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# Residential location, commuting and non-work travel in two urban areas of different size and with different center structures

Petter Næss, Arvid Strand, Fitwi Wolday and Harpa Stefansdottir

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## Abstract.

There is an extensive literature on relationships between the built environment and travel, but the vast majority of such studies rely solely on statistical analyses of available travel survey data, with limited possibilities for demonstrating causality. This article presents findings from a methodologically novel study drawing on a combination of a tailor-made questionnaire survey and in-depth qualitative interviews, including cross-sectional as well as longitudinal analyses. Our mixed-methods approach offers stronger evidence of causal influences than in most previous studies on the built environment and travel. We illuminate such relationships in two metropolitan areas differing considerably in their size and urban structure: the relatively monocentric Norwegian capital Oslo and the smaller, predominantly polycentric Stavanger area. The study encompasses travel distances and modes for both commuting and intra-metropolitan non-work purposes. The paper thus offers a comparison of the influences of built environment characteristics on travel across metropolitan contexts as well as for different travel purposes.

In both metropolitan areas and for commuting as well as non-work trips, inner-city dwellers make a higher proportion of trips by non-motorized modes and a lower share by car. Inner-city residents in both metropolitan areas also travel shorter distances for non-work purposes than their suburban counterparts do. In the relatively monocentric Oslo metropolitan area, commuting distances also tend to increase substantially the further away from the city center the workers live. In the more polycentric Stavanger metropolitan area, commuting distances are first and foremost influenced by the location of the dwelling relative to a large suburban employment center, and only secondarily by its distance to the city center of Stavanger. Commuting distances as well as travel modes for both commuting and non-work travel depend mostly on the distance from the dwelling to the main or second-order centers of the urban region. Local built environment characteristics play a greater role for trip distances to non-work destinations, particularly in the Oslo region.

The results generally support urban containment as a strategy to promote sustainable mobility, with inner-city densification as particularly favorable.

# 1. Introduction

The purpose of this paper is to shed light on influences of residential location and local built environment characteristics on commuting and non-work travel in two different – in size and center structure - metropolitan areas in Norway. More specifically, the paper examines the causal mechanisms through which built environment characteristics influence travel behavior for commuting and non-work purposes; differences across travel purposes in such influences; and how the influences vary with metropolitan size and between predominantly monocentric and more polycentric urban regions. Compared to mainstream research on land use and travel, this study is methodologically innovative, combining a comprehensive, tailor-made travel survey with in-depth qualitative interviews, and applying cross-sectional as well as longitudinal analyses. The empirical cases are the metropolitan areas of Oslo and Stavanger, Norway. The two regions are different in population size (Oslo is more than four times as large as Stavanger) as well as in their center structure (Oslo relatively monocentric and Stavanger predominantly polycentric).

Over the past three decades, a large number of studies have been carried out in cities across the world to illuminate the effects of built environment characteristics on travel. The aspect of the urban built environment that has attracted the greatest amount of research regarding its impacts on travel behavior is the location and neighborhood characteristics of residences. The urban structural situation of the dwelling – and the size of the city - influences how long or short distances the residents will need to travel in order to reach various opportunities for activities (job, school, shopping, leisure activities, etc.), and which means of transportation will be possible and attractive to use for these trips (Christaller, 1966; Hägerstrand, 1970; Boarnet & Crane, 2001). The urban structural situation of the dwelling also has bearing on the accessibility to green areas and other places where outdoor recreation and physical activity can be exercised (Nielsen & Hansen, 2007).

There are thus strong theoretical reasons for believing that residential location influences travel behavior. Yet, doubt has repeatedly been raised about such relationships, sometimes based on model simulations (Ehenique et al., 2012) but in recent decades particularly based on arguments about residential self-selection based on travel attitudes (Bagley & Mokhtarian, 2002; Van Wee, 2009). Much of the literature is based on data from low-density and sprawling American cities where weaker relationships could be expected to exist between urban form and travel. The vast majority of studies of residential location and travel have also relied solely on statistical analyses of available travel survey data, and their contribution to explaining causal mechanisms is therefore limited.

This paper aims to go beyond these limitations by drawing on an exceptionally rich data material obtained through a combination of qualitative and quantitative research methods. Our methodology has been developed and refined through previous studies in metropolitan areas in Denmark (Næss & Jensen, 2002, 2004; Næss, 2005, 2006), China (Næss, 2010, 2013) and Portugal (Næss, 2015a), with the present study as the most thorough one. By investigating the interviewees' rationales for choices of activity locations and travel modes, and by investigating changes in travel behavior and activity patterns among interviewees who have moved from one residential address to another within the metropolitan area in later years, the study brings stronger evidence of causal influences of residential location on travel than in most previous studies.

In European countries, the compact city is often regarded as the most sustainable and least car-dependent urban form. However, planners' ideas about more compact built environments do not only refer to inner-city densification in relatively monocentric cities. Internationally, ideas of developing polycentric, more compact urban neighborhoods have long had a quite strong position (Healey and Williams, 1993; Archibugi, 1997), evident in ideas such as 'new urbanism' (CNU, 2005), 'smart growth' (EPA, 2017) and 'transit-oriented development' (Sustainable Cities Institute, 2017). In studies of built environment and travel in USA there has been a tendency to focus on the neighborhood scale, often without taking the location of the investigated neighborhoods within the wider urban structure into consideration (Cervero, 2003; Cao et al., 2009). In Europe, studies including the distance from the dwelling to the city center and sub-centers within the metropolitan area have been more common (Headicar, 2000; Hickman & Banister, 2005; Næss, 2012), and such studies have over the past decade become more common in America and Asia as well.

