedestrian mobility as the only redistributive effect, and its incidence over low-qualified populations as the only equity concern, according to the vulnerability status discussed at the end of the last section. The specification of qualification levels uses the vector of variables *F2* derived from the factor analysis done in Chapter 2.

Map 5.1: Case study: *Via Longitudinal*



The effects on community severance are the most suitable indicator of the costs of new road in terms of pedestrian mobility, given the geographic context. In Chapter 2 (p.56), we defined this indicator as the proportion of the population-interaction potential in an enumeration district's set of pedestrian destinations that cannot be reached on the street network unless crossing a barrier. In most sections, the *Via Longitudinal* will not be a physical barrier for the crossing of pedestrians. However, as the main longitudinal arterial road in the region, it will have multiple lanes and high levels of traffic and average speeds, limiting the mobility of pedestrians. In this part of the metropolitan area, the concept of community severance also captures a broad range of social concerns about local mobility, being an indicator not only of the effects of the new road on intra- or inter-community interaction but also of the changes in the accessibility to local urban facilities. These concerns apply not only to walking trips but also to trips by bicycle or local buses, as these trips will suffer delays and will be associated with increased accident risk and increased exposures to noise and air pollution at the intersections with the new road.

The use of community severance has also methodological advantages over other indicators of pedestrian mobility and local environment quality, as it depends only on the location of infrastructure and allows an unequivocal identification of the set of neighbourhoods affected when the road crosses a given point, as the new road will not cross any pedestrian route more than once[40]. We can calculate the effect on each neighbourhood by selecting all the routes that link the neighbourhood with its pedestrian destinations and that cross that point. This information is then used to estimate the proportion of population-interaction potential that those routes represent in the set of all destinations of the neighbourhood. The definition of pedestrian destinations and their population-interaction potential uses the methods presented in Chapter 2 and detailed in Appendices 2.3A and 2.4.

The objective is to find the route that minimizes the social cost of the project, considering the financial cost of construction and the cost in terms of community severance, on which alternative distributive concerns apply. The indicator of community severance in the "do-nothing" option is close to zero in almost all neighbourhoods, including those close to existing or planned motorways (See map in Appendix 9, p.266). We can then ignore perspectives of equity based on the distribution of relative increments of costs and focus on the absolute variation of the indicator and on concerns about the priority assigned to the vulnerable group. The social cost of the project in a given point *r* is defined as the sum of the construction cost of the road in that point (*s*) and the value of the severance effects across all affected enumeration districts (*i*) when the road crosses that point.

$$C_r = s + \frac{1}{v}\sum_i P_i * \Delta CS_{r,i} * Exp(-\varepsilon * F2)$$

We assume that the cost of construction (*s*) depends only on slopes, taken as proxy for the construction of tunnels, viaducts or bridges[41]. The cost is defined as 1 when the slope is 0, and increase 25% for each percentage increase in the slope[42]. The value of the community severance effects for the population living in the enumeration district *i* is the increase in the

[40] This property differs from the cases of exposure to noise (of individuals at home or walking around the neighbourhood), whose estimation depends on future traffic levels and on the dispersion patterns of noise emitted from different sections of the road.

[41] Watercourses are not included in the analysis, as all major rivers in the region run transversely and have to be crossed by all possible routes.

[42] We arrive at this value by assuming that the route alignment of existing roads in the metropolitan area minimizes the financial cost of construction. We then estimate the slope-weighted shortest routes for the whole set of arterial roads and motorways in the AML using different weight values and identify the weight value that

severance indicator ($\Delta CS_{r,i}$), weighted by the district population P_i and by an exponential function of the qualifications factor (*F2*) and an unobservable parameter ε measuring the degree of priority assigned to the areas where qualifications are below average. The value of the parameter *v* converts community severance costs to the same units as the financial cost of construction of the road in one point. This parameter reflects society's views on the value of use of pedestrian mobility, irrespectively of the group affected. The highest the value of *v*, the lowest is the value of the community severance cost relative to the financial cost. We assume that society's valuation of community severance is linear on its variations and that the distribution of the effects within each district is irrelevant.

The weight structure is defined asymmetrically, as it is not applied to the populations with qualifications above average (that is, $\varepsilon=0$ when $F2>0$)[43]. This assumes that community severance costs are always socially relevant, but this relevance increases when costs are borne by the less qualified populations, whom we consider vulnerable to losses in pedestrian mobility. The use of an exponential function for the distributional weights means that the degree of vulnerability increases more than proportionally as we consider populations with qualifications farther from the mean. For a given value of *v*, the utilitarian principle of distribution is represented by the case $\varepsilon=0$, corresponding to the minimum sum of financial costs and unweighted pedestrian costs. The higher the value we assign to ε, the higher the concern to the vulnerability of less qualified populations, that is, the higher the costs assigned to the community severance effects on the areas inhabited by those populations. The analysis is restricted to values of ε in the interval [0, 2][44].

The approach followed is to test the sensitivity of the optimal route alignment to the application of alternative judgements, implicit in the pairs of values assigned to the unobservable parameters ε and *v*. We compare the different routes in terms of the areas crossed and of statistics of several cost elements, using as a base of comparison the routes found for the utilitarian case and the planned route, as figured in the municipal master plans.

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yields the closest approximation to the actual routes.

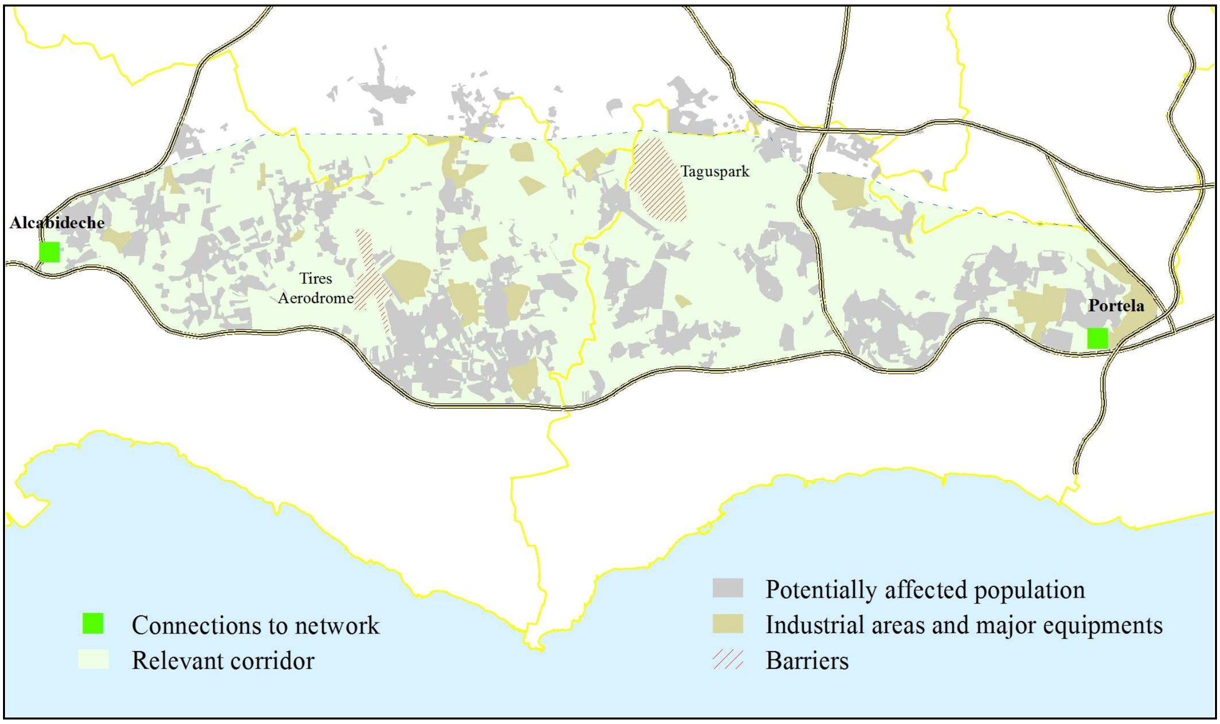
[43] This factor refers to the metropolitan area and not to the set of the two municipalities. This means that qualification levels are assessed in relation to a "general" standard, that of the metropolitan area.

[44] For $\varepsilon=2$, a district with a level of qualifications one standard deviation below the mean receives a weight of 7.39. As a reference, in the more familiar case of weights based on relative incomes raised to a variable exponent, if we follow the suggestion of [Cowell and Gardiner 1999, p.33] of using -4 as the lower limit for this exponent, the weight of 7.39 would correspond to an income level of around 60% of the mean income.

We assume that the formulation of the latter did not take into account the level or the distribution of community severance costs.

The estimation of the optimal routes uses Dijkstra's least-cost algorithm, implemented in ArcGIS 9.2 Spatial Analyst. The routes link the two future junctions with the existing network (given by the information in the municipal master plan) and are calculated over a cost surface modelled with GIS raster data with a resolution of 40m. The problem is also bounded by a set of constraints regarding the feasibility of each cell in the surface [**Map 5.2**]

Map 5.2: Elements for the estimation of optimal routes



The set of feasible areas is restricted to a corridor, based on the rationale of the project. This corridor is defined by existing or planned motorways[45], except in the north part, where it follows roughly the two municipalities' borders[46]. The enumeration districts potentially affected by the new road are the ones for which at least one pedestrian destination is only reachable by crossing a point inside the relevant corridor of analysis. We also assume that the new road cannot cross a set of areas inside the corridor, including the *Tires* Aerodrome, the

[45] The A16 motorway, which defines the western border of this corridor, opened in 2009. It is included in the analysis because it figured in the National Road Plan in effect in 2001 (our hypothetical moment of decision for the *Via Longitudinal*.)

[46] In the cases where the municipality borders are also the limits of residential areas, we allow for the possibility of the new road to bypass those communities, crossing areas north of the border.

Taguspark[47], and locations with cultural or environmental importance [IGP d2008]. Further restrictions are imposed on residential areas, industrial sites and major urban facilities, where the road can only use the space already accommodating arterial roads. This condition implies that in that space, the project corresponds to the upgrade of existing roads and not to the construction of a new road. We allow the same possibility in the space occupied by the three transversal motorways bordering or crossing the area, which is thus included in the feasible space for the new road.

Map 5.3 shows the set of optimal routes and **Figure 5.1** gives the pairs of values for ε and v that are associated with each route. In the middle section, all the estimated routes cross the same area, about 1km to the north of the area crossed by the project as planned. The consideration of community severance is decisive in this shift, as the routes cross through vacant land, which does not imply the separation of neighbouring communities, unlike in the case of the planned route. The role of different valuation and distributive concerns is only relevant in the sections close to the two extreme points, with three different routes found in each case.

In the eastern extreme, all utilitarian solutions (the ones obtained for $\varepsilon=0$) follow route A, regardless of the valuation of community severance costs (v). Small increases in the distributional parameter lead to solution B, which is similar to solution A. For relatively strong distributive concerns (high ε) and high values assigned to community severance (low v), the route appears slightly to the south (solution C), using the same space as the planned route and avoiding a highly populated and low-qualified community in the southeast extreme.

In the western extreme, each value of the distributional parameter is associated with two solutions, depending on the valuation parameter. The utilitarian solutions (solutions 1 and 3) use the space of the planned A16 motorway, which implies a lower number of affected neighbourhoods, as there are only a few neighbourhoods on the other side of the motorway (See **Map 5.1**). As in the case of the eastern extreme, a shift from the utilitarian solutions leads to a route similar to the planned project (solution 2). However, comparing with that case, the shift is achieved for smaller values of the distributional parameter, but requires a higher value assigned to community severance.

[47] The first sections of this office park opened in 1993. This area could accommodate the new road, but given its economic importance, it seems unlikely that plans for the new road (as devised in 2001) could have lead to a reformulation of existing built-up areas or to changes in plans for developing the remaining areas in the park.

Map 5.3: Pedestrian-optimal solutions for the *Via Longitudinal*

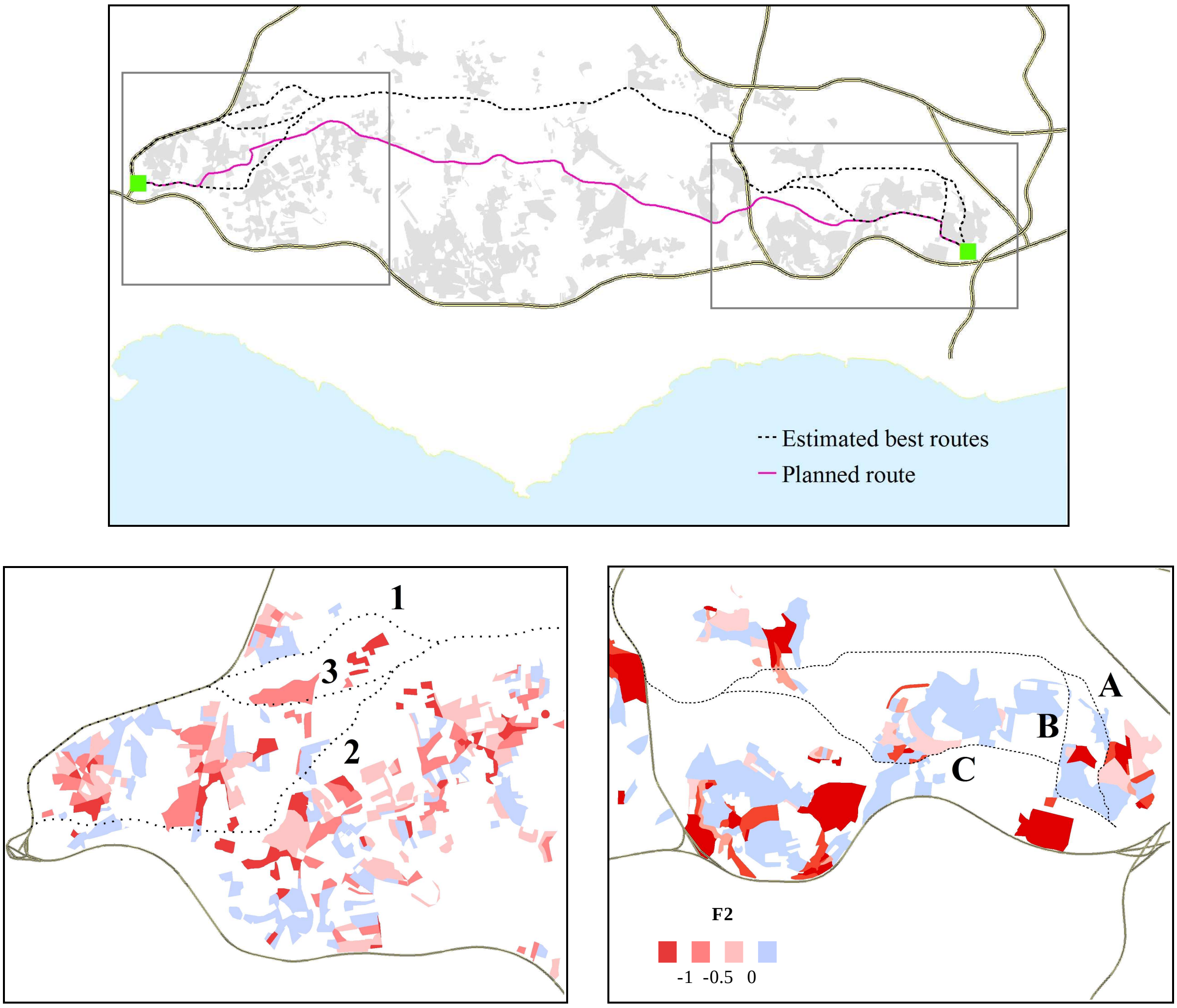
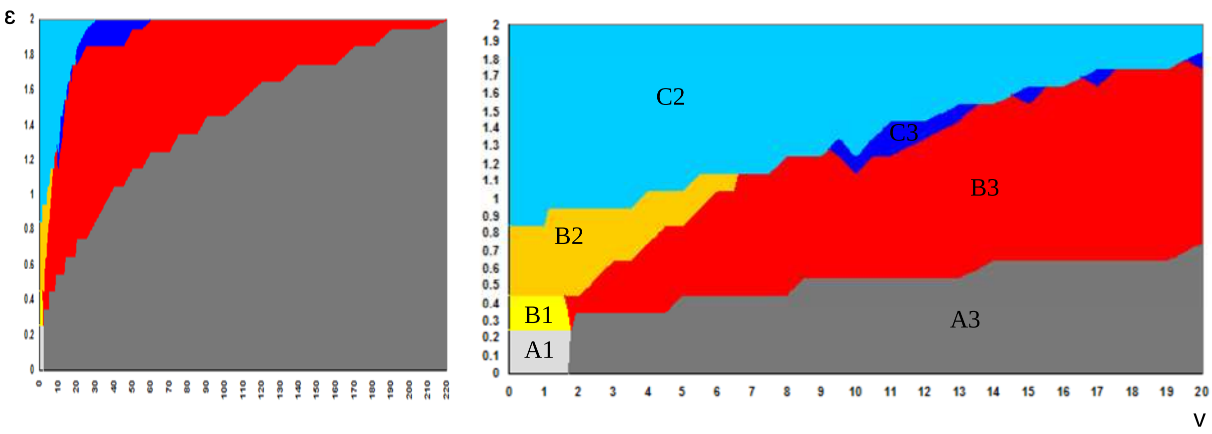


Figure 5.1: Pedestrian-optimal solutions: Project locus



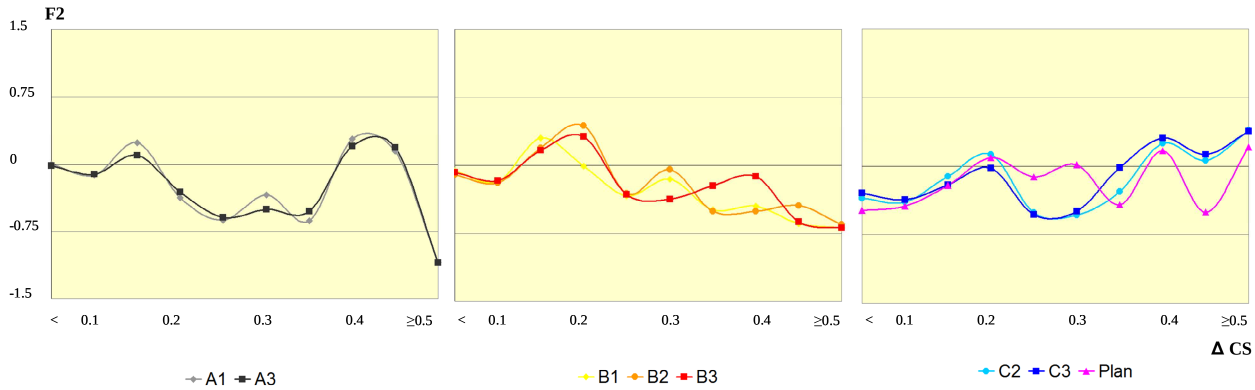
The differences between the optimal routes can be assessed by statistics of their aggregate costs and of the distribution of those costs. The left side of **Table 5.1** gives the slope-weighted length of the routes, the aggregate sum of the community severance effect across the region (weighted by population), and the average of the qualifications factor (*F2*) in the districts of the region (weighted by their population and by the severance effect). All the estimated routes have longer slope-weighted lengths but lower severance effects than the planned route, given the slight detour to the north to cross the least populated corridor in the region. While the effects of the planned route are almost neutral in terms of the qualification levels of the affected population (average of -0.07 for the *F2* factor), in all sections of the estimated projects, apart from section "C", the effect is higher in areas with less-qualified populations (average of *F2* below 0). This aspect reveals a gap between attending to proportionality in the distribution of the severance effects (which leads to the planned route) and attending to the aggregate sum of the effect (which leads to one of our estimated routes). The difference arises in this case because the middle sections of the planned and the estimated routes cross through different corridors, since at the two extremes the planned route is similar to the options with the strongest distributive concern. These differences between attending to proportions and to aggregate effects also add empirical evidence to philosophical doubts regarding the legitimacy of the proportionality criterion in the distribution of local environmental costs [Perhac 1999].

Table 5.1: Pedestrian-optimal solutions: Elements of cost

			Endogenous			Exogenous			
			Length x Slope	Pop x ComSev	F2 w.avg.	Time gain w.avg.	Land use (%)		
							Built	Agric.	Ecol.
Sections	West section	1	7359.3	2391.8	-0.46	0.13	10.2	3.9	6.7
		2	7996.6	2783.2	-0.33	0.14	36.2	9.6	34.9
		3	6570.2	2502.9	-0.44	0.12	13.2	3.9	19.8
	Middle		19386.8	1410.4	-0.49	0.25	2.4	2.8	13.8
	East section	A	10524.6	3621.0	-0.72	0.03	18.6	0	4.1
		B	10299.7	4835.0	-0.41	0.03	24.0	0	4.0
		C	9434.2	10699.2	0.26	0.08	54.4	0	13.1
Projects	Estimated routes	Min	35391.1 [C3]	7423.1 [A1]	-0.67 [A1]	0.09 [B3]	8.4 [A1]	2.3 [B1]	9.6 [B1]
		Max	37683 [B2]	14892.8 [C2]	0.08 [C2]	0.11 [C2]	22.5 [C2]	3.8 [C2]	18.8 [C2]
	Planned route		33661.1	18209.9	-0.07	0.14	25.4	16.7	24.2

The qualifications profile of the severance effects of each route is shown in **Figure 5.2**, which plots the average value of the qualifications factor (*F2*) for each value of the severance effect. The redistributive effect of including equity concerns in the project depends mainly on the road alignment in the eastern extreme. Only the "C" projects and the planned route have a profile that can be described as "progressive" (that is, severance effects rising with qualification levels). However, we can make different interpretations of the equity in the distribution of the severance effect, depending on the value of the effect we define as the acceptable minimum standard. For example, both "A" projects imply that the highest levels of severance (when the new road blocks more than 50% of the walking potential of a neighbourhood) will affect the districts one standard deviation below the qualifications mean (right side of first plot).

Figure 5.2: Community severance effects of estimated routes: Qualifications profile



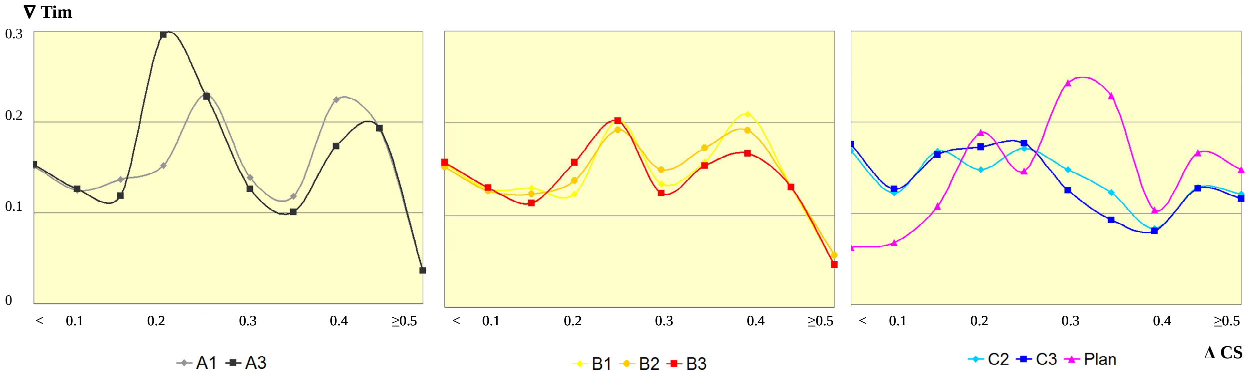
While the benefits in terms of increased accessibility did not enter the estimation of the optimal route, we can use information on their distribution as a criterion to assess the suitability of the routes obtained. The principle of distribution implicit in this assessment is that the allocation of costs should be consistent with the allocation of benefits of the project. We identify accessibility benefits as the gains in the average time to work for the workers living in each district, using the methods described in Chapter 2 (p.44) to compare the initial value (in 2001) with the value obtained when adding the new link to the private transport network[48]. The middle column of **Table 5.1** gives the average of the estimated time gains (in minutes) in the districts of the region, weighted by their working population and by the community severance effect. The highest value is obtained for the planned route. Within the set of estimated routes, the differences are slight.

Figure 5.3 shows the benefits profile of the distribution of severance costs of the different

[48] We suppose that bus services will not use the new road. This hypothesis is based on the analysis of the existing bus network in the region, as there are very few services using the existing motorway.

routes, plotting the average time gains in districts with different values for the severance effect. The plots resemble the ones obtained for the qualifications profile presented in **Figure 5.2**, as time gains and qualification levels are indirectly related via income level and private car use. The three plots of **Figure 5.3** are also slightly similar among themselves, as they represent differences in the three options for the eastern extreme, where time gains are small. The principle of distribution of costs according to benefit is only perceptible in the case of the planned route. The "C" projects are relatively neutral. In contrast, in the "A" and "B" projects, the highest severance costs will be borne by populations having the lowest benefits (right side of the plots). The preference for the option "C" over "A" and "B" will then be associated not only with a distribution of severance costs more favourable to the less-qualified groups (as seen in **Figure 5.2**) but also with a distribution of costs that is not inconsistent with the distribution of benefits.

Figure 5.3: Community severance effects of estimated routes: Allocation of time gains



The relative merits of each option can also be assessed by statistics of cost elements that were not included in the determination of the optimal routes (right side of **Table 5.1**). The first column gives the percentage of road length on built-up land, which is an indicator of the local environmental cost in terms of pollution exposures associated with increased traffic levels[49]. The other columns give the percentage of road length on land mapped in municipal master plans as areas with agricultural potential or subject to environmental protection. These indicators assess the economic and ecological opportunity costs of the new road. The analysis of these statistics shows that the planned route uses a higher percentage of all three types of land use, when comparing with the estimated routes. Within the set of estimated routes, the

[49] This statistic is also an indicator of construction cost savings, given the constraint placed on the crossing of built-up areas, which implies the reformulation of existing roads in detriment of the more expensive option of building a new road.

highest costs occur for the utilitarian (*A1*) and "quasi-utilitarian" (*B1*) solutions that are obtained with high relative values attached to community severance (low value for the parameter *v*). In other words, a project with (distributionally neutral) concerns for pedestrian mobility contributes to savings in the environmental or opportunity costs associated with project. In contrast, attending to both pedestrian mobility effects and distributive concerns (low *v* and high *ε*) leads to the highest land use costs (project *C2*).

These conclusions are relevant for road infrastructure planning in other semi-rural regions that are similarly heterogeneous in types of land uses and in the socio-economic structure of the different neighbourhoods. We showed that there are trade-offs between the attention to the social distribution of the severance effect and the achievement of other objectives, related with the aggregate level of the effect and with other environmental and economic costs. The implications of holding different views on the value of community severance also depend on the level of fragmentation of the residential areas and on the spatial distribution of the different groups. In our study area, the inhabited areas in the eastern region are relatively dispersed and their population is diverse in terms of qualifications. In this case, route alignments are sensitive to the distributional parameter, because there is a wide set of options regarding the areas crossed and the characteristics of the affected populations. However, the alignment is not sensitive to the valuation parameter because options with lower financial costs (assessed by the road length) have considerably higher aggregate severance costs, a trade-off that neutralizes variations in the valuation parameter. In the western region, the vacant areas are narrow and the qualification levels are relatively homogeneous. In this case, the alignment is less sensitive to the distributional parameter than in the eastern region, as the set of options is small. However, the alignment is sensitive to the valuation parameter, because options with lower aggregate severance costs have also lower financial costs. As such, shifts in the optimal route alignment only occur when assuming different relative values for the two types of costs.

5.3. Traffic restriction

This section extends the case of the previous section by relaxing some of its assumptions. The objective is to estimate the impacts of a traffic restriction policy on the social distribution of several dimensions of mobility (time to work and exposure to noise by pedestrians walking around the neighbourhood and on the way to work) among several groups of concern (elderly and low-qualified populations). We use the information on the distribution of these impacts to test the implications on the assessment of the policy's social value of holding different assumptions about the degree of priority attached to the groups of concern and about the relative value of use of accessibility and pedestrian mobility.

Traffic restriction policies are limitations to the connectivity or to the use of some links of the road network by certain modes of transport. The concept of "area-wide traffic restriction" refers to the case when a whole neighbourhood is closed to car traffic or to all motorized traffic, usually in city centres. The growing asymmetry between centres and suburbs has long been identified as an urban planning issue [Badcock 1984]. Policies to improve environmental quality and pedestrian mobility in central areas address one aspect of that asymmetry, as the local populations tend to be disproportionally exposed to road traffic's negative effects, due to higher reliance on walking and to exposures to high traffic levels. This aspect is especially relevant in continental Europe, where city centres have a high proportion of elderly and low-income populations. Traffic restriction can therefore increase the equity in the distribution of space between car users and pedestrians and address the needs of individuals who are vulnerable to the deterioration of pedestrian mobility. The measures can also affect positively the pedestrian mobility of people living in other areas but walking in the centre on their way to work or to shops and urban facilities.

Proposals for the application of these policies have had prominent place in the political agenda in the Lisbon Metropolitan Area, but have very rarely progressed beyond the discussion stage. The two exceptions are the city centre of Almada in the South Bank and some of the old neighbourhoods in Lisbon. The reluctance in the application of traffic restriction measures is linked to doubts on the nature of its distributive effects and on their effectiveness in reducing traffic levels and in achieving other objectives. In fact, car users may respond to the policy by reducing the number of trips, choosing other transport modes or using alternative routes. There is a welfare loss in all cases, either in terms of unfulfilled preferences or in the time lost using longer or more congested routes. Furthermore, if bus traffic is also restricted, the policy may affect disproportionately the accessibility of public transport users, due to the increase in interchange time or to the reduction in the available options. The effectiveness of the policy in decreasing traffic-related problems at the city scale is also open to debate, due to the changes in the distribution of traffic and to the increase in car parking space or cruising for parking at the fringes of the restricted areas. These changes may lead to an increase of traffic levels and congestion and contribute to the deterioration of the local environmental conditions of residents and workers in those areas. Finally, the nature of the effects of the policy on retail business and employment in the affected areas is also subject to controversy.

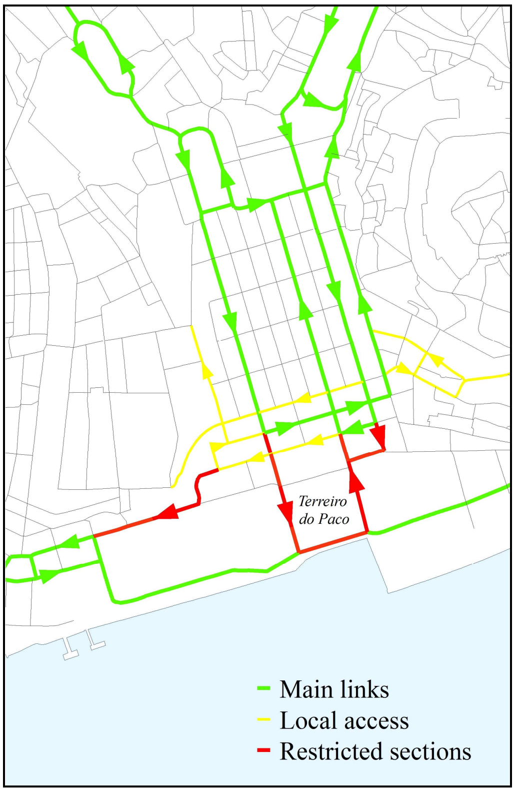
Our analysis focus on a traffic restriction policy proposed for the Lisbon city centre (*Baixa*). The traffic-related problems in this area arise from Lisbon's radial structure, as economic activity, employment and urban facilities are concentrated along two radial axes emanating from the city centre. This is aggravated by large traffic flows from other municipalities, which use a radial road network converging in Lisbon. The city centre is therefore crossed by a large volume of private and public transport traffic. This area has been steadily losing residents, while the densely populated and built-up neighbourhoods around it are inhabited by a rapidly ageing population. The maps prepared for the revision of the Lisbon Municipal Master Plan reveals that the *Baixa* is a collection of superlatives within the set of Lisbon's neighbourhoods: highest ratio of workers to residents, second highest number of jobs and retail businesses, highest proportion of vacant dwellings, origin or destination for the second highest number of trips, destination for the highest proportions of both non-work trips and public transport trips and highest number of buses per hour at both peak and off-peak times. The main square (*Terreiro do Paço*) is also one of the links with the highest congestion indices [CML-DMPU 2004a, p. 28-30, 51-52, 63-64, 68, 73, 103, 156].

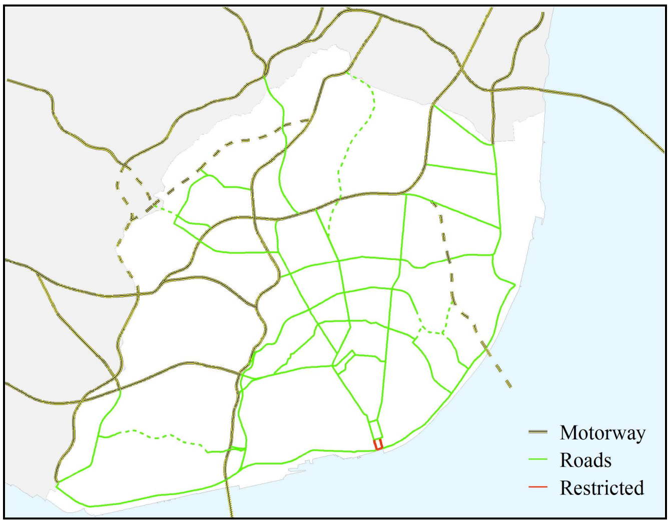
The proposal for restricting traffic in this area has suffered several modifications over the years. In the analysis that follows, we use the version contained in CML (2009b), which is described in **Map 5.4**. While the policy only restricts the connectivity of a couple of links, this ensures that car traffic will not be able to cross the city centre lengthwise or use the arterial road on the waterfront that currently links western and eastern parts of the city[50]. Access to the old neighbourhoods bordering the city centre is still possible (yellow links), while public transport routes remain largely unchanged. The policy is implemented in conjunction with the

[50] As a response to protests, in later versions of the policy, the waterfront side of the main square is no longer

increase of parking space, so that access to the city centre itself is still possible for car users. The main question lies therefore on the effects of the policy for users crossing the area to access other destinations, and on the political and social legitimacy of forcing these users to find alternatives. The proportion of crossing traffic has been one of the points of contention between the municipality and the automobile lobby, which have presented traffic studies where crossing traffic is estimated at respectively 74% and 35% of all traffic [CML 2008, CESUR 2009]. The right side of the map shows that the alternatives for this traffic are a series of circular itineraries, some of which are still at the planning stage (dashed). However, the existing circular roads are some of the most congested road links in Lisbon [CML-DMPU 2004a, p.103], while in the hilly, densely constructed areas closer to the river there are no viable alternatives. The motivation for our analysis is to add to this debate by studying the effects of the policy among different age and socio-economic groups, focus on aspects of pedestrian mobility. These aspects are subjacent to the policy's objectives but have not been assessed quantitatively.

Map 5.4: Case study: ***Lisbon City Centre Traffic Circulation Plan***



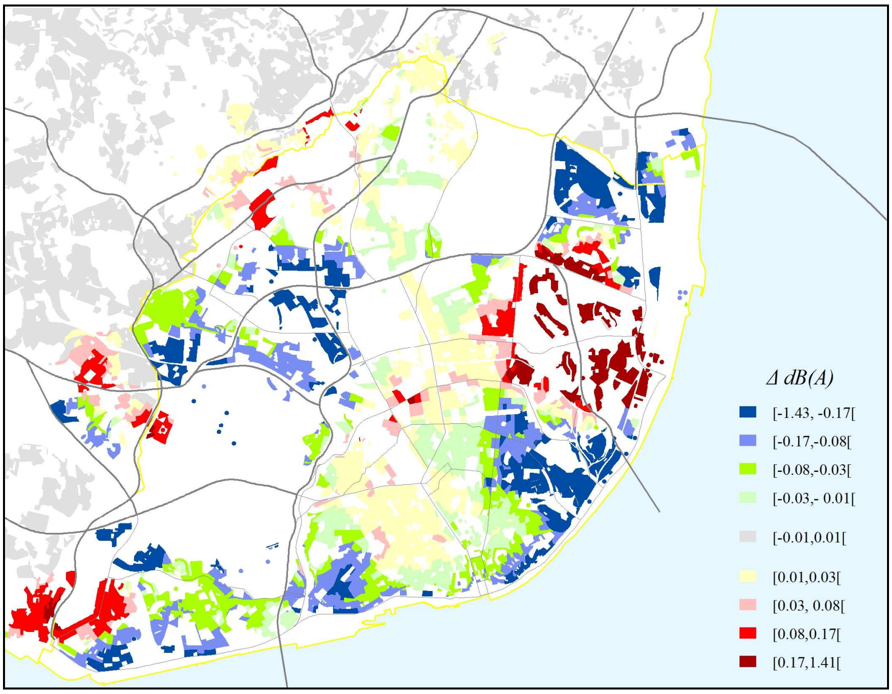


restricted to car traffic.

We compare the scenario in 2001 (genesis of the first version of the policy) with a hypothetical scenario after the policy is implemented, where the spatial distribution of the population is given by the 2001 Population Census, but the private transport network does not contain the restricted streets. We assume that the public transport network is not affected by the policy. We use the methods described in Appendix 6 and Chapter 2 to derive the changes in traffic levels and the changes in the indicators of time to work and pedestrian exposures to noise at the enumeration district level. We re-estimate car traffic levels that correspond to commuters by computing the fastest routes on the private transport network from every enumeration district to every centre of employment in the metropolitan area. The resulting traffic levels are assigned to each link of the network. Private transport trips with other purposes are also re-estimated and the resulting traffic flows are added to commuting traffic. In the cases where the final destination is the city centre, the trips are restricted to end at one of the existing or proposed car parks, forcing the rest of the trip to be made on foot. The traffic levels are used to compute congestion and noise levels. This information is then used to estimate average time to work and pedestrian noise exposures around the neighbourhood and on the way to work. For each district, we compare the values of these indicators obtained in the 2001 and in the scenarios after the policy is implemented.

Map 5.5 shows the effects of the policy on the average exposure to noise for pedestrians walking around the neighbourhood. With a few exceptions, the effects of the policy are limited to the districts within the municipality borders. However, these effects are spread throughout the city and are higher in districts far from the area of application of the policy. We assume that private transport users react to the policy by choosing the fastest route to their destinations under the new conditions, not by shifting to public transport. The effects of the policy on local environmental conditions then depend on the reassignment of the traffic to the alternatives routes. In this case, the distribution of positive and negative effects is explained by the shift from using local roads to arterial, circular roads or motorways. The area with the highest change in noise exposures is the Eastern area (*Marvila*), which as we mentioned in Chapter 2, is also a relative disadvantage in terms of accessibility (p.46) and is one of the areas with lowest qualification levels in Lisbon **[Map 2.1]**.

Map 5.5: Effects of the circulation plan on exposure to noise around the neighbourhood

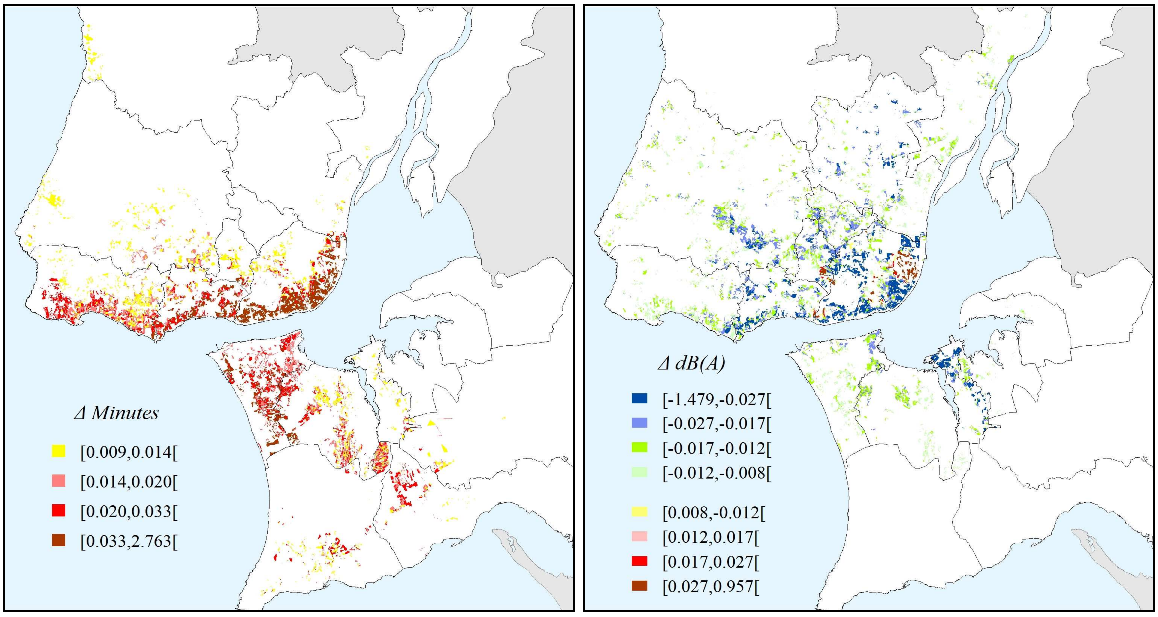


The effects of the policy in average time to work and noise exposure on the way to work are distributed throughout the metropolitan area **[Map 5.6]**. The distribution of the first type of effects depends on changes in the routes taken by private transport commuters to Lisbon and on changes in congestion levels. The distribution of the second type of effects depends on changes in noise levels in the area of application of the policy and in other areas, as we are assuming that individuals are exposed to noise when they wait or walk to stops and stations.