The present study investigates urban form characteristics at the metropolitan, urban district as well as neighborhood scale, comparing the influences of built environment characteristics across these different scales. By investigating these relationships in two urban areas differing in their size and center structure, we also examine how the influences of built environment characteristics on travel differ, depending on the different urban contexts. The study encompasses travel distances for both commuting and intra-metropolitan non-work purposes, as well as trip frequencies and distances traveled by car, transit and non-motorized modes. The data material thus facilitates a comparison of the influences of residential location on commuting with those on non-work travel. Showing that the magnitude of these influences are highly context-dependent, the study also demonstrates that the increasingly popular endeavor of conducting statistical meta-analyses to identify average elasticities between various built environment variables and travel behavior (e.g. Ewing & Cervero, 2010; Stevens, 2017) may not be very fruitful.

As mentioned above, mainstream literature on land use and travel depicts attitude-based residential self-selection as a potential major source of error. In several papers (including a forthcoming one based on the present study), we have argued that the importance of self-selection is exaggerated (Næss, 2009 and 2014; Wolday et al., 2017). However, since it is still a dominant view that control for residential self-selection is important, the study addresses the challenge of residential self-selection partly by drawing on information from the qualitative interviews about the interviewees' motivations for previous and possible future residential locations and changes in activity patterns and travel after moving, and partly by including answers to survey questions about residential preferences as control variables in the statistical analyses.

In the next section, existing literature on influences of residential location and local environment characteristics on travel will be reviewed, with a particular focus on differences between polycentric and monocentric urban areas. Section 3 presents the methodology of the study, including its ontological and epistemological standpoint, the research design and how the chosen methods were actually applied. Section 4 introduces the two chosen metropolitan cases, Oslo and Stavanger. Section 5 displays the results from the analyses of influences of residential location on travel distances, whereas Section 6 shows the results of similar analyses on travel modes. Each of these sections includes sub-sections about cross-sectional and longitudinal statistical analyses, examples from qualitative interviews as well as a sub-section discussing causal mechanisms drawing on the qualitative interview material. Based on the findings in sections 5 and 6, section 7 compares the influences of residential location and local environment characteristics on travel for commuting and non-work purposes, respectively, and between the more monocentric Oslo and the more polycentric Stavanger context. Section 8 discusses the results in relation to earlier research and on-going debates, whereas section 9 rounds off the paper with some concluding remarks.

# 2. Literature review

The expansion of urban settlements during the last century from predominantly monocentric and compact urban forms resulted in various new kinds of metropolitan urban structures. The two cases studied in this article (Oslo and Stavanger) represent two broader such categories, the relatively monocentric and the relatively polycentric metropolitan area. Polycentric metropolitan structures may be the result of a conurbation process where two or more neighboring cities have grown into one continuous urbanized area, as with the previously separate cities of Stavanger and Sandnes. Polycentric metropolitan development may also arise as a result of planning, easing of mobility constrains (both access and cost) or as an adjustment process to mitigate efficiency loss associated with urban growth.

Among the earliest studies, the conclusions about the implication of different metropolitan urban structures on travel behavior were mixed. Many researchers contended that dispersed spatial structures were associated with shorter commute times (Gordon et al., 1989, Gordon et al., 1991, Levinson and Kumar, 1994, Gordon and Lee, 2015). These authors argued that dispersed urban structures created better conditions for job-residence co-location. However, using travel time as a measure of travel behavior does not give a sufficiently nuanced picture of built environment influences on travel behavior.

Crane and Chatman (2003), using panel data from the American Housing Survey for the years 1985-1997, found that job suburbanization indeed appeared to be associated with shorter commutes. However, a further analysis found strong differentiation by employment trades, which is indicative of the distinction between specialized and non-specialized jobs in job location (Christaller, 1966) and the associated agglomeration effects. Crane and Chatman's (2003) analysis showed that, while suburbanization of service employment (e.g. construction, wholesale) was associated with shorter commutes, suburbanization of manufacturing and finance were associated with longer commutes. Analyzing a two-period data set from polycentric regions in Denmark, Grunfelder and Nielsen (2012) also concluded on a similar note. Their findings show that, although travel time in general appeared to remain relatively stable between the two periods, greater between-group differences were observed. For example, managers and professionals tended to have longer commuting times and distances while commuting distances for students, technicians, clerks and service workers tended to be shorter.

The co-location narrative is countered by other studies (Hickman and Banister, 2015, Næss, 2006, Næss, 2007, Næss and Sandberg, 1996) who found little evidence in support of systematic and wide-spread job-residence co-location. Næss (2006), employing qualitative and quantitative analysis from Copenhagen metropolitan area, showed that individuals did not necessarily use the closest available facility for a given type of activity, but often traveled further to reach a facility they perceived as better. In particular, this applied to job opportunities. Their travel distances therefore depended on the distance from the dwelling to concentrations of activities rather than to the single closest facility. For a monocentrically structured metropolis, the city center is the center of gravity for many trip destinations, leading to shorter overall travel distance, reduced car use, and higher shares of active travel for central urban residents (Næss, 2005, 2006, 2010). Næss (2006, 2012) also argues that since the job diversity outside these concentrations tends to be sparse, dispersion in the location of specialized jobs might increase both travel distance and time as employees might be forced to travel across longer distances to find jobs that fit their qualifications, as also illustrated by Ehenique & Donald (2015).

In a monocentric metropolitan structure, built environment factors such as density, mixed development and residential proximity to the city center are often associated with shorter commuting distances and a modal split favoring environmentally sustainable trends (Næss, 2006, Næss and Jensen, 2004, Zegras, 2010). For polycentric urban regions however, mixed signals still linger in the literature. Hickman and Banister (2015) found that higher residential density is associated with shorter commuting distances and lower energy consumption. Grunfelder and Nielsen (2012), using Danish data obtained from polycentric regions, also found that while residential distance from the city center exerted strongest effect in reducing travel time, other urban form variables such as access to transit and employment density were mainly associated with commuting modes choice.

The other important dimension covered in this article, in addition to the comparison between different metropolitan urban structures, relates to the distinction of travel by purpose. Travel behavior can be best understood when analyzed based on travel purpose, which can also impart important policy lessons. Hägerstrand (1970) and some years later Ås (1978) categorized travel decisions in terms of on the one hand the desirability of an activity in the priority list of an individual and on the other hand the spatio-temporal fixity of the activity in question. Travel scheduling is highly susceptible to whether an activity is mandatory or optional. Understanding travel patterns associated with non-work travel is vital for a couple of reasons. One, non-work travel constitutes a major share of the overall travel. According to the latest Norwegian National Travel Survey, 67 per cent of daily trips were non-work related (Hjorthol et al., 2014). For the US, the corresponding number is 72 per cent (Santos et al., 2011). Another important reason relates to the spatial or temporal flexibility of non-work travel and the possibility it can render for manipulation by urban planners towards the intended outcome.

Non-work travel has been accorded a growing level attention in the literature, although not as much as commuting travel. Researchers such as Elldér (2014) and Boarnet and Greenwald (1999) reported a weak link between built environment and non-work travel. At the same time, when varying geographic scales (a zip code level as opposed to neighborhood scale) were considered, built environment was found to influence non-work travel (Boarnet and Greenwald, 1999).

Travel can largely be understood as a derived activity. People travel because of the expected benefits at the destination. Closing the distance gap involves incurring a ‘friction’ (Lloyd and Dicken 1977) or a cost, which, among others, is a function of travel mode and how far one travels. Non-work travel is a composite term that includes a variety of travel types with varying spatio-temporal fixity, frequency of occurrence and spatial reach. Consequently, the responsiveness to change in built environment is also likely to differ among the various non-work travel decisions. Lumping all non-work travel into one basket would therefore be less informative in highlighting the relationship between non-work travel and built environment. To avoid long-range and probably non-frequent components of non-work travel overshadowing the local but frequent travel types, this article addresses seven important intra-metropolitan non-work travel types.

Travel behavior is contextual, and therefore built environment attributes that may influence travel behavior at certain spatial scales may be less relevant in other spatial contexts (Dieleman et al., 2002, Kwan, 2012, Kwan and Weber, 2008, Milakis et al., 2015). Furthermore, moderating effects due to traveler’s idiosyncratic characteristics may have an amplifying or diminishing influence on the observed outcome between built environment characteristics and travel behavior. Untangling such a complex web of interrelationships and seeing through to the causal patterns requires more than just a statistical rigor. It requires understanding the mechanisms of causal flows.

One of the significant representations of the built environment's effects on travel behavior is residential distance from the city center and other significant concentration of facilities. The link between residential distance from these centers and the ensuing travel behavior does not only epitomize the built environment-travel behavior nexus, but also serves as a comparative benchmark for analyzing travel behavior between different metropolitan urban structures. Generally, living close to the main center of a monocentric city has been found in several studies to lead to higher proportion of travel by transit, less car use, and higher share of travel by non-motorized modes (Næss, 2006; Zhou & Kockelman, 2008; Zegras, 2010).

The disparity between our two metropolitan case-regions is not limited to their metropolitan urban structure. The urban regions also differ in size, both in spatial reach and population-wise. Obviously, the cross-city distance, that is, the distance from one outskirt of the city to an outskirt on the opposite side, is longer in a large city than in a small city. Partly, in response to the higher interaction costs (Gordon and Lee, 2015) associated with longer average distance from the center, larger cities tend to be denser, particularly in and close to the city center (Levinson & Kumar, 1997). An elevated density together with larger urban size has significant implication for the distribution of potential activities and transit access, which affects modal split, amount of car use, and active travel.

Density, as also epitomized by the concepts of 3D's (Cervero and Kockelman, 1997) and the 5D's (Cervero et al., 2009), is strongly associated with travel behavior. At the scale of the continuous urban area of cities, Newman and Kenworthy (1989a, 1999, and 2015) reported a strong inverse association between high-density cities and energy consumption for transportation. Næss et al. (1996), based on a study of 22 Nordic cities, also concluded on the same note that lower consumption per capita of urban area (which is the same as higher city-scale urban density) contributed to significantly reduce transport-related energy consumption.

Conversely, neighborhood-scale population density is found to portray, at times conflicting, but mostly modest effect (Ewing and Cervero, 2010) on travel behavior. This, at least in part, is likely the result of geographic scale. Like many built environment variables, the influence of neighborhood density on travel behavior is not scale invariant (Milakis and van Wee, 2015). Higher local density, by creating the conditions for higher local accessibility by non-motorized transport, may influence modal split for local travel. Nevertheless, the share of the overall travel distance carried out on foot or by bike in a dense suburban neighborhood may be suppressed due to the shorter lengths of the non-motorized local trips compared to the trips to non-local destinations (notably commuting). In a study by Næss, Røe & Larsen (1995), neighborhood density had negligible effect on total travel distance. A different study in Copenhagen (Næss, 2011) found a modest effect on car travel while Cao and Fan (2012) found a sizable influence (a reduction by about 18.6 %) on vehicle miles traveled per person. Higher local density was also found to lead to a higher proportion of travel by transit (Næss, Røe & Larsen, 1995) and when local neighborhood density is coupled with workplaces in high-density areas, it tends to generate more transit commutes and fewer car commutes.

Internationally, relatively few studies have included qualitative interviews (Røe, 2001; Tillberg, 2001; Nielsen, 2002; Næss & Jensen, 2004 and 2005; Næss, 2005, 2013 and 2015b; Scheiner, 2005). These studies were situated in different urban contexts, from large metropolitan areas to small towns. One common finding in these studies is that people do not necessarily use the closest ones among available facilities. Daily travel distances therefore tended to be influenced more by the distance from the dwelling to the city's main concentration of facilities than by its distance to local centers. In our earlier studies, we used the concept of *transport rationales* as a framework for identifying the considerations and motivations that influence people's travel behavior within a city or metropolitan area (see section 5.3). Although the actual importance of different built environment characteristics on travel behavior varies with the city context, the transport rationales identified in qualitative studies so far show a high degree of commonality.