The map shows the differences in the spatial patterns followed by the two types of effects. Outside Lisbon, the increase in time to work affects the high-income municipalities in the West corridor and in the south bank, given the higher levels of car use and the limitations that the policy poses on the access to the eastern part of Lisbon from those areas, by restricting the connectivity of the road along the waterfront. When it comes to exposures to noise on the way to work, there are both losers and winners. The former are the population living in districts in Lisbon where noise exposures around the neighbourhood also increases, as the increase of traffic levels affects noise levels on the pedestrian routes from homes to bus stops. The winners are populations who rely on public transport and use the city centre as final destination or as interchange. This is especially the case of the middle peninsula in the South Bank, where due to the reliance on ferry services, all public transport users accessing the North Bank need to interchange at the Lisbon ferry terminal in the city centre. This peninsula is also one of the most economically disadvantaged regions in the metropolitan area.

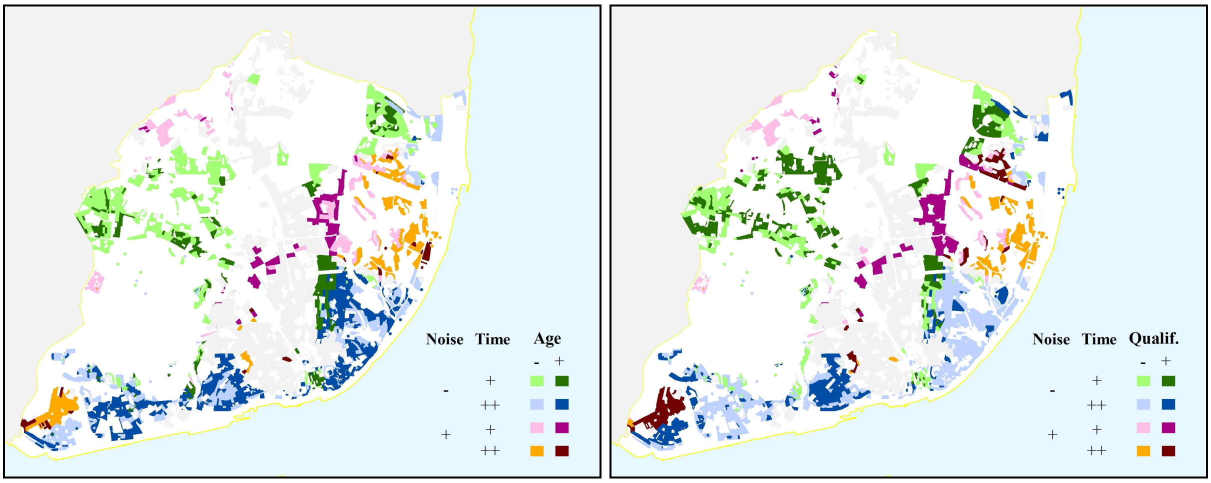
Map 5.6: Effects of circulation plan on commuters' well-being

Average time to work **Average exposure to noise on the way to work**



The distribution of the effects in Lisbon according to social groups is given in **Map 5.7**. The maps are the result of the overlay of the effects on noise exposures around the neighbourhood (negative or positive), increase in time to work (below or above the Lisbon mean) and the distribution of the *F1* (Age) and *F2* (Qualifications) factors obtained in Chapter 2 (classified here as above or below the Lisbon mean). The districts where the noise exposure changed only slightly (<0.03 in absolute value) are not depicted. Adopting a principle of distribution based on vulnerability, a desirable distribution would minimize the time losses falling on the less qualified populations and maximize the environmental benefits received either by elderly populations or less qualified populations. There is no evidence that the policy meets the first criterion, as the highest time losses (blue or brown) occur in neighbourhoods with qualifications both above and below average. The same can be said regarding decreased noise exposures (green and blue), which are evenly distributed according to age and qualification levels. On the other hand, increased noise exposures (rose and brown) occur mainly in neighbourhoods with younger age structures and apart from the already mentioned eastern neighbourhood of *Marvila*, tend to affect areas with relatively high qualifications. Attention to vulnerability appears therefore only at the level of the distribution of the unintended side effects of the policy (the increase in noise exposures in some areas), on which other criteria can apply, such as the legitimacy of imposing costs on those areas in order to achieve what are symmetrical benefits elsewhere.

Map 5.7: Social distribution of the effects of the Circulation Plan in Lisbon



We now use the distributional information analysed above to address the question of whether the policy has social value. This assessment depends on the way we compare changes in the two kinds of mobility (accessibility to places of work, as measured by time to work; and pedestrian mobility, as measured by pedestrian noise exposures) and the priority assigned to each group of concern. In practice, this corresponds to the conversion of both types of changes to a commensurate scale and to the assignment of distributional weights in the aggregation of both changes across the affected areas. We assume that elderly populations are vulnerable in terms of pedestrian exposure to noise walking around the neighbourhood and less qualified populations are vulnerable in terms of changes in time to work and pedestrian exposure to noise walking around the neighbourhood or on the way to work.

We transform the changes in average time to work and in both noise exposure indicators into a linear scale using the score range procedure; that is, expressing the deviation from a given standard as a proportion of the maximum possible deviation. We assume that this standard is the minimum value above which society should start to care, while the maximum deviation from the standard occurs when a change in the transport system raises the value of the indicator from this standard to its maximum feasible value. For the case of exposure to noise, this maximum is taken as 85 dB(A), which is the case where all the pedestrian destinations of a given district are reached only by routes next to a busy motorway. In the case of average time to work, we assume that the maximum feasible value is 70 minutes, which corresponds to the maximum value obtained in the enumeration districts in the AML in the hypothetical case that all private transport commuters in the district used only roads (not motorways) to access their set of daily destinations as observed in 2001.

The key for the analysis that follows is the fact that for the case of exposure to noise there are relatively consensual standards, determined using scientific procedures (assumed here to be 55dB(A)), while for the average time to work, the definition of a standard is subjective and depends on the geographic context, political priorities or ethical perspectives. Different assumptions on the standard of average time to work will then imply different ways to convert the changes in this indicator into the scale that is used to assess changes in pedestrians' exposure to noise. As such, those assumptions define an implicit social trade-off between the social value of changes in accessibility and pedestrian mobility, that is, the degree to which society considers that increases of accessibility compensate for increases in noise exposure for the populations affected, independently of subsequent distributional weights applied to both type of changes. The higher the standard of time to work, the lower the value of changes in time to work in relation with changes in noise exposures.

The social values of variations in exposure to noise (ΔN_i) and time to work (ΔTim_i) at a given district i are then given by the formulas below, where L_t is the standard of time to work, N_i and Tim_i are the initial values and N'_i and Tim'_i are the values of the indicators after the policy is implemented. The formula to valuate changes in noise exposure applies to pedestrians walking around the neighbourhood and walking on the way to work.

ΔN_i

	$N'_i < 55$	$N'_i > 55$
$N_i < 55$	0	$(N'_i - 55)/30$
$N_i > 55$	$(55 - N_i)/30$	$(N'_i - N_i)/30$

ΔTim_i

	$Tim'_i < L_t$	$Tim'_i > L_t$
$Tim_i < L_t$	0	$(Tim'_i - L_t)/(70-L_t)$
$Tim_i > L_t$	$(L_t - Tim_i)/(70-L_t)$	$(Tim'_i - Tim_i)/(70-L_t)$

The formulas below translate the judgments on the social value (*SV*) of changes in the three types of mobility. The changes in noise around the neighbourhood (ΔNar_i) are first weighted by the population in each district (P_i), while changes in average time to work (ΔTim_i) and noise on the way to work (ΔNwk_i) are weighted by the working population (E_i). An additional weight measures distributive concerns. This weight is defined in a similar manner to the weights in the last section, but now allowing different parameters to apply to changes in noise exposures and in time to work and considering different alternatives for the socio-economic groups defined as "vulnerable". F_n and F_t are the socio-economic factors defining the group vulnerable to changes in exposure to noise and time to work, while the unobservable parameters ε_n and ε_t measure society's degree of priority for those changes. The weights are defined asymmetrically, applying only to the values above (in the case of age) or below the metropolitan average (in the case of qualifications). The cases of $\varepsilon_n=0$ and $\varepsilon_t=0$

represent the utilitarian principle of justice applied to the separate distributions of each type of mobility. Since the values of the changes vary in the interval [0, 1] and are multiplied by the district's population, its aggregation across society can be interpreted as the sum of "affected population", while distributive concerns act as inflators of the terms of this sum in the cases where the population is judged as vulnerable.

$$SV(\Delta Nar_i) = \sum_i P_i * \Delta Nar_i * Exp(\varepsilon_n * F_n)$$

$$SV(\Delta Nwk_i) = \sum_i E_i * \Delta Nwk_i * Exp(\varepsilon_n * F_n)$$

$$SV(\Delta Tim_i) = \sum_i E_i * \Delta Tim_i * Exp(\varepsilon_t * F_t)$$

While a sensitivity analysis similar to the one used in the last section is theoretically possible, it is of difficult illustration, as we have three quantities whose aggregation into a single index is a function of three unknown parameters (L_t, ε_t and ε_n). A more tractable approach is to invert the problem by expressing the values of one of the parameters as a function of the other two and assuming pair-wise relationships between the three quantities expressing social value. The aggregate variations of noise exposures are supposed to be negative (as this is the main aim of the policy), while the aggregate variation of time to work is always positive (as the restriction of the network forces all commuters to use second-best routes to work). The first two quantities can then be considered as social benefits, while the third is a social cost. We assume that the policy has social value if it creates benefits in terms of reduced exposures that are at least as great as the costs in terms of time losses. We relate time to work and the two exposures separately. The method is to estimate for each pair of values assigned to the distributional parameters ε_n and ε_t, the minimum value of the standard of time to work L_t for which the net social value of the policy (benefits minus cost) is positive[51]. As in the previous section, the analysis is restricted to the values for the distributional parameters in the interval [0, 2].

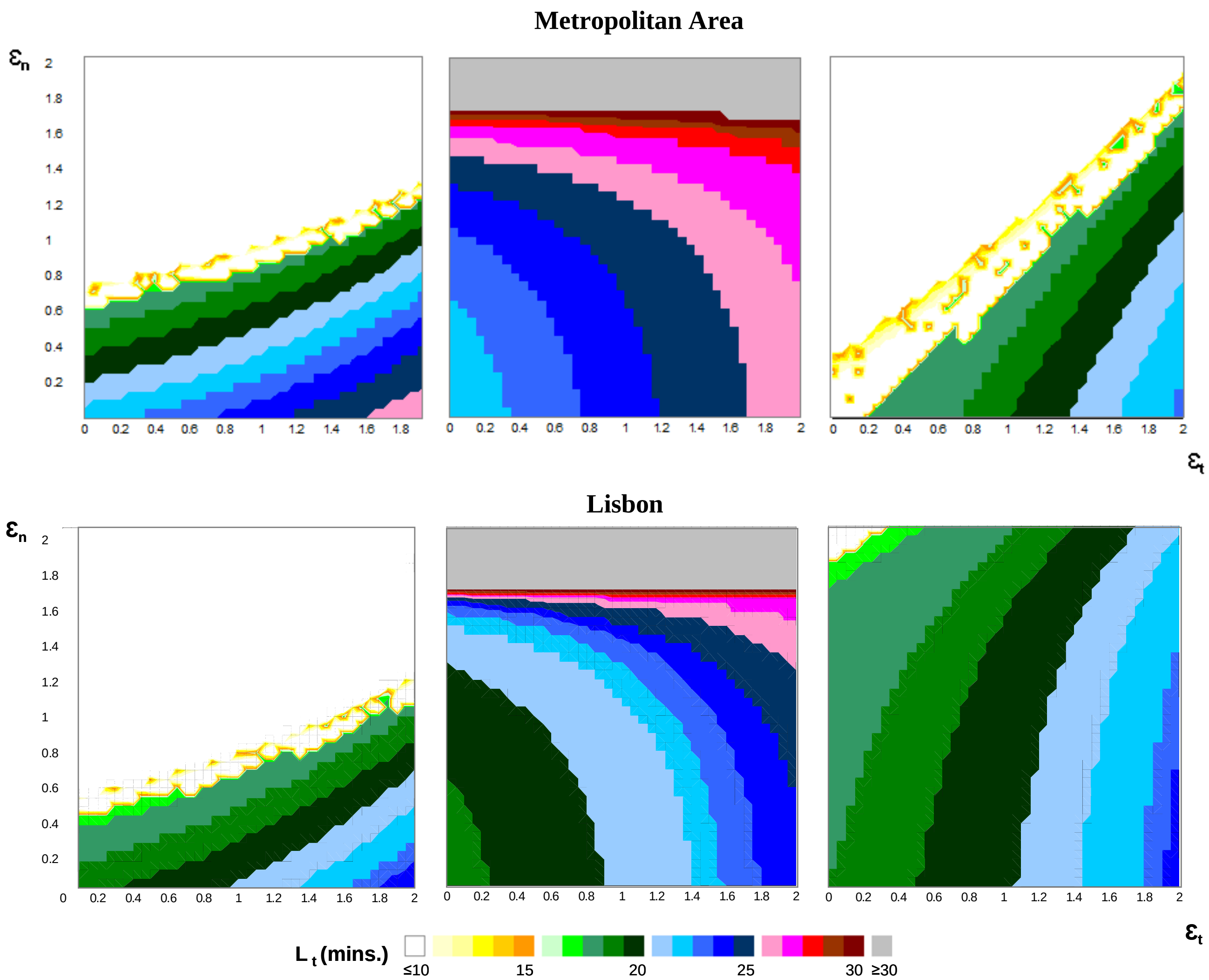
Following the rationale used in the last two chapters, we compare the results obtained at two spatial scales: the metropolitan area and the Lisbon municipality. In the latter case, the aggregation and weighting of costs and benefits is limited to the enumeration districts in Lisbon. We assign distributional weights to the changes in time to work affecting the

[51] This calculation is possible because except for very small values of the standards for time, the estimated relationships between the social value of the policy and the value of the standard are monotonic and positive.

populations with lower-than-average qualifications. When changes in time to work are compared with changes in noise exposures around the neighbourhood, we consider two alternatives for the classes on whose changes we attach the distributional weights: elderly populations and low-qualified populations. When changes in time to work are compared with noise exposures on the way to work, the distributional weights are attached to the changes in the exposures of less-qualified populations. The figure below reports the results of the three cases, giving the minimum values of the standard of time to work that produces a positive social value for the policy, for different combinations of the distributional parameters.

Figure 5.4: Social evaluation of the standard of time to work for different weight structures

	Weights		
Exposure	Noise around	Noise around	Noise on way to work
Concern	Elderly (*F1*)	Low-qualified populations (*F2*)	Low-qualified populations (*F2*)



In all cases, the value of the standard of time to work depends positively on the distributional parameter assigned to changes in time to work (ε_t), a result that derives from the type of weight structure we used. Since weights are asymmetrical and used only to inflate the value of changes in time to work of the less qualified populations, increasing the weights will decrease the net social worth of the project unless we relax the relative importance assigned to changes in time to work, by increasing the value of L_t.

A less obvious result is the difference in the patterns obtained when we assume different weight structures. In the cases of weights assigned to noise exposures around the neighbourhood to elderly populations and exposures on the way to work to low-qualified populations, the standard of time to work has a negative relationship with the distributional parameter assigned to changes in noise exposure (ε_n). In the case of weights assigned to noise exposures around the neighbourhood to low-qualified populations, the relationship in positive. In other words, starting from a "break-even" position, to decrease the priority to noise exposures around the neighbourhood of elderly people or to exposures on the way to work of low-qualified populations will render the project undesirable unless we assume a higher relative value to noise exposures comparing with time to work (that is, a higher L_t). In contrast, we can decrease the social priority of changes in noise exposure around the neighbourhood for less qualified populations while assuming a lower relative value to noise exposures (lower L_t) and maintaining a positive social value for the project. These results arise due to presence of "negative benefits" in the aggregation of changes in exposure to noise around the neighbourhood, since exposures increase in some of the neighbourhoods in Lisbon. As such, attaching a lower weight to areas with low-qualified populations can result in an increase in aggregate benefits if, in average, these areas are more affected by exposure increases than decreases.

Two further comments should be made regarding the results in **Figure 5.4**. The first is that the relative sensitivity of the standard of time to work to the two distributional parameters is different for the three weight structures. The sensitivity of the standard of time to work to the values of the two distributional parameters is considerably higher when weights are attached to noise exposures around the neighbourhood of elderly populations. The second comment regards the fact that the evaluations in the context of Lisbon always imply a lower value for L_t for all pairs of weights on time to work and noise exposures around the neighbourhood, when comparing with the metropolitan context. In contrast, the evaluations in Lisbon produce higher values for L_t for all pairs of weights on time to work and noise exposures on the way to work. The consideration of the distributive effects depicted in the previous maps reveals that the two results in this paragraph are explained by the same fact: changes in noise around the neighbourhood are limited to a small set of neighbourhoods in Lisbon while changes in noise on the way to work are more extensive, spreading throughout the metropolitan area. The implication of both results is that social judgements on a policy's worth are inseparable from the spatial scale we are considering.

To sum up, the assessment of the distributive effects of traffic restriction policies depends on two main factors. The first factor is the set of trade-offs that the policy-maker is prepared to assume regarding the relative value of use of different types of mobility, the dimension of pedestrian mobility that is object of concern and the degree of priority to different groups of concern. We saw that the relationships between the degree of priority to low-qualified populations and the valuation of noise exposures are different when the focus is the exposure around the neighbourhood and the exposure on the way to work. In addition, the relationships obtained when focusing on the same type of exposures (around the neighbourhood) are different when the groups of concern are the elderly and the low-qualified populations. The second factor influencing policy assessment is the compatibility between the social trade-offs and the spatial distribution of the effects of the policy, especially the balance between the characteristics of the populations living in the areas affected by the unintended negative effects of the policy.

5.4. The political economy of mobility

The political organizations responsible for transport planning have their own interests and motivations, which are the aggregation of the interests of its members. The pursuit of these interests may lead to clashes with the social good. In the context of this chapter, this means that a politically biased policy may lead to a social distribution of transport's positive and negative effects that is not consistent with society's equity concerns. This section will look into the influence of party-political factors on decisions regarding the location of transport infrastructure and the evaluation of traffic restriction policies. We reformulate the two case studies of this chapter, by assuming that the policy-maker considers its own "political pay-off", and then compare the optimal route alignments and the distributional trade-offs of traffic policies with the ones obtained in the previous sections.

In general, the application of public policies is subject to the interaction of three different types of political structures: political parties, interest groups and social movement organizations [Burstein and Linton 2002]. The policy-makers' decisions depend on their assessment of potential electoral gains or losses and may be permeable to lobby pressures or to social protest by the groups affected by the policy. However, some groups in society may have little power to influence the policy-maker's decisions. According to the "median voter theorem" governments tend to follow the preferences of the median voter [Black 1948] and if preferences follow income, then public policies will be biased towards the preferences of the middle classes and not of minority, under-privileged or vulnerable groups. At the level of lobbying and protest, we can also argue that corporate interests with concentrated power structures are more effective at organising than local communities made up of a large number of unconnected individuals, especially when they lack economic resources [Olson 1965].

The influence of political factors is especially relevant in the case of transport planning, as there is an asymmetry between the political power of well-organized lobbies, such as the car industry, and the power of other potentially interested parts, such as local business organizations, residents' associations, small environmentalist groups and non-car users. For example, Hillman (1997, p.72-77) argues that pedestrians and cyclists are systematically discriminated against in public policy, at the level of information gathering and decision-making. Empirical studies have also proved the influence of political factors on the regional allocation of investments in transport infrastructure [Congleton and Bennett 1995, Castells and Solé-Ollé 2005] and on decisions about investment and disinvestment in public transport infrastructure [Boschken 1998; Brent 1976, cited in Brent 2006, p.56-58].

Political bias is also an issue in environmental policy. For example, Camacho (1998, p.18) argues that environmental inequalities arise because the governments depend on the resources of upper-class groups and large business. Empirical studies also show that differences in the communities' political characteristics and especially in political power (understood as the probability of local populations of engaging in collective action) may explain options taken in environmental policy and in the location of pollution facilities [Hamilton 1993, 1995, Brooks and Sethi 1997, Earnhart 2004]. Lastly, individuals or communities with higher socioeconomic status are more likely to take social action against local noise pollution [Guski 1977, Miedema and Vos 1999], a pattern which may be partly explained by the greater political potency of those groups.

The motivation for the study that follows is to contribute to the literature on the role of political aspects at the level of individual transport projects, as empirical work of these issues in transport policy deals mostly with broad options at the regional level, while studies in environmental policy tend to focus on the location of point sources of pollution. In the specific case of Portugal, political factors have been analysed in terms of municipal expenditure and opportunistic political cycles [Cruz 2007], but the case of transport is under-researched. Our approach is not to assess empirically the hypothesis of political bias, but to assume that the propensity of a given policy-maker to attend to his political interests is variable and depends on several factors, measured by the political characteristics of the populations affected by the projects and policies. The objective of our analysis is then to assess the implications of different hypothesis about the nature of the political motivations of the policy-maker.

The analysis relies on the results of a preliminary study to electoral data, which used factor analysis to extract from elections data a vector of variables quantifying "political payoff" for the municipal governments in the two regions of concern: the western municipalities and Lisbon. The analysis is performed separately for the two cases, yielding different factor structures. The assumptions, methods and results of this preliminary analysis are described in Appendix 8.

The approach followed in this section was to reassess the two case studies assuming that the policy-maker attaches weights on the changes in accessibility and pedestrian mobility affecting the populations with high scores on the political factors, comparing the results with the previous sections, when weights were attached to the effects on low-qualified or elderly populations. The comparison is possible because, like socio-economic factors, political factors are expressed in standard deviations from a zero mean and so the distributional weights are expressed in the same unit in both cases.

Via longitudinal **revisited: the party-political factors**

This sub-section analyses the influence of political factors in the determination of the best route alignment for the *Via Longitudinal*, studied in Section 5.2. We assume that there is a single policy-maker, that is, the same party is holding the governments of the two municipalities involved. This policy-maker attends to three political factors: Factor *P1* is an indicator of the relative importance of "Left-wing voters" in a given enumeration district, while the symmetrical (*–P1*) factor quantifies "Right-wing voters". *P2* is a measure of the local population's interest in the political process. *P3* is a measure of the potential for attracting new votes from the electors living in the district. The assignment of these factors to the political interest of a policy-maker of a given party is open to interpretation, as it depends on the political context at the time of decision and the strategy adopted by this party (for example, the choice between focusing on securing votes or on attracting new votes). Our objective is to assess the implications of using these factors as measures of potential political bias in the assessment of transport projects.

We define the politically optimal route alignment as the one that minimizes the aggregate community severance costs across the region, assuming that the policy-maker places a higher weight on the costs borne by the population with certain political characteristics, measured by the factors described above. To simplify, we assume that only severance costs matter, that is, the financial cost of construction is set at a value close to zero. The cost of the road crossing point r is then the sum of the severance effects in all the affected enumeration districts ($\Delta CS_{r,i}$), weighted by the number of electors EL_i, and by an exponential function of one of the political factors (Px). The parameter ε measures the degree of priority assigned to the areas where the political factor is above the mean. The value of this parameter is zero when the political factor is below the mean.

$$C_r = \sum_i EL_i * \Delta CS_{r,i} * Exp(\varepsilon * Px)$$

Figure 5.5 shows the optimal route alignments obtained for each value of the parameter ε.

The routes are mapped in **Map 5.8**. Because the extracted political factors vary over a wide range, the estimation of the optimal routes becomes unstable after a certain value of the parameter ε, as the value of the community severance costs in neighbourhoods clearly below the mean of the political factor becomes extraordinarily inflated when using an exponential formulation. Therefore, the illustrations only show the results obtained in the interval [0, 0.8] for the parameter ε.

The figure shows that considerations of political interest do not change the project when the weights are placed on the right-wing factor (-*P1*), as the optimal solution is the utilitarian option *A1* found in the previous analysis (**Figure 5.1**), regardless of the value of the parameter ε. On the other hand, the route is sensitive to the placement of weights on the left-wing factor *(P1)*. Furthermore, the changes in the routes obtained for higher deviations from the utilitarian case (that is, for increased values of ε) do not follow the same pattern as in the case of the weights placed on the low-qualified populations studied before (compare with **Figure 5.1**, for *v=0*). While in the original case, the first changes associated with increased values of ε occur in the eastern end of the road (from *A* to *B*); in the present case, they occur in the western end (from *1* to *2*). More importantly, while before the assignment of the highest values for ε implied a further shift in the eastern end (from *B* to *C*), the shift occurs now in the middle section (to "*p*"), which in the original case is stable for all possible parameter values. The same route for the middle section is also obtained when weights are placed in the *P2* measuring the degree of attachment to politics (*P2*), but for lower values of the distributional parameter, when comparing with *P1*.

These results show that the introduction of political bias in the planning of a new road may lead to inconsistencies with criteria of equity based on the vulnerability of some classes, even though the two perspectives may be based on population characteristics that are correlated (for example, **Table A.5** in Appendix 8 shows that lower qualifications are related with left-wing political inclinations). On the other hand, political criteria may be consistent among themselves. In this case, even though the factors measuring left wing voters, levels of political participation and potential electoral gains are largely independent by definition (as they were obtained by factor analysis), they lead to common projects or common choices in some sections of the project, for some combinations of the respective distributional parameters.

Map 5.8: Politically optimal solutions for the *Via Longitudinal*

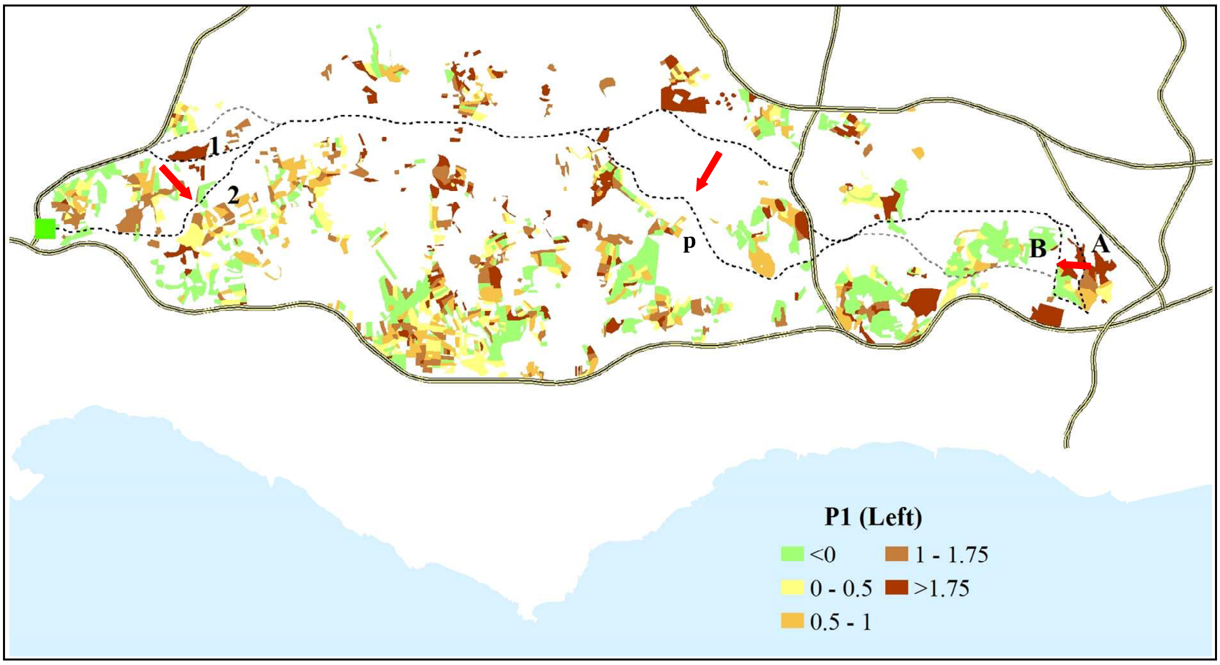


Figure 5.5: Politically optimal solutions: Project locus

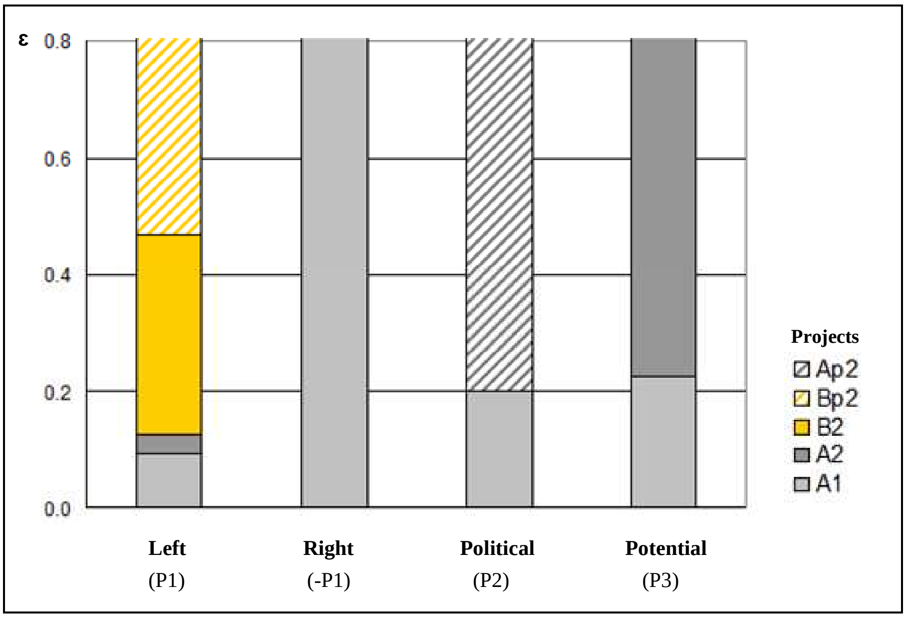
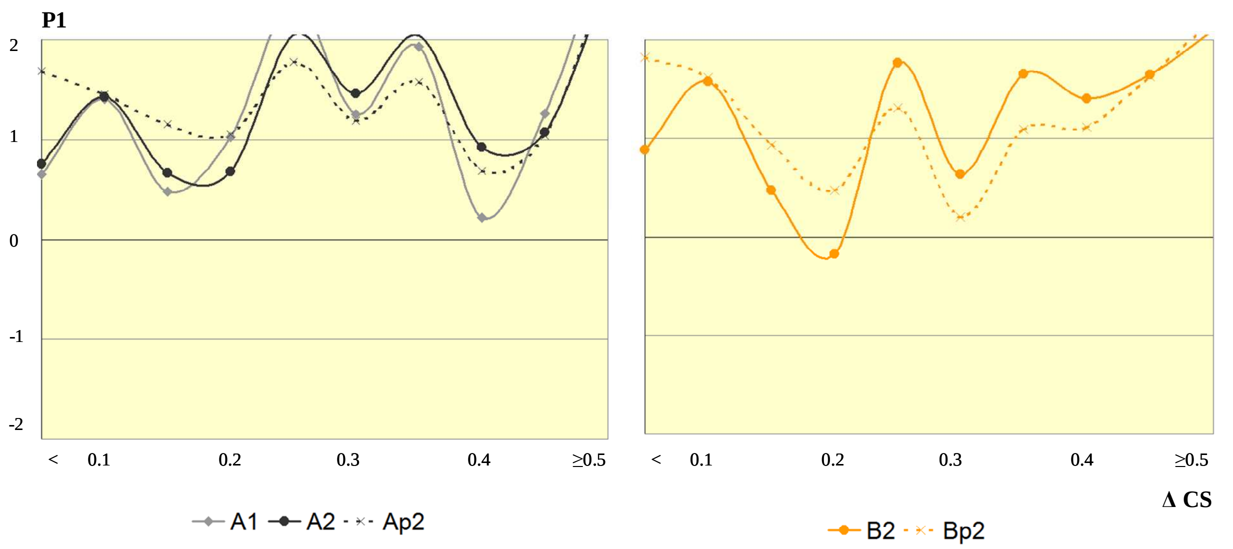


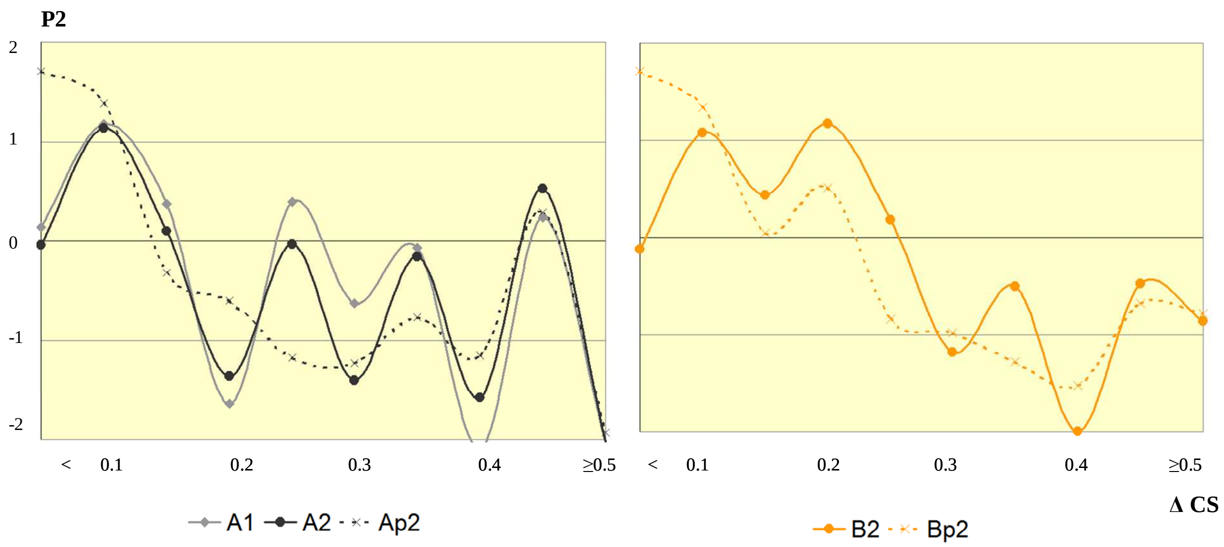
Figure 5.6 shows the effects of politically biased route formulations in the distribution of the costs of the projects among populations with different political characteristics. The charts plot the average value of the factors that measure left-wing (*P1*) and "political" voters (*P2*) for each value of the severance effect. Political bias has the highest impact in the case of projects that use the new middle section (routes *Ap2* or *Bp2*). Both projects have cumulative effects, as they alter the distributional profile of the project according to the two political factors. We can also see the differences in the political allocation of costs among the different projects in the left side of **Table 5.2**, which gives the averages of the three political factors for each project, weighted by number of electors and the size of the severance effect.

Figure 5.6: Community severance effects of politically optimal projects: Political profile

Left-wing electors



Politically-concerned electors

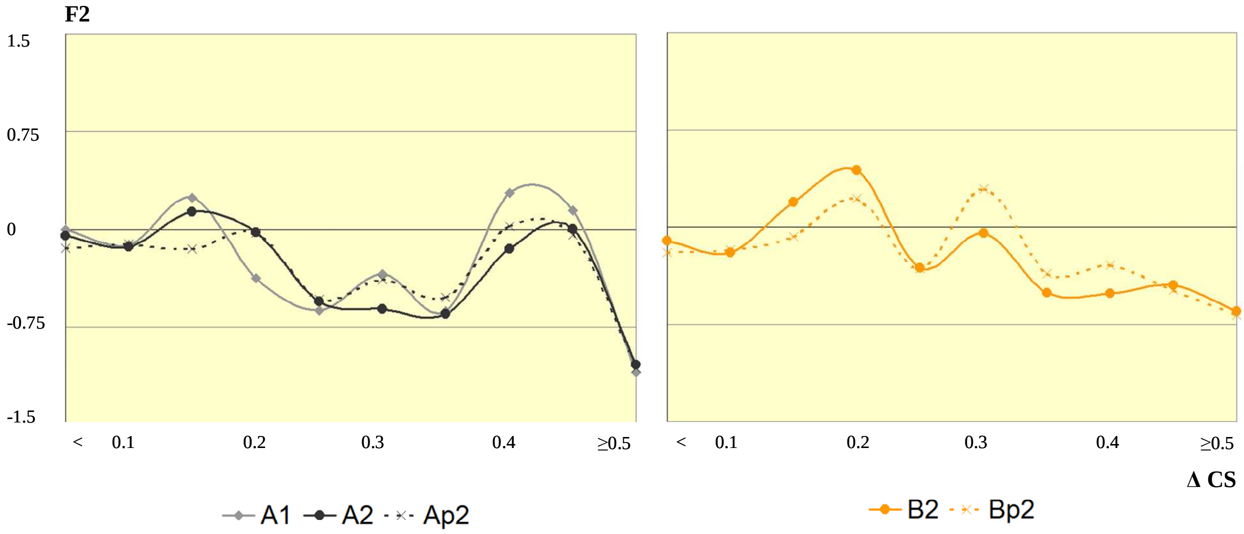


Finally, we can see the impact of political bias on efficiency (the aggregate costs of the project) and on the distribution of those costs (right side of **Table 5.2** and **Figure 5.7**). With only one exception (*A2* to *B2*), incremental departures from the utilitarian position towards political-biased distributions (following the patterns in **Figure 5.5**) are associated with longer weighted lengths and with greater aggregate severance effects. These losses are especially noticeable when we move to projects that use the new middle section (*Ap2* and *Bp2*). On the other hand, the increase in political bias is associated with an increase in the weighted average time gain, with a reduction in the weighted average of the qualifications factor (*F2*) in the affected areas and with changes in the qualifications profile of the costs [**Figure 5.7**]. In sum, political bias is consistent with principles of equity based on the balance between costs and benefits or on the priority to vulnerable classes. The main effect of political bias is therefore at the level of efficiency.

Table 5.2: Politically optimal solutions: Elements of cost

Projects	**Political factors** (weighted averages)			**Other elements**			
	P1 (Left)	P2 (Political)	P3 (Potential)	Length x Slope	Pop x ComSev	F2 w.avg	Tim w.avg
A1	1.86	-0.82	-0.74	37270.7	7423.1	-0.61	0.31
A2	1.63	-0.69	-0.51	37908.0	7814.6	-0.56	0.35
B2	1.32	-0.25	-0.45	37683.0	9028.6	-0.40	0.38
Ap2	1.47	-1.00	-0.26	38590.7	8146.4	-0.54	0.40
Bp2	1.20	-0.53	-0.23	38365.8	9360.5	-0.39	0.43
Planned route	0.50	0.11	-0.14	33661.1	18209.9	-0.07	1.08

Figure 5.7: Community severance effects of politically optimal projects: Qualifications profile



***Lisbon City Centre Circulation Plan* revisited: the party-political factors**

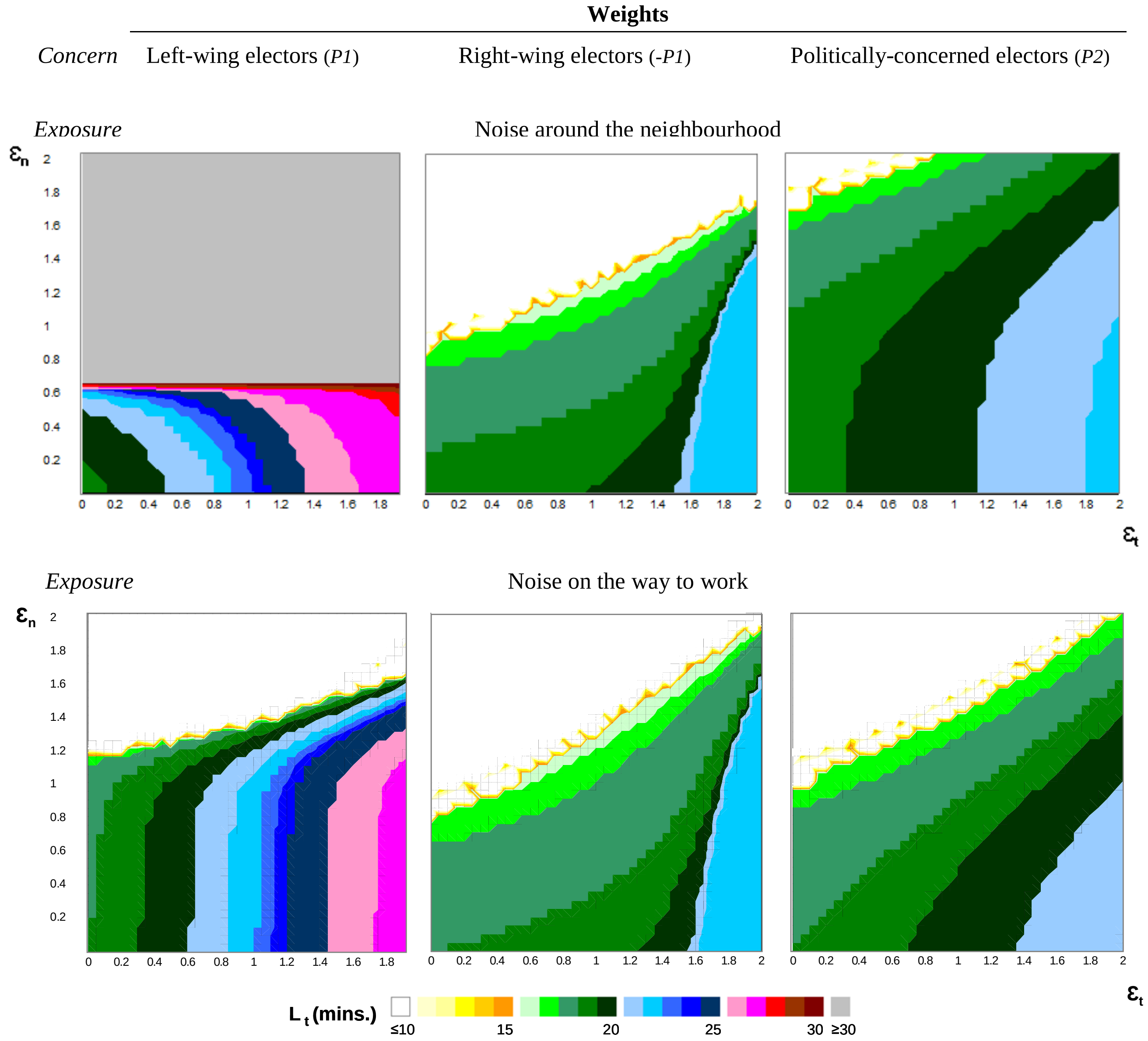
This sub-section reassesses the case of the traffic restriction in the Lisbon city centre, considering the influence of political factors. The implications of political bias in this case are potentially more complex then in the previous case, as political interest is defined at the scale of the municipality but the effects of the policy are spread throughout the metropolitan area.