As can be seen above, there is already a vast body of literature on the relationship between the built environment and travel behavior. Most of these studies are, however, purely quantitative and based on cross-sectional analyses only. While applying increasingly sophisticated statistical techniques, there is often little focus on how to avoid *model specification error* (Lewis-Beck, 1980). Few studies seem to be informed by explicit theoretical reflection or use qualitative empirical input to guide which urban structural and control variables to include or not to include in the analyses (Clifton & Handy, 2003:3; Næss, 2015c). The authors of this paper therefore side with Susan Handy's (2017:28) statement in a recent paper:

> "I would discourage researchers from producing yet more cross-sectional studies, even if their data are better and their statistical techniques more innovative than those of previous ones. We need to shift our efforts to different kinds of studies. … First, we need before-and-after evaluations of the impact of changes in the built environment on VMT and other aspects of travel behavior … Second … We need qualitative explorations of the processes by which households decide where to live and the formation of their preferences for different types of residential environments."

This paper aims to improve the state of knowledge by investigating how commuting and non-work travel behavior are influenced by the location and neighborhood characteristics of residential areas in two metropolitan areas differing in their size and center structure (see Figure 1). We assume that urban structure, sociodemographic characteristics as well as the attitudes influence travel behavior. In addition, sociodemographic characteristics as well as attitudes influence where people choose to live. On the other hand, the experiences and habits that people develop when living at a particular residential location may also influence their attitudes.

Compared to mainstream literature, this study is methodologically novel in that it has applied a combination of quantitative (travel survey) and qualitative (in-depth interviews) research methods and conducted cross-sectional as well as longitudinal analyses. It aims at answering the following research questions:

- Through which causal mechanisms do built environment characteristics influence travel behavior for commuting and non-work purposes?
- Are the influences of built environment characteristics on commuting and non-work travel similar or different?
- Are the built environment influences on travel the same in more monocentric as in more polycentric urban contexts and across city sizes, and if not, in which way do they differ?

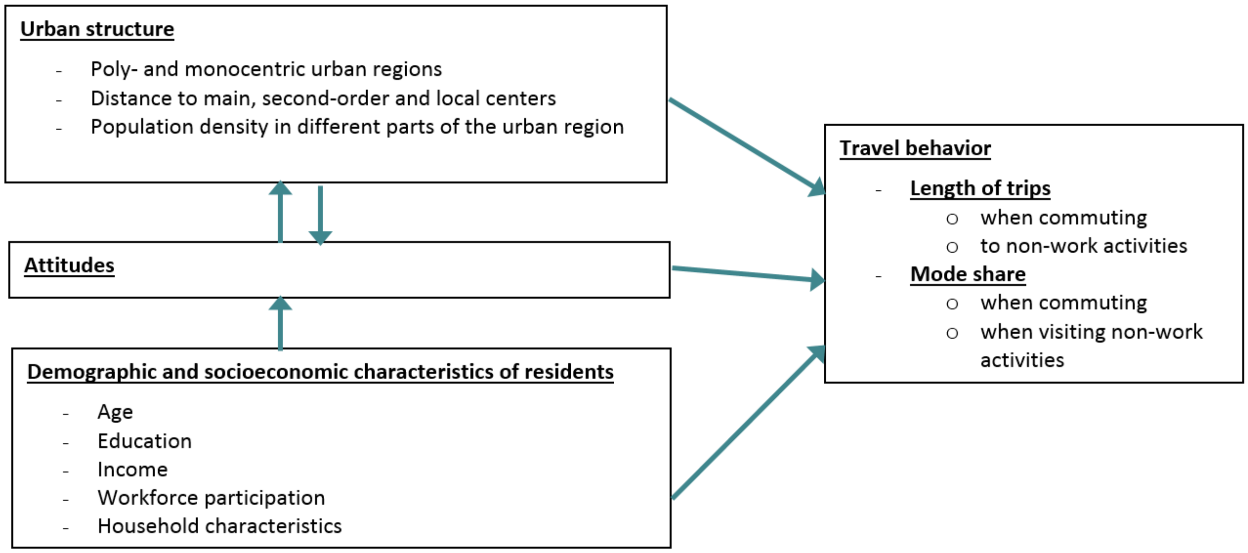


Figure 1: Key aspects investigated in the study.

# 3. Theoretical foundation and methods

## 3.1 The causal status of the built environment

This paper is based on an understanding of causality in terms of causal powers operating in different combinations in normally non-closed systems. Ontologically and epistemologically, our study leans on the position of Critical Realism (Bhaskar, 1993, 1998 and 2008; Sayer, 1992; Archer, 2000; Danermark et al., 2001). According to critical realist ontology, objects have properties enabling them to exercise certain forms of influences on other objects and/or make them liable to certain kinds of influences from other objects. Reality is understood to consist mostly of more or less open systems where empirical regularities rarely occur spontaneously. Critical Realism acknowledges human agents and social structures as well as the natural environment as capable initiators of mechanisms that might (or might not) result in empirical events that we as researchers try to comprehend. Causal mechanisms can also involve attitudes and knowledge resources of individuals, as well as intersubjective production of meaning. Critical Realism's conceives of the events and situations that occur as the resulting from the combined causal mechanisms at work in the actual situation. Many different causal powers operate simultaneously. Some amplify each other, others counteract each other, and some are only activated under the influence of other causal powers. All this varies with the specific context (Bhaskar, 2008). This understanding fits well with the multiple-cause situation a researcher is facing when trying to explain travel behavior.

The location of the dwelling relative to various centers and facilities, combined with connecting transport infrastructure, determines how accessible these centers and facilities are from the residence. Accessibility is inversely proportional to the friction of distance (Lloyd and Dicken 1977), which depends on the time consumption, economic expenses and inconvenience involved when traveling from one place to another. Other things equal, accessibility will obviously be highest for the closest facilities. In addition, ease of access varies with travel mode, depending on circumstances such as the layout of the transit network, driving conditions along roads, conditions for walking and biking, and individual mobility capabilities.