The analysis adapts the methods used in Section 5.3. We use the same weight structure and the same methods to convert into the same scale changes in time to work and in noise exposures. The difference is that we apply the weights to the effects on districts according to the political characteristics of their electors. We consider that these characteristics are measured by two political factors, *P1* (Left-wing) and *P2* (Political), which have similar interpretations as the factors used for the western municipalities. The structure of these factors is detailed in appendix 8. We distinguish between the effects of the project on pedestrian exposure to noise around the neighbourhood and changes in noise on the way to work and allow three possibilities for the assignment of distributional weights: priority to left-wing voters (*P1*), to right-wing voters (*-P1*) and to voters with high degree of propensity to engage in the political process (*P2*). We use the same "inverse approach" explained in Section 5.3, modelling the relationship between the distributional parameters attached to changes in time to work and noise exposures (ε_t and ε_n) and the standard of average time to work (L_t), for a break-even point in the net social value of the policy.

The results are shown in **Figure 5.8**, which should be analysed alongside the part of **Figure 5.4** that represents Lisbon. The patterns found in the case of weights placed on changes affecting left-wing electors (*P1*) have a similar shape to the ones found when weights are attached to less-qualified populations. When weights are placed on noise exposures around the neighbourhood, the standard of time to work (L_t) depends positively on both distributional parameters. When weights are placed on noise exposures on the way to work, the standard of time to work depends positively on the distributional parameter for time to work and negatively on the parameter for noise exposures. However, for both weight structures, the standard of time to work is more sensitive to the noise distributional parameter, when comparing with the cases of weights attached to less-qualified populations.

When the weights are attached to the changes affecting right wing electors (*-P1*), the parameter L_t depends negatively on the noise factor. The relationship follow a shape relatively similar to the case of weights placed on the elderly population analysed in the previous section, although the sensitivity of the standard to work to the two distributional parameters is now lower. The assignment of weights on politically-concerned electors (*P2*) yields similar results, but the relationships between the two distributional parameters are convex, while in the case of weights based of right-wing electors, they are concave.

Figure 5.8: Political evaluation of the standard of time to work for different weight structures



These results show that the assessment of a traffic restriction policy by a policy-maker attaching distributional weights according to his political interest is in some cases compatible with the assessment of the same policy in terms of equity concerns. In fact, some of the trade-offs between the standard of time to work and the distributional parameters of time to work and noise exposures follow similar shapes in some of the social and political assessments. For some political factors (right-wing and "political" factors), the type of trade-offs is relatively similar for the two types of noise exposures, however, for other factors (left-wing), there are considerable differences. Finally, some political factors are compatible among themselves, even though they are largely independent, by definition. In this case, the results suggest that attending to right-wing electors creates similar trade-offs than attending to politically concerned electors, while attending to left-wing electors have independent effects of both.

Conclusions and further considerations

The motivation of this chapter was to further understanding on the implications on transport policy of holding alternative judgements on the distribution of accessibility and pedestrian mobility impacts and on the relative value of those impacts. We analysed the cases of the formulation of road infrastructure projects and of the social appraisal of traffic restriction policies. We found that separating the two types of judgements reveals trade-offs that may not be apparent when the valuation of the impacts of the policy relies on a single method (which usually involves conversion to monetary units). The consideration of higher valuations for community severance effects may lead to optimal route alignments that are different from the ones obtained by increasing the degree of concern for the effects on vulnerable classes. In the same vein, the consideration of higher relative values for changes in exposures to noise, comparing with changes in time to work, may lead to evaluations of the social value of traffic policies that are different from the ones obtained by increasing the levels of concern for the changes affecting vulnerable classes.

There are also limitations to the effectiveness of including equity in the formulation or evaluation of transport projects. Our first case study showed that attending to equity in the design of a road might lead to higher aggregate pedestrian mobility costs, depending on patterns of land use. The second case study showed that traffic restriction policies might increase noise exposures in neighbourhoods far from the restricted areas, which may be inhabited by the same vulnerable groups the policy is aimed at. Finally, the possibility of application of policies based on criteria of equity depends to which political factor and to which type of policy impacts the policy-maker assigns priority.

Due to the need for simplification, the analysis provided a partial assessment of the projects and polices considered, which could be extended into a full multi-criteria evaluation, accommodating efficiency, equity and other concerns. We also used a simple method of transformation of different types of impacts into comparable units and a single way to combine the social value of both. These limitations could be surpassed by using value functions that describe more comprehensively the societal preferences regarding the relative values of accessibility and pedestrian mobility and regarding different distributive outcomes. Finally, it is important to consider the role of uncertainty about the actual receivers of benefits and costs. As we saw in the previous chapter, changes in neighbourhood attributes may trigger household relocation, eventually changing the social structure of the areas affected by the project. Furthermore, individual and social preferences may change over time, due to social and cultural trends or the macroeconomic context at each moment.

We should also note some of the possible extensions in the study of the two types of project. The analysis of the optimal route alignment omits relevant costs, such as the financial and social costs related to the compulsory purchase of land for the new road. There are also questions regarding the coordination of a project involving more than one municipality and the compatibility with other planned road infrastructure. The evaluation of traffic restriction measures is also limited by the simplification of the impacts of the policy on travel behaviour (omitting effects on transport demand and modal shift) and on accessibility (omitting time losses for freight traffic). Further analysis could also consider the compatibility of the policies with other interventions, such as the construction or improvement of alternative routes, improvements on the public transport network and the implementation of parking policies.

The analysis of political factors could also benefit from a further exploration of the policy maker's motivations, including the role of ideology and the extent to which governments balance political interest and the "common good". In the analysis of policies with wider spatial scope than the ones in this chapter, there is also the need to attend to interactions between different levels of policy-making. The protest to decisions taken by national governments are often lead by local leaders and so the assessment of the political characteristics of local populations should include information on whether local governments are hold by a different party.

At a more abstract level, distribution does not exhaust the concept of social justice. There are losses of welfare every time a policy has negative effects. The size of these losses is relevant, as one can argue that there is a right to a minimum standard of accessibility and pedestrian mobility, leading to the question on whether distributive considerations can override the respect for these rights. Within our analysis, the implication of this position would be for example to impose a restriction for the maximum value of the negative impacts of the project in any neighbourhood. We can also question the compatibility between the assessment of projects based on criteria of equity and the actual societal preferences. In fact, any attempt to "correct" individual preferences or to attach different values to preferences for some goods and by some people can be criticised as paternalistic or anti-democratic. Even in the cases where policy-makers are neutral, the formulation of policies incorporating equity concerns cannot ignore questions of socio-political feasibility.

Chapter 6

The wider context

This thesis set out to explore the multidimensionality of the transport equity problem. The starting point was the realization that urban transport affects the mobility of individuals in different ways and has redistributive effects that can be measured along different social lines. The disadvantages of some groups in the distribution of mobility have a spatial dimension, as they depend on patterns of residence location and commuting. Our intended contribution to the existing knowledge on this problem was to introduce pedestrian mobility as a distributive concern of urban transport policy, based on the hypothesis that the quality of this type of mobility is negatively affected by traffic infrastructure and motorized traffic. We tested for social inequalities in the joint distribution of several dimensions of pedestrian mobility and accessibility among the different neighbourhoods in the city, looked at the sensitivity of those inequalities to the definition of areas of comparison and assessed some of the processes leading to those inequalities, including neighbourhood recomposition and the development of new urban land. We also proposed methods to test the implications on policy formulation and evaluation of holding different views on the relative value of use of pedestrian mobility and the distributional priority attached to the groups of concern. The analysis was based on the changes occurring in the transport system of the Lisbon Metropolitan Area (AML) in the period 1991-2001, a region characterised by differences in the spatial distribution of age and socio-economic groups and heterogeneity in patterns of land use and commuting.

This chapter concludes the study, by setting the results of the empirical analysis in a wider context, while recuperating some of the threads introduced in each chapter when discussing policy implications and possible extensions for the analysis. The first section reviews the major findings of the analysis and outlines some aspects related to the empirical study of the transport equity problem. Section 6.2 discusses the relevance of the thesis in face of transport policy alternatives, societal objectives and current socio-demographic trends. The curtain closes with a list of suggestions that, in face of the questions left unanswered by this dissertation, we judge would merit further analysis.

6.1. Synthesis

Major findings

The distributional aspect of transport policies differs from other public policies, due to the need to resolve a series of welfare trade-offs, related to the distribution of different effects over populations with different characteristics. This thesis examined how these trade-offs have been dealt upon in the AML, testing if spatial inequalities reinforce social inequalities and if there are cumulative disadvantages for some groups in the spatial distribution of various local effects. These hypotheses have been tested elsewhere for the cases of multiple dimensions of accessibility and multiple dimensions of environment quality, but never focused on the interrelationships between both aspects. Another novelty of our analysis was to assess patterns of spatial inequality at two moments in time, for the same definition of groups of concern and indicators of mobility. This allowed us to quantify the effects of a set of policy interventions, which gave priority to the construction of new road infrastructure.

Our first research question (p.28) related to the assessment of the distribution of several dimensions of accessibility and pedestrian mobility across the different neighbourhoods in the metropolitan area. We found that due to their relative concentration in the central parts of the metropolitan area, elderly populations have good levels of accessibility but at the same time, they tend to be at disadvantage in the distribution of pedestrian mobility. Low-qualified populations tend to be at disadvantage in terms of both accessibility and pedestrian mobility. However, the disadvantages in accessibility derive mostly from lower levels of private transport usage and not from insufficiencies in the provision of transport in the areas where those populations are relatively more concentrated. The comparison of the patterns in two moments of time also showed that policies giving priority to road infrastructure benefit private transport users in detriment of pedestrians and public transport users. In fact, the densification of the road network around the main city in the period of concern improved private transport accessibility, but lead to community severance and to an increase in noise exposures of pedestrians walking around their neighbourhood or commuting using public transport. In general, these negative effects were disproportionately distributed, affecting especially areas with elderly and low-qualified populations.

The assessment of social inequalities depends however on the set of neighbourhoods that are directly compared (research question 2). We confirmed that processes that lead to transport inequalities are specific to each location and operate at scales smaller than the metropolitan area. The hypothesis of non-stationarity in patterns of transport inequality within urban areas had not been tested in previous work. Our analysis showed a high degree of spatial variability in the relationships between the distribution of the effects of transport and the social structure of the neighbourhoods affected, with the suburban area being the region where inequalities are most evident. We found that when focusing on the central areas, older populations are associated with better pedestrian mobility. The geographic patterns of the inequalities between populations with different qualification levels changed over time, with an extension of the inequalities in times to work to the outer suburbs and an intensification of the inequalities in noise exposures in the centre and inner suburbs. There was also a reduction in the advantages of the elderly in the distribution of noise exposures within central areas. The role of accessibility and pedestrian mobility in the explanation of neighbourhood recomposition and of social patterns of settlement in newly developed areas is also different in the centre and in the suburbs.

We have also gathered evidence on the processes that lead to transport inequalities and in particular on the adjustments between changes in mobility and social patterns of residence location, which was the object of our research question 3. Our analysis showed that changes in levels of mobility and other local attributes are linked to the renovation of the population living in each neighbourhood. Our main contribution to existing knowledge on this issue was to assess the role of pedestrian mobility. Changes in community severance and pedestrian exposure to noise were found to be significant in the explanation of the probability of neighbourhood recomposition. The two types of changes are also related to changes in qualification levels within the central area. We also found that exposure to noise integrates the same vector of neighbourhood change that private job accessibility in both central and suburban areas, although in the first case they two types of change are negatively correlated and the in the second case they are correlated. This result suggests either that preferences for one of this type of changes are dominant or that the preferences for both are jointly determined but differ in the two regions.

The empirical analysis of patterns of transport inequality in two moments in time was complemented with a simulation of the implications on transport policy of attending to equity concerns (research question 4). We added to previous research by testing the effects on holding different perspectives not only on the distribution of different impacts among different groups of concern, but also on the valuation of the different impacts. We found that the design of the route alignment for a new road in a region with land use heterogeneity is very sensitive to parameters specifying equity concerns. The social evaluation of traffic restriction policies in city centres also varies when the focus is on noise exposures of residents of those areas or of workers on the way to work. We then extended this analysis by considering the role of party-political factors in transport policy, which answered our research question 5. We found that the possibility of application of policies based on criteria of equity depends to which political factor and to which type of policy impacts the policy-maker assigns priority.

These results are useful to assess the relevance of the set of relationships depicted in our conceptual framework of analysis (**Figure 1.4.**, in Chapter 2). The answers to research question 1 suggest that when we assess distribution at the level of the metropolitan area, the existence of inequalities is related to households' decisions on travel modes but not necessarily to their decisions on residence location and travel destinations or to the policy-maker's decisions on location of transport infrastructure. The analysis of question 2 indicates however, that when distribution is assessed within sub-sets of the metropolitan area, there are significant relationships between the location of transport infrastructure and households' residence location. The existence of a long-term link between changes in accessibility and pedestrian mobility, changes in the individuals' welfare, household relocation and changes in the neighbourhoods' social structure is also confirmed by our analysis of research question 3. The analysis of question 4 reveals that the link between the policy-maker's policy interventions, the distribution of accessibility and pedestrian mobility and the assessment of this distribution in terms of justice is highly dependent on the adopted definition of social justice. Finally, the answers to research question 5 expose the implications on distributional patterns and social justice of the existence of links between the local populations' political characteristics and the policy-maker's decisions.

Further considerations

The analysis in this dissertation also sheds some light on some aspects related to the empirical research of social inequalities related to urban transport. A controversial aspect in this kind of research is the normative assessment implicit in the definition of the transport equity problem. We saw that the application of different perspectives produces different solutions to this problem. These perspectives are implicit for example in the definition of the areas of comparison for each neighbourhood (what we called in chapter 3 as "communities of justice"), which have implications on the assessment of relationships between the residence location of social groups and the distribution of accessibility and pedestrian mobility. We obtained different patterns of inequality when comparing times to work or pedestrian exposures to noise among neighbourhoods with similar positions of centrality and with similar patterns of commuting. In some cases, the advantages of one group in one region when using one definition for the area of comparison turn to be disadvantages when we use a different definition. The consideration of the role of subjectivity in the quantitative assessment of issues of equity is also important in the evaluation of transport projects, as the identification of the groups of concern and the value assigned to changes in pedestrian mobility have implications on judgements about the social desirability of the projects. Overall, our results emphasize the need to clarify the assumptions implicit in the methods used in the research of the transport equity problem. They also reveal the benefits of informing policy decisions by providing results obtained using multiple perspectives.

The development of methods was another of the motivations of this study. The use of alternative indicators revealed the differences between the distribution of dimensions of pedestrian mobility that depend on the transport infrastructure (community severance) and dimensions that depend on traffic levels (exposures to noise). We saw that changes in these dimensions have different roles in the process of neighbourhood change. We also found differences in local patterns of inequality and in the assessment of traffic policies based on dimensions that depend only on residence location (community severance and noise exposure around the neighbourhood) and dimensions that depend on choices of daily destinations and modes (noise exposure on the way to work). Other methods proposed in this thesis also showed potential for practical application. For example, the formulation of optimal route alignments can benefit groups of activists, as it revealed the existence of feasible alternative solutions for future projects that differ considerably from the projects as planned. While activists usually present alternatives, these are seldom justified in terms of the equity in the distribution of benefits and costs or as evidence of political bias in the governments' proposals.

We should also mention the major theme that the present work did not cover but that underlies the questions analysed. Our focus was on the role of space as an explanatory factor for the patterns shown by variables observed in areal units. However, a parallel dissertation could be written approaching the main question of every chapter under an economic perspective. Housing and transport costs determine the choices made by households regarding residence location and travel behaviour, with an influence on their levels of accessibility and pedestrian mobility. Policy intervention in the transport market also depends on criteria of efficiency and has other effects on individual welfare apart from the ones that are based on local effects. For example, new infrastructure is financed through the tax system, while traffic policies generate revenues. The allocation of these costs and benefits may or may not follow the same principle of equity as the distribution of local changes.

6.2. Policy solutions and future challenges

This section uses the results of the thesis as a base to analyse a set of transport policies to address redistributive effects that have a spatial dimension. We discuss the potential for these policies to address accessibility and pedestrian mobility simultaneously and the restrictions posed by demographic and economic forces affecting the transport market.

The improvement of public transport may decrease inequalities in the distribution of accessibility. We saw that the inequality of low-qualified populations in the realization of accessibility potential is mainly related to their higher usages of public transport, allied to the fact that public transport is slower than private transport in almost all routes. The effect of improvements in public transport is probably not offset by future relocation movements, since the spatial sorting of groups with different socio-economic status is mainly associated with improvements in private transport accessibility (Chapter 4). The policy can also contribute to modal shift, reducing traffic levels, congestion and local environmental effects at the major entrances to the main centres, which as we saw in Chapters 2 and 3, are the areas where social inequalities in the distribution of those effects are most visible. In a deregulated transport market, it is difficult, however, to control the way that the different operators fulfil the needs of populations. In addition, levels of car ownership and use in middle-income cities such as Lisbon are still below the European average and may continue to grow if the gap is explained by a time lag in the response to social, demographic and economic forces that affected other cities in the past. On the other hand, population ageing may contribute for a reduction in car use, while the development of new communication technologies and telecommuting may reduce road traffic levels and contribute to the closure of accessibility gaps between different groups in society [Kenyon *et al* 2002].

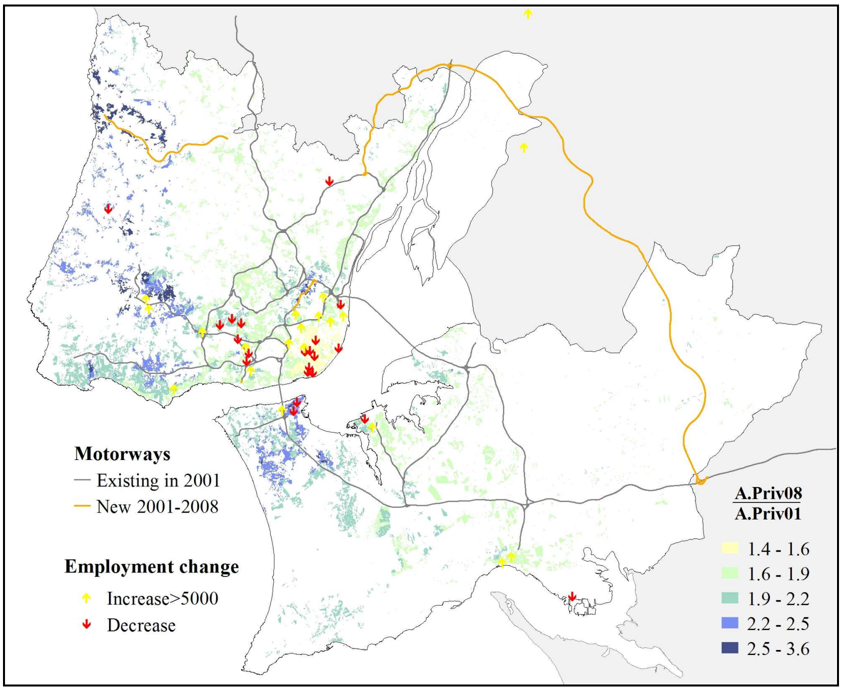
Modal shift also requires measures to dissuade the use of private transport. The application of this policy in the city centre has clear effects on the quality of pedestrian mobility of the populations in these areas, which in Lisbon as in similar European cities, have a high proportion of elderly and low-income households. On the other hand, in cities which lack viable alternatives to the links restricted to car traffic, due to relief or to the existence of historical areas, the policy may have unintended effects on the pedestrian mobility of populations in other areas of the city, as shown in our analysis in Chapter 5. The effects of the policy in levels of congestion and pollution affecting populations living in different areas and having different commuting patterns depend on the patterns of spatial redistribution of traffic.

The literature also shows us that alternatives, such as road pricing schemes, have uncertain distributive outcomes, which depend on the choices over the links and travel modes included in the policy [Mitchell 2005] and on the effects of the policy on the individuals on the margins of car ownership and use [Levinson 2010]. Environmental policies such as fuel taxes or vehicle emission standards also have complex distributive effects, depending on geographic and economic factors [Bae 1997].

Improvements of the pedestrian network have also effects on pedestrian mobility and on on realized accessibility (Chapter 2). However, the distributive effects of these improvements need careful attention, as this policy requires the application of traffic restriction measures, reallocation of road space or reorganization of traffic, reducing the mobility of private transport users. Judgements on the relative "value of use" of each type of mobility become unavoidable. For example, Vasconcellos (2001, p.221) defends that the right to circulate refers to the person and not to the vehicle and so an equitable allocation would divide road space accordingly. The overall distributive effect of these measures depends, however, on their impact on the accessibility of the each social group. To achieve a balance between the social redistribution of pedestrian mobility and accessibility would then require that measures aimed at the former take into account the effects over public transport and the accessibility of the groups dependent on it. These conditions would mean for example that when road space is reallocated to pedestrians, principles of equity should also apply to the allocation of the road space lost by private and public transport users.

Public transport and pedestrian mobility are also linked to urban planning. We saw in Chapter 4 that the development of new urban areas accelerates the adjustment process of individuals with different qualification to differences in mobility, given the differences between old new and old areas and within the set of new areas. The distribution of mobility is also affected by the fragmentation of urban space and by the tendency in most cities, including Lisbon, for employment to relocate away from the city centres to areas around motorway interchanges, which benefits the accessibility of populations in new urban developments on the outer suburbs, in areas with easy access to these motorways **[Map 6.1]**. New residential areas and centres of employment often lack public transport and have poor pedestrian access. In order to address these issues, urban policy-makers need to subject decisions on the development of new urban land to the availability of local public transport and to give priority to mixed land uses, in order to match places of residence with potential pedestrian destinations. These strategies have limitations, due to the problems in financing unprofitable public transport routes and in persuading businesses to locate in areas with relatively high transport costs, far from motorway junctions.

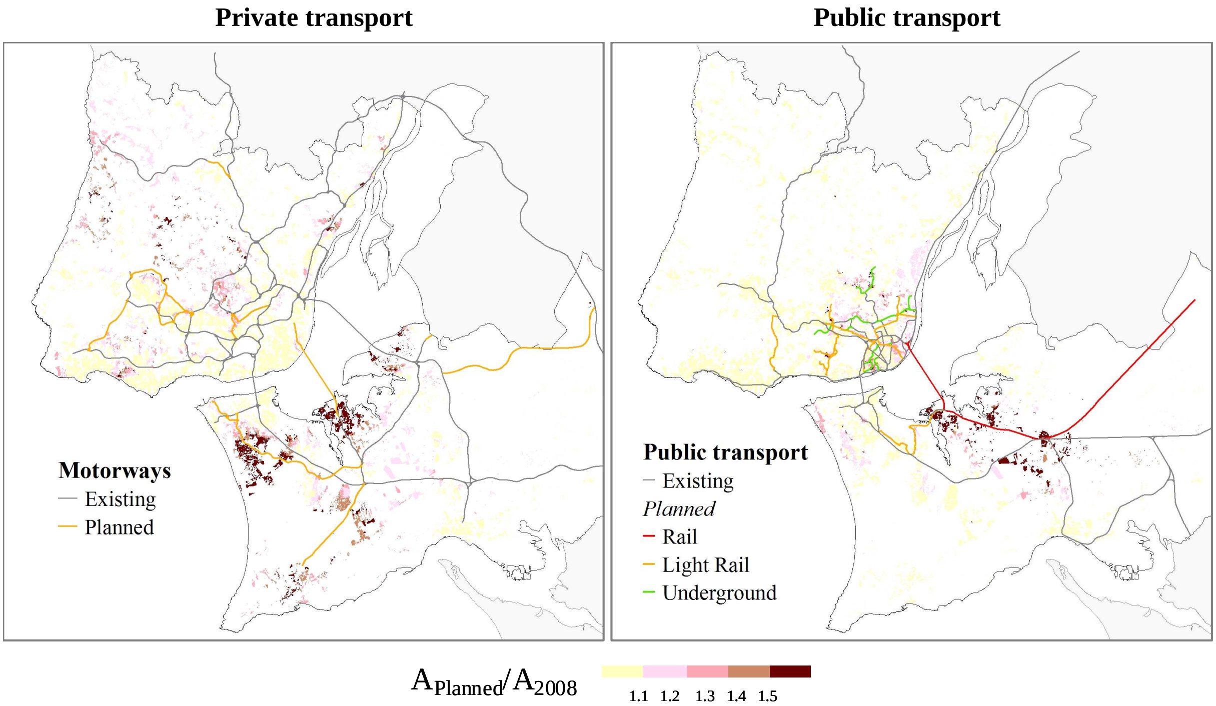
Map 6.1: Changes in transport, employment and private transport job accessibility 2001-2008



Notes: Accessibility based on indicator described in Chapter 2. Employment changes are proportional to changes in number of workers of the companies registered in each area [Appendix 2.1]. Data from INE (d1990-2007).

Given the density of motorways surrounding most cities, we can also question the advantages of expansions in the road transport infrastructure. The maps and numerical analysis in Chapter 2 show that the construction of new infrastructure does not always improve realized accessibility in the areas served, but contribute to community severance due to the existence of multiple links in narrow transport corridors. The analysis throughout the thesis confirmed that these patterns have a socio-economic dimension. Road projects seem to address issues of equity when they close gaps in the network or alleviate bottlenecks, reducing traffic levels and congestion. On the other hand, projects that duplicate the capacity of existing corridors or create new ones tend to encourage the growth of car usage. There is also an asymmetry between the effects of motorway construction on private transport accessibility and the effects of new public transport on public transport accessibility, as the latter are usually more limited in scope. **Map 6.2** illustrates this points for the case of the AML. At a more detailed level, the judgement of the equity of the distribution of benefits and costs of new roads depend on the actual road alignment and on the effects on community severance (Chapter 5). While the distributive effects of new infrastructure on pedestrian mobility are seldom included in project assessment, equity considerations may be incorporated as compensation of the populations affected. However, there is no clear definition of the object of compensation. Existing procedures usually focus on economic losses (reduction of the market value of land or homes) and not on welfare losses derived from the deterioration of local environment conditions.

Map 6.2: Future changes in job accessibility



Note: Based on the distribution of the population in 2001 Census, distribution of employment in 2008 and plans for future infrastructure [Appendices 4.1 and 5.1].

Finally, our results may be useful for the understanding of distributive issues in other metropolitan areas where transport planning faces the same context of land use heterogeneity and inexistence of policy structures at an intermediate level (between the municipal and national levels). We saw in Chapter 3 that patterns of inequality depend on the scale of analysis, while in Chapter 5 we saw that the evaluation of the redistributive aspects of traffic policies differs whether one considers only the effects in the municipality where the policy is applied and the effects over a broader area. The formulation of policies to address inequalities in transport then needs to understand the geographic and political context where these inequalities arise. and understand the specific mobility needs of the vulnerable groups in each region. This approach is dependent, however, on the availability of policy instruments at the required spatial scale and on the level of coordination of governments in different administrative units. The role of space may also lose some of its relevance in the future due to the growth in car ownership rates. The group of individuals who walk or use public transport are becoming a minority, where low-income groups are increasingly represented. The identification of these individuals using spatial data and the development of policies to meet mobility needs assessed at different locations will then lose some of their effectiveness.

6.3. The road ahead

The results of our study suggest a series of topics that could provide further glimpses on the transport equity problem and on its possible solutions. In this final section, we identify some of the hypothesis that we think require further empirical evidence and propose some extensions to the sets of groups of concern and dimensions of pedestrian mobility that were object of analysis in this work.

The main limitation of a geographic approach is the assumption that the groups of concern are clustered at the level of the spatial unit used in the analysis, which constrains policy implications to the scale of that unit and increases the probability of introducing distortions such as the ecological fallacy (p.8) and the MAUP (p.66). Transport research has been increasingly making use of data at the household and individual level, coming from mobility surveys or postcode-based commercial databases. Most of the applications of this data in transport inequality analyses deal with the spatio-temporal constraints of accessibility, through the integration of a time component in accessibility indicators [Kwan 1998] or the analysis of individual "activity spaces" [Schoënfelder and Axhausen 2003]. Another possibility is the comparison of individual mobility and area-based indices of mobility, which allows the analysis of the different types of interaction between these dimensions in the process of transport-related social exclusion [Preston and Rajé 2007]. Finally, individual data may allow for the test of the hypothesis of persistent inequalities as individuals relocate within the city or change commuting patterns over a long period. These possibilities are, however, data intensive and only suitable for small regions.

There is also a lack of strong evidence on the interactions between multiple social and spatial aspects in creating disadvantages for some groups. For example, the constraints posed by lack of access to cars and the effects of motorized transport on pedestrian mobility among groups such as women and the elderly depend on socio-economic status, which is then linked to disadvantages based on patterns of residence location [Lucas 2004, Priya Uteng and Cresswell 2008]. Research on these questions requires the definition of indicators that reflect inequalities within those groups. In the case of women, these indicators would measure for example levels of public transport accessibility or the role of space-time constraints, while in the case of the elderly, the emphasis could be on the quality of walking access to community centres, day-care centres and health centres.

The study of some aspects of pedestrian mobility could also benefit from a further exploration of possible quantitative indicators. One of those aspects is pedestrian safety. Research on spatial inequalities in the distribution of accident risk has used data on pedestrian injuries and fatalities. However, these are imperfect indicators of risk, as “the fact that a road has a low accident rate might mean not that it is safe but that is so terrifying dangerous that few people try to cross it” [Adams 1988, p.346]. The construction of indicators incorporating people’s perception could increase our understanding of the effects of motorized transport on the mobility of pedestrians. Another aspect is the visual blight of transport infrastructure. Previous research has proved the advantages of GIS methods in the quantification of this effect within hedonic models to house prices [Bateman *et al*. 2001]. These methods could be adapted to assess the quality of pedestrian trips. We propose an indicator similar to our measure of pedestrian exposure to noise, assessing the “amenity-value” of the routes of pedestrian accessing destinations around their homes, where different weights could be applied to sections crossing transport infrastructure and sections crossing through parkland, residential and industrial areas.

The interpretation of the results of the present work would also profit from the empirical assessment of some of the hypotheses that we used in the analysis of the processes leading to social inequalities. The first of these hypotheses is the capitalization of differences in pedestrian mobility in the housing market. Existing hedonic studies have included measures of pedestrian access and of local environment quality but have not focused on the effect on house prices of the interaction between the two issues. The second hypothesis is the influence of political bias in urban transport planning. This issue could be analysed by modelling historical patterns on transport decisions, the political characteristics of the populations affected and other information about the political context of the decision. The options taken in transport or land use planning could also be analysed in terms of the choice set available to the policy-maker at the time of the decision. One possibility is to search for evidence that differences in levels of present or future accessibility explain the priority to develop certain residential areas or the priority to clear certain slum areas, in detriment of other areas within the set that was included in municipal master plans.

The methods we proposed in Chapter 5 for the analysis of trade-offs in the social evaluation of transport projects can also be used to study related issues. For example, the method for formulation of optimal route alignments according to the distribution of losses in pedestrian mobility could be used in the formulation of optimal public transport routes, taking into account the distribution of accessibility gains according to the vulnerability of the populations served. On the other hand, the method for the evaluation of traffic restriction policies could be applied in the evaluation of new road infrastructure or public transport routes.

We have also mentioned in several points of this work the role played by subjectivity in the empirical analysis of issues of social justice in transport. In fact, due to its multidimensional nature, the transport equity problem can be approached from different angles and by researchers from different scientific backgrounds. The analysis may also be influenced by political or personal agendas. An interesting topic for a meta-analysis would then be the comparison of the results of studies conducted by the three main groups of researchers studying this problem: policy-makers, activists and academics. The objective of this analysis would be to assess whether the patterns of social inequality found in the studies by one group are consistent and significantly different from the other group.

A final question regards the complexities in identifying the role of transport policy within the multiple relationships between transport and urban land use, no matter how much spatial information is available. A clearer statement of the policy implications of quantitative analyses would help to increase its applicability. In fact, due to the difficulties in assessing these implications, to attend to equity in the social distribution of local mobility is as much a question of detailed geographical or statistical analysis as it is of political and ideological discussion. Policies that affect a sensitive issue as social justice may tend therefore to be the product of ad-hoc political decisions. Despite these limitations, the large body of theoretical and empirical work on the spatial dimensions of transport inequalities produced in recent years have raised awareness to an issue of increasing relevance in contemporary cities.

Appendices

Appendix 1

Spatial distribution of population

The study area is the set of 18 municipalities that are members of the Association of Municipalities of the Lisbon Metropolitan Area (AML). The municipality of Azambuja was part of the AML until 2004, but it is not included in this study, due to the unavailability of some datasets covering this municipality and to its weak functional relationship with the rest of the Metropolitan area in terms of employment [INE 2004c, p.17, 159] or access to goods and services [INE 2004d, p.38-50].

The unit of analysis is the census enumeration district (ED), which in urban areas corresponds roughly to city blocks and in the semi-rural areas corresponds to a small village or hamlet. The Lisbon Metropolitan Area contained 18758 and 27397 inhabited enumeration districts in 1991 and 2001, with an average population of 134 and 83 respectively. We restrict our analysis to the districts that contained at least three individuals, three families, three buildings and three dwellings. This is in order to minimize the number of statistical outliers derived from the calculated of variables in areas with small populations. The borders of the districts in 1991 and 2001 are given by the official Geographic Information Referencing Base *(BGRE/BGRI)* [INE d1991a, d2001a]. The comparison of these borders uses a separate map giving the areas common to both years [INE d2001e]. The selection of Census data used in this study is limited to the database provided by the National Statistics Office to external researchers [INE d1991b, d2001b]. We identified a small set of outliers, corresponding to districts with collective dwellings, which had a very high value for variables included in our analysis, such as families per dwelling and dwellings per buildings. These values were replaced with the mean of surrounding districts.

Although the available census data cannot be disaggregated further than the ED level, it is both possible and convenient to assess indicators of accessibility and pedestrian mobility at a more detailed level. This is because the effects of transport infrastructure and traffic levels on pedestrian mobility are not uniform within each ED. In addition, the effects of congestion vary according to the position of each area in relation with the major road exits of the neighbourhoods and the location of motorway junctions. Finally, a disaggregation of the different population concentrations within each ED is useful for the mapping of the indicators at the metropolitan level. This is because the usual choropleth representation of the EDs presents a distorted view of the distribution of our indicators, given that the largest EDs in the AML, which are located in the rural areas, are also the EDs with the smallest populations. Due to the problems above, we model the spatial distribution of the population of each ED at a higher level of resolution, based on the method proposed by Langford and Unwin (1994), which combines binary dasymetric mapping with a spatial smoothing procedure.

Binary dasymetric mapping is a technique to represent the spatial distribution of a quantitative variable according to the boundaries derived from the spatial distribution of the phenomenon the variable represents, regardless of the scale at which the data is collected. This is usually achieved by overlaying the original data with a set of ancillary information. In our case, we use this technique to disaggregate the spatial distribution of population according to data on land use, assuming that the population concentrates only on residential areas. For the case of 1991, we use land use data from the *Cartus-AML* 1990 map constructed by the New University of Lisbon (eGeo-UNL) and which, at the 1:25000 scale, provides a very detailed representation of types of land use in the AML [e-Geo d1990]. We consider that residential areas belong to the following classes: "Historical Centres", "Metropolitan Multi-functional", "Single Family Housing" and "Multi Family Housing"[52]. For the case of 2001, this data is updated with the changes identified in the European Environment Agency's Corine Land Cover [53] 1990 and 2000 datasets [EEA d1990, d2000], by adding the areas that in the Corine dataset change to "Urban Continuous" or "Urban Discontinuous" and subtracting the areas which cease to be in these two categories.

The procedure above accounts for the within-ED population distribution of around 90% of the districts. For the districts that do not intersect with the datasets above, we use a sequential process, retaining the areas that intersect with the following maps:

[52] Due to the one-year gap between the Cartus-AML reference year and the census year, we also include in the set of residential areas the land classified as "Allotted Areas", in the cases where there is enough evidence that the land is indeed inhabited in 1991. If we assume that the lots existing in 1991 have all been built-up and settled by 2001, then the set of lots that are inhabited in 1991 are the ones located in EDs whose population does not change significantly between 1991 and 2001.

[53] Although Corine Land Cover data exists for both years, we opted to use the Cartus-AML data alongside the changes in the Corine data, as that dataset refers specifically to land use (as opposed to land cover) and provides more detailed information (Corine data is only available at the 1:100 000 scale).

- The areas in the municipal master plans (PDM) classified as "Consolidated Urban", as given by the dataset containing the municipal maps harmonised with the classification adopted within the framework of the AML Regional Plan (PROT-AML) [AML d2003a].

A $40m^2$ buffer around the locations of villages, hamlets and groups of houses, as given by their geographic coordinates in the National Gazetteer [IGP d2008].

These overlays still leave 3-4% of the EDs unaccounted in each year. Within this group, we consider that the population occupies all the area of the ED when this area is below $5000m^2$ or concentrates in a 40m buffer around the ED centroid in other cases.

The intersections of EDs with land use data create a dataset giving the areas of each ED that we assume to be inhabited in each year[54]. We then take each group of contiguous inhabited areas in each ED as separate units for further analysis. The assignment of the ED population to each part is based on its area, giving a higher weight to the areas classified as "Metropolitan Multi-Functional" and "Multi-Family Housing". In the most urbanized areas, we correct the weights with information on the location of high-rise buildings, which are identified in orthophotomaps for years around 1991 and 2001 [IGP d1995, IGeoE d2001, d2004].

The calculation of indicators of accessibility and pedestrian mobility then reflects the conditions in all inhabited parts of each ED, averaged by the respective estimated population. We assume that the distribution of employed population and the population who need to walk are the same as the distribution of the total population. In each part, a representative point defines the origins of the trips involved in the calculation of the indicators. This point is the centroid of the ED part, constrained to be located inside the ED part[55] and snapped to the road or street network, to ensure that it represents a valid origin for all trips.

Some of the procedures in the estimation of our indicators require a model of the population distribution at a higher resolution than the ED part. This is the case of the estimation of the attractiveness of destinations for pedestrian trips [Appendix 2.3], which we assume that depends on the population for which that point is the nearest. We then need to

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[54] The intersection of EDs and land use maps produces in most cases a number of small slivers, which we only assume to be real concentrations of population (and not the effects of an imperfect overlay of data from different sources) if their area is above $1600m^2$ or if it represents more than 50% of the total area of the ED.

[55] Centroids are the centre of mass of an object in 2 dimensions. The centroids of irregular objects may be located outside of the object.

model population as a continuous surface[56]. The areal-based map of ED parts is converted to the GIS *raster* format, giving a grid of values for the population at a resolution of $40m^2$. As the population data is based on the borders of EDs, which do not necessarily define real discontinuities in the distribution of population, we also need to apply a "floating window" technique, in order to obtain a smoother distribution. This is done by taking neighbourhood statistics to each cell in the dataset, giving the average population within a radius of 400m from each cell. The resulting population surface is a satisfactory model of the population distribution in the AML, as it accounts for 97.6% and 99.9% of the population in 1991 and 2001 respectively.

[56] We apply this procedure to the whole population of the AML and not only to the EDs that were considered as units of analysis.

Appendix 2

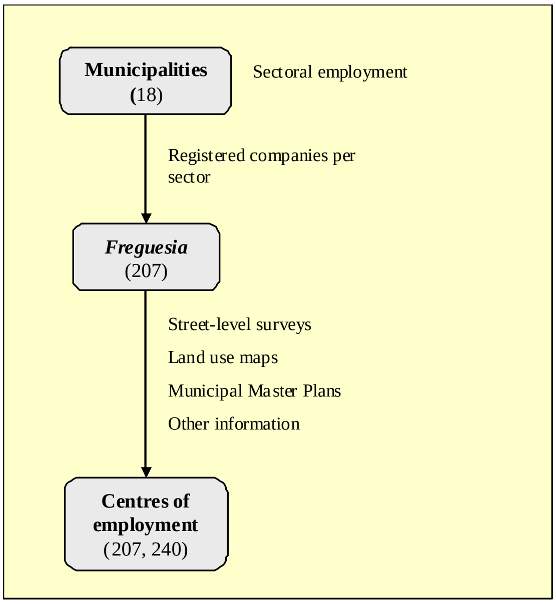
Destinations

1. The spatial distribution of employment

Spatial data on employment is available at the municipality level (*concelho*). This data is contained in the 1991 and 2001 Census Commuting Database [INE d1991d, d2001d], which includes the number of workers and students in each sector of activity commuting to each municipality. The analysis of accessibility in our study refers to workers only and not to students, as for the latter, it is difficult to make an interpretation of accessibility to schools in terms of spatial "opportunities" since for some levels of study, students are assigned to schools in pre-defined catchment areas. It is also difficult to assess actual destinations for students in each enumeration district as data on student commuting do not disaggregate flows according to the level of study or transport mode used.

The estimation of indicators of potential accessibility and average times to work require a set of destinations at a more detailed scale than the municipality and as such, the data above was disaggregated into smaller units, according to the method sketched below:

Figure A.1: Disaggregation of employment data



At a first level of disaggregation, we assign the jobs at municipal level among its sub-units (*freguesias*). For each sector of activity, the distribution of employment is proportional to the number of employees of the companies registered at each *freguesia*. This procedure makes use of the National Statistics Office database on companies and businesses for the years 1990/91 and 2000/01 [INE d1990-2007]. This data is matched to the municipality employment per sector based on the common classification of employment into 31 sectors of activity, following the official classification of sectors of activity (CAEv1/v2.1).

Within each *freguesia*, the jobs in each sector of activity are then assigned to different locations, taking into account a set of auxiliary information. To facilitate the identification of employment centres, at this stage we reclassify the CAE sectors into a more manageable system of 15 sectors (Administration, Agriculture, Commerce, Construction, Domestic, Education, Extractive Industries, Finance, Industry, Organizations, Health, Services, Transport, Tourism and Utilities). In the case of Commerce, which usually includes activities with very distinct locations, the assignment of jobs distinguishes between the locations of wholesale and distribution, large retail and small retail, while for Services we distinguish between personal services and services to companies. We assume that domestic workers do not need to commute.

Land use maps [e-Geo d1990, IGP d1990, EEA d1990, d2000] are the main source of information for the identification of employment in the sectors of Agriculture, Industry, Extractive Industries, and Wholesale and Distribution. This is complemented with information and maps from the municipal master plans. Although less straightforward, the same methods are also used in the identification of employment in the Construction sector, which we assume to concentrate in small industrial sites, allotted areas and areas under development or regeneration.

The distribution of employment in Education, Health and Large Retail is based on precise locations and uses the municipalities' on-line GIS and maps or lists with the locations of universities and schools [CML d2001a, part 6; AML d2004], hospitals and health centres [http://www.portaldasaude.pt, AML d2006] and large supermarkets and shopping centres [APCC 1999, AML d2008].

Small retail and personal services are activities whose markets are usually located in their vicinity and as such, the distribution of employment in these sectors can be approximated by the location of their markets and these by the distribution of population as given in Appendix 1. However, this is not always valid in the case of Lisbon, due to its role as a service centre for the population in the metropolitan area and in the rest of the country. In this case, the assignment of retail and service jobs used maps from street-level surveys representing the concentration of retail and service companies by street [CML 1992; d2001a, part 5] and the distribution of companies at the enumeration district level [CML 2001a, *loc.cit.*].

The employment in the Administration and Organizations sectors does not have a correspondent in the companies' database and is disaggregated directly from the municipality level to its estimated locations. This disaggregation is based on the number of public institutions and international organizations at the vicinity of each candidate location. We follow the list available in the Guidebook of Portuguese Public Administration *Guia da Administração do Estado* (2007), which is applied to both 1991 and 2001, except in the cases where there is knowledge that an institution did not exist in one of those years or changed location.

The distribution of employment in the Financial, Transport, Tourism and Utilities sectors is less clear. With the exceptions of the municipalities that conducted street-level surveys [CML 1992, d2001a, CM Amadora 2001], the assignment followed the locations of the biggest employers in each of those sectors, using the information available in the metropolitan GIS [AML d2008], the municipalities' on-line GIS and the locations available in the National Gazetteer. Finally, the distribution of employment in the Services to Companies sector is assumed to be proportional to the distribution of employment in all other sectors.

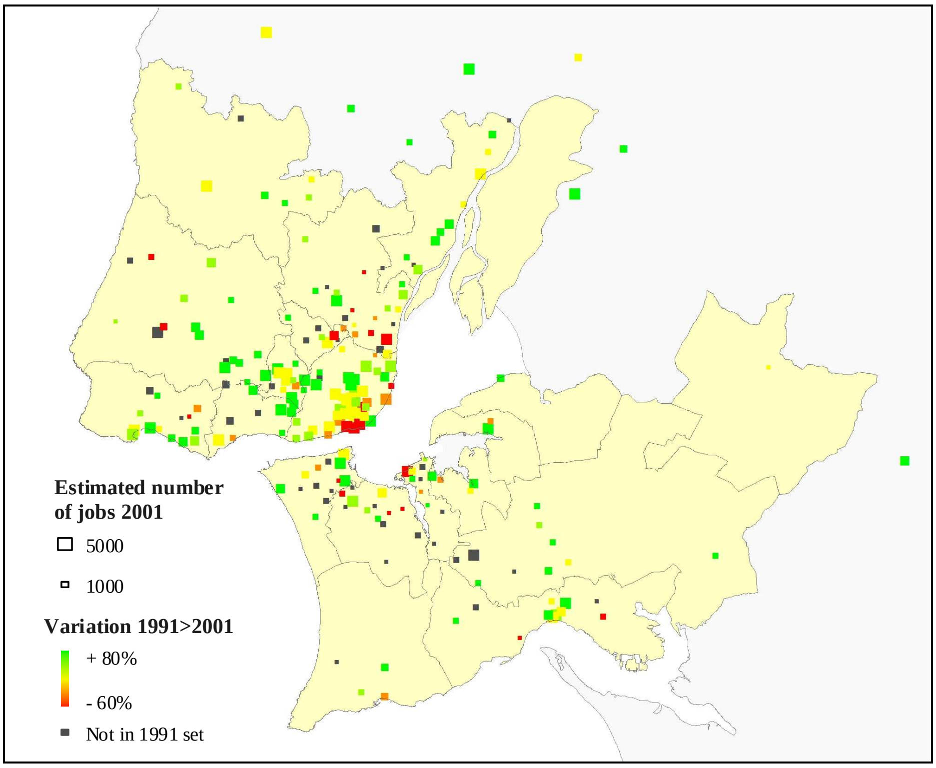
In all cases, the assignment of employment among the different candidate locations at each *freguesia* was based on a proportional distribution according to the site area, population in the area of influence or, where available, employment or financial data of major employers. The assignment followed an interactive process, assigning sectoral employment among the different candidates and summing up the total employment at each location. At each stage, the locations with less than 1000 jobs were excluded and their estimated jobs re-assigned among the nearby locations proportionally to their estimated number of jobs at that stage and inversely proportional to their distance. In this process, we allow jobs to be relocated across *freguesias.* This means that the final sum of jobs in all locations at each *freguesia* does not match precisely the initial estimated number of jobs. In addition, some small *freguesias* are not assigned any location, if there is no clear concentration of employment at any candidate location.

The threshold of 1000 jobs is imposed in order to reduce the computation time in subsequent analysis, which involves the calculation of times on the private and public network from a number of points at each ED to each destination point. The limitation of the set of destinations to a few hundred locations in each year does create some distortion, as the areas around each destination are the endpoint of a relatively large number of trips, which contributes to an overestimation of noise levels and correspondent exposures to the people living and working around those points. A possible solution to this problem was to reduce the number of origins and increase the number of destinations to extrapolate shortest times to all origins based on the values obtained for the reduced set of origins. However, we did not follow this approach, as the estimated set of destinations in Lisbon is dense enough in order to ensure that the trips crossing the road links around each destination will also cross the major links in between **[Map A.1]**. In other regions, centres of employment are more clearly defined and are usually located at key points in the municipal capitals or at major industrial sites. As such, they have a high degree of correspondence with the real spatial distribution of jobs.

Some of the populations in the periphery of the semi-rural municipalities of the AML are under the area of influence of the job market of large towns outside the metropolitan area and as such, we include nine of these towns in the set of potential destinations for workers. This option also minimizes the “edge effect” inherent to our spatial analysis, which is based on a pre-determined demarcation of the study area according to municipality borders. The criterion used to select destinations outside the AML was to include a location in the cases when the time on the private or public transport networks from the capital of a given *freguesia* in the AML to that location in either 1991 or 2001 is lower than the average private or public transport time taken by commuters of that *freguesia* to destinations inside the AML. The rationale is that the population in the metropolitan area will not consider commuting to outside destinations if the time exceeds the usual time taken to commute to a destination inside.

The map below presents the spatial distribution of the destinations in 2001, where dot size represents levels of employment in 2001 and colours represent the variation in employment from 1991 to 2001.

Map A.1: Spatial distribution of employment



The distribution of employment levels is used in the estimation of indicators of potential and average time to work. In the first case, employment levels are considered as indicators of the attractiveness of each location and included in a gravity measure. In the second case, they are used to disaggregate the commuting flows between enumeration districts and municipalities, in order to estimate average times to work for each ED. The proportion of the flows from an ED to a given destination within a municipality is then proportional to the level of employment at that destination. Given the small dimension of an ED and the large number of cells in the resulting commuting matrix, the values obtained for the flows ED-destination are in most cases smaller than one. However, as these values are only used as relative weights in the estimation of average times to work, they can be interpreted as the probability that the workers in an ED commute to each destination.

2. Urban facilities

The location of health centres is given by data from the Association of Municipalities of the AML [AML d2006], which includes the year the centres started operating. Each health centre has several extensions inside its area of influence. We chose not to include these extensions in the analysis, as they provide a smaller number of services than the main facility and because the objective is to emphasize the access to facilities that cannot be reached on foot. The analysis can then focus on the role of the public transport system on accessibility and on its insufficiencies when comparing with the private transport option.

The location of tax departments follows the information in the publication *Guia da Administração do Estado* (2007), with small adjustments based on the researcher's knowledge of changes occurring since 1991. We do not consider health centres and tax departments outside the AML, given the assumption that all users are required to use facilities inside their own municipality.

3. Destinations for pedestrians

A: Set of destinations

The set of destinations of pedestrians living in each ED is used in the estimation of average time to work and of indicators of pedestrian mobility. The set is based on a sample of all inhabited 40m cells in the study area, using the population raster model obtained using the methods in Appendix 1. The sampling process was implemented in the Hawth's Tools extension for the ArcGIS software and is the largest possible sample such that all points are at least 400m apart and the probability that each point is included in the sample is proportional to its estimated population density. We consider that pedestrians in each part of each ED will only consider destinations within 800m straight-line distance. These restrictions on the spacing of destinations and on the set of destinations accessible at each origin ensure that each ED part has a maximum of 12 destinations as options, reducing the computation time in subsequent analysis.

The process above does not ensure, however, that all ED parts have a destination, especially in the case of EDs in remote areas. To the sample obtained, we then add the locations of hamlets and groups of houses extracted from the National Gazetteer. For the 1.5% of EDs that were still without any destination after this addition, we take as destinations all the representative points of nearby EDs (see p.204) or, as a final resort, an individual sample of 4 points located within a radius of 800m, where the sampling probability is conditional to population density.

We assign to each point in the final set of destinations the population in the population raster model for whom that point is the nearest. The resulting sum is treated subsequently as a proxy for both the concentration of jobs (in the estimation of daily flows for workers walking to work) and the population-interaction potential of that point (in the estimation of the probability of non-work pedestrian trips around home).

B: Barriers

The identification of barriers to pedestrian mobility used in the construction of the indicators of community severance uses the definitions below:

In the case of barriers posed by transport infrastructure, we distinguish between "strict" barriers and other barriers. "Strict barriers" exist when pedestrian crossing is only possible at a very limited number of locations, using footbridges and overpasses. Other barriers exist where crossing is possible at a larger number of locations, but there is a severance effect due to the intimidation effect of large transport infrastructure and the accident risk involved in pedestrian crossing. In the first type of barriers, we include motorways, dual carriageways and railways. In the second type, we include all roads classified as "Improved" [Appendix 4.1 C].

"Industrial" barriers to pedestrian mobility are areas that, due to its morphological or aesthetical characteristics, have a noticeable negative effect on pedestrians' propensity to walk or on the amenity-value of walking. These barriers are identified in the Cartus-AML land use map and include the following categories: "Ports, Industrial and Storage Area", "Mining Area/Quarry", "Military Installations" and a selection of the areas classified as "Metropolitan Equipments" (including airports, aerodromes, water reservoirs, electricity transformation poles and waste management centres). The identification of these equipments in the Cartus-AML map uses the information from the digital National Gazetteer. In the case of 2001, to the groups of areas above, we add/subtract the areas that from 1991 to 2001 changed to/cease to be in equivalent categories in the Corine Land Cover datasets.

C: Neighbourhood attributes and pedestrian accessibility

Some of the variables used in Chapter 4 to measure neighbourhood attributes are estimated with reference to the street network. These variables are calculated for Lisbon and for the suburban area only.

Two of these variables are measures of pedestrian accessibility to specific destinations: shops and green space. Accessibility to shops is measured by the number of shops that can be reached within 500m walking distance. Accessibility to green space is the weighted number of green spaces that can be reached within 800m, where the weights are given by the site area. The values for the maximum distances are based on the proposals in the "Streets for Life" urban design concept developed at Oxford Brookes University [Burton and Mitchell 2006], which takes into special consideration the experiences of older pedestrians. This study suggests as reasonable walking distances the values of 500m for the case of access to primary services and facilities (*e.g.*, food stores, post offices) and 800m for secondary services (e.g. parks, libraries). The location of shops in 1991 and 2001 is based on information on the location of shopping centres [APCC 1999, AML d2008] and maps from street-level surveys [CML 1992; CML d2001a, part5; CM Amadora 2011]. We define two indicators of green space, one based on urban parks and large leisure and recreation areas, and another for forests and other natural areas. The location of these areas is given by the Cartus 1990 land use map [e-Geo d1990], and by information in CML (d2001a, part 8) and in street maps. The second indicator is not calculated in the case of Lisbon, due to the inexistence of forests or other natural areas.

The third variable is the indicator of car parking space. We assume that residents wish to park their cars within 100m of home. This value is a compromise between maximum values suggested by Balcombe and York (1993) and Borgers *et al.* (2008). The indicator then uses as a base the length of the street network within 100m of the ED representative points. To this base, we subtract the length that corresponds to paid parking space, identified in street maps for 1991 and 2001. We assume that even when some residents have access to private parking space, a deficit of free public parking spaces has an effect on other car users, who will cruise for parking and cause time losses for those residents. The indicator then measures the loss of welfare for local residents due to the lack of parking.

The fourth variable is the proximity to slum areas. We work with the hypothesis that the residents in one neighbourhood may not wish to interact with residents of a slum area. Our variable is based on potential interactions on the street. We identify the streets within 800m of each ED representative point and within 800m of the slum areas. The indicator of proximity to slums for a given ED is the total length of the intersection of the two sets of streets, weighted by the slum population. The location and population of the slum areas in 1991 and 2001 is Lisbon is given by LNEC (1990), CML (1997) and EPUL (2007, Part 4). In the suburban areas, the location of slum areas in 1991 is based on data collected for the 1993 inventory done in the framework of the Special Re-housing Programme (PER) [CM Odivelas 2005, CM Amadora d2007 and CM Oeiras 2008]. The location of slums in 2001 is based on the list of slum areas cleared since that inventory, given in the same documents. In the case of the Loures municipality, we use the information of a municipal study [CET 1992] and visual inspection of orthophotomaps for 2001 [IGeoE d2001, d2004].

4. Trips

The disaggregation of the daily trips to work in each enumeration district is used in the estimation of average time to work [Chapter 2, Section 2.2] and in the estimation of road traffic levels [Appendix 6]. We assume that all EDs inside each *freguesia* have the same proportion of workers walking to work, given by the 1991 and 2001 Census Commuting Database [INE d1991d, d2001d]. Walking trips are distributed to every pedestrian destination within 800m according to its concentration of jobs (using the nearby population as a proxy, as defined in Section 3A of this appendix). The number of workers walking to work is subtracted from the total number of workers in each ED, giving the workers commuting by motorized transport. The trips by these workers are then split into private and public transport, using categorical data from INE (1999, 2004b)[57] and into intra- and inter-municipality trips, using census data. The inter-municipality trips in each ED are assigned to municipalities using the *freguesia*-municipality OD matrix by sector of activity, available from the Commuting Database. The intra- and inter- municipal trips are then assigned to specific destinations inside each municipality according to its estimated employment levels by sector (Section 1 of this appendix)[58]. Finally, the number of workers of all sectors is aggregated for each pair of districts and destinations.

The probability of non-work walking trips from each ED part to each pedestrian destination is used in the estimation of indicators of pedestrian mobility [Chapter 2, Section 2.3]. This probability is assessed for destinations within 800m only. The probability is proportional to the destinations' population-interaction potential (measured by the number of people living nearby) multiplied by a correcting factor of 0.5 in the cases where the destination is within 500-800m straight-line distance. These values are based on the indicative distances of the "Streets for Life" concept mentioned above.

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[57] It should be noticed that this data includes both workers and students and as such incorporates choices that are not based on the journey to work.

[58] The use of proportions in the process of disaggregation of trips used in this section and in Appendix 6 is a simplification, as in reality the distribution of trips among destinations inside each municipality depends not only on differences in the attractiveness of destinations but also on differences on the time to reach them.

Appendix 3

Time

The estimation of indicators of accessibility and pedestrian mobility depends on the distribution of trips throughout the day and as such, they incorporate assumptions about time. In the present study, we restrict our analysis to the period 6:00-00:30, which we divide into two periods: Peak (6:30-9:30 and 16:30-19:30) and Off-Peak (9:30-16:30 and 19:30-0:30). The night period (0:30-6:30) is not considered. The delimitation of these periods was based on the starting time for the vast majority of the jobs in the AML and on distinctions between levels of provision in public transport services. The probability of an individual making a given trip in a given period then depends on the trip purpose.

We consider that jobs start either in the morning peak period or in the afternoon off-peak period and end in the corresponding evening periods. This is consistent with the fact that morning and afternoon periods account for 90% of the trips to work in the AML, and the evening period accounts for two thirds of all trips with home as destination [DGTT and INE d1998][59]. We also assume that the distribution of trips within each period is uniform and that the two evening periods are a mirror image of the morning and afternoon periods, in terms of public transport provision and levels of congestion. For both 1991 and 2001, the disaggregation of workers' commuting flows between the two periods of the day is based on the results of the 1998 mobility survey of the population of the AML, which provides a matrix of the number of trips between each municipality by purpose of the trip and period of the day [DGTT and INE d1998].[60] As this matrix does not disaggregate flows by transport mode, we assume that the distribution of trips is the same for all modes.

Access to urban facilities is based on a three-leg trip including a trip from home to the first type of facility, a trip between the two facilities and a trip back home. We assume that the first trip occurs in the morning peak period, while the others occur in the morning/afternoon off-peak period. This division covers the opening times common to most facilities (9:00-

[59] This includes the return leg of trips from work and trips made for other purposes, hence the relatively low value.

[60] There was a previous mobility survey, commissioned by the Lisbon Underground and conducted in 1993. The tables with the results of this survey were not made available for the present study.

16:30) and assumes that individuals want or need to be at the first facility shortly after its opening or at a time that requires them to use the transport network during the morning peak-time.

The propensity to walk around the neighbourhood is assumed to be constant throughout the day from 7:30 until 19:30, and as such the exposure to noise for pedestrians is a weighted average of exposures in the peak and off-peak period:

$$Nar = \frac{5}{12} Nar_{Peak} + \frac{7}{12} Nar_{OffPeak}$$

Appendix 4

Private transport network models

1. Components

A: Links

The private transport network is modelled for four moments in time: 1991, 2001, 2008 (representing present time) and the future. The two last cases are used for illustrative purposes in the final chapter of the dissertation. The private transport network includes motorways, roads, street links that available for private vehicles, and pedestrian links connecting parking spaces with final destinations.

The private transport network also includes links beyond the AML. In some cases, these are links connecting origins and destinations inside the AML, as in the case of the connections between North and South Banks used before the opening of the *Vasco da Gama* Bridge in 1998. In other cases, the links outside the AML connect origins in the metropolitan areas with the destinations located outside, as defined in Appendix 2; or origins outside with destinations inside the AML, having an influence on traffic levels inside the AML [Appendix 6.1D].

B: Road classification

The use of the road network as a base to estimate times to destinations and exposures to noise must rely on a road classification scheme, which has influence on average speeds and therefore on the optimal paths estimated for each trip and resulting traffic levels on each road section. The official classification used by the Portuguese Roads Institute does not provide a useful guideline for our desired type of road classification, as it does not refer to the present state of the road network but to a future "ideal" situation, including links that may not be built. Furthermore, there are inconsistencies in the classification and numbering scheme, in face of the distinct roles and characteristics of the roads and of the perceptions that users have of them. For the reasons above, the classification adopted in this dissertation does not follow the official classification into national and municipal roads and considers instead the roads' functional role inside the metropolitan space, distinguishing between motorways, arterial roads, local roads and streets. The characteristics of the roads in terms of road capacity and road surface quality are object of a separate classification, which is treated in the next section.

Motorways are treated as a separate network from other roads, with different assumptions on connectivity and methods to estimate average speeds. In this group, we also include dual carriageways (“*Via Rápida”*), as in the AML they have the same characteristics as motorways (limited access, grade-separated junctions and minimum of two lanes in each direction) [DGTT 2000, part B1].

Roads are defined as the links that can be used by both motorized vehicles and pedestrians. We distinguish between arterial roads and local roads. Arterial roads are defined as the set of the links that fulfil one of the following roles:

- main alternatives to motorways
- main connections to motorways or connections between other arterial roads
- main connections between municipality or *freguesia* capitals
- main connections between capitals and other important towns, centres of employment or other relevant destinations (such as regional-level urban facilities).

Local roads are defined as the links that do not fulfil any of these roles but where motorized traffic is still the main element.

The main sources of information for the identification and classification of motorways and roads and the evolution of both since 1991 were:

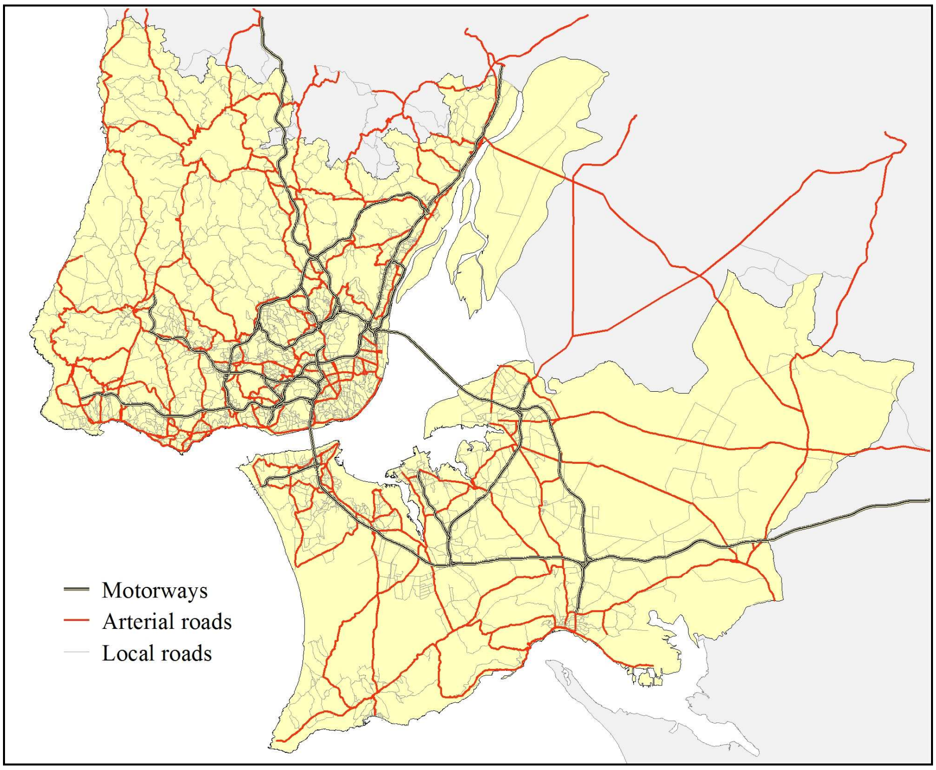
- The National Road Plans of 1985 and 2000 (Decree-Law 380/85 of 26/09, Decree-Law 222/98 of 09/07) and their subsequent alterations.
- The hierarchy of municipal roads as given in the legislation and maps of the original municipal master plans and their on-going revisions. This is the main source of information in the case of complex municipal road structures such as in Lisbon [CML d2001a, part 10], Loures [CM Loures 2004, part VI] and Almada [CM Almada 2002].
- The list of changes in the motorway, national and regional road networks in the period 1991-2000, as given by the Directorate-General for Land Transport (DGTT 2000, part B1).
- The maps published by the National Road Institute in the yearly Traffic Counting Reports [IEP 1990-2004, Estradas de Portugal 2005-2007].
- Road maps for the years around 1991, 2001 and 2008.

The identification of future changes in the motorway and road network derives from information in the current National Road Plan, the AML Regional Plan [CCR-LVT 2002, part III.4], the current municipal master plans, documents with the municipal strategic or transport plans, preliminary studies and newspaper articles.

The GIS modelling of the information above used as a source the digital road maps produced by the AML association of municipalities, representing the private transport network in 1990 and 1998 [AML d2003b, d2003c]. We use this data as a reference to trace the actual road alignments over the borders of the enumeration districts, in the cases where they coincide with roads. This option was taken in order to ensure complete accuracy in subsequent GIS overlay operations of the transport network with EDs. For the links beyond the AML, we use the road map layer of the digital version of the official 1:500 000 topographic map [IGeoE d1999], while for future links we used the road alignments mapped in the Environmental Impact Assessment documents of approved road plans. The modelling of the network and the subsequent estimation of indicators used the ArcGIS 9.2 software and a set of geoprocessing scripts such as Hawth's Tools 3.27 and ET Geowizards 9.7

Map A.2 gives the locations of motorways, arterial roads and local roads in 2001.

Map A.2: Private transport network in 2001: motorways and roads



The final level in the private transport network is that of streets, which are identified as the links where pedestrians are the main element, including both urban streets and footpaths in rural areas. Streets are accessed by both cars and pedestrians, with the exceptions of pedestrian-only areas in the city centres. Streets were modelled for 1991 and 2001 only.

The compatibility between street data for the different municipalities is problematic and in some cases, we chose not to use some detailed datasets available for some areas as this could create distortions in the estimation of indicators of pedestrian mobility when comparing with areas where the available data is poorer. Therefore, we chose to construct the street network based on the borders of the enumeration districts, as for the vast majority of the areas in urban municipalities, EDs are defined by the structure of roads and streets. This process is imperfect as there are some exceptions to the rule above. The method also does not cover the street network in the rural areas, where in most cases EDs correspond to whole villages. For this reason, the information above was edited by referring to information from the following sources:

- The annual series of topographic maps issued by the Portuguese Army Geographic Institute (IGeoE), at the 1:25000 and 1:50000 scales [IGeoE d1991-1993, d1988-2005]. The vast majority of the sheets in the 1:25000 map series covering the AML territory were updated in the years 1991 to 1993.
- Street maps and orthophotomaps at the municipalities' on-line GIS, which in many cases portrait the situation in a year around 2001. This information is complemented by two sets of orthophotomaps from the IGeoE, which together cover most of the territory of the AML [IGeoE d2001, d2004].
- Street maps of major cities for years around 1991 and 2001.
- The borders between areas with different types of land use in each year, as given by land use maps and maps in the municipal master plans.

As the same source of information is not always available for both years of concern, the coherence of the information on the evolution of the street network was judged by comparing the resulting maps with changes in the borders of the enumeration districts and changes in land use from 1991 to 2001. This is because most of these changes correspond to the creation of new streets or alterations in the street pattern, especially in the cases where new land is developed and built up or where areas are cleared for the construction of new transport infrastructure.

C: Road characteristics

The classification of roads according to its functional role is independent from the characteristics of the road itself. We make this distinction in order to incorporate both aspects in the estimations of average speeds and traffic noise. The classification of the road quality was based on the visual inspection of the roads in both years of concern and took into account lane width, surface quality and existence of central reservations. We classify roads into three categories: "Improved", "Normal" and "Path/Poor". The information used for this classification was:

- for the case of 1991, the orthophotomaps available at the National Geographic Institute on-line GIS ("O País Visto do Céu"), which refer to the situation in 1995 [IGP d1995].
- for the case of 2001, photomaps at the 25:0000 scale in the publication *Aeroguia - Lisboa e Área Metropolitana* (2000), complemented with orthophotomaps from the Army Geographic Institute [IGeoE d2001, d2004].
- for the case of 2008, the image layers available in Google Earth.

D: Network integration

The road and the motorway networks connect at motorway junctions. The location and evolution of these is taken from the websites of the companies currently managing each motorway. The modelling of link connectivity in the case of motorways and arterial roads also includes information on non-connecting nodes, such as overpasses and tunnels, taken from IGeoE (d1991-1993, d1988-2005, d1999).

A series of restrictions is placed on some links of the network. These are the cases of the links where access is limited to some users, such as "bus-only" links and lanes and "pedestrian-only" areas. The first case uses data from CML-DPPE (1995a) and CML-DMPU (2004a), while the second case uses data from street maps.

The two directions of a road link, one-way links and banned turns are modelled only for motorways and arterial roads. The modelling is based on the information available on road and street maps. In order to capture the effects of morning congestion at some motorway links, nodes are expanded in the case of motorway junctions, where all turning movements are modelled, using diagrams available in the publication *Aeroguia* (2000).

2. Crossing times

Crossing times for light vehicles in each link of the private transport network are estimated for peak and off-peak periods and refer to normal meteorological conditions. The average speeds are based on an initial value for the "natural" speeds in each type of road [Section A] to which we apply the effect of limiting factors [Sections B and C].

A: Base speeds

The modelling of road speeds in Portuguese roads is bound to be imperfect unless we consider the proportion of road users that drive above the speed limit, which tend to be the highest of all OECD countries. As such, we model the base average speeds considering speed limits by type and characteristics of the road and including information on the percentage of road users above the speed limit, as given by the results of a study made by the National Laboratory for Civil Engineering (LNEC) [DGV 2000, p. 69]. The estimation of the base speeds follows the structure below:

Table A.1: Base speeds of light vehicles

Type of link	Speed Limit	Serious traffic offence	Speed (well-behaved)	Speed (badly-behaved)	% above [LNEC survey]	Average speed
Motorway	120	150	105	135	54%	121.2
Dual C.way	100	130	95	115	72%	109.4
Road	90	110	70	105	48%	86.8
Road (Town)	50	70	40	60	83%	56.6
Street	30	50	25	40	68%	35.2

Note: Case of roads with "Normal" quality and slope=0. Values in km/hr

Speed limits and speeds considered as "serious traffic offence" are based on the legislation existing in 2001 and depend on type of link. In the case of roads, they also depend on location, with separate speed limits for roads within towns. Road sections crossing town borders are therefore divided in two sections in our network model.

We assume that in all types of road there are two kinds of drivers, the "well-behaved" and the "badly-behaved", who drive at speeds within a different interval of values. For the first group, this interval is defined by the speed limit of the roads in the level of the hierarchy immediately below[61] and the speed limit for that link. For the second group, the interval is

[61] We make an exception for the case of motorways, where we consider that the lower limit is the speed limit of roads, and not the speed limit at dual carriageways.

defined by the speed limit and the speed corresponding to a serious infraction. The case represented in the table above is for roads classified as “Normal” and crossing flat areas. We assume that in this case the average speed for each group is the mid-point of the respective interval. The average speed of all users is then average of the speeds of two groups weighted by their proportion, as given by the LNEC survey results.

In the cases of the other two levels of road quality (“Improved” and “Poor/Path”) and roads crossing non-flat areas, we assume that the speeds of each group is a weighted average of the two interval endpoints. In improved roads crossing flat areas, all users in each group drive at the speed given by the higher endpoint, while for slopes above 10%, they drive at the speed given by the lower endpoint. In poor roads crossing flat areas, all users in each group drive at the speed given by the lower endpoint, while for slopes above 10%, the well-behaved drive at 15km/hr and the badly behaved drive at 20 km/hr. The variation of the speeds of each group for slopes between 0 to 10% is proportional to the variation of the slope.

The data used in these calculations is the delimitation of “places” (cities, towns and villages) as given by the General Information Referencing Base [INE d1991a, d2001a] and corrected by the borders of built-up areas, given in land use maps. Slope data is given by [AML d2003e] and in the case of links outside the AML, estimated from the altitude data available on the digital Environmental Atlas of Portugal [APA d1982].

B: Restrictions

In the case of roads and streets, to the base speeds above we then deduct the time lost at intersections. We do not model the dynamic aspects of queue building at junctions, but instead add a penalty time to the links connected by the junctions. With the exception of roundabouts, each link is assigned 50% of the time lost at the junctions in each of the link’s endpoints.

The time lost depends on the hierarchy of the roads as defined in Section 1B of this appendix and following the structure in **Table A.2**. The stopping times in the fifth column are values measured by the authors in key locations in Lisbon and Loures in 2006. We assume that traffic lights exist at the junctions in urban areas where at least one of the links is an arterial road. The calculation of the time lost in these cases is based on a uniform distribution of cars within the red light period. For junctions without traffic lights, we consider that the probability of stopping at an intersection is 50%. We also assume that in rural areas, traffic in arterial roads is always given priority.

Table A.2: Time lost at intersections

Area	Type of road	Junction with	Traffic lights	Stop time	Time lost
Urban	Arterial	Arterial	Yes	45	11.5
	Arterial	Local	Yes	60	5.2
	Local	Arterial	Yes	30	20.3
	Local	Local	No	30	15
Rural	Arterial	Arterial	No	30	15
	Arterial	Local	No	0	0
	Local	Arterial	No	30	15
	Local	Local	No	15	7.5

The definition of priorities in the table above is also used to define a speed restriction regarding the length of the link, which is applied to all road sections whose length between stops is below 100m. In these cases, we consider that all cars will drive at a cruising speed, taken as the speed for a street with the same slope.

C: Congestion

The effect of congestion in the reduction of average speeds uses a simple speed-flow relationship, given by the UK Department of Transport [UK DOT 1985, cited in Ortúzar and Willumsen 2006, p.325-327][62]. This relationship considers that for traffic flows above a certain threshold, speed decreases linearly up to the capacity of the link, after which it becomes a non-linear function decreasing on traffic flow and increasing on the length of the link. Traffic levels are calculated separately for peak and off-peak periods and so road average speeds depend on the period of the day. As we integrate the time lost at junctions in the crossing speeds of the links they connect, we assume that the speed in a link is not affected by flows in other links and delays at junctions. We should note that this assumption is valid for motorways and long links in rural areas, but does present some limitations in other cases.

The relationship between average speeds incorporating congestion (S_{cong}) and traffic flows is the following:

[62] Although these formulas have been subsequently updated by the UK DOT, incorporating more realistic assumptions, we chose them due to their simplicity.

$$S_{cong} = S_{ff} - \frac{(S_{ff} - S_{cap})(T - T_{ff})}{T_{cap} - T_{ff}} \qquad \text{if } T_{ff} < T \leq T_{cap}$$

$$S_{cong} = \frac{S_{cap}}{1 + \left(\frac{S_{cap}}{8d}\right)\left(\frac{T}{T_{cap}} - 1\right)} \qquad \text{if } T > T_{cap}$$

In this formula, T_{ff} is the maximum flow at which free-flow conditions prevail and S_{ff} is the corresponding speed, while T_{cap} is the capacity flow and S_{cap} is the corresponding speed. In the second expression, d is the length of the link. The value of S_{ff} is understood as the "natural" speed of the link, as calculated in the previous sections, while the values of the other parameters are deducted from road speeds and capacities estimated for motorways and major roads in Lisbon in 2001 [CML-DMPU 2004a, p. 102-105], which are then extrapolated to 1991. In the rest of the metropolitan area, we use capacity flows equal to 1800 passenger car units per hour and lane, which is a rule of thumb generally used in transport studies [Willumsen 2000, p. 167]. We make an exception for roads classified as "Improved", where capacity is taken as 2000, and for specific cases where measurements are available in transport studies done in the framework of the municipal master plans. The final speed is constrained to be above 15km/hr, which was the minimum speed observed at the major entrances in the study above [CML-DMPU 2004a, p. 107].

In these calculations, traffic levels refer to the hourly traffic at peak and off-peak periods, determined using the methods described in Appendix 6. The determination of the number of lanes uses the same sources of information used in the classification of road quality.

3. Optimal paths

The optimal paths on the private transport network are used in the calculation of both potential and realized accessibility to places of work. In the latter case, we consider that private transport network users comprise the commuters using the travel modes "Car, as drivers", "Car, as passengers" and "Company/school transport".

The route choice for private transport users assumes a rational traveller, choosing the best available route in terms of its preferences over route attributes. In order to facilitate the interpretation of accessibility indicators, we assume that time is the only attribute considered. However, preliminary analysis revealed that the inclusion of distance (which is an often-used proxy for monetary cost) as a cost alongside time does not have a substantial impact on most of the estimated routes. This result is due to the segmentation of the AML transport network into separate radial corridors containing a small number of route alternatives.

The method of traffic assignment allocates to a single route all trips from an origin to a destination ("all-or-nothing assignment"). As such, all drivers travelling from the same enumeration district to the same centre of employment choose the same route. The assumptions are that they have the same preferences over the attributes of each route, face the same constraints over available choices and have the same perceptions of both.

The optimal route estimation procedure is implemented in ArcGIS 9.2 Network Analyst, which uses the Dijkstra algorithm [Dijkstra 1959]. The routes are estimated for both the peak and off-peak speeds. Routes start at the EDs representative points and end at the points representing centres of employment. In the case of major urban areas, the routes are constrained to end at parking areas, with the rest of the trip being made on foot. We do not consider walking from home to parking areas as we assume that car users have access to parking areas inside or near the buildings where they live. Cruising for parking is not included, assuming that individuals have made arrangements ensuring daily access to parking spaces at places of work or parking areas.

Traffic assignment is based on the set of travel times that do not incorporate congestion. The resulting traffic levels on each link are then used to re-calculate travel times with congestion, as described in the previous section. The assumption underlying this procedure is that users do not consider congestion in their choice of routes. This ignores the interdependence between congestion and route choices, as congestion alters the relative times between alternative routes. A solution to this limitation would be to implement a sequential all-or-nothing assignment representing adjustments of traffic flows to travel times. However, in many cases the shortest routes will oscillate between different alternatives and the flow pattern does not converge (Ortúzar and Willumsen 2001, p.337-340). Furthermore, in the case of AML, congestion occurs in links connecting areas for which no feasible alternative routes exist, especially in the North corridor (Loures), where all traffic converges to a single access point in Lisbon. As such, the limitation posed by the assumption above has only a minimal effect on the estimation of optimal routes.

The distribution of traffic within each period of the day is constant, following the assumptions about time stated on Appendix 3. As such, we do not consider the dynamic aspect of traffic assignment, the effects of congestion over time and the choice of different departure times as a strategy to reduce the time to work.

Appendix 5

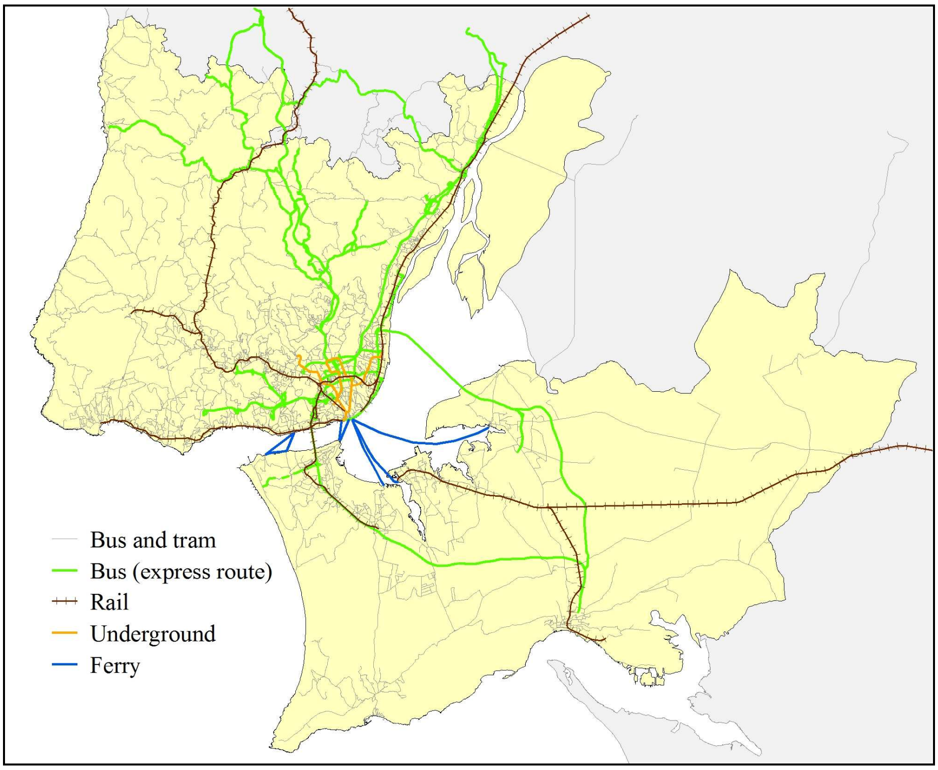
Public transport network models

1. Components and crossing times

The public transport network infrastructure and services are modelled for 1991, 2001, 2008 and the future. The information on infrastructure and services existing in 2008 is based on the public transport integrated information system (TransporLis) available at www.transporlis.sapo.pt. In the areas that are not covered by this system, we use the information on the operators' websites. The average travel times on each section of the network are identified for the peak and off-peak periods and refer to winter weekday schedules.

The identification of changes occurring from 1991 to 2008 uses the information described in the next sections. Information on future links on the rail, light rail and underground network is extracted from regional and municipal transport plans, the operators' strategic plans, preliminary studies and newspaper articles. In all cases, the information is integrated in the GIS using as a base a series of data layers provided by the AML association of municipalities (AML d2003d). This data is adjusted to overlay with both the street network and the borders of the EDs. For the links extending beyond the AML, geographic data is extracted from IGeoE (d1999). Changes in the system occurring after 2001 and future proposed links and stops and stations are modelled based on existing digital maps, when available, or edited directly over the 2001 GIS data file. The modelled network for the case of 2001 is presented in **Map A.3**.

Map A.3: Public transport network in 2001



A: Bus

The bus system in the AML comprises the Lisbon bus network (CARRIS) and a series of operators serving groups of contiguous municipalities and connecting these municipalities with Lisbon. We distinguish between normal services and express routes, considering them as separate networks, with different stops and average speeds and different levels of availability in the peak and off-peak periods.