Residents' individual resources, motivations, and social environments influence their motivations for activity participation (including the balance between motivation to participate in activities and the friction of distance) and activity location (notably the balance between proximity and quality of facilities). Combined with the accessibility of various facilities, such motivations (or *rationales*, see the next section and section 5.3) influence the frequency of activity participation as well as the actual locations chosen for the various activities. The total distance traveled is a product of the geographical locations chosen for the activities in which the resident participates, the distance along the transport infrastructure network from the residence to these locations, and the frequencies at which the various activities are carried out.

## 3.2 Research design and data

As mentioned in the introductory section, the study employed a mixed-methods research design, sometimes referred to as 'The Explanatory Qualitative-Quantitative Method' (Næss, 2015a, 2017). An important strength of this research design is its better ability to identify causal mechanisms than in studies relying solely on travel survey data. The qualitative interviews provide insight into the backgrounds, motivations, and justifications that agents draw on when they make transport-relevant decisions about their participation in activities, location of these activities, modes of transportation, and the routes followed.

The data collection of the Oslo and Stavanger studies took place in the summer of 2015. We sent invitation letters for the web-based questionnaire survey to 15,000 addressees in each metropolitan area. The gross samples were drawn randomly among inhabitants living within broadly defined distance belts around the centers of each metropolitan area, supplemented with inhabitants of 112 new residential developments (73 in the Oslo and 39 in the Stavanger case) identified by main developers and realtors. In total, we received around 3400 acceptably completed questionnaires, yielding a response rate of 11.3 %. Although not very high, the response rate is within the mainstream for studies on this topic[1]. Some respondents turned out to have moved away from the case regions and were therefore excluded. The samples used in the analyses consisted of 1904 persons in the Oslo case and 1328 in the Stavanger case, totaling 3232.

The households to which the respondents and interviewees belong are on average bigger than for the population in their counties, and households with more than one breadwinner are somewhat overrepresented. The respondents, and particularly the interviewees, also have higher education than typical for the county populations. Together, these circumstances contribute to household income levels considerably higher among the respondents and interviewees than among the inhabitants of the respective counties. On the other hand, there is also a higher proportion of pensioners among the respondents and interviewees than in the general population of the counties, reflected in higher age and lower proportions of workforce participants in our samples. Auto ownership levels are similar to those of the county populations, and the same applies to the gender distribution among the respondents. Since this study does not aim to describe univariate distributions of travel behavior investigate its relationship with residential location characteristics when controlling for sociodemographic and residential preference characteristics, the overrepresentation of certain groups of people in the sample is not expected to substantially affect the results (Babbie, 2007; Crano et al., 2015).

We recruited participants of the qualitative interviews among questionnaire respondents who had stated their willingness to be interviewed. When selecting interviewees, we considered it important to include persons in each metropolitan area living at different types of residential locations (inner-city, close to second-order center and non-central), and to include persons from different population groups in terms of household composition, employment and education. Altogether, 33 interviews were carried out, 17 of which in the Oslo and 16 in the Stavanger metropolitan area. The interviews, each lasting for 1 – 1.5 hours, were audio-recorded and transcribed. The topics addressed in the interviews were chosen based on theoretical considerations and experience from our previous projects on residential location and travel. Besides a brief information in the invitation letter, which filled the role as an interview guide for the interviewees, we had written a much more detailed 'back-stage' interview guide to be used for our own preparation for the interviews, including main questions and follow-up questions to be asked. This background document was intended as a flexible framework, and we usually only looked at it once towards the end of each interview to check whether there were any important issues that had not been addressed. The main purpose of the qualitative interviews was *explanatory*, although we also aimed to be open for new, previously overlooked aspects. An interpretation scheme, designed for explanatory qualitative research, had been developed in our earlier studies (Næss, 2005, 2013, 2015a; Næss and Jensen, 2004) as an important tool for interview analysis and was refined and developed further in the present study. This scheme originally comprised around 30 research questions that we, as researchers, tried to answer, based on the information given by the interviewees. During the interpretation work of this study, the number of questions increased to 41. Two project team members interpreted each interview, and subsequent synthesizing of each group of research questions across the 33 interviews was also carried out by at least two project team members.

The following residential location variables are included in each of the multivariate analyses:

- Distance from the dwelling to the city centers of Oslo and Stavanger, respectively
- Distance from the dwelling to the closest second-order center or, in some of the Stavanger analyses, to the city center of Sandnes or the Forus employment center[2]
- Distance from the dwelling to the closest local center
- Local-area population density (measured within the 1 $km^2$ grid square within which the dwelling is located).

In the analyses of commuting distances and modes, the distance from the workplace to the city center was also included among the independent variables.

The possibility that respondents with particular socioeconomic characteristics and attitudes that predispose them to certain types of travel behavior (e.g. a preference for local facilities and travel by bicycle) will be overrepresented in certain locations necessitates multivariate control for such characteristics when assessing statistically the influence of urban structural variables.

Besides the urban structural variables, the multivariate analyses include the following demographic, socioeconomic and attitudinal control variables: gender; age; education level; personal gross income; number of household members below 7 years of age; number of household members 7-17 years; number of household members 18 years or older; possession of driver's license for car, and six residential preference variables. The latter variables are indexes based on a factor analysis of the respondents' answers to 19 questions about residential preferences (see Cao et al., 2017) and include the following six factor groups: "shopping opportunities", "good for children", "favorable investment", "proximity to transit", "local amenities" and "physical exercise"[3].

We deliberately chose not to include car ownership among the control variables, since the needs and incentives for car ownership are considerably influenced by residential location (Giuliano & Narayan, 2003; Næss, 2009). This is also evident from cross-sectional and longitudinal survey data as well as qualitative interviews of the present study (Cao et al., 2017). In both the Oslo and Stavanger metropolitan area, suburban living contributes to higher car ownership rates than living close to the city center.