In the case of Lisbon bus system, bus routes in 1991 and 2001 are extracted respectively from CML-DPPE (1995a) and CML-DMPU (2004a), which cover the situation in the years of concern. The modelling of the services of companies operating outside Lisbon uses the maps available in the AML Public Transport Guidebook, which refers to the situation in 2001 [AML, DGTT and CML 2001] and gives the availability of the services at peak and off-peak periods and the bus route maps of all operators. The maps in this publication are generalizations and do not always show all the streets served, in which case the gaps were covered using the detailed routes for 2008 found at the *TransporLis* GIS. The situation in 1991 is deducted from the 2001 maps, based on temporal changes identified in the old versions of the operators' websites, archived at the internet *Wayback Machine*. The maps of the Lisbon tram network and data on respective average speeds are taken from CML-DPPE

(1995a) and DGTT (2000, part B2.1.2).

The location of bus stops for both normal and rapid services in 1991 and 2001 follows the location of stops in 2008, available from the *TransporLis* GIS and from the operators' websites. This method does not apply when we have evidence that the bus stop did not exist in 1991 or 2001, which we assume to be the case when there is no population or centres of employment in a radius of 500m from that stop. The modelling of bus stops in the links that are not served by the bus network in 2008 assumes that the location of bus stops is regular, at the same length interval as nearby links with bus services.

The crossing times on the bus network are not based on their schedules, but estimated based on average speeds at peak and off-peak times, using the same framework used for private vehicles. This is because schedules for urban services are usually given as the average frequency of services. Congestion has also a substantial impact on the average duration of bus trips, especially in the morning peak-time. We follow a method similar to the one used for private vehicle average speeds [Appendix 4.2]. However, the estimation of bus speeds differs in the following points:

- Speed limits and speeds considered as serious traffic offences are those for heavy vehicles.
- We assume that all drivers are "well-behaved".
- Buses stops not only at junctions but also at bus stops. We assume that regular bus services stop have a probability of 50% of stopping at a bus stop and that the average stop is 15 seconds. Rapid bus services always stop at the scheduled stops, with an average stop of 45 seconds.
- The length threshold below which buses drive at cruising speed is calculated on the sections between each stop and junction.
- The minimum value for the speed in congested links is assumed to be 9km/hr, which is a compromise value between the minimum average speed observed for buses in Lisbon [CML-DPPE 1995a, DGTT 2000, part B2.1.1] and estimated relationships between traffic levels and bus speeds in some of the most congested routes in 2002 [Vieira 2004].

B: Rail

Rail services in the AML include five suburban lines, managed by two operators (*CP* and *Fertagus*), and a series of services connecting Lisbon with other parts of the country, serving some of the stations within the AML. Information about the evolution of infrastructure since

1991 is taken from CML-DPPE (1995a) and DGTT (2000, part B3.3). We also model the lines used only by freight traffic, as this traffic has an impact on noise levels. The exact location of stations is based on information provided by the national rail infrastructure company [REFER d2001]. A series of complementary information is associated with each section of the network and later used in the estimation of noise levels, including the type of line, width, location of bridges and tunnels and number of tracks. This information is extracted from the official railway directory [REFER 2007], from the railways layer map in IGeoE (d1999) and in some cases from orthophotomaps covering the years around 1991 and 2001.

The information on the services provided on each section of the network is taken from the Portuguese Railways annual guide [CP 1991, 2001, 2008] and from the 2001 and 2008 timetables of the private operator (Fertagus). In each line, we distinguish between regular and express services, which are treated separately in the estimation of speeds, noise levels and optimal routes on the public transport network. The average number of cars in a train is identified using images for 2008 available in Google Earth and is used in the noise modelling process.

The crossing times on each section of the network is not based on the times between stations but on average speeds calculated along longer stretches of the track, in order to minimize the measurement error implicit in the fact that published timetables are rounded up to the nearest minute.

C: Other modes

The evolution of the Lisbon underground system, on-going works and planned improvements are identified in maps provided in the operator's webpage. The estimation of crossing times between stations is based on average speeds calculated over long sections of each line, using data for 2008. These values are extrapolated to the lines existing in 1991 and 2001, based on the evolution of the average speed in the network [CML-DPPE 1995a, DGTT 2000, part B2.3].

Light railways integrate the AML transport system only in 2008, after the opening of the light railway system in the South Bank (MST). Although a large number of plans for future lines have been proposed, we only include in the modelled future network the cases where the actual implementation of the projects seems more likely: the expansion of the MST, new links connecting railways and the regeneration of old tram routes in Lisbon. Crossing times on the existing lines are based on the respective schedules. The related average speeds are then used to model all future lines.

The evolution of ferry routes, terminals and crossing times is based on maps and information in CML-DPPE (1995a) and DGTT (2000, part B3.4). We did not consider the short-lived link between Lisbon Oriente and the South Bank not the car ferry between Setúbal and the Tróia Peninsula, located outside the AML limits, as the estimated number of jobs at the destination is below the 1000 threshold defined in Appendix 2.

D: Network integration

The public transport network connects with the road and street network at stops and stations. The different layers in the public transport network connect directly at transport terminals, or indirectly through the road/street network or through pedestrian links between stops and stations. To simplify the modelling process, the different routes of the same bus company are included in the same layer and as such, all the road links served by the company are directly connected. In all cases, rapid services are modelled in separate layers, connected with the rest of the network only at designated stops or stations.

The public transport network does not connect directly with the origins of trips at each ED or with the destinations. The trips from stops and stations to those points are therefore made on foot. The road and street network available for pedestrians comprises all links that are not limited-access (such as motorways and some arterial roads). The network includes links that are not available for cars or buses, such as street elevators, pedestrian precincts and footbridges over motorways and railways. The identification of these is based on the same image sources used to classify roads and rails. The estimation of crossing times for pedestrians depends on slopes and borrows the formulas and parameters used in the Global Map of Accessibility research project [European Commission n.d.]:

$$Speed(km/hr)= 5*e^{-3*[Slope]}$$

2. Optimal paths

The optimal paths on the public transport network are used in the calculation of indicators of both potential and realized accessibility to places of work. In the latter case, we consider that users considered all travel means available and not only the means reported in available commuting data, which states only the main travel mode used.

The optimal path on the public transport network is based on itineraries ("single optimal routes") and not on possible strategies of users when faced with different services linking the same nodes with different frequencies. As with the case of the private transport network, we assume that users of the public transport network are rational and well-informed and make their decisions based on travel time only. We should notice that this assumption is potentially more serious in the present case, as the monetary cost of public transport trips is more perceivable, especially for multi-modal trips involving different companies without an integrated fare structure, as was the case in most of the AML until very recently. The effect of travel time is also complex, as the time spend in different stages of the trip is judged differently by users, with waiting and interface time usually carrying larger weights. As in the case of private transport, we consider that public transport users do not consider the effect of congestion on the relative times of different travel modes or of alternative routes.

In the calculation of time to work and time to urban facilities, we consider that the available public transport options are the ones that, in any day of the week, allow passengers to arrive at the destination in the relevant period (morning or afternoon) and to return from that destination in the corresponding evening period, as defined in Appendix 3. This assumption is made in order to account for the irregularity in the number of the departures throughout the day and for the unavailability of suitable connections in the rural parts of the study area. Due to this condition, we do not consider the services offered in a large part of the rail network in the South Bank. We impose no restrictions on the departure or arrival time at home and as such there is no upper bound on the times associated with the optimal routes from EDs to destinations.

The total journey time of a given route in the peak or off-peak periods includes the sum of times used in the crossing of each link, based on the schedules or speeds at the respective periods of the day. To these times, we add the walking time from home or place of work to the first stop or station used, the interchange time between different modes or services and the waiting times at the first and at all intermediate stops and stations on the route.

We consider that the expected waiting time at the first stop depends on the frequency and reliability of the services. The base waiting time is equal to half of the service headway, which assumes that passengers arrive at random at the stop/station and that vehicles have no capacity constraints. We impose a maximum of 10 minutes waiting time, as we assume that users are aware of the exact schedule of less frequent services and arrive just before departure. To the base waiting time, we add a penalty in order to account for irregular departure times due to delays and variations in service headway due to congestion. The penalty for the case of rail services is 5 and 2.5 minutes in 1991 and 2001. In the case of buses, the penalty is 7.5 and 5 minutes for buses departing from Lisbon, and 5 and 2.5 minutes from buses departing from other municipalities.

The interchange time between different modes or companies includes transfer walking time (taken as 2.5 minutes) and waiting time for the connecting service. Waiting time uses the same values as in the case of the first stops/stations used in the route, but without defining a maximum wait, as passengers cannot adjust the arrival at the stop with the departure of the service. These methods do not apply to the interchange time between different services offered by the same company, as they are modelled in the same network layer. In these cases, we assume that services tend to be perfectly adjusted and add a token penalty value of 2.5 minutes to the final route when the services connect different municipalities.

Appendix 6

Traffic levels

The traffic data collected and published annually by the National Roads Institute is limited to a series of monitoring stations at national roads. However, in many cases, municipal roads have higher traffic levels than national roads covering the same corridors. In addition, the data available from the municipalities is not always consistent with the National Roads Institute database, as the methods of estimation differ. Due to these limitations, in the present study we model traffic levels for all links of the 1991 and 2001 private and public transport networks.

We estimate traffic levels for the peak and off-peak weekday periods. The distribution of traffic within each period is uniform and the two evening periods are mirror images of the morning and afternoon periods. Private vehicle traffic levels are based on the disaggregation of commuting flows [Section 1]. The estimation of public transport road traffic and rail traffic [sections 2 and 4] uses data on the supply side.

1. Private vehicle traffic

Private vehicle traffic is estimated by trip purpose, considering trips to work, personal trips for other purposes and work-related trips.

A: Trips to work

The number of private transport trips to work that use each link of the road network is estimated by aggregating the traffic flows obtained when assigning commuters to the optimal routes from the representative points of each enumeration district to places of work. The trips from ED to destination by private transport are obtained using the methods described in Appendix 2.4. The proportion of these trips that correspond to workers using private vehicles as drivers is based on the modal split available from the 1991 and 2001 Census Commuting Database at the *freguesia* level. These trips are interpreted as number of vehicles and aggregated to each link of the network. As stated in Appendix 2, in most cases the values obtained in each individual route are fractional and interpreted as the probabilities that the drivers from a given ED will travel to a given destination using a given link.

B: Other personal trips

For trips with home as an origin, and whose main destination is not the place of work, we assume that the set of origins and destinations is the same as the one used for trips to work, but considering different factors to measure the attractiveness of each destination. The routes taken from origins to destinations use the same optimal routes as the trip to work.

For trips for educational purposes (made by students), we use the commuting database from the 1991 and 2001 census, applying a process of disaggregation similar to trips to work. The number of students is given by the census results at the ED level. The split between private and public transport users in each ED is the same as in the case of the trip to work. We also assume that the choice of travel destinations is the same in all EDs in a *freguesia*. The destinations in each municipality are proportional to the estimated employment in the education sector. The resulting number of trips that refer to students using car as drivers is then assigned to each optimal route and finally disaggregated by period of day according to the results of the 1998 mobility survey.

Trips with purposes other than employment and education are not given in the commuting database, as they are not necessarily made on a daily basis. We use the results of the mobility survey to extrapolate from the matrix of trips to work the number and geographic distribution of trips for other purposes in both 1991 and 2001[63]. Trip purposes include shopping and services, health, recreational, transport of family members, and visits (social). For each pair of municipalities, we assume that the ratio between the number of private transport trips for a given purpose and the number of private transport trips to work is the same as the one observed in the survey. This ratio is applied as a factor to the number of trips to work from ED to municipality, obtaining a matrix of number of trips for each purpose. The number of trips to each destination inside each municipality is then assumed to be proportional to a variable standing as a proxy for the degree of attractiveness of that destination for trips for each purpose. These proxy variables are the following:

[63] The estimation of trips for other purposes assumes that these trips start at home, an assumption that is not explicitly stated in the questions of the mobility survey.

Table A.3: Trip purposes and proxies for trip attraction

Trip purpose	Proxy
Shopping and Services	Employment in the Administration, Commerce (Retail) and Services sectors
Health	Employment in the Health sector
Recreational	Employment in the Tourism sector
Transport of family members	Population
Visits (Social)	Population

In the last two cases in the table, the population assigned to each destination is the sum of all the population for whom that destination is the nearest, using the population raster model obtained with the methods described in Appendix 1.

The number of trips obtained for each purpose is finally disaggregated by period of the day and finally converted into vehicles by using values on average occupancy of private vehicles per municipality. Both operations use data from the 1998 mobility survey.

C: Work-related trips

Work-related trips are the ones made during work time. This group includes trips as diverse as trips between offices in private vehicles and freight transport in light or heavy vehicles. We assume that trips start and end at one of the points considered as centres of employment (which in trips for other purposes were considered only as destinations) and that the type of vehicle used (light or heavy) depends on the sector of activity of the person making the trip.

The estimation of work-related trips also uses as a base the results of the 1998 mobility survey. The ratio between the number of work-related trips between two municipalities and the total number of workers at the origin in 1998 is applied to the 1991 and 2001 levels of employment by municipality, producing the inter-municipality matrices of the total number of work-related trips in 1991 and 2001.

Trips are then disaggregated according to centres of employment at the origin and destination. We assume that the number of trips made by each type of vehicle to access one location depend on the levels of employment by sector at that location. We define a measure of the potential of each sector for generating work-related trips by each type of vehicle, according to the nature of the sector. For example, the potential for work-trips in the industrial sector is defined as one (maximum) for heavy vehicles and zero for light vehicles, while for the services sector we take the values of 0.5 and 0.75 respectively. Levels of employment by sector are then summed using the values above as weights. The result is a pair of values for each location giving its potential for generating or attracting work-related trips using light vehicles and heavy vehicles. These values are finally used to disaggregate the values of the inter-municipality matrix of work-related trips at both origin and destination. In this process, we use simple proportions and assume that the distribution of destinations is conditional to the distribution of origins. The result is the number of trips between pairs of locations by type of vehicle, which are then disaggregated by period of the day.

Light vehicle trips are converted into number of vehicles using the average levels of private vehicle occupancy at the origins. Heavy vehicle trips are identified as number of vehicles. Vehicles are assigned to the optimal routes connecting each pair of locations using the private transport network, which after summed up yield the number of vehicles in each link of the road network.

D: Non-AML traffic

Traffic flows in and out of the study area are modelled for all trip purposes, using the same methods as internal traffic. We model the flows that we assume to correspond to regular trips. The other flows in and out of the AML that are contained in the commuting database are considered to be sporadic.

The set of destinations and the definition of regular flows for the case of commuters to municipalities outside the AML are described in Appendix 2.1 (p.209). In the case of flows from outside the AML, we take as origins a set of 52 locations corresponding to capitals of *freguesias* nearby, using geographic data from the National Gazetteer. A location is included in the set if the time on the private transport network to some municipal capital in the AML in either 1991 or 2001 is lower than the sum of the average time to work of private transport commuters within the AML and the average time to work of private transport commuters in the rest of the country. The rationale is that regular commuters to the AML from outside will be prepared to travel the usual length of time in order to reach the border of the AML and then the usual time taken in the AML to travel from one place to another. The estimation of the number of trips by year, purpose, type of vehicle and period of the day use the same methods as in the last sections, considering average values imported from the AML in the cases where parameters are not available from the 1998 survey. Vehicles are assigned to the optimal routes on the 1991 and 2001 private transport network from the considered locations to each destination.

Trips whose origin and destination is not inside the AML but which use links on the metropolitan transport network are modelled only for the case of motorways. The modelling is based on the proportion of traffic crossing the AML in the total traffic of each motorway section. This information is given by the company managing the motorways crossing the AML (BRISA), consulted in AML and INE (2001).

2. Bus traffic

Contrary to the case of car traffic, the estimation of the bus traffic levels does not use the information contained on the optimal routes obtained for commuters using the public transport network, as the vehicles' occupancy levels vary among bus companies and regions. As such, we need to refer to the actual number of vehicles crossing each section of the road network. In the case of the Lisbon bus system, this information is obtained from CML-DPPE (1995a) and CML-DMPU (2004a). Outside Lisbon, the estimated traffic levels are based on data on the average frequency of the services of each company at peak and off-peak times in 1991 and 2001, using the sources of data mentioned before.

3. Total road traffic

The sum of all private vehicle and bus traffic is assigned to each link in the road network. Bus traffic and heavy vehicles in work-related trips are previously converted to passenger car units, using the relation 1 heavy vehicle = 2.5 car units. In links with more than one lane per direction, traffic is divided equally to all lanes. Finally, traffic is divided equally by the number of hours in the respective period of the day. The final result is the level of traffic expressed in passenger car units per lane and per hour, estimated for each year, road link and period of the day.

4. Rail traffic

The number of standard and rapid passenger trains running in each period in each section of the rail network is based on the 1991 and 2001 schedules. The accounting includes services not considered in the estimation of accessibility, such as inter-city trains connecting Lisbon with the rest of the country and not stopping in stations within the AML. Freight traffic is only included in the lines where demand is higher [REFER 2007].

Appendix 7

Noise

Noise maps are available for some parts of the study area (7 municipalities) for recent years (between 2001 and 2007). We have not made direct use of this information, as the present study requires data on the conditions in 1991 and 2001 and covering the metropolitan area. In addition, the available noise maps refer to periods (daytime *vs.* nighttime) that are not consistent with our division of the day into peak and off-peak periods. The solution to these limitations was to model noise levels for both years, focusing on two main sources of noise: roads (including motorways) and railways. The models are based on available or estimated data on the location of infrastructure, traffic levels, compositions and speeds, and on a series of other spatial variables.

Noise levels are estimated for a 40m grid covering the study area. The calculation distinguishes peak and off-peak periods, which correspond to different traffic levels, as estimated by the methods described in Appendix 6. The estimation procedures are adaptations of the formulas given by the United Kingdom's Department of Transport for the calculation of road traffic and railway noise [UK DOT 1995, 1998][64]. These formulas predict noise levels at different distances from the sources assuming normal meteorological conditions.

The road and rail links in each year are first divided in segments, which are subsequently treated as separate noise sources[65]. The segment boundaries are defined by junctions, connections with other transport network (e.g. motorway junctions or rail stations) and by variations in the conditions that affect noise emission and propagation. The estimation of noise is a three-step process, first assigning a noise level for each segment and then estimating the noise at the reception point, considering the attenuation due to noise propagation over space and the features of the site layout. The contributions of all segments of all road and rail sources are then combined for each grid point to derive an overall predicted noise level.

[64] We use the UK models since there is no specific noise estimation methodology for the Portuguese case. Although the output of the model for road noise is a statistical measure (L_{10}), which needs a further conversion to equivalent noise levels, we use these models in order to ensure consistency between the methods of estimation of road and railway noise, and because thee models have been validated in several countries outside the UK.

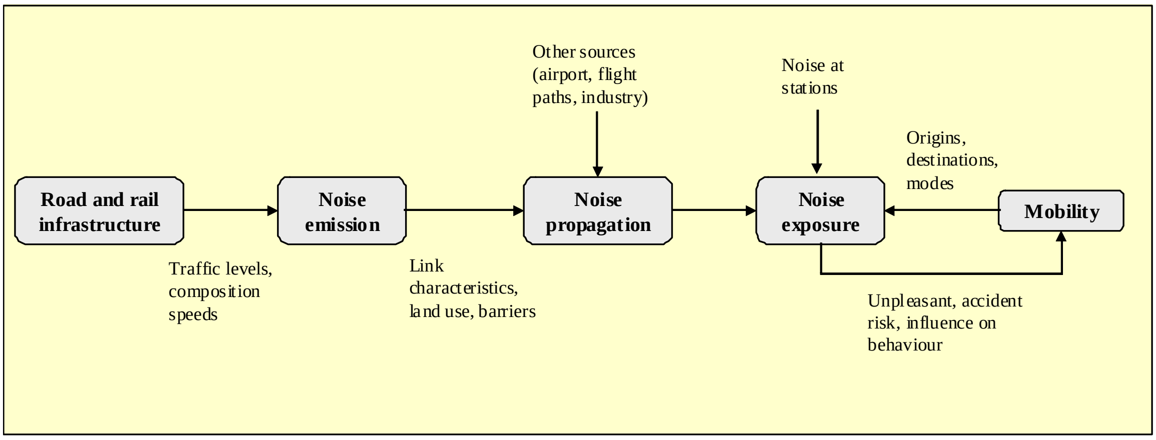
[65] Segments with tunnels are not considered as a noise source.

Other sources of noise and respective propagation patterns are identified on available noise maps[66]. This is the case of the noise from the Lisbon International airport, flight paths, aerodromes, the Lisbon tram system and major industrial sites. This information is used to estimate noise levels in 1991 and 2001 and in the municipalities where data is not available. In both cases, we use simple regressions between noise levels and traffic volumes or site area.

The noise from the Lisbon underground is only modelled on the sections of the line on the surface, applying the same methods used for railway noise. However, the noise from arrival, stop and departure of trains at the underground has an impact on indicators of exposure to noise on the way to work. Therefore, the associated noise levels are added directly to the estimated indicators, using data from measurements in the Lisbon underground system by Davis and Zubkoff (1964) (results reproduced in Bugliarello *et al.* 1976, p.89). This data applies to the 1991 indicators. Given the improvements in the network from 1991 to 2001, to the values above we subtract 5 dB(A) in 2001.

The method of estimation of noise levels and they way it integrates into the objectives of the dissertation are illustrated below:

Figure A.2: Noise: estimation methods and relationships with mobility



1. Noise emission

The emission of noise from a given source is estimated at a reference position from the segment (10m for road and 25m for rail) and depends on traffic levels, traffic composition and

[66] Noise maps were provided by CML [d2001b], CM Loures [d2004], CM Mafra [d2005], CM Montijo [d2005], CM Palmela [d2007], CM Vila Franca de Xira [d2007] and CM Almada (2004). Small-resolution versions of noise maps of other three municipalities were extracted from published reports: Amadora [dbLab 2006], Seixal [Santos 2006] and Oeiras [Garrett and Almeida 2007].

speeds, and type of infrastructure:

A: Road

The noise levels at peak and off-peak time assigned to a road segment are given in terms of the L_{10} measure, which gives the noise level exceeded for just 10% of the time over a given period. This indicator is defined as a function of the road traffic flows in the relevant period[67]:

$$L_{10,peak}=34.42+10\ log_{10}(T_{peak}) \quad \text{dB(A)}$$

$$L_{10,offpeak}=31.41+10log_{10}(T_{offpeak}) \quad \text{dB(A)}$$

where T_{peak} *and* $T_{offpeak}$ are the sum of the traffic flows in both directions at peak and off-peak times.

These formulas are then adjusted for the effect of traffic speed and composition, by adding a correction factor given by

$$33log_{10}(S+40+500/S)+10log_{10}\ (1+500p/S)-68.8\ dB(A)$$

where S is the mean traffic speed (km/hr) and p is the proportion of heavy vehicles in the total traffic. Data for these parameters come from the calculations described in Appendices 4.2, 5.1 A and 6.

Further corrections to noise levels apply to roads with certain characteristics. This is the case of roads on a gradient, to which we add *0.3G dB(A),* where *G* is the average percentage gradient of the road segment, which uses data from AML (d2003b). A correction of *-3.5 dB(A)* is subtracted in the case of roads with pervious road surfaces, which we identify as those classified as “Path/Poor” condition (p.221). A correction of *-1 dB(A)* applies to roads with impervious surfaces where the speeds are below 75km/hr.

B: Rail

Railway noise levels are estimated in terms of sound exposure level (SEL). This is the level that, if maintained constant for a period of one second, contains the same amount of acoustic energy as the noise from the actual noise event (the passage of the train). The SEL of a railway segment is estimated for each track and for each train type and is a function of speed and the number of vehicles in the train. As such, normal and rapid services are considered as different sources of noise. Locomotives are also treated as a separate train and their noise levels are estimated separately from the rolling vehicles. The SELs are given as below, where *N* is the number of vehicles comprising the train.

$$SEL=46+20log_{10}(Speed)+10log_{10}(N)\ dB(A)$$ (vehicles and electric locomotives)[68]

$$SEL=112.6-10log10(Speed)\ dB(A)$$ (diesel locomotives)

This formula is then corrected for some types of track structure. To the SELs above we add a correction of *+1 dB(A)* for concrete bridges and viaducts and of *+6.5 dB(A)* in the specific case of the section of line on the 25 Abril Bridge [CM Almada 2004, p. 34].

2. Noise propagation

The effects of propagation of noise are the reduction of noise levels that occur due to the distance, absorption and screening from obstacles in the noise propagation path from the noise source to the reception point. We estimate for each grid point in the study area the level of noise from all network segments within 500m, corrected for the mitigation effects of propagation. The reception point is assumed to be 1.5m above surface, which accounts for the level of intrusion of noise on all affected pedestrians, adults and children. For road traffic, the noise source line is assumed to be in the middle of the road and 0.5m above the road surface. For rail rolling vehicles and electric locomotives, the source line is the railhead, while for the case of diesel locomotives, it is 4m above the railhead.

The corrections require a classification of noise sources based on whether the propagation is obstructed or unobstructed by intervening obstacles between the source and the reception point. We consider that the main obstacles in the noise propagation path are buildings. Obstruction occurs when the line connecting source and reception crosses through built-up land. We identify built-up land in the Cartus-AML 1990 land use map as the set of residential areas defined in Appendix 1 (p.203) and the areas classified as “Metropolitan Equipments”, “Ports, Industrial and Storage Area” and “Shopping Centres”. In 2001, to this set of areas we add or subtract areas corresponding to equivalent categories in the Corine Land Cover 1990 and 2001 datasets. In the case of motorways and railways, we also consider the location of noise barriers, which are identified in orthophotomaps for years around 1991 and 2001 and in

[67] These are adaptations of the UK DOT hourly-based formulas to the 6-hour peak and 12-hour off-peak periods.

[68] The UK DOT formulas for vehicles depend on the specific type of vehicle. We have no information in the case of Lisbon, so we assume that noise levels for vehicles are the same as for electric locomotives.

existing noise maps.

The obstruction posed by buildings also depends on whether they form a continuous barrier or there are gaps between buildings, in which case there is only partial obstruction. We identify the first case as the built-up land classified in the Corine Land Cover maps as “Urban Continuous” and the second case as the land classified as “Urban Discontinuous”. In the second case, the segment is treated as two separate segments, one being obstructed and the other unobstructed.

A: Distance correction

The correction of emitted noise levels for the effect of distance applies to both obstructed and unobstructed propagation and refers to noise dispersion and absorption by the air along the propagation path. The correction is applied on the slant distance from the reception point to the segment at the source position, which for simplification we assume to be the point in the segment which is the nearest to the reception point. The slant distance is calculated as $d' = [h^2 + d^2]^{1/2}$, where d and h are respectively the horizontal and vertical distances between the two points. The vertical distance is given by the difference in the heights of source point and reception point, which takes in consideration their altitude, the height of the noise source segment above the ground (in the case of bridges and viaducts/overpasses) and the height of both points above the road surface or railhead, as assumed above. Altitude data is taken from CML (d2001a), APA (d1982) and from municipal on-line GISs.

In the case of road noise, the correction applies for horizontal distances $d \geq 7.5$ and depends on the level of traffic, with an extra attenuation for roads with low traffic flows, which comprise most of the streets and minor roads in the rural parts of the AML.

$$-10\log10\ (d'/10) \qquad \textit{(traffic>200 veh/hr)}$$

$$-10\log10\ (d'/10)-16.6*\log10(30/d')*\log10(q/200) \qquad \textit{(traffic<200 veh/hr)}$$

For the case of railway noise, the correction applies for slant distances $d' \geq 10$ and depends on the type of train. In the case of vehicles, to the simple geometric correction we subtract an extra value accounting for air absorption:

$$-10\log10\ (d'/25)+0.2-0.008d' \qquad \textit{(vehicles and electric locomotives)}$$

$$-10\log10\ (d'/25) \qquad \textit{(diesel locomotives)}$$

B: Ground absorption

When the propagation of noise is unobstructed and the ground surface between the segment and the grid point is of a soft nature, there is also a ground absorption correction. We assume that unobstructed propagation applies to all areas except the ones classified as Urban Continuous, where we assume that all area is paved. In 1991, we consider as absorbent ground the areas classified in the Cartus-AML land use map as “Agriculture”, “Agro-forestry”, “Forests”, “Shrub” and “Beaches, Rocky Coast and Seaside Vegetation”. For the case of 2001, to these areas we apply the changes in equivalent categories in the 1990 and 2000 Corine Land Cover datasets.

The ground correction depends on the mean height of propagation (the mean height above the ground calculated on the line connecting the source and reception points). In relatively flat areas, such as most of the agricultural areas of the AML, the mean height of propagation can be approximated by $H=h_s+0.5h$, where h_s is the height of the source point, as assumed above and h is the vertical distance between the two points. The ground correction is then a function of the proportion of absorbent ground (A) calculated in the area defined by the segment ends and the reception point.

For the case of road noise, the ground correction is applied for $d \geq 7.5$ and is given as below

$$5.2 * A * \log_{10}(X/d)$$

where $X=3$ if $H<0.75$ and $X=6H-15$ if $0.75 \leq H<(d+5)/6$.

For railway noise, the ground correction is applied for $d>25$ and depends on the type of train and infrastructure. An additional correction of $-1.5\ dB(A)$ accounts for the attenuation of vehicle noise in multiple rail tracks in the cases when the track support is a layer of ballast (which, except for bridges, is the case of all railways in the area of study). The correction is then given as below

$$X * A * \log10(d/25)+1.5 \qquad \text{(vehicle and multiple tracks)}$$

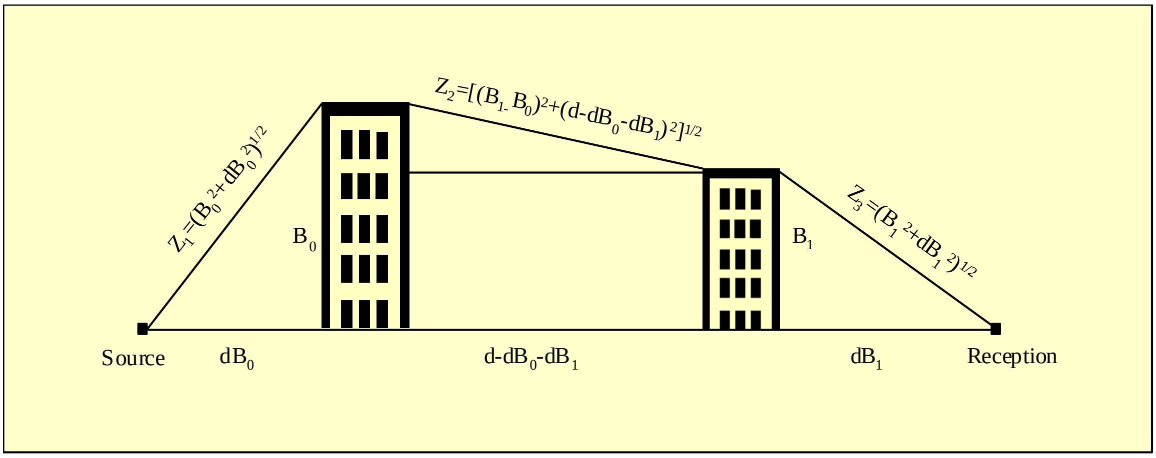
$$X * A * \log10(d/25) \qquad \text{(locomotive or single tracks)}$$

where $X=-3$ if $H \leq 1$ and $X=-0.6*(6-H)$ if $1<H<6$.

C: Screening

In the case of obstructed propagation, we also have to attend for the attenuation effects of screening of the source line, as the propagation of sound changes direction when it is obstructed by obstacles. The method to calculate the screening correction is an adaptation of the procedures given by the UK DOT. The correction depends on the difference between the length of the direct propagation path between source and reception points and the diffracted path (which passes over the top of the obstacle between the two points). For ease of calculation, we assume that the direct path is estimated along the horizontal distance (and not the slant distance) between source and reception. The estimation of the diffracted propagation path uses the distance from the source and reception segment to the nearest building or barrier and the height of these, according to the sketch in **Figure A.3**. Here, dB_0 and dB_1 are the positions of the first and last built-up point along the line that connects source and reception, while B_0 and B_1 are the heights of the buildings in those points. The building heights are the average number of floors in the enumeration district (calculated from the 1991 and 2001 census) multiplied by 3, the usual height of a floor (Instituto do Ambiente 2007, p.9).

Figure A.3: Noise screening



The difference between direct and diffracted paths is then given by

$$\delta=Z_1+Z_2+Z_3-d$$

For the case of road noise, the screening correction is a function of the logarithm of the path difference $Y=log_{10}\,\delta$. The correction is applied for values of Y in the interval $[-3,1.2]$:

$$-15.4-8.26Y-2.787Y^2-0.831Y^3-0.198Y^4+0.1539Y^5+0.12248Y^6+0.02175Y^7$$

with the values being -5 for $Y<-3$ and -30 for $Y>1.2$.

For the case of railway noise, the correction is a direct function of the path difference δ and is applied when $0< \delta<2.5$:

$$-7.75*log_{10}(5.2+203\ \delta)$$

with -21 when $\delta>2.5$.

3. Site layout

The estimated noise at the reception point should also take into account the geometric relationships between the segment and the reception points, including the length of the segment and effects of noise reflections.

The adjustment to the length of the segment is estimated by considering the segment's angle of view, which is the angle subtended by the segment ends at the reception point. For the areas classified in Corine Land Cover maps as Urban Discontinuous, we assume that the angle of view is divided in half in obstructed and unobstructed parts[69]. The angle of view is approximated by making use of the trigonometric relationship between the angles and sides of a triangle defined by the segment ends and the reception point:

$$\alpha = \frac{180}{\pi} ArcCos\left(\frac{E_0{}^2 + E_1{}^2 - L^2}{2E_0 E_1}\right) \quad \text{(degrees)}$$

where L is the length of the segment and E_0 and E_1 are the distances between the reception point and the two segment ends.

For both road and rail, the correction for the angle of view is then given by:[70]

$$10log_{10}(\alpha/180)$$

Finally, we have to consider the effects of reflection from buildings at both source and reception points. As we require noise levels to estimate exposure for pedestrians, we assume that noise levels always refer to outdoor environments (streets). We then need to take into account the reflection effects of noise from facades of buildings in front of the reception point. This effect is added if the reception point is located inside a built-up area and is equal to *+2.5 dB(A)*. There is also a reflection effect from facades of buildings on the opposite side

[69] The assumption is that the average opening between buildings is equal to the average length of the buildings.

[70] In the case of railway noise, an accurate correction value would also need to consider the orientation of the segment along the trajectory of the track. To simplify the calculations, we assume that the correction is similar to the case of road noise.

of the source point. This is added when this point is inside a built up area and given by *1.5 (r)*, where *r* is the proportion of the angle of view from each grid point that is occupied by buildings. In line with the presuppositions stated previously, this proportion is taken as one if the area is classified as Urban Continuous and 0.5 if it is classified as Urban Discontinuous.

4. Conversion and combination of noise sources

The output of the UK DOT method for the calculation of road traffic noise is the L_{10}, which is a quantile-based measure, while the output for railway noise is the *SEL*, which is a single-event measure. As we need to estimate average exposures for pedestrians walking throughout the two periods of the day, we must convert the two indices to average-based measures. We use the equivalent continuous sound level (L_{Aeq}), which is the noise level that, over a defined period, contains the same amount of acoustic energy as the actual varying noise.

In the case of road traffic, it is possible to estimate statistical relationships between the equivalent noise and the quantile measure. We make use of the value of the regression model estimated by TRL (2002)[71]:

$$L_{eq(road)}=0.77+0.94*L_{10}$$

The conversion of SEL to equivalent continuous sound level for the case of railway noise is given by UK DOT (1995). This conversion applies to each segment, track and train type and takes into account the number of trains and the period concerned. The adaptation of the UK DOT formulas for the peak and off-peak periods are:

$$L_{eq(rail),peak}=SEL-43.33+10*\log_{10}T$$

$$L_{eq(rail),off\text{-}peak}=SEL-46.34+10*\log_{10}T$$

where *T* is the average number of trains passing the rail segment in the period concerned.

After applying the conversions above, we can combine the noise level contributions of all noise sources to a grid point. At a first stage, we combine the obstructed and unobstructed parts of the segments in areas classified as Urban Discontinuous and the different contributions of each train type and track for each rail segment. At a second stage, we combine the noise of different segments and noise sources. This combination is done by

[71] Although these relationships refer to one-hour indices, they can be applied in our case because we assume that the distribution of hourly-noise is the same within each period of the day.

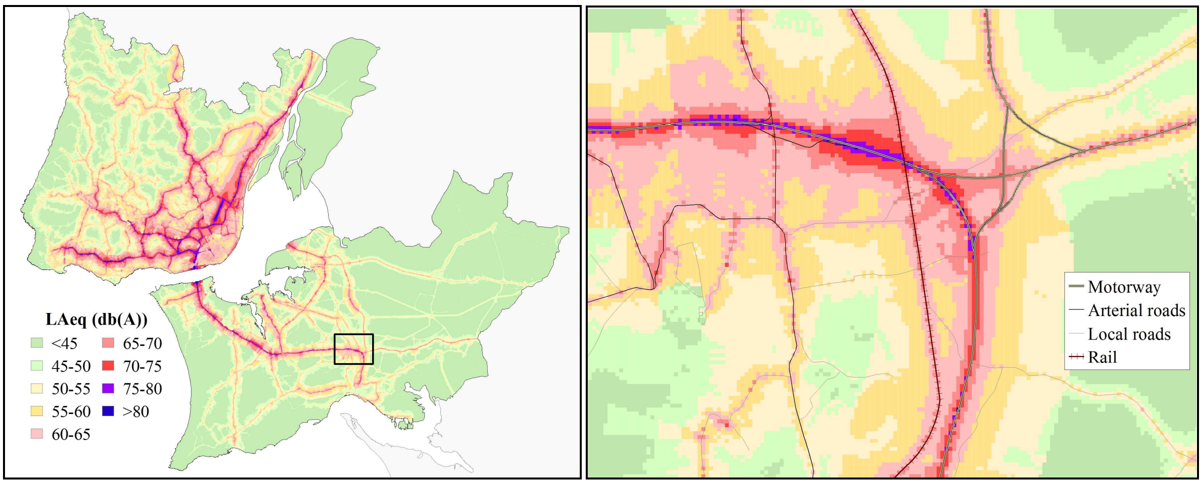
adding logarithmically the contributions for all road and railway sources and the non-traffic sources identified in noise maps[72]. The level of background noise is also included and accounts for all the sources that were not modelled. This level is assumed to be 45 dB(A) in areas classified as Urban Continuous, 40 dB(A) in Urban Discontinuous and 35 dB(A) in non-urban areas. The noise in each grid point in then given as:

$$L_{Aeq} = 10 * \log_{10}(\sum_i 10^{\frac{LAeq_i}{10}})$$

where $L_{Aeq(i)}$ is the noise from source *i*.

The peak and off-peak noise grids are finally converted to the GIS raster model, in order to obtain a continuous surface, at a 40 m^2 resolution. The map below presents the case of peak-time period noise in 2001:

Map A.4: Peak-time noise in 2001: AML and detail



[72] The noise levels for the additional sources of noise which are obtained from existing noise maps are given as L_{Aeq} measures for the day and night periods. We apply the value of the daytime noise for both peak and off-peak periods assuming that there are no differences between the two periods in either between airport and industrial noise.

Appendix 8

Political factors

The analysis of the influence of political factors on transport planning (Chapter 5) assumes that policy-makers attend to their political interests, which depend on the political characteristics of the populations living in each neighbourhood. In order to map the distribution of political interest, we have to make some assumptions regarding the rationality of the policy-maker. The main political interests of the party holding the national or local governments are the maximization of the probability of re-election in future elections and the minimization of socio-political protest. Protest has an indirect influence on the results of future elections and is an indicator of the extent to which the government's policies and activities can run smoothly, contributing to the present welfare of the incumbent party. In the context of transport policy, the party in government can expect electoral gains in areas that benefited from a project and electoral losses or protest in areas affected by its negative effects. The probability of these events depends on the political characteristics of the populations living in each area, including their political affinities, political power and degree of mobilization.

In our analysis, we follow a data-driven approach to measure potential political interest. We conduct a factor analysis of a set of previous elections and interpret the resulting components as independent elements in possible political strategies for the policy-maker. The focus of analysis is not the behaviour of a specific party, but of an abstract policy-maker, whose political interests are multidimensional and depend on the political characteristics of each neighbourhood, as expressed by their electoral patterns. In the analysis in Chapter 5, we then assume that these characteristics determine the degree to which the policy-maker will attend to the welfare of each community.

The hypothetical moment of decision for the projects and policies analysed in Chapter 5 is 2001. We consider that the political characteristics of each community are measured by patterns occurring in the set of all elections hold in Portugal since 1991. The data come from the official election results database [STAPE d1991-1999] and include the 1991, 1995 and 1999 General Elections, the 1993 and 1997 Local Elections and the 1994 and 1999 Elections for European Parliament. For each election, we define six variables. The first two variables are the vote shares of the two parties that dominate the political spectrum in Portugal, which we label here as “Orange” (right wing) and “Pink” (left wing). As possible indicators for social protest, we include the shares of blank and null votes and the shares of a set of left-wing parties with traditionally active militancy and labelled “Red”. As issues of pedestrian mobility have an environmental dimension, it is also relevant to include the vote share of the two Portuguese environmental parties, labelled as “Green”[73]. The final proportion is the abstention rate, which can assess both the probability of electoral gains and the potential for social protest.

Possible electoral gains and losses for a party depend on the size and loyalty of its electoral base in each neighbourhood, while similar considerations apply to the probability of social protest, as measured by the associated electoral behaviour. As such, we construct two groups of variables aggregating the data from the seven elections considered. The first group contains the averages of the variables defined above for each election, while the second group contains their standard deviations. The two sets of variables are then entered in the factor analysis, which uses methods similar to the analysis of census data in Chapter 2 (Section 2.1). The analysis is conducted separately for the two western municipalities and for Lisbon, as the projects analysed in chapter 5 are the product of decisions by these municipalities.

The unit of analysis is necessarily the smallest administrative area (*freguesia*) and as such, the resulting factor scores need to be disaggregated at the enumeration district level. This is done by estimating a regression model between the political factors and the five socio-economic factors derived in Chapter 2 and averaged at *freguesia* level. We then use the regression model to predict the political characteristics of the population in each district[74]. This operation carries the double assumption that the spatial differences in both political characteristics and in the relationships of these characteristics with socio-economic aspects at the level of the *freguesia* also apply at a smaller scale. It should be noted that this assumption poses some limitations, due to a possible “ecological fallacy” (see Chapter 1, p.8) and to the fact that administrative borders do not follow necessarily the spatial distribution of voters. **Table A.4** presents the results of the two factor analyses, while **Table A.5** shows the results of the regressions between political and socio-economic factors. The factor models are

[73] One of these parties forms a long-term coalition with one of the parties in the “Red” group. The assignment of votes of the coalition was proportional to the number of members of parliament of each party.

[74] While we use a regression model to explain political factors using socio-economic factors, it is also reasonable to think that political factors are contained within the residuals of the regression model (what Hamilton (1995) calls the “pure politics” factor).

satisfactory, extracting high proportions of the total variance and of the variance of each individual variable[75], while the regression models are satisfactory for all but one of the political factors.

The most distinctive factor in both regions (*P1*) is the “Left” x “Right” ideological opposition. The factor is characterized by high loadings on the historical averages of the shares of the parties representing the two ideological poles and by high loadings with opposite signs on the standard deviations of those shares. The regression models show that this factor is explained in both regions by qualification levels (*F2*) and to a smaller degree, by age (*F1*) and urbanization levels (*F3*), although the effect of this last factor is different in the western municipalities and in Lisbon.

The second most important factor (*P2*) groups variables suggesting the level to which communities are willing to participate in the political process. The variables with high negative loadings within this factor are the abstention rate (in both regions) and the shares of blank and null votes (in the western municipalities), In Lisbon, the main explanatory variables for the P2 factor are the socio-economic factors measuring age (*F1*) and location of informal settlements (*F4*), both with a negative coefficient. In the western municipalities, the P2 factor depends mostly on the degree of urbanization (*F3*).

The main difference between the two regions respects the nature of the third factor. In the western municipalities, this factor is related to a low but variable abstention rate and to the variability in the shares of the Orange and Rose parties. This can be understood as a measure of the potential for both parties to increase their electoral base. This factor depends negatively on the urbanization level (*F3*) and on the location of informal settlements (*F4*). In Lisbon, the third factor is the relevance of the “Green” vote. This factor is not included in the analysis in chapter 5, as socio-economic factors can only explain 14% of its variation.

[75] See comments on **Table 2.1** in Chapter 2 for methodological details that apply to **Table A.4**.

Table A.4: Factor analysis of elections data (1991-1999)

		Western municipalities				Lisbon			
		P1 Left	**P2** Political	**P3** Potential	*Comm.*	**P1** Left	**P2** Political	**P3** Green	*Comm.*
% of variance		50.2%	18.6%	14.8%		51.6%	20.7%	9.3%	
Averages	Orange	-0.96	-0.08	-0.16	0.94	-0.97	-0.17	-0.11	0.97
	Rose	0.92	-0.10	0.21	0.90	0.95	0.15	-0.03	0.93
	Red	0.91	0.29	0.00	0.91	0.94	0.12	0.11	0.91
	Green	0.88	0.34	-0.02	0.89	0.36	0.57	0.56	0.77
	Blank/Null	0.50	-0.71	0.24	0.81	0.73	-0.24	-0.04	0.59
	Abstention	0.38	-0.68	-0.45	0.82	0.07	-0.93	0.18	0.90
Std. Errors	Orange	0.71	-0.10	0.62	0.89	0.90	-0.07	0.24	0.88
	Rose	-0.29	-0.68	0.63	0.94	0.69	-0.56	0.00	0.80
	Red	-0.72	0.25	0.25	0.64	-0.74	-0.14	0.35	0.69
	Green	-0.92	-0.11	0.22	0.91	-0.95	0.08	0.13	0.93
	Blank/Null	-0.54	-0.50	0.05	0.55	0.23	-0.32	-0.63	0.55
	Abstention	-0.18	0.51	0.75	0.85	0.14	0.84	-0.40	0.89

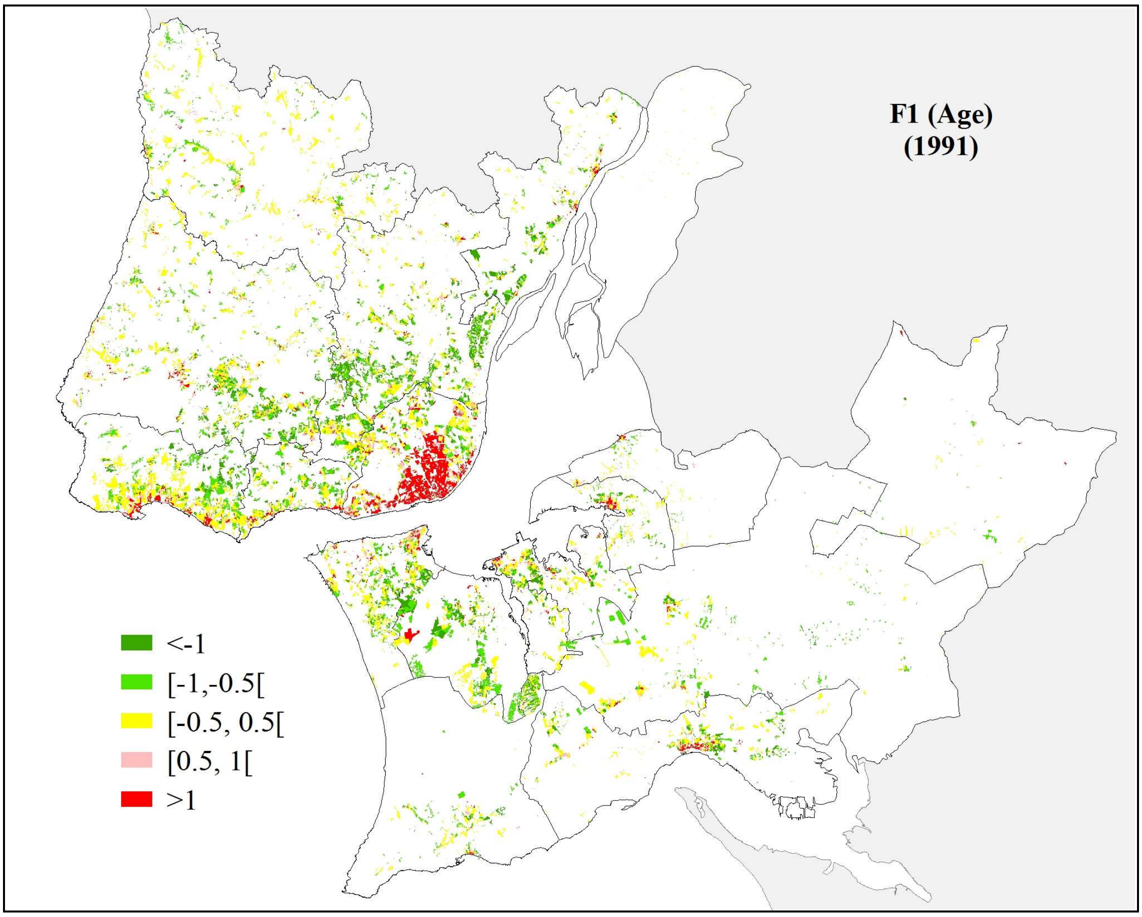
Table A.5: Regression between political and socio-economic factors

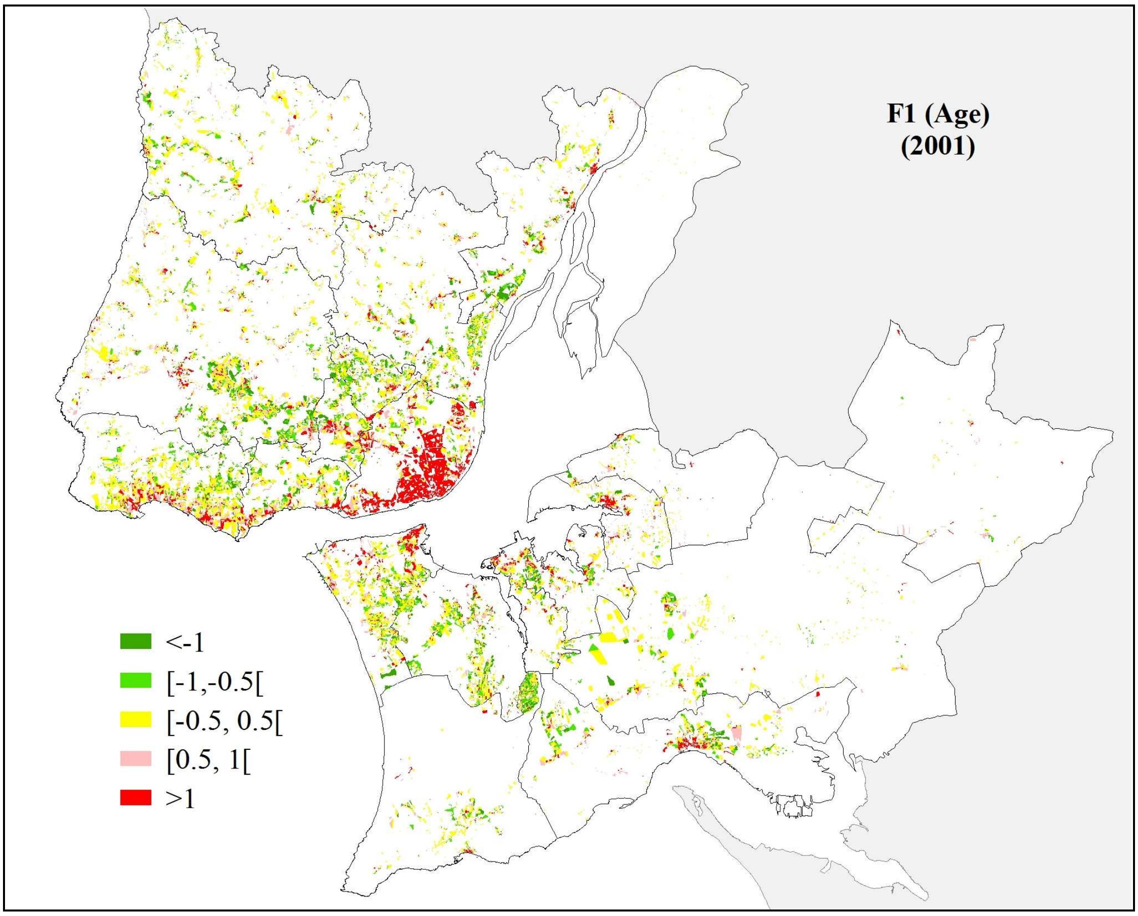
	Western municipalities			Lisbon		
	P1	**P2**	**P3**	**P1**	**P2**	**P3**
R^2	0.85	0.68	0.58	0.89	0.55	0.14
F1 (Age)	-0.24	-0.25	-0.11	-0.37	-0.44	-0.12
F2 (Qualification)	-0.84	0.08	0.24	-0.76	0.22	0.13
F3 (Urbanization)	0.21	0.90	-0.52	-0.21	-0.03	0.16
F4 (Inf.Settlements)	0.10	-0.33	-0.47	-0.03	-0.51	0.18
F5 (Migration)	0.19	0.10	-0.33	0.13	-0.09	-0.17

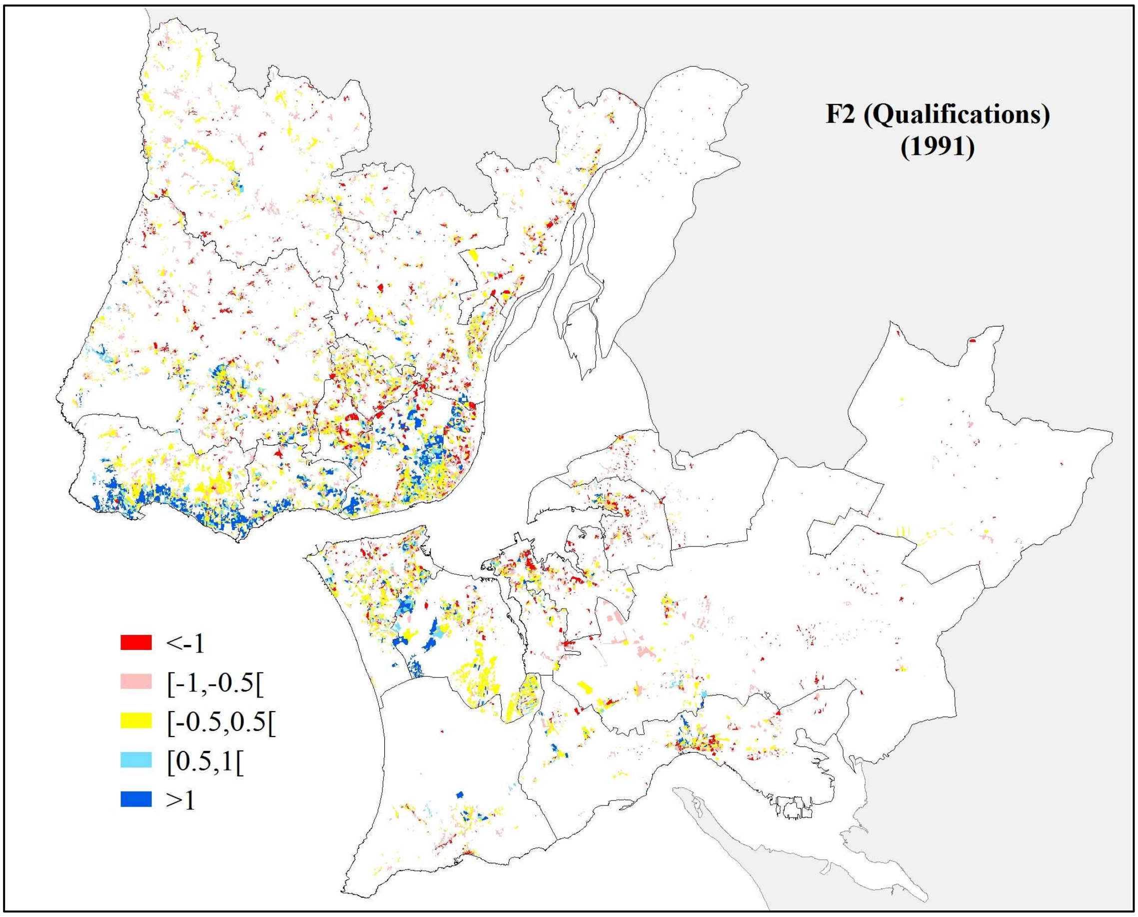
Appendix 9

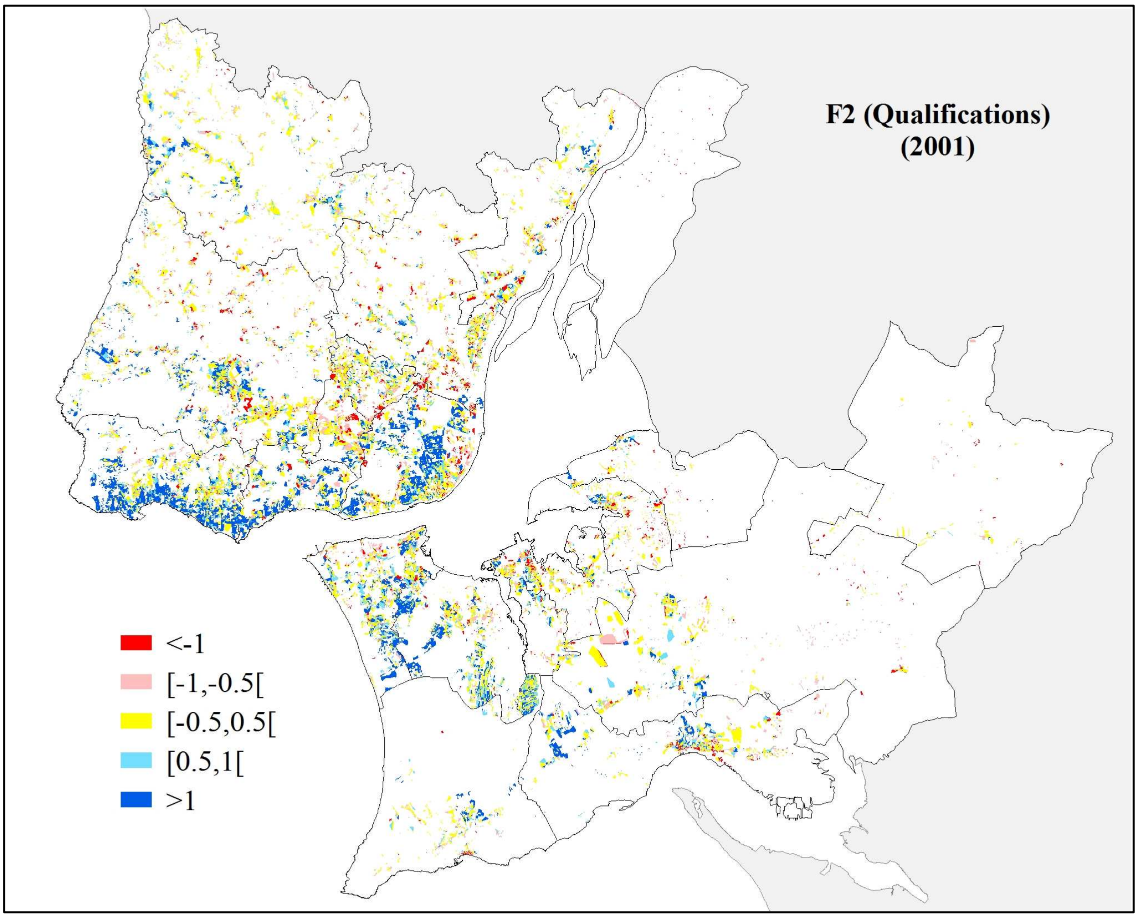
Socio-economic factors and indicators of mobility

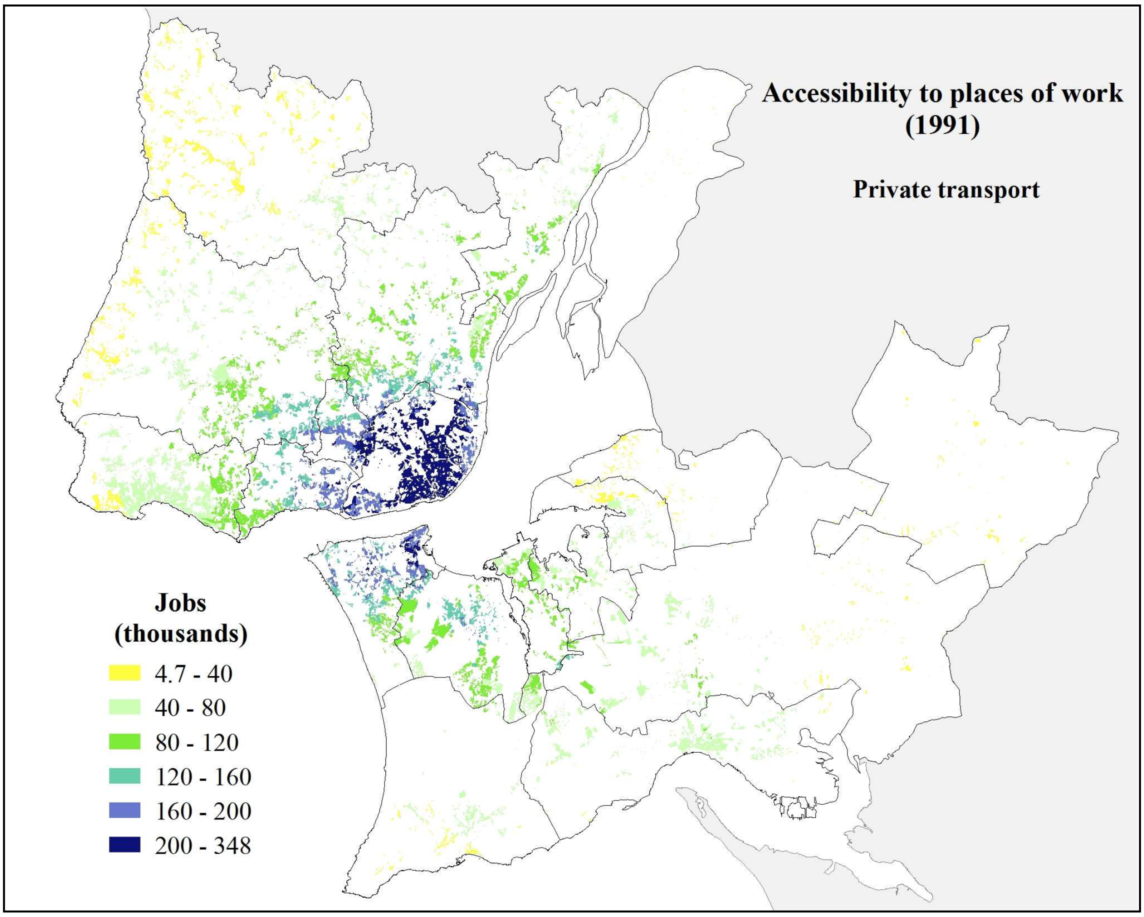
The maps in this appendix show the distribution of the two main factors of socio-economic differentiation in the Lisbon Metropolitan Area (Age and Qualifications) and the distribution of indicators of accessibility and pedestrian mobility in 1991 and 2001. The estimation of both is described in Chapter 2. The last four maps describe the effects on accessibility of changes in the transport network in the period 2001-2008 and of changes projected for the near future.

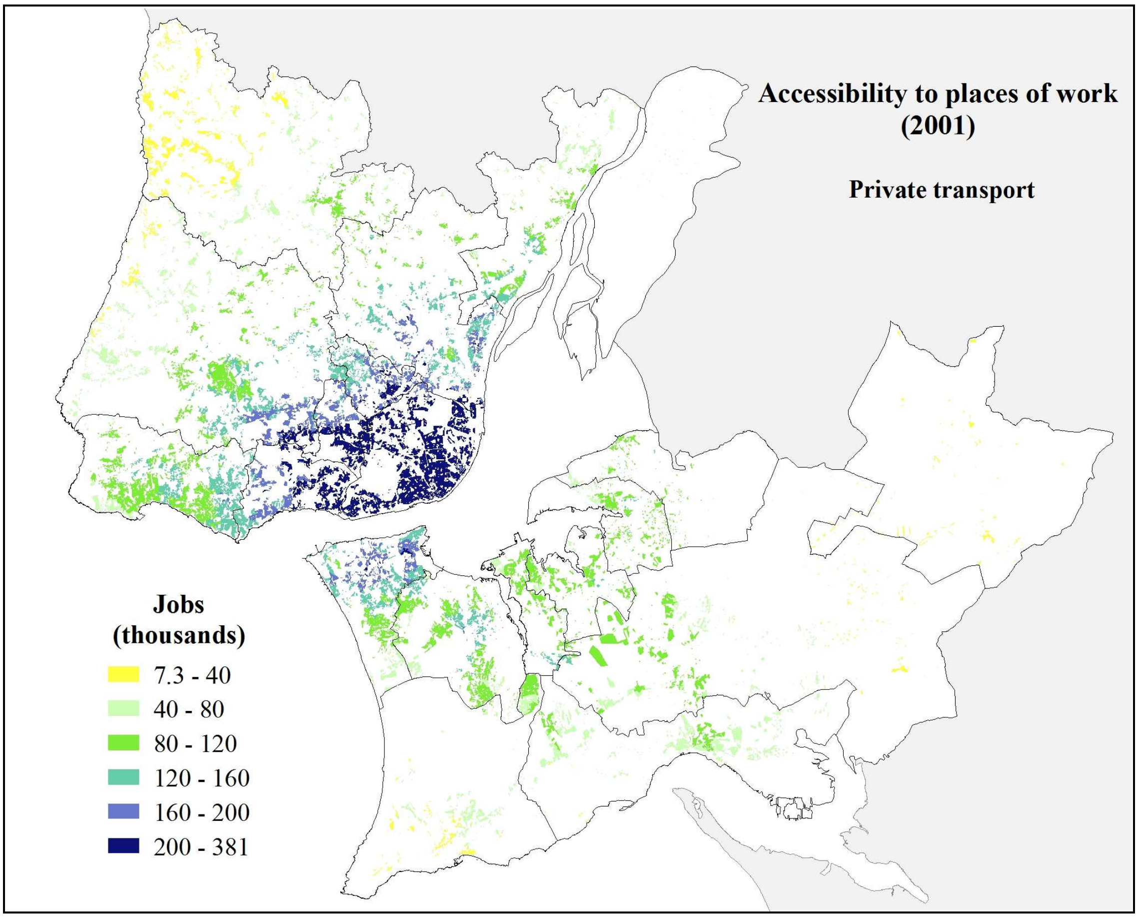

F1 (Age)
(1991)
<-1
[-1,-0.5[
[-0.5, 0.5[
[0.5, 1[
>1

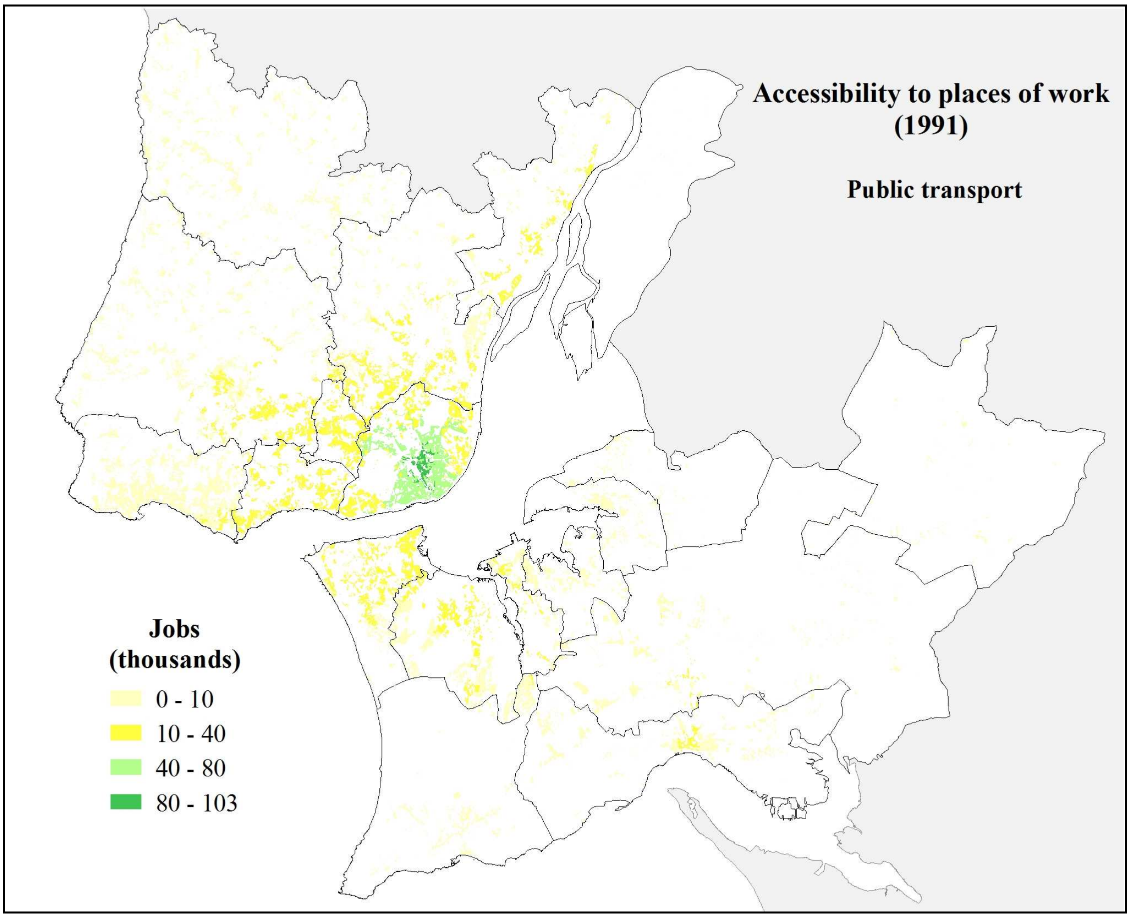

F1 (Age)
(2001)
<-1
[-1,-0.5[
[-0.5, 0.5[
[0.5, 1[
>1

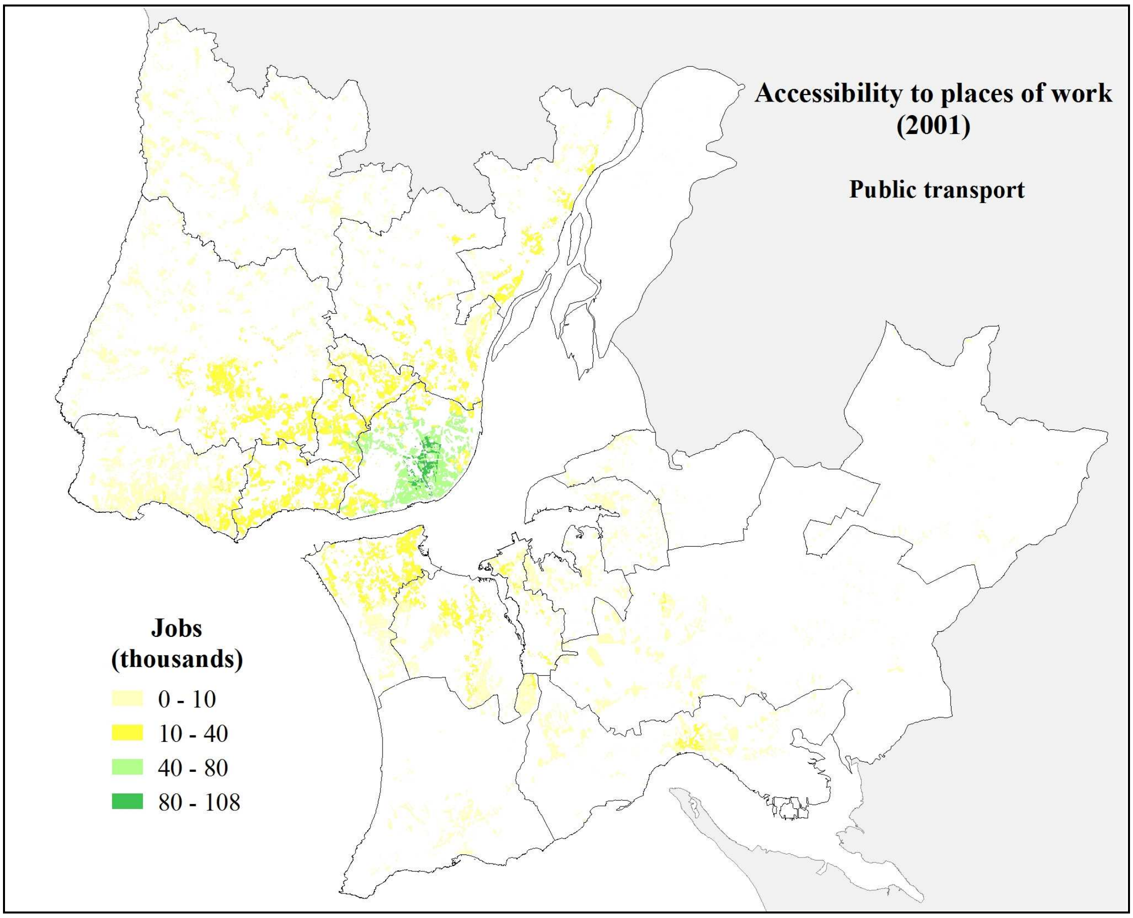

F2 (Qualifications)
(1991)
<-1
[-1,-0.5[
[-0.5,0.5[
[0.5,1[
>1

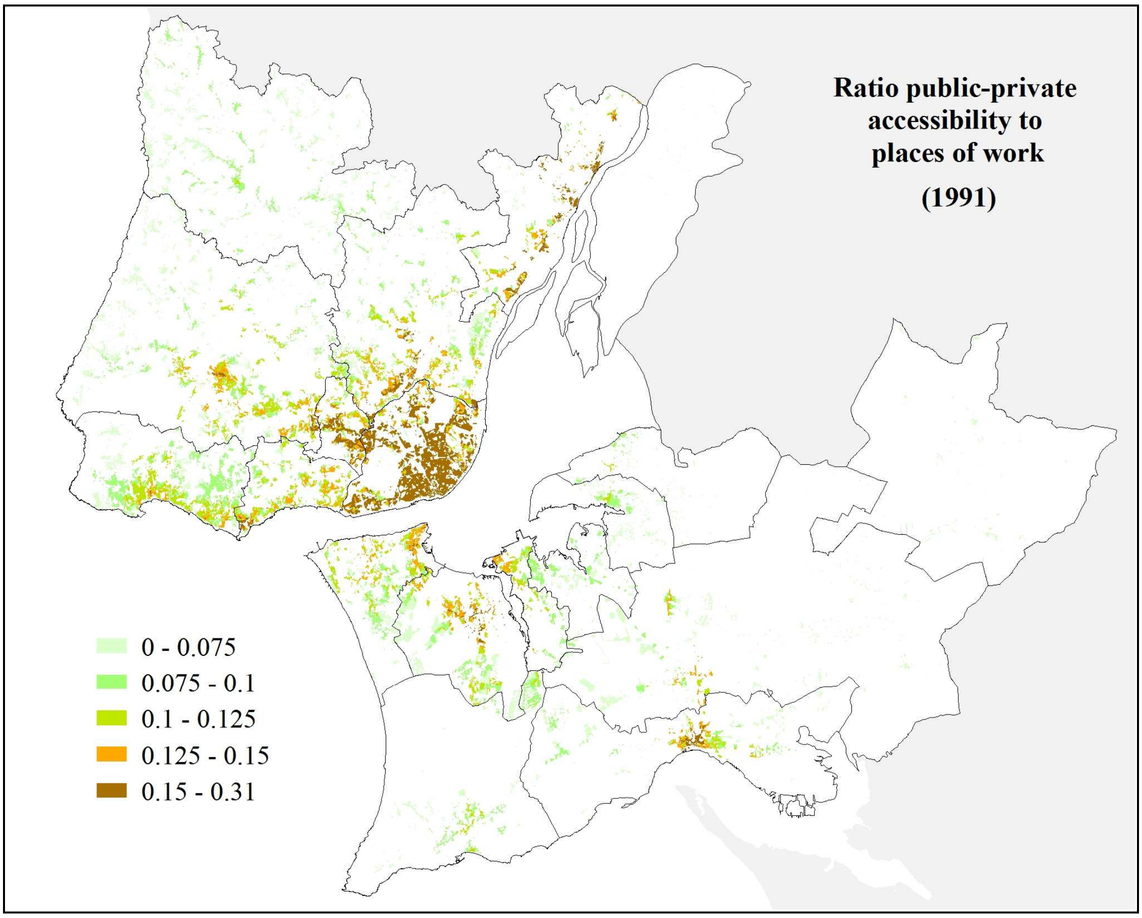

F2 (Qualifications)
(2001)
<-1
[-1,-0.5[
[-0.5,0.5[
[0.5,1[
>1

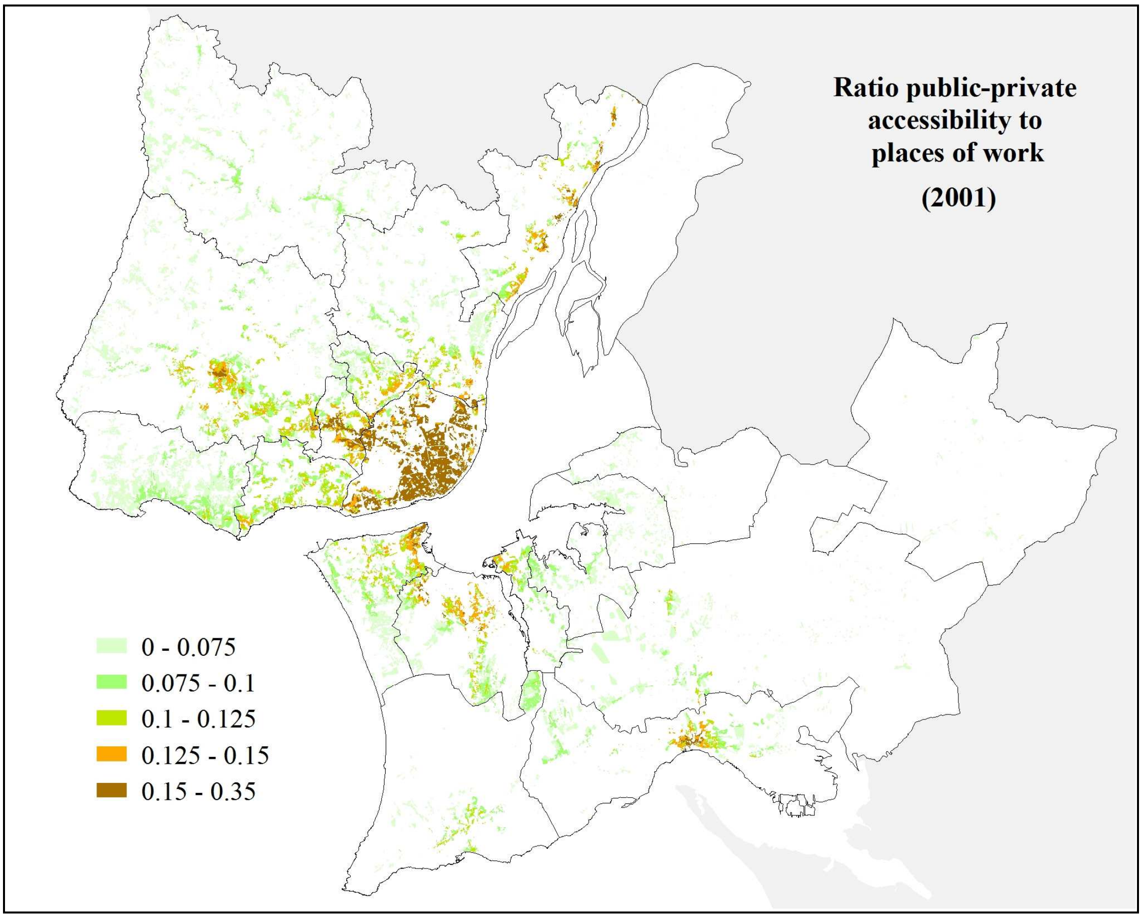

Accessibility to places of work
(1991)
Private transport
Jobs
(thousands)
4.7 - 40
40 - 80
80 - 120
120 - 160
160 - 200
200 - 348

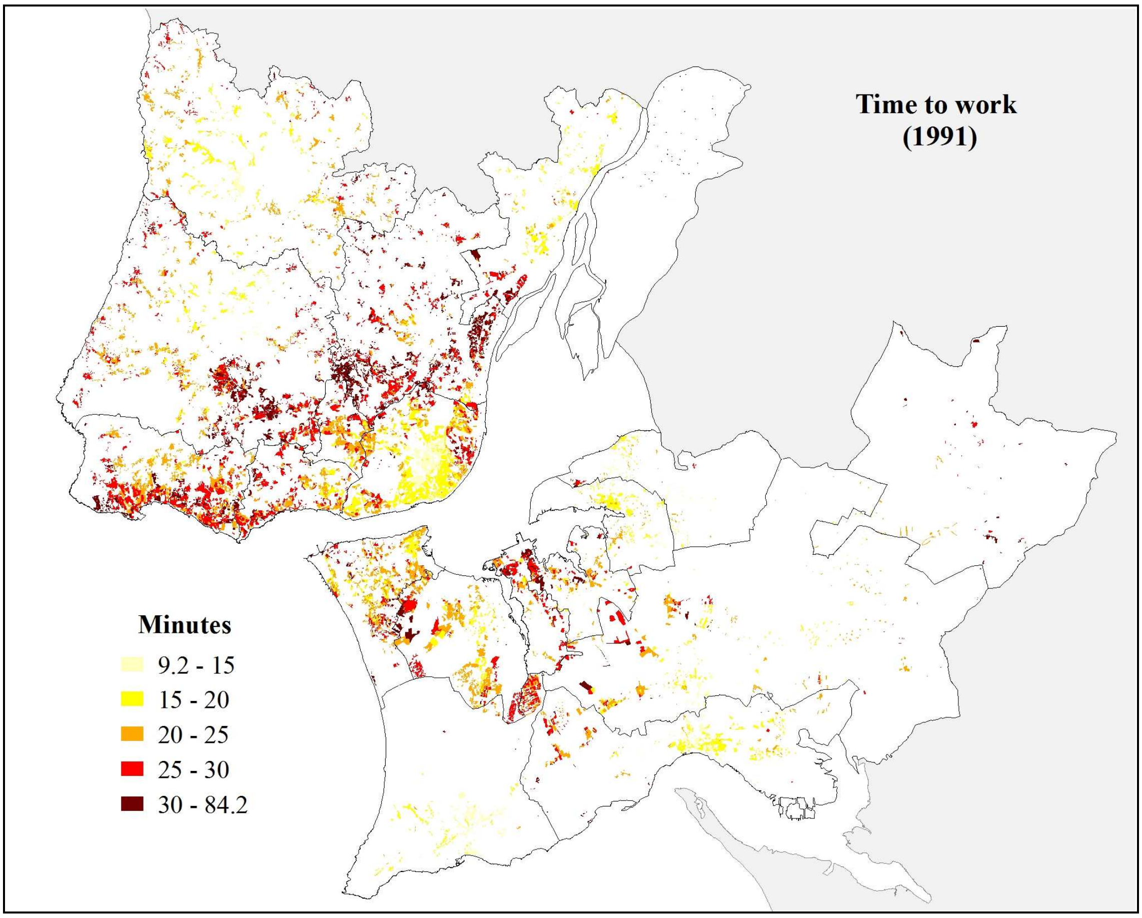

Accessibility to places of work
(2001)
Private transport
Jobs
(thousands)
7.3 - 40
40 - 80
80 - 120
120 - 160
160 - 200
200 - 381