It should be noted that the inclusion of local-area population density among the independent variables tends to underestimate the influence of the distance to the city center when a single equation approach is used, since the distance to the city center exerts strong influence on local-area density as well as other built environment variables at the neighborhood level (see Table 1 in Section 4). The causal order of regional versus neighborhood-scale is such that metropolitan-scale built environment characteristics precede the local-scale characteristics (at least in Norway). The decision about where to build thus comes before the decision about how to build. Deciding whether to densify or expand the city outward largely decides whether to build apartments or single-family houses. Therefore, distance to the city center has an indirect influence on travel behavior via local district or neighborhood-scale characteristics, in addition to its direct effect (Figure 2). The substantial indirect effects of the distance from the dwelling to the city center via local-area density and distance to lower-order centers should therefore be borne in mind when interpreting the results of the following analyses.

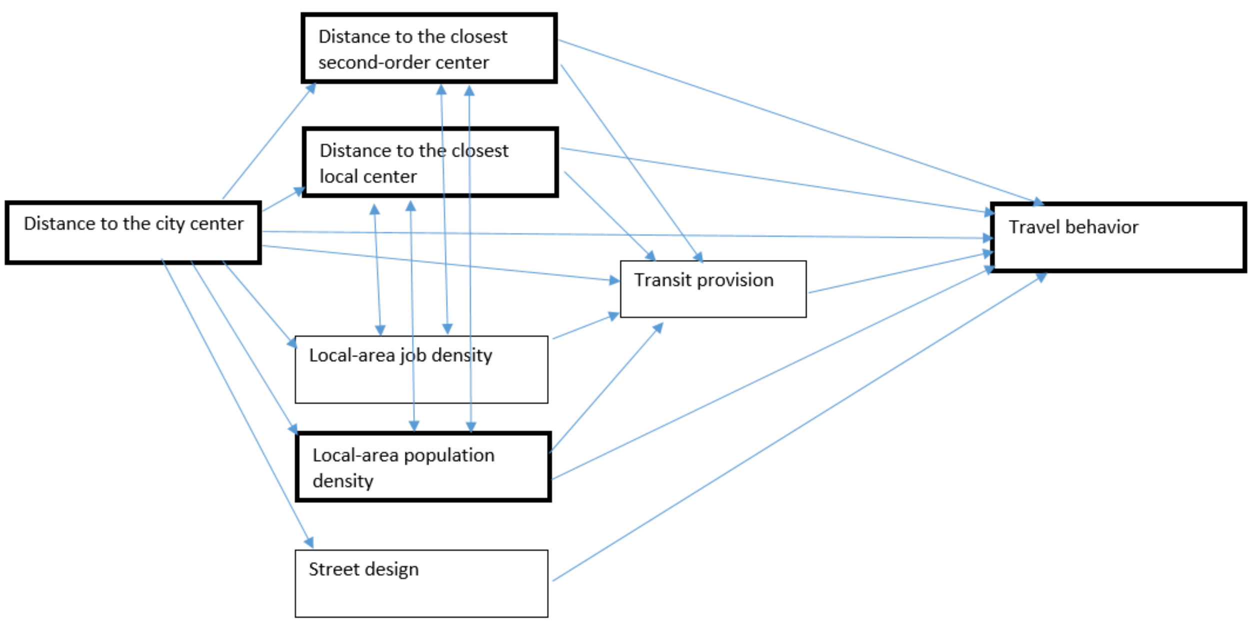


Figure 2: Assumed causal relationships between different built environment characteristics and travel behavior. Characteristics included in the statistical analyses of this paper are shown with bold outline.

# 4. The urban cases of the study

**Oslo,** the capital of Norway, had in the beginning of 2016 about 977 000 inhabitants within the continuous urban area, of which 653 000 live in the municipality of Oslo and the remaining 324,000 in nine surrounding municipalities in the county of Akershus. The city center is situated at the end of the Oslo fjord, from which the city sprawls out in three distinct ways: inland north-eastwards, and southwards along both sides of the fjord. To the north and east, forested areas (Marka) surround the city.

Oslo Municipality has expressed high sustainability ambitions and has for a long time had a focus on land use planning that can reduce the need for car travel. Oslo has for several decades pursued (and is still pursuing) a quite consistent urban containment policy (Næss et al., 2011; Næss, 2014). Population density within the continuous urban area of Greater Oslo increased by 37% over the period 1985–2016 (from 26.7 persons/hectare in 1985 to 36.7 in 2016), with particularly high density increase in its central parts (Næss et al., 2011; Statistics Norway, 2016). Within the inner city of Oslo, the density increase was substantial, where the urban population density increased by 66% from 1989 to 2016 (Municipality of Oslo, 2009 and 2016).

**Stavanger metropolitan area** is the third-largest in Norway, a population-wise smaller than Oslo and more polycentric urban region. It consists of the two previously separate cities of Stavanger and Sandnes, with a large employment center, called Forus situated in-between. The continuous urban area of Stavanger-Sandnes had about 213,000 inhabitants in the beginning of 2016 (Statistics Norway, 2016). Population density data for Stavanger metropolitan area are available only for the period since 2000. Between 2000 and 2016, the population density within the continuous morphological urban area of Stavanger/Sandnes increased by 9 %, up to 29.0 persons per hectare.

Figures 3 and 4 show how population and job densities, respectively, vary between different parts of each of the two metropolitan areas.