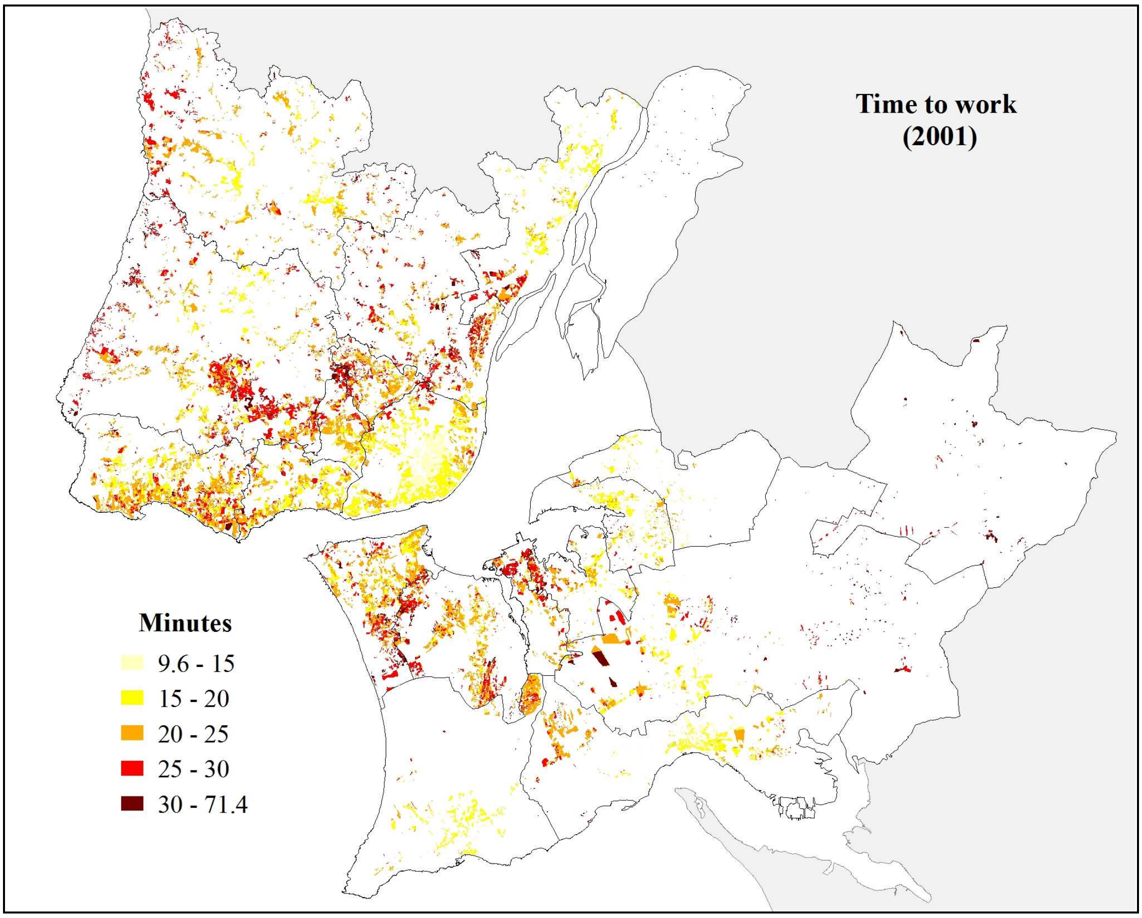

Accessibility to places of work
(1991)
Public transport
Jobs
(thousands)
0 - 10
10 - 40
40 - 80
80 - 103

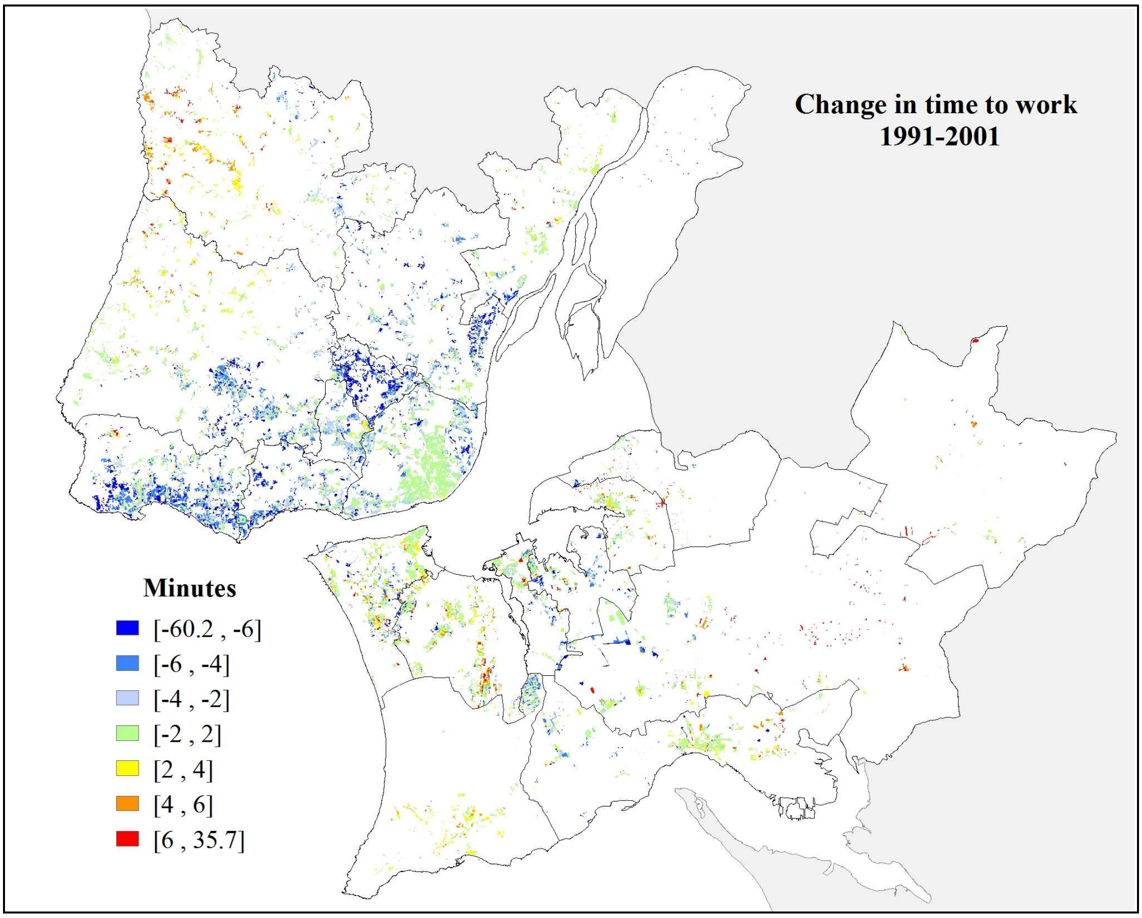

Accessibility to places of work
(2001)
Public transport
Jobs
(thousands)
0 - 10
10 - 40
40 - 80
80 - 108

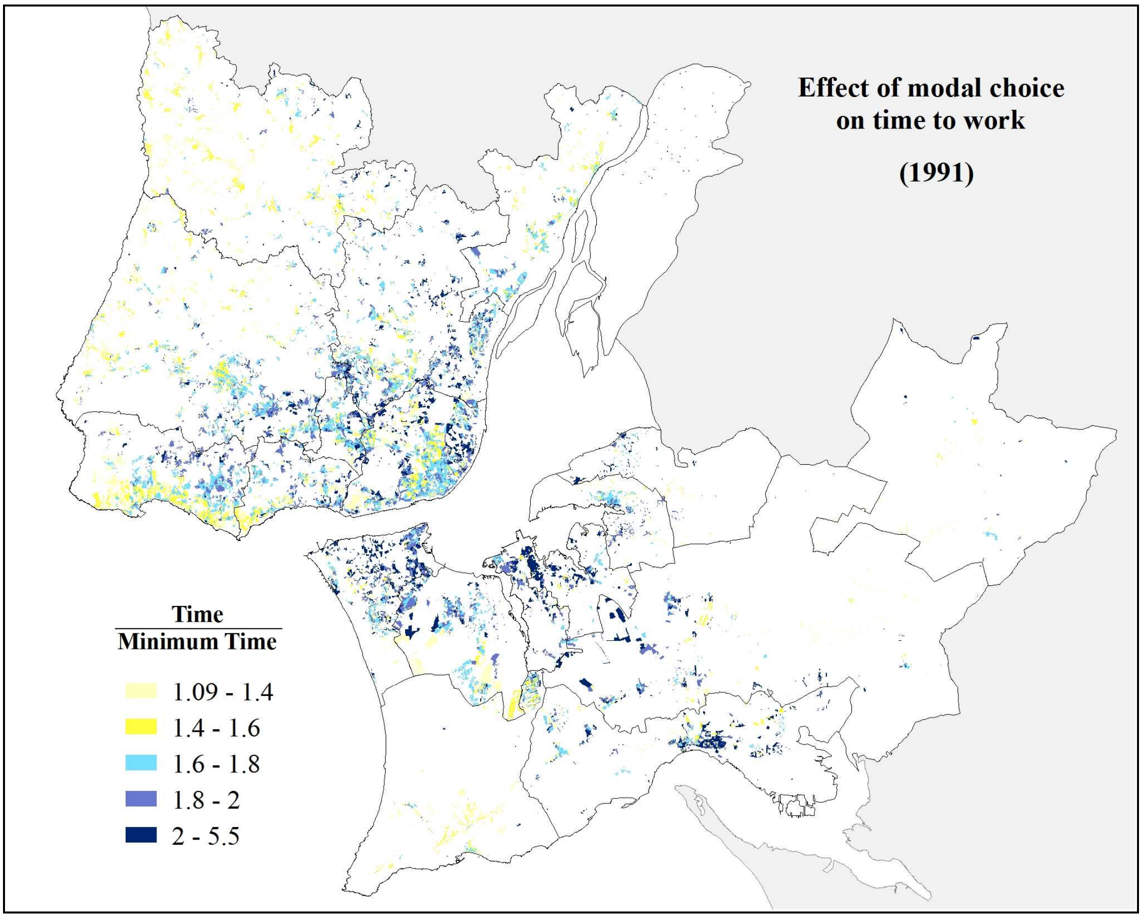

Ratio public-private
accessibility to
places of work
(1991)
0 - 0.075
0.075 - 0.1
0.1 - 0.125
0.125 - 0.15
0.15 - 0.31

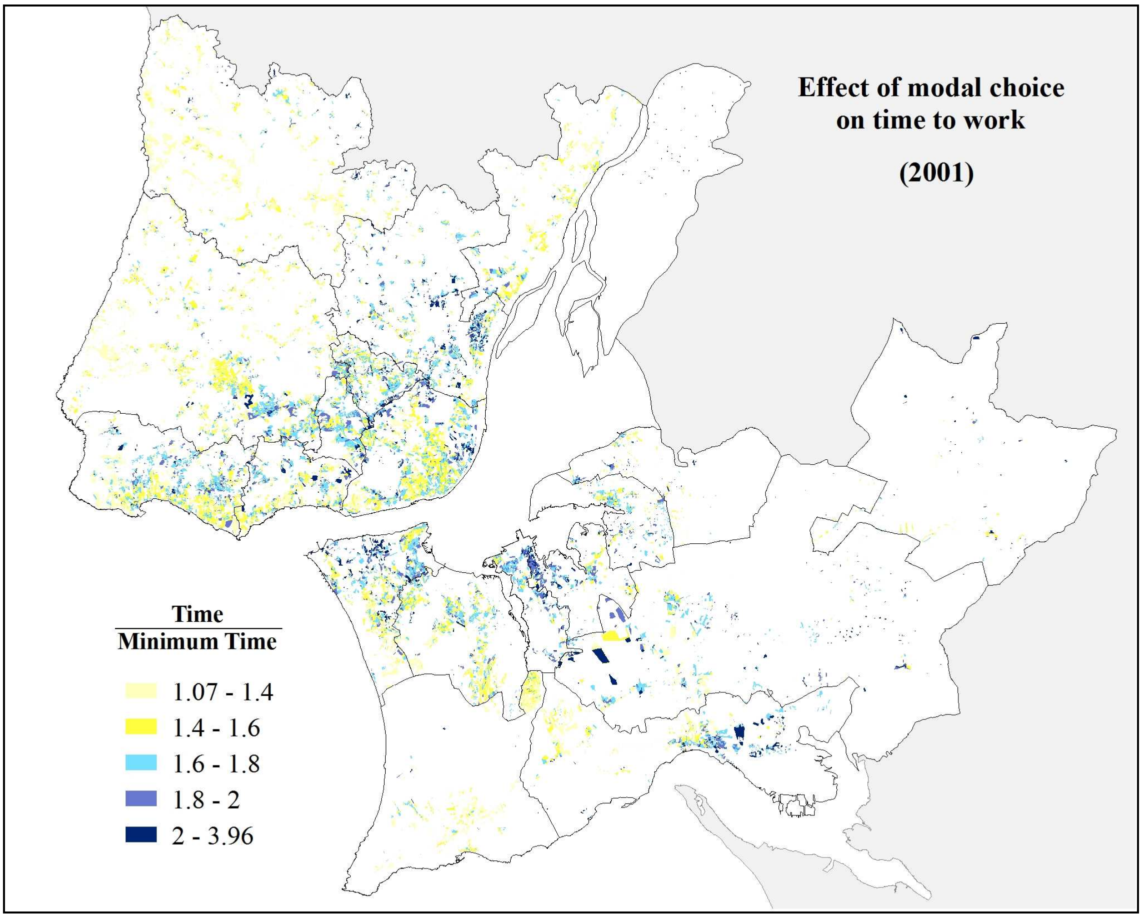

Ratio public-private
accessibility to
places of work
(2001)
0 - 0.075
0.075 - 0.1
0.1 - 0.125
0.125 - 0.15
0.15 - 0.35

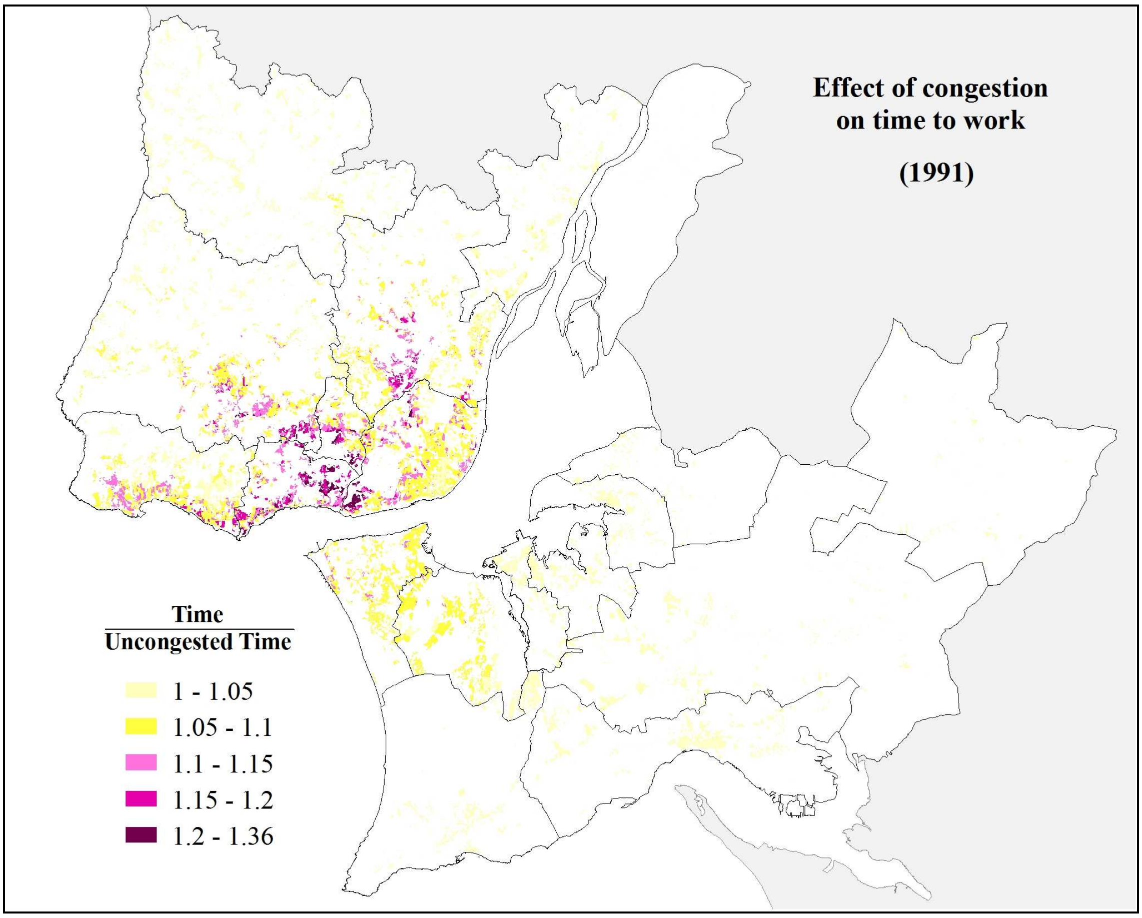

Time to work
(1991)
Minutes
9.2 - 15
15 - 20
20 - 25
25 - 30
30 - 84.2

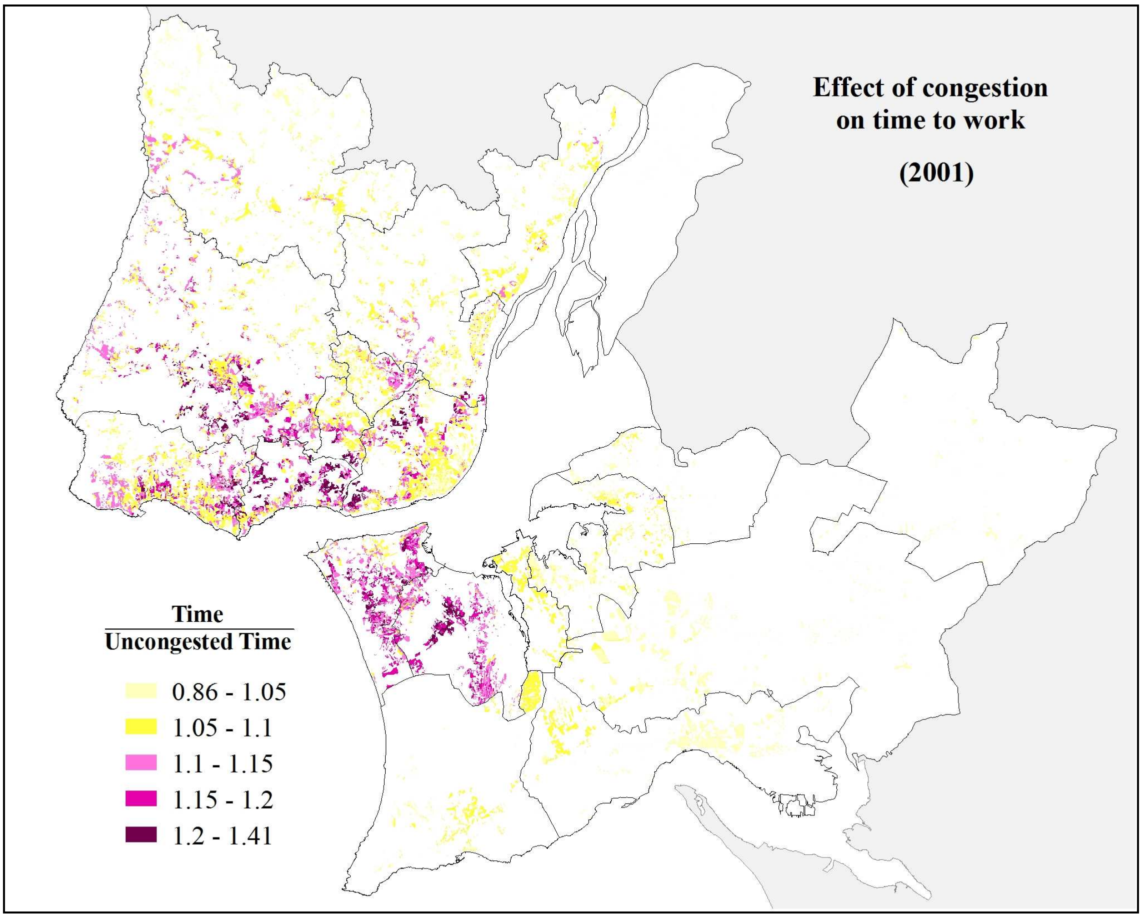

Time to work
(2001)
Minutes
9.6 - 15
15 - 20
20 - 25
25 - 30
30 - 71.4

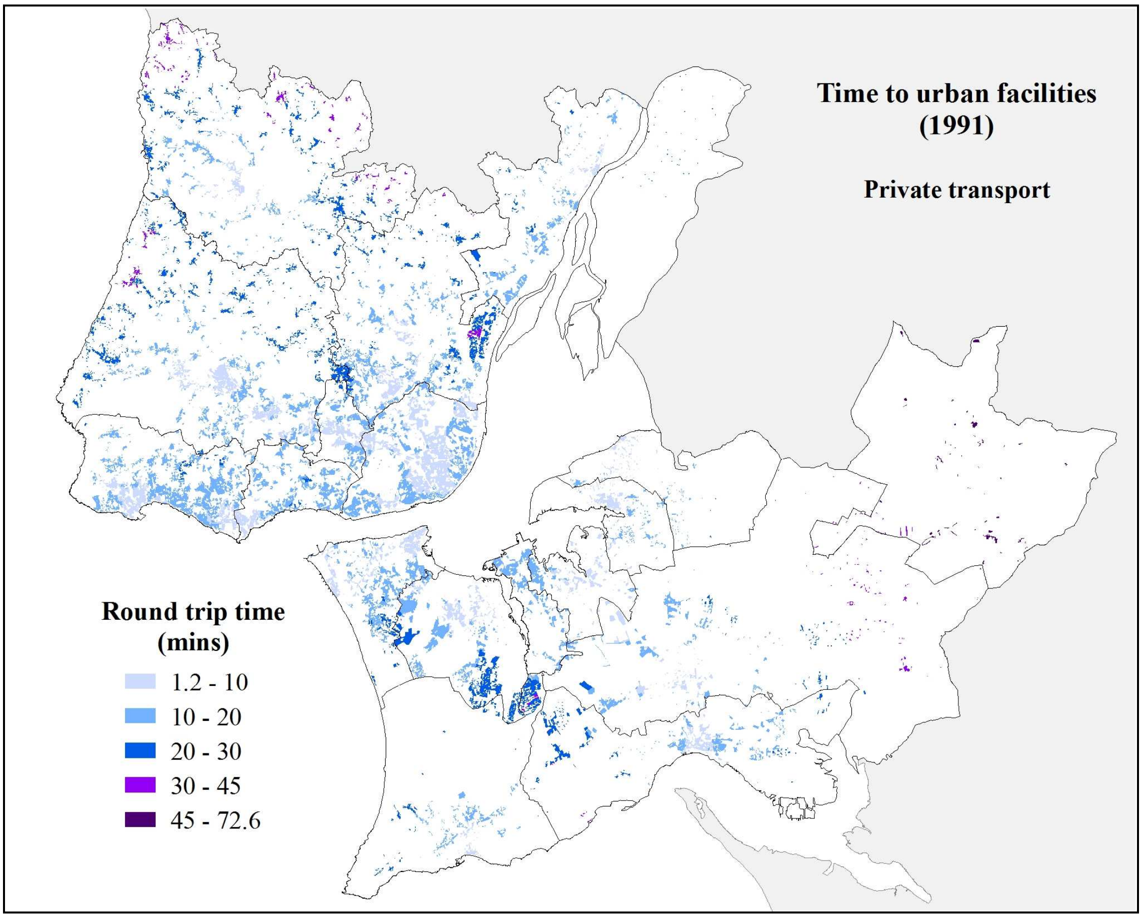

Change in time to work
1991-2001
Minutes
[-60.2 , -6]
[-6 , -4]
[-4 , -2]
[-2 , 2]
[2 , 4]
[4 , 6]
[6 , 35.7]

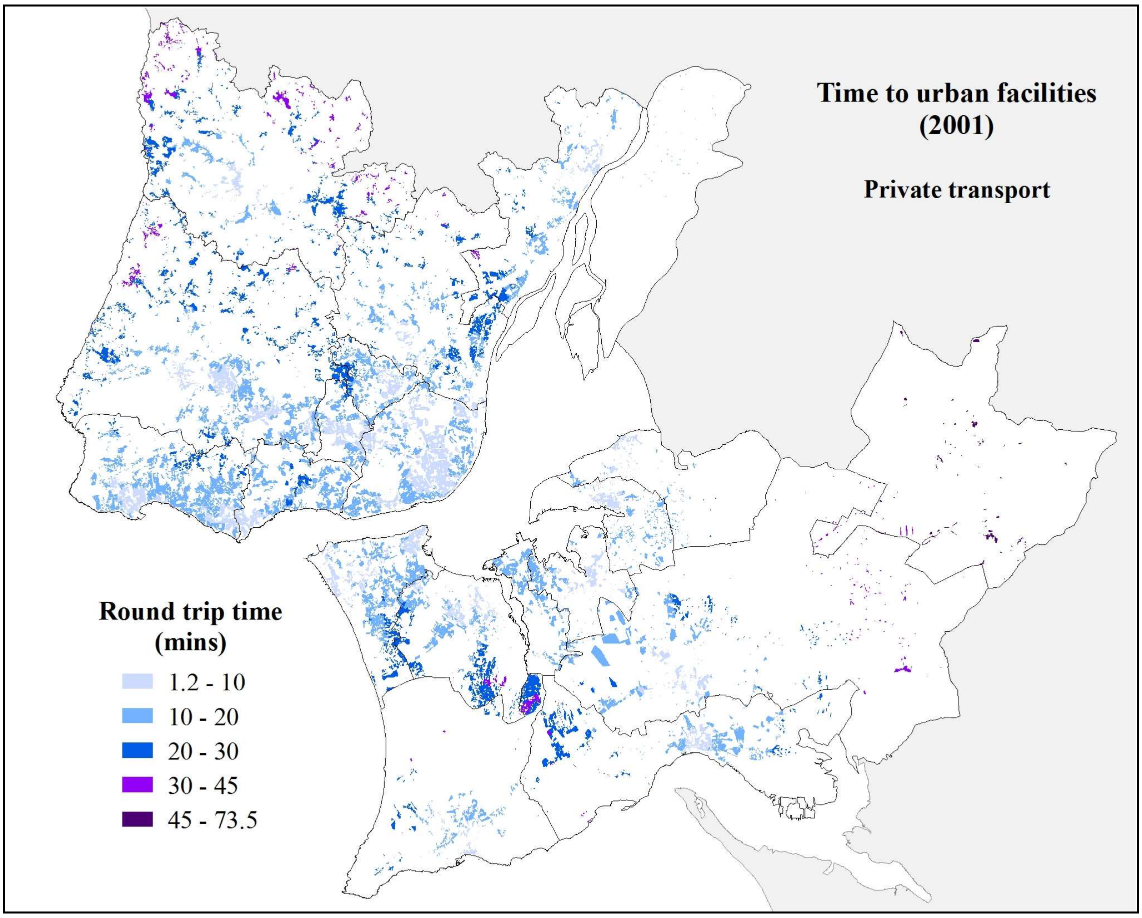

Effect of modal choice
on time to work
(1991)
Time
Minimum Time
1.09 - 1.4
1.4 - 1.6
1.6 - 1.8
1.8 - 2
2 - 5.5

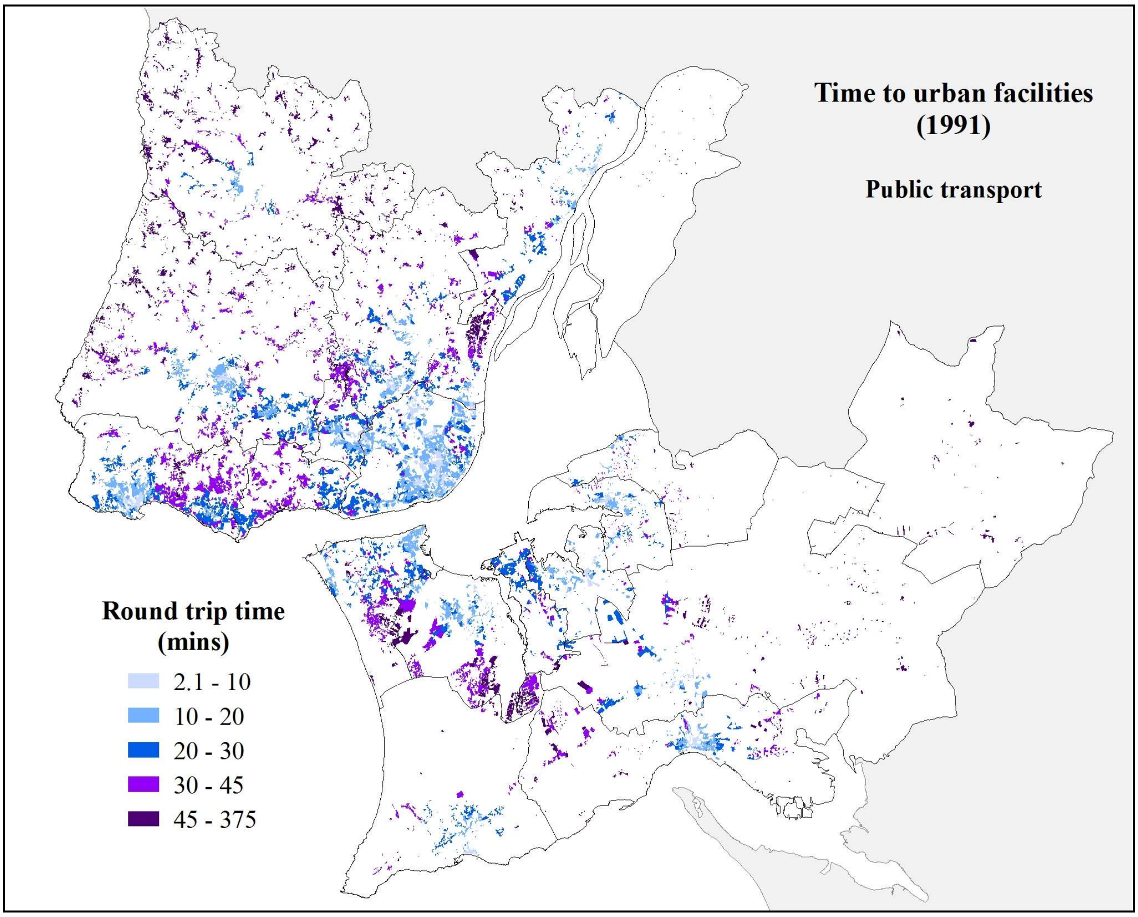

Effect of modal choice
on time to work
(2001)
Time
Minimum Time
1.07 - 1.4
1.4 - 1.6
1.6 - 1.8
1.8 - 2
2 - 3.96

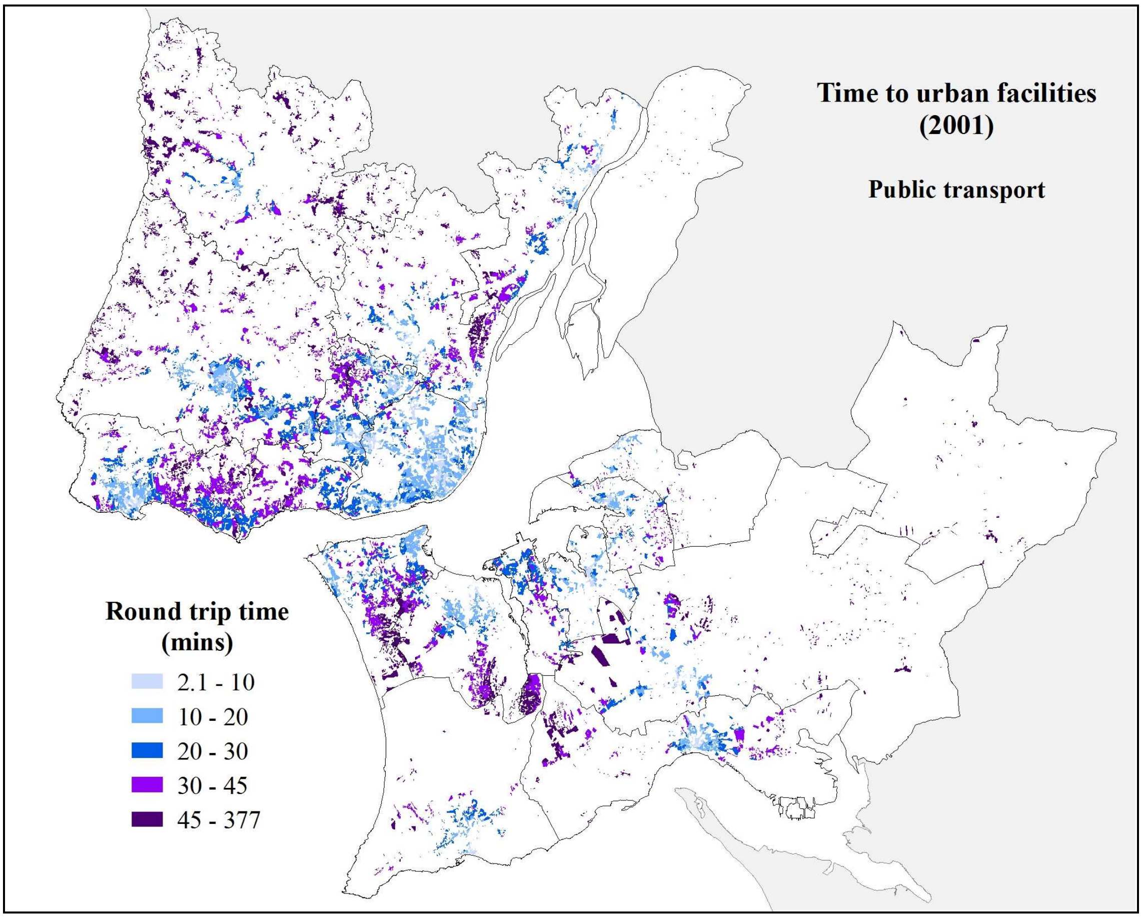

Effect of congestion
on time to work
(1991)
Time
Uncongested Time
1 - 1.05
1.05 - 1.1
1.1 - 1.15
1.15 - 1.2
1.2 - 1.36

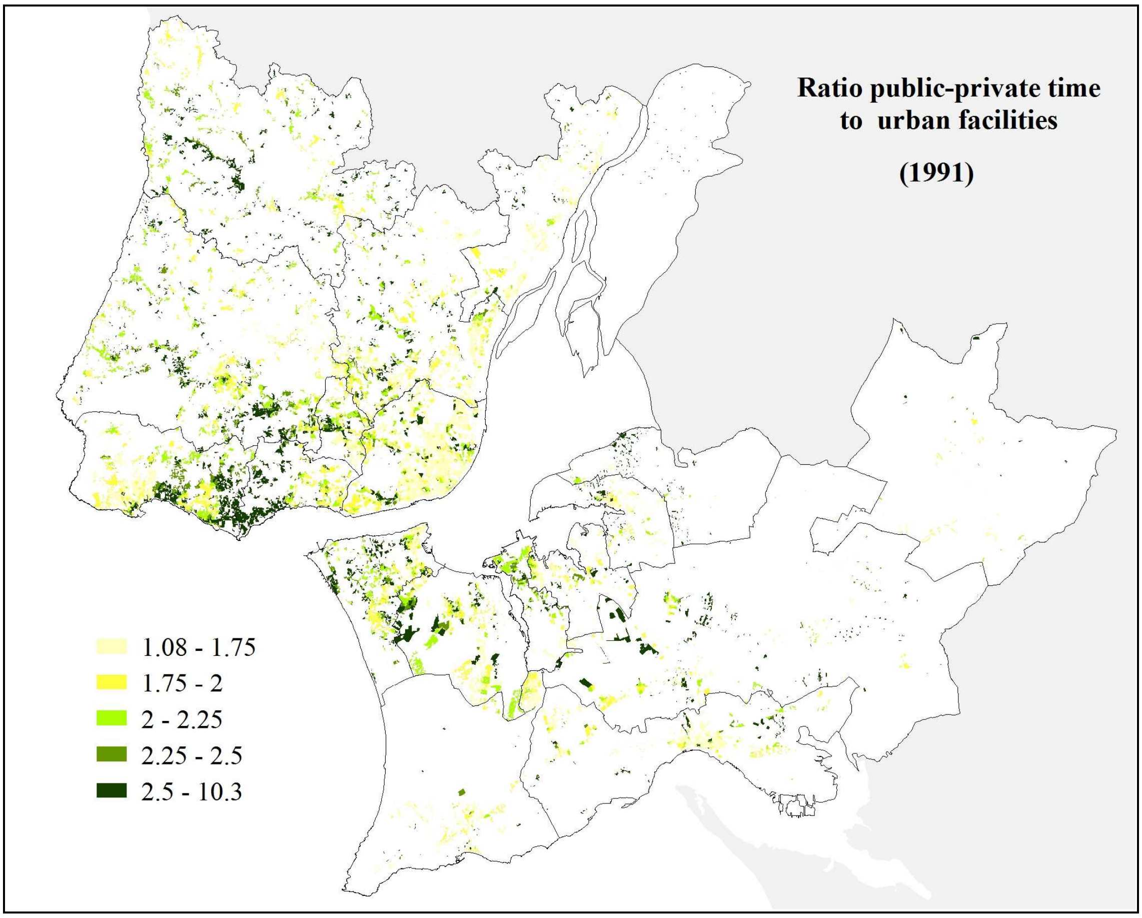

Effect of congestion
on time to work
(2001)
Time
Uncongested Time
0.86 - 1.05
1.05 - 1.1
1.1 - 1.15
1.15 - 1.2
1.2 - 1.41


Time to urban facilities
(1991)
Private transport
Round trip time
(mins)
1.2 - 10
10 - 20
20 - 30
30 - 45
45 - 72.6

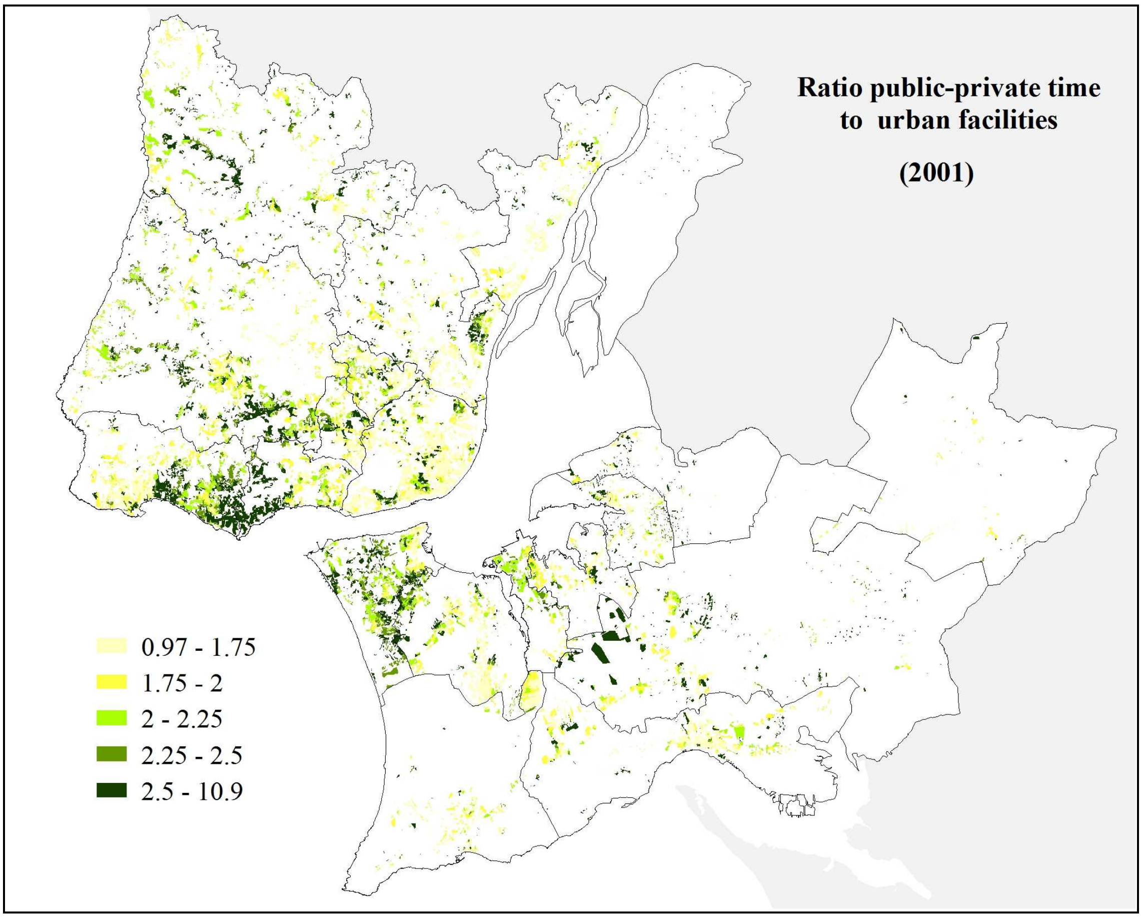

Time to urban facilities
(2001)
Private transport
Round trip time
(mins)
1.2 - 10
10 - 20
20 - 30
30 - 45
45 - 73.5


Time to urban facilities
(1991)
Public transport
Round trip time
(mins)
2.1 - 10
10 - 20
20 - 30
30 - 45
45 - 375

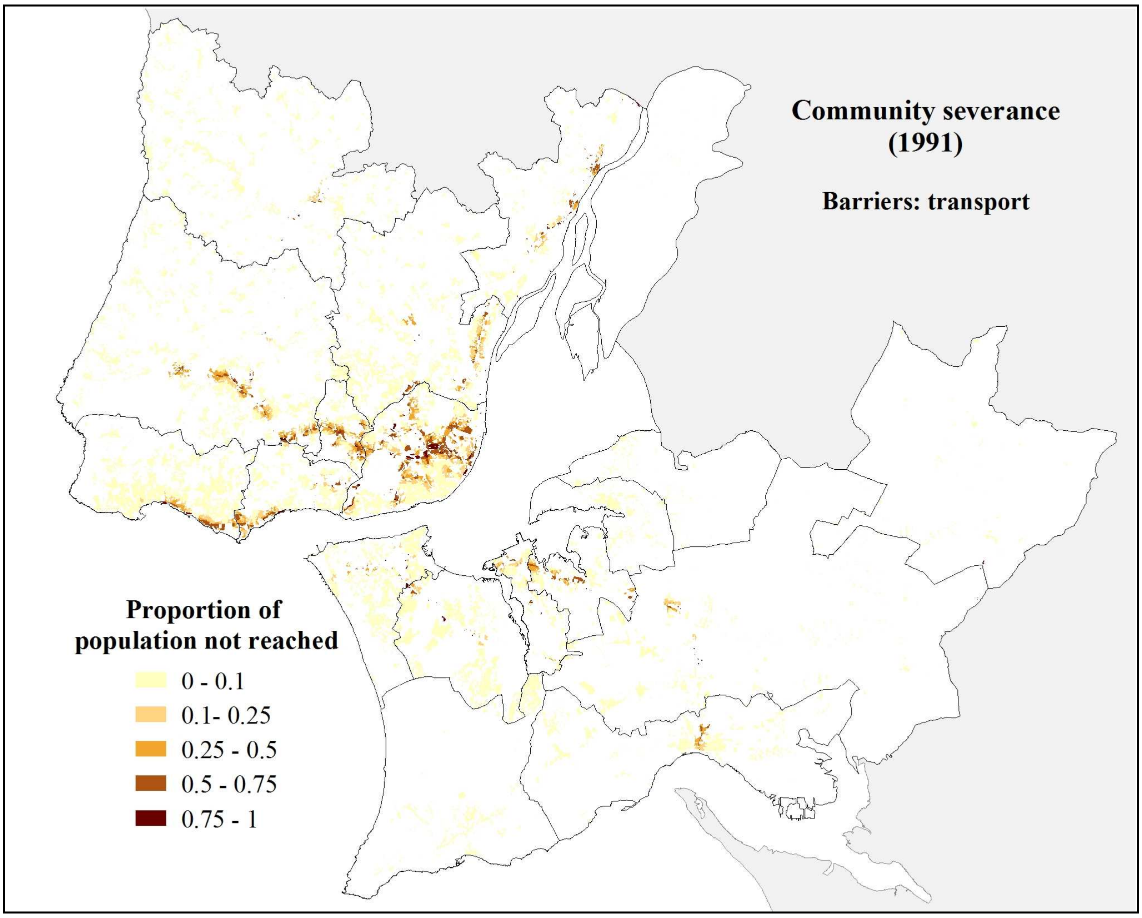

Time to urban facilities
(2001)
Public transport
Round trip time
(mins)
2.1 - 10
10 - 20
20 - 30
30 - 45
45 - 377



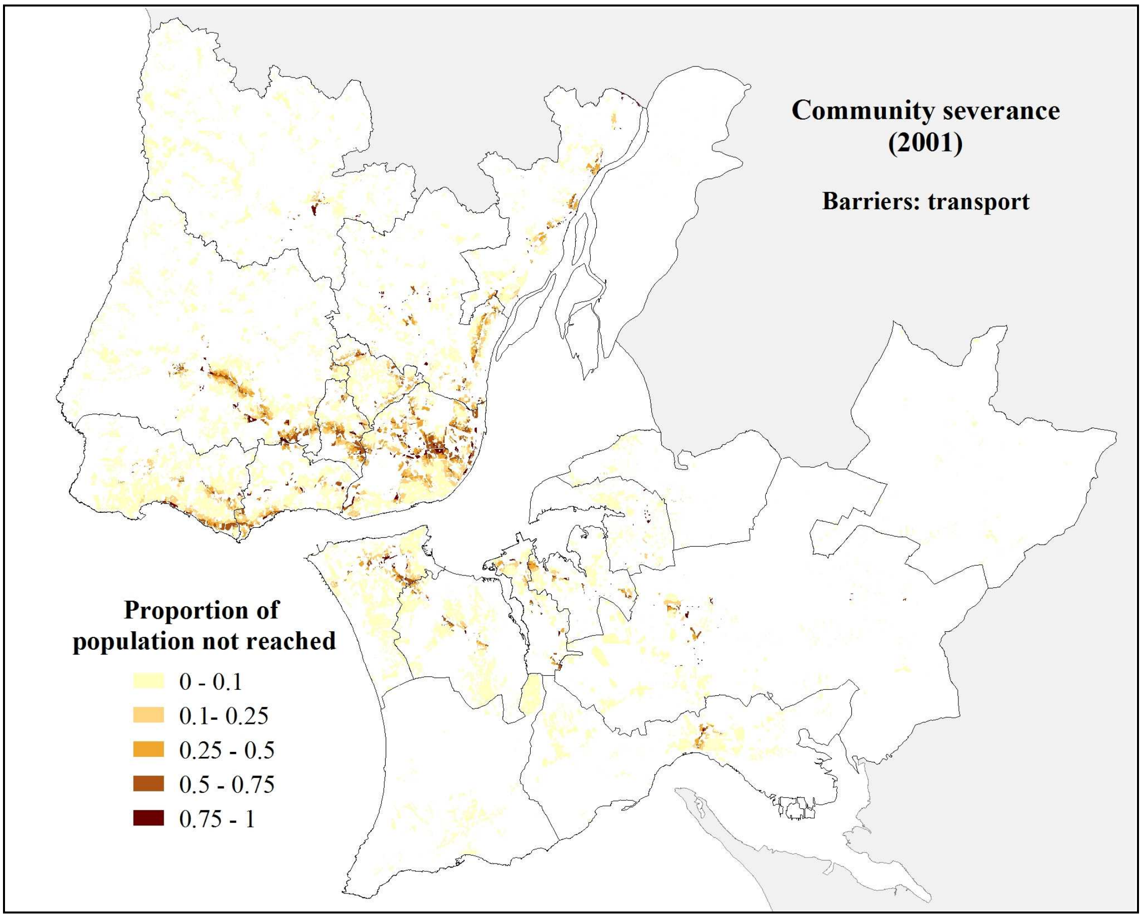
Ratio public-private time
to urban facilities
(1991)
1.08 - 1.75
1.75 - 2
2 - 2.25
2.25 - 2.5
2.5 - 10.3



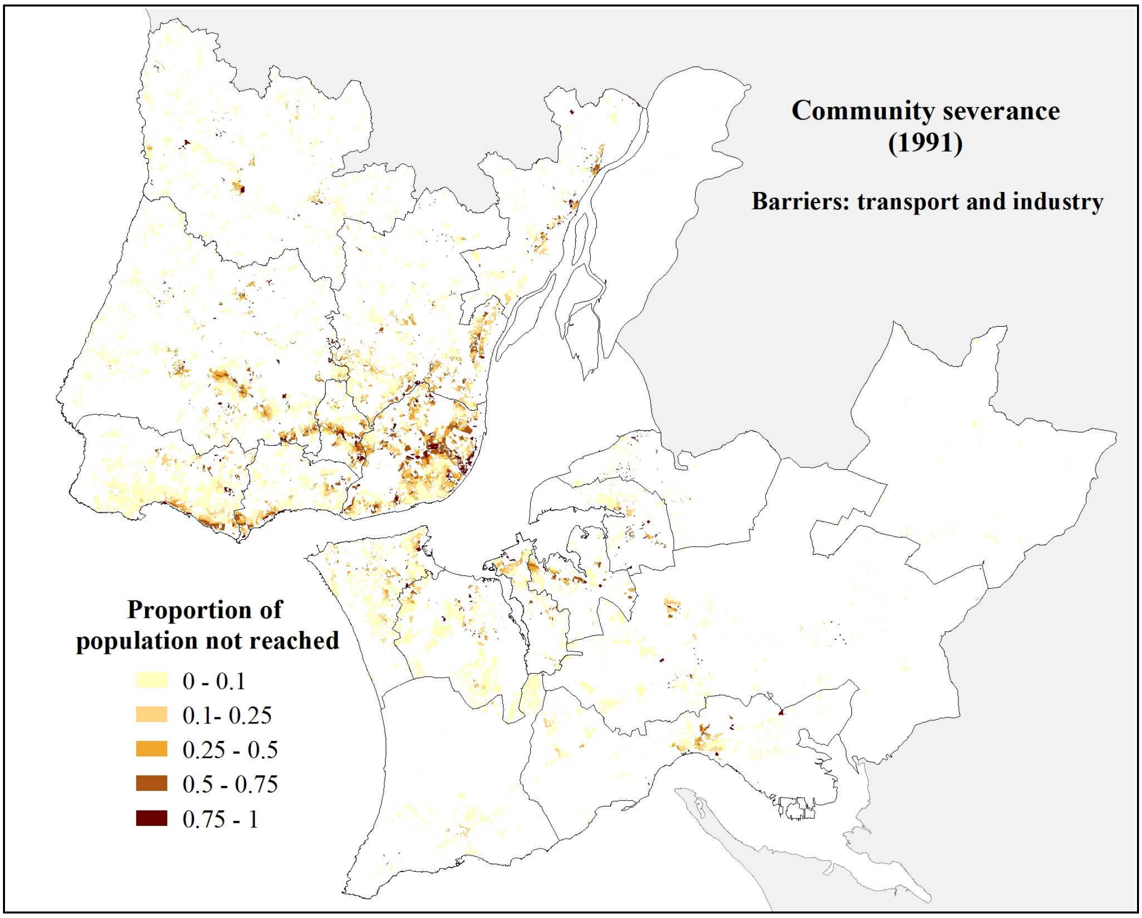
Ratio public-private time
to urban facilities
(2001)
0.97 - 1.75
1.75 - 2
2 - 2.25
2.25 - 2.5
2.5 - 10.9

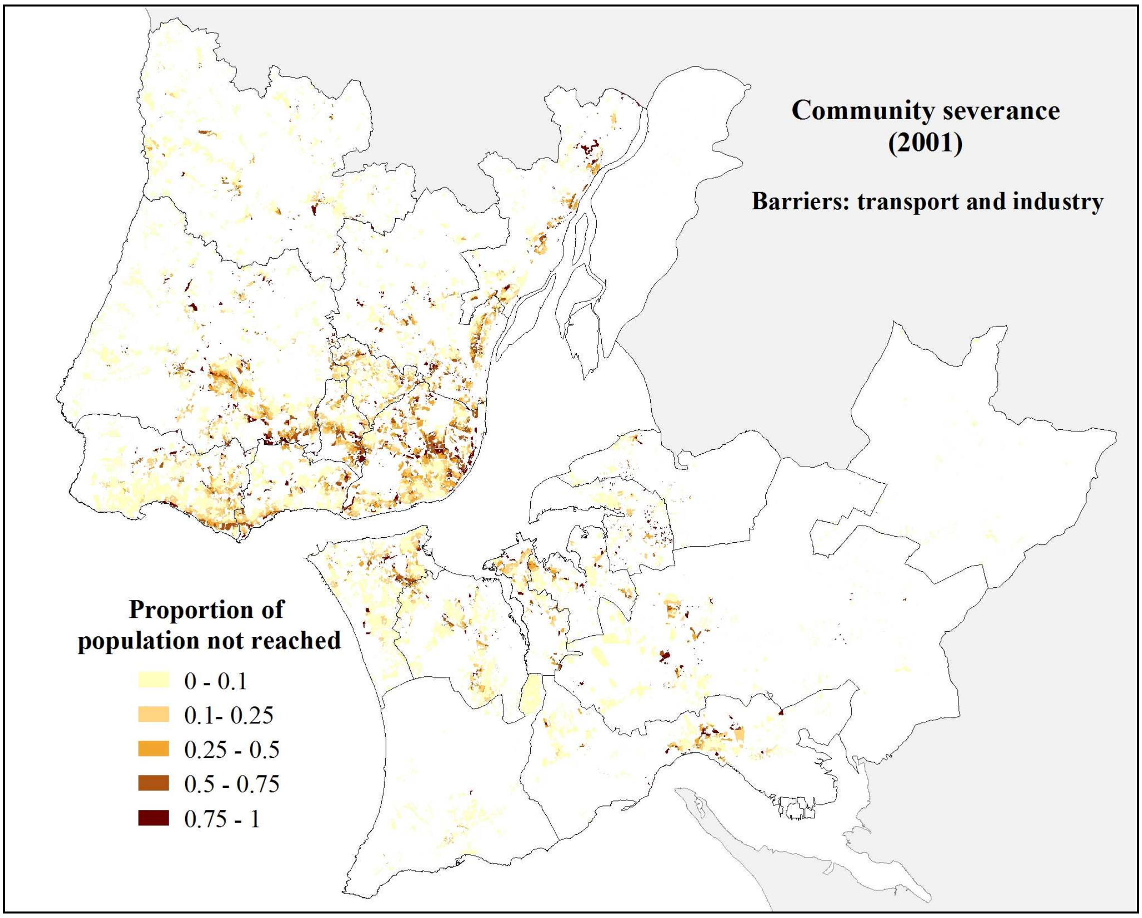


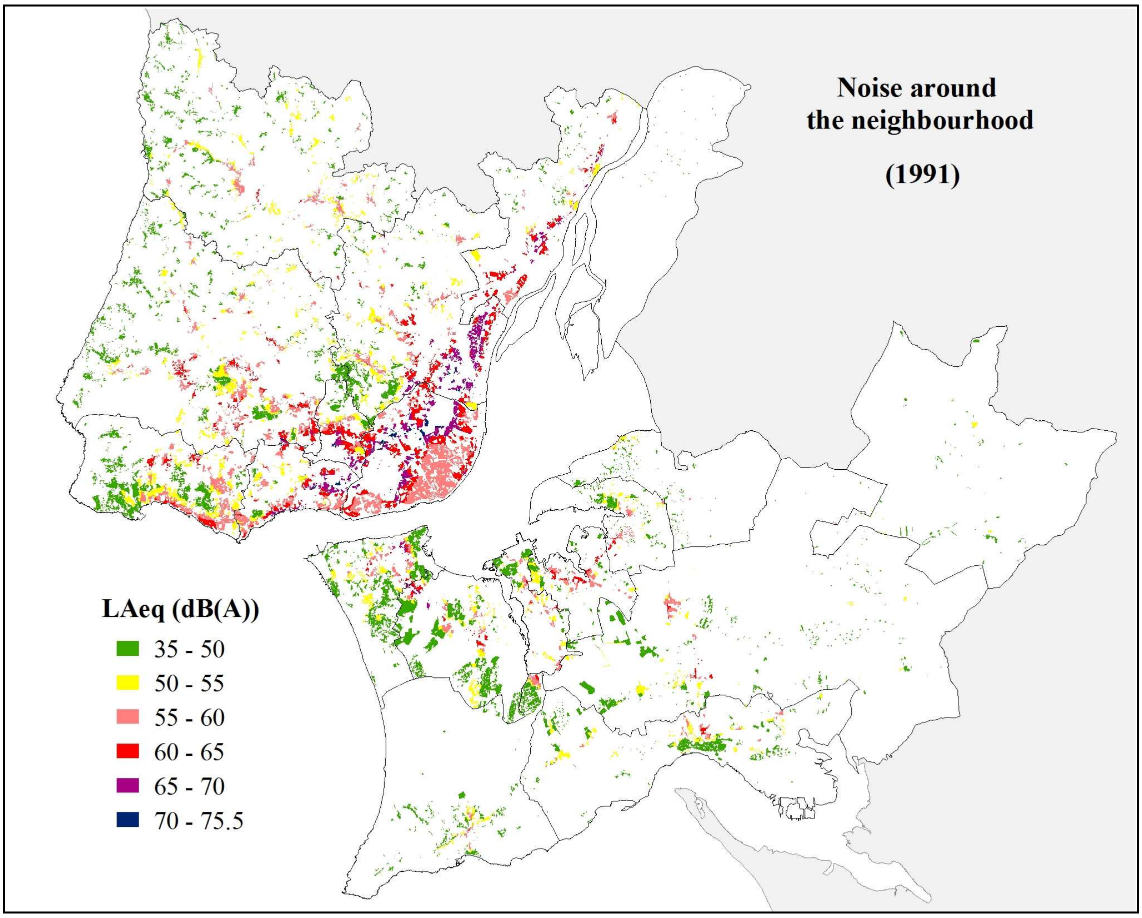
Community severance
(1991)
Barriers: transport
Proportion of
population not reached
0 - 0.1
0.1- 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1

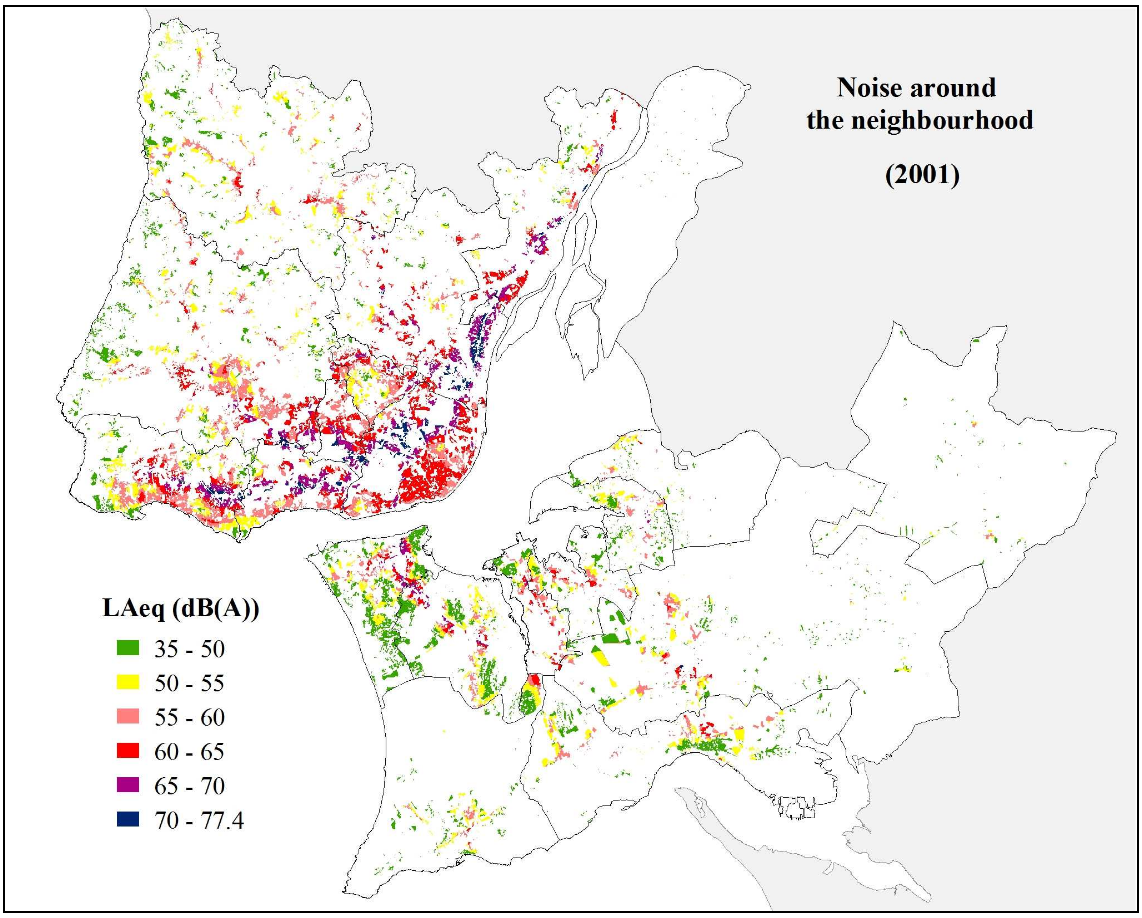


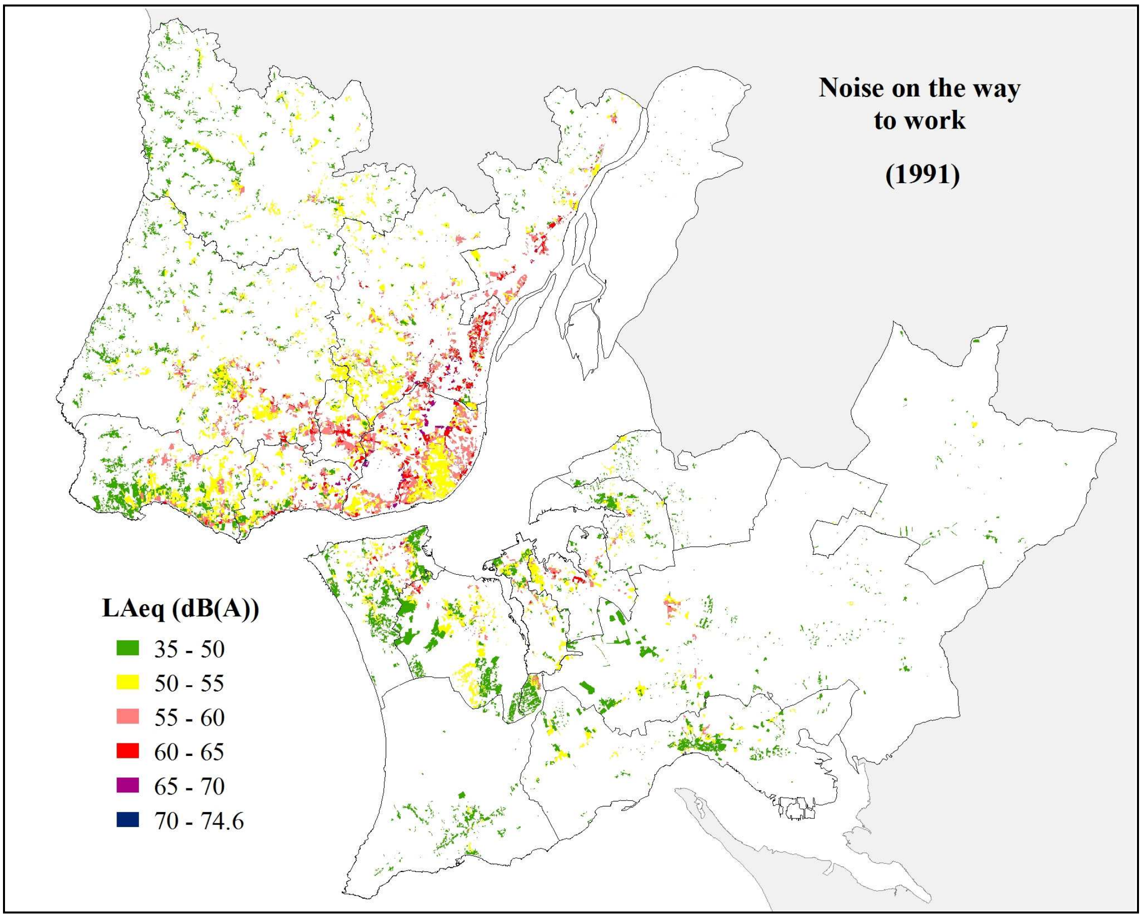
Community severance
(2001)
Barriers: transport
Proportion of
population not reached
0 - 0.1
0.1- 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1

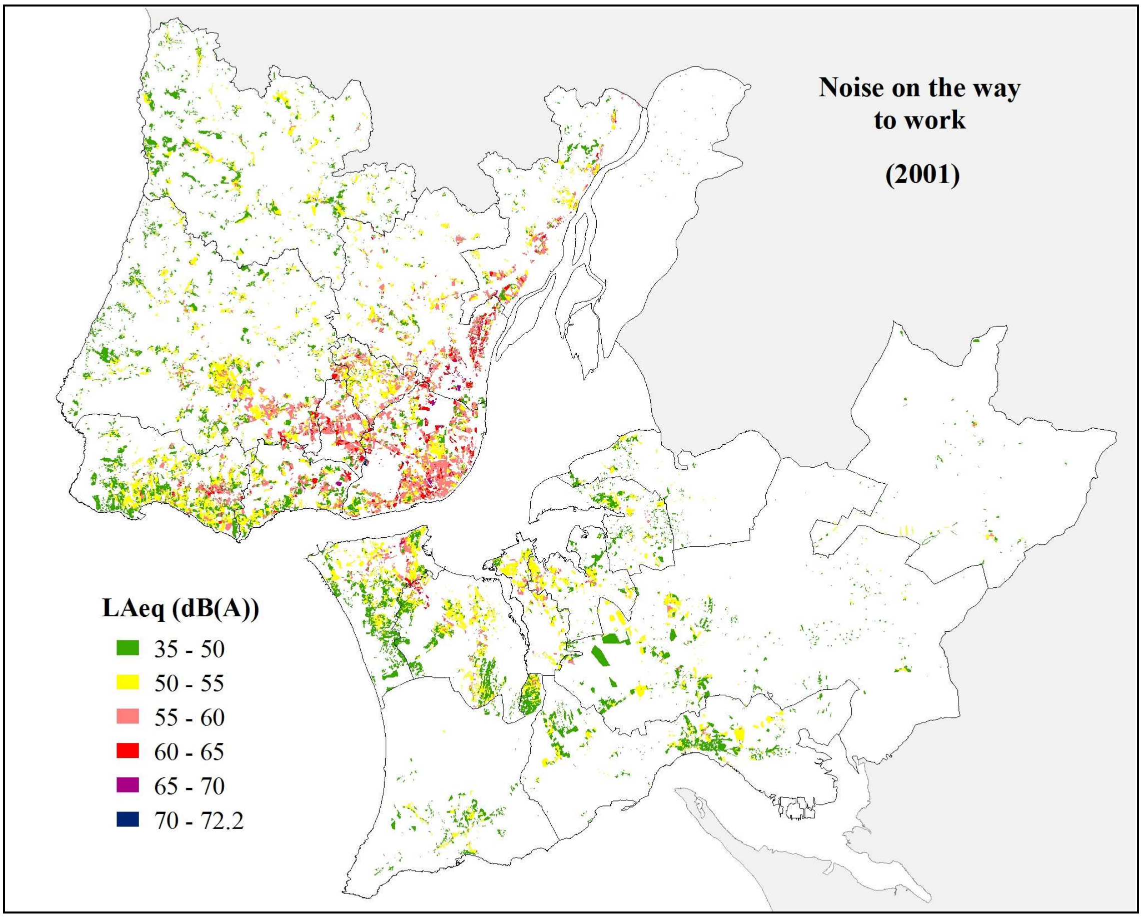

Community severance
(1991)
Barriers: transport and industry
Proportion of
population not reached
0 - 0.1
0.1- 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1

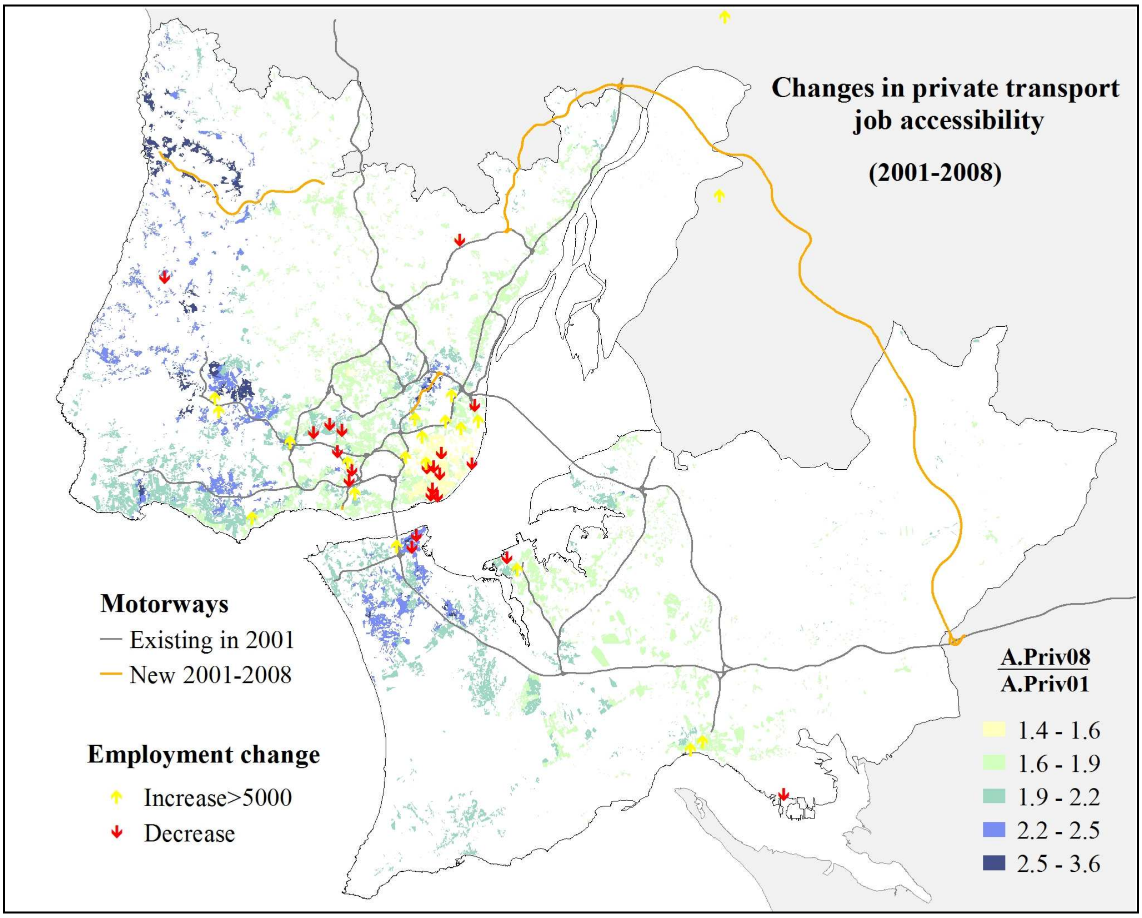

Community severance
(2001)
Barriers: transport and industry
Proportion of
population not reached
0 - 0.1
0.1- 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1


Noise around
the neighbourhood
(1991)
LAeq (dB(A))
35 - 50
50 - 55
55 - 60
60 - 65
65 - 70
70 - 75.5

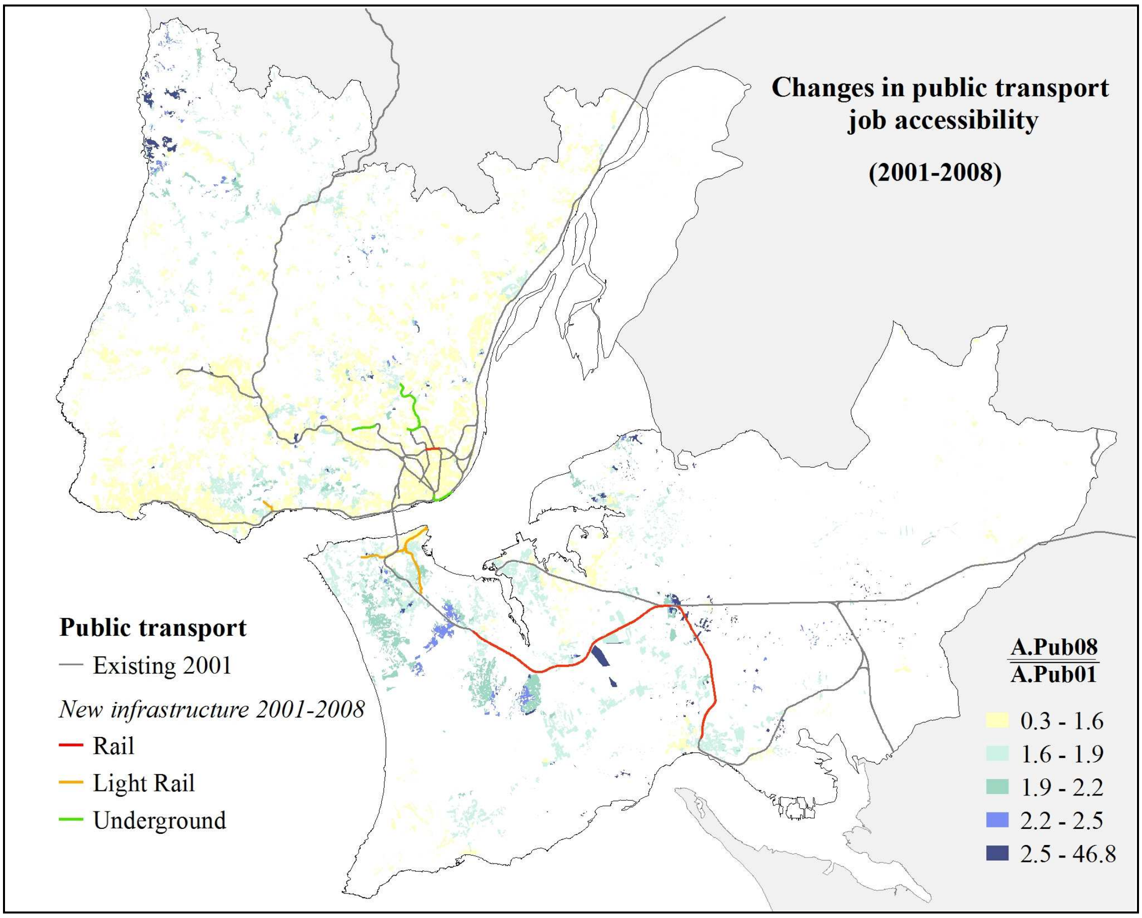

Noise around
the neighbourhood
(2001)
LAeq (dB(A))
35 - 50
50 - 55
55 - 60
60 - 65
65 - 70
70 - 77.4


Noise on the way
to work
(1991)
LAeq (dB(A))
35 - 50
50 - 55
55 - 60
60 - 65
65 - 70
70 - 74.6

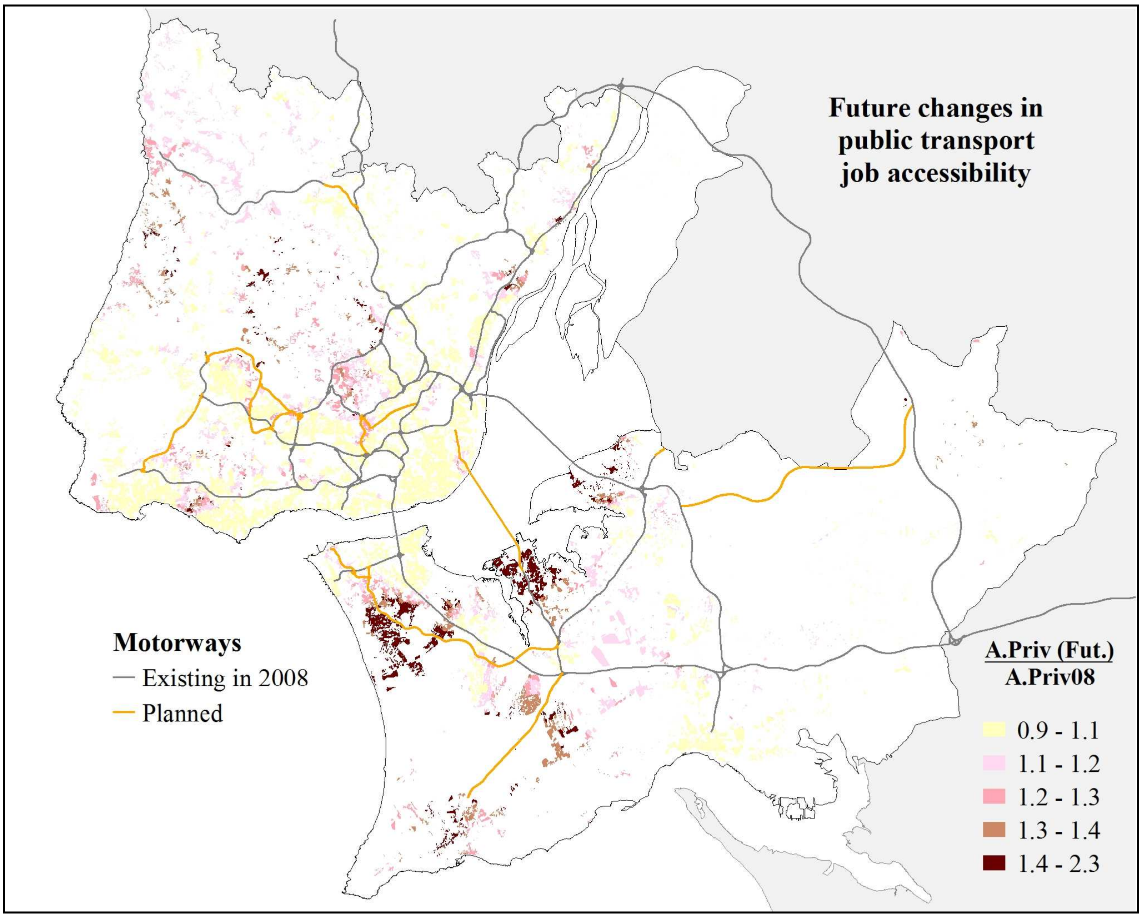

Noise on the way
to work
(2001)
LAeq (dB(A))
35 - 50
50 - 55
55 - 60
60 - 65
65 - 70
70 - 72.2



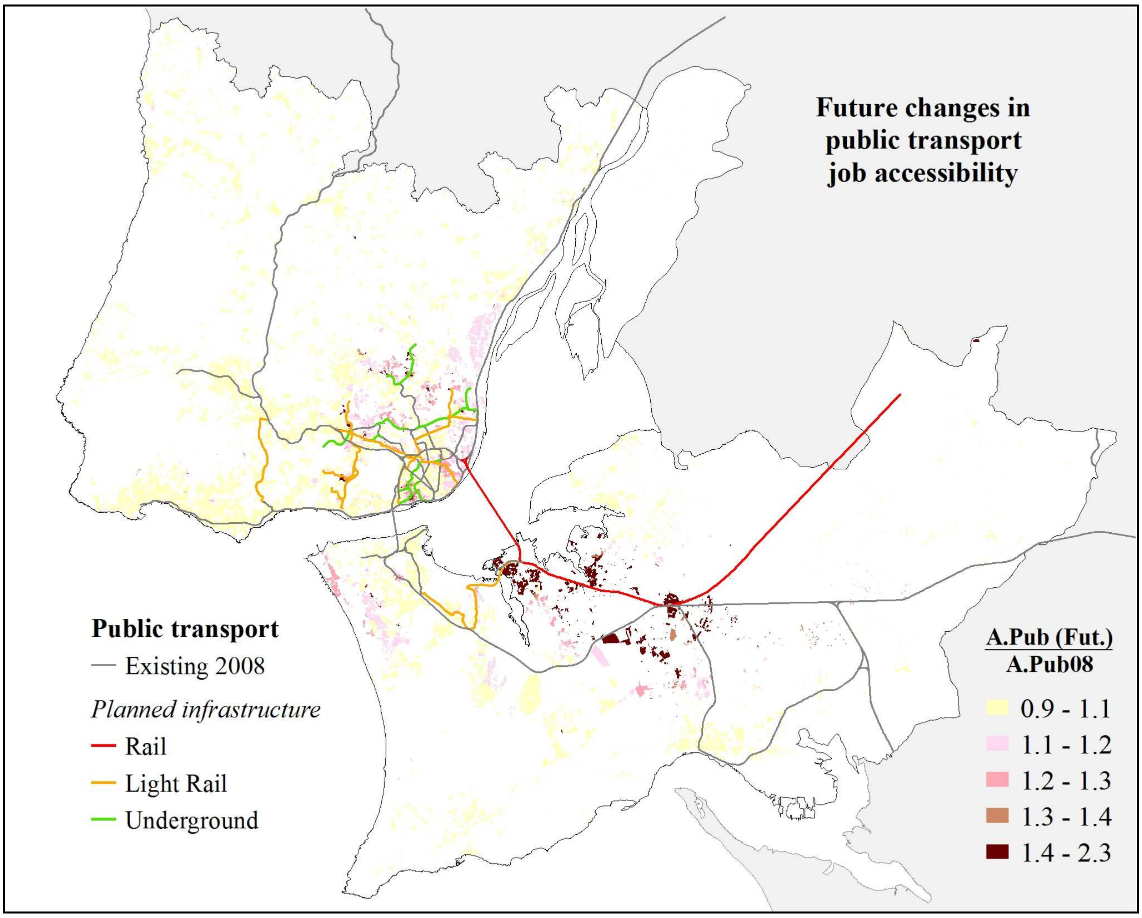
Changes in private transport job accessibility
(2001-2008)
Motorways
Existing in 2001
New 2001-2008
Employment change
Increase>5000
Decrease
A.Priv08
A.Priv01
1.4 - 1.6
1.6 - 1.9
1.9 - 2.2
2.2 - 2.5
2.5 - 3.6



Changes in public transport job accessibility
(2001-2008)
Public transport
Existing 2001
New infrastructure 2001-2008
Rail
Light Rail
Underground
A.Pub08
A.Pub01
0.3 - 1.6
1.6 - 1.9
1.9 - 2.2
2.2 - 2.5
2.5 - 46.8



Future changes in
public transport
job accessibility
Motorways
Existing in 2008
Planned
A.Priv (Fut.)
A.Priv08
0.9 - 1.1
1.1 - 1.2
1.2 - 1.3
1.3 - 1.4
1.4 - 2.3



Future changes in
public transport
job accessibility
Public transport
Existing 2008
Planned infrastructure
Rail
Light Rail
Underground
A.Pub (Fut.)
A.Pub08
0.9 - 1.1
1.1 - 1.2
1.2 - 1.3
1.3 - 1.4
1.4 - 2.3

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