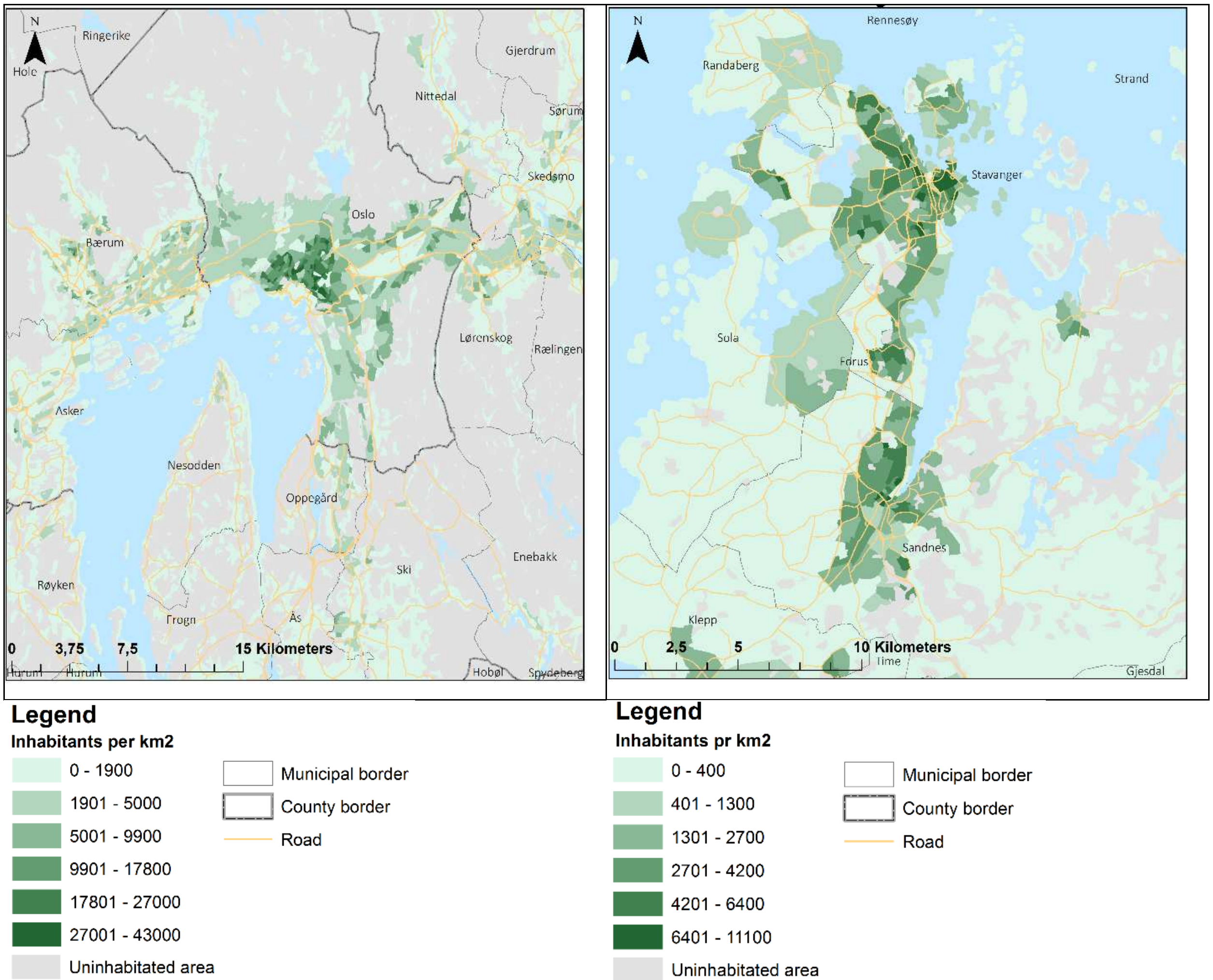


Figure 3: Population densities within different parts of the metropolitan areas of Oslo (to the left) and Stavanger (to the right). In order to highlight intra-metropolitan variation, the color scales differ between the two geographical cases, reflecting the generally higher densities in Oslo. Maps by Anja Fleten Nielsen, Institute of Transport Economics.

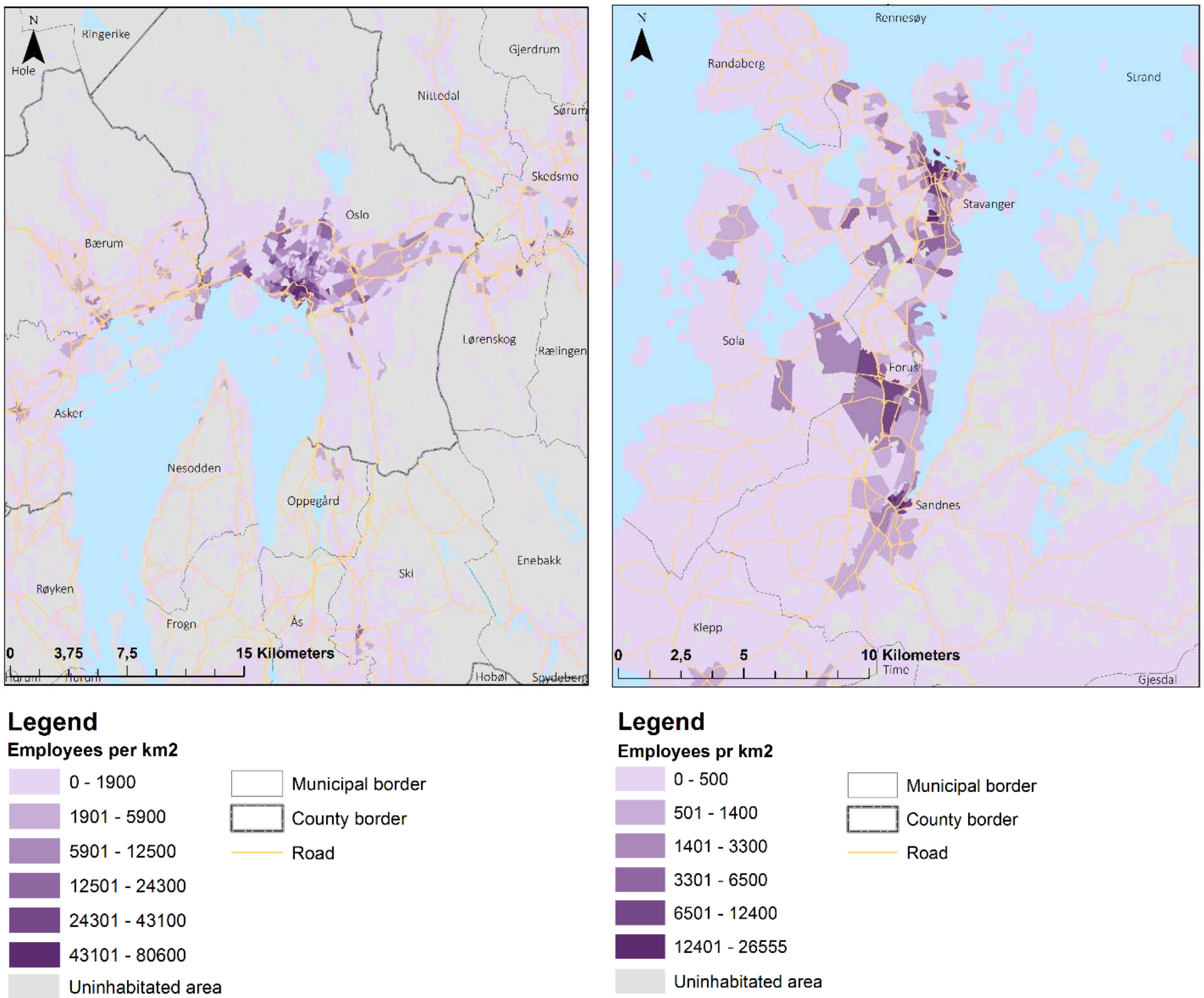


Figure 4: Job densities within different parts of the metropolitan areas of Oslo (to the left) and Stavanger (to the right). In order to highlight intra-metropolitan variation, the color scales differ between the two geographical cases, reflecting the generally higher densities in Oslo. Maps by Anja Fleten Nielsen, Institute of Transport Economics.

Population densities within the continuous urban areas of Oslo and Stavanger (37 and 30 persons per hectare, respectively, cf. above) are lower than in a major European city such as Berlin (54 pers./hectare in 2005), but considerably higher than in US cities such as San Francisco and Washington, with 19 and 13 persons per hectare, respectively (Kenworthy & Inbakaran, 2011). Although both urban areas include a hierarchy of major and minor centers, Oslo metropolitan area (henceforth Oslo for short) is, according to the typology of metropolitan urban structures proposed by Martens (2006), a relatively monocentric urban area, with one dominant downtown area where many jobs are concentrated. In contrast, Stavanger metropolitan area (henceforth Stavanger for short) has a clearly more polycentric employment structure, with job concentrations in the central part of Stavanger and the neighboring town center Sandnes, and not the least in the second-order center Forus. The latter area is located between the centers of Stavanger and Sandnes and was developed in the 1980s and 1990s with several major enterprises, including the Statoil oil company.

Among the Oslo respondents, the average distance from the dwelling to the city center of Oslo is 14.4 km, compared to 9.7 km between their jobs and the city center. Moreover, since the entire metropolitan area is largely one common housing and labor market (mean commuting distance among the respondents is 12.5 km), especially for specialized jobs, the likelihood for suburbanites to choose and be selected for jobs at local workplaces is not very high. In the context of the urban structure of Greater Oslo, suburban residents working at suburban workplaces will often have to travel via the inner part of the metropolitan area on their way to the job site unless the dwelling and the workplace are located in the same transport corridor.

The number of workplaces in the central area of Stavanger is about 25,000, compared to about 40,000 at Forus (dropped from 45,000 in 2013 due to the downturn in the oil business) and about 10,000 in the central area of Sandnes (Tjeldflaat, n.d.; RA Dagsavisen, 2017). For other facilities than workplaces, the historical center of Stavanger is still the dominant center of the region. Distinct from the more centralized location of jobs than dwellings in Oslo, the dwellings and jobs of Stavanger respondents are located at relatively similar distances from the city center of Stavanger (10.1 km and to 9.2 km, respectively). The dwellings are on average located closer to Forus (8.3 km) than to the city centers of Stavanger as well as Sandnes.

Residential location variables influencing local area population and job densities in the metropolitan areas of Oslo and Stavanger are shown in Table 1.[4] In line with theories of how land values vary with the distance from the city center (Alonso, 1964) as well as cultural conceptions of appropriate densities in inner-city and suburban contexts (e.g. Fishman, 1996), there is a clear center-periphery gradient in the density of population as well as jobs. Population densities decrease as distance from the city center in both Oslo and Stavanger increases. Population densities also decrease slightly in Oslo as distance from the closest second-order center increases whereas in Stavanger, it falls dramatically with increased distance to Sandnes second-order center.

Table 1 also shows that factors influencing job densities are in line with those influencing population densities in Oslo. In Stavanger, proximity to the Forus second-order center has the strongest impact on job densities, but there is also a considerable effect of proximity to the main city center.

Table 1: Residential location variables influencing local area population and job densities in the metropolitan areas of Oslo and Stavanger. Densities measured as person and jobs, respectively, per hectare within the 1 $km^2$ grid square to which the dwelling belongs. N = 1850 (Oslo) and 1291 (Stavanger). Adj. $R^2$ = 0.583 and 0.364, respectively, for population densities, and 0.581 and 0.238, respectively, for job densities.

| Metropolitan area | Unstandardized coefficient (standard error in parenthesis) | | Standardized coefficient (Beta) | | Level of significance (p value) | |
|---|---|---|---|---|---|---|
| | Oslo | Stavanger | Oslo | Stavanger | Oslo | Stavanger |
| *Factors influencing population densities* | | | | | | |
| Logarithm of the distance (in km) to the main city center | -33.45 (0.72) | -11.79 (0.45) | -0.743 | -0.721 | 0.000 | 0.000 |
| Logarithm of the distance (in km) to Sandnes second-order center | --- | -6.91 (0.44) | --- | -0.425 | --- | 0.000 |
| Logarithm of the distance (in km) to the closest second-order center | -2.23 (-0.62) | --- | -0.057 | --- | 0.000 | --- |
| Logarithm of the distance (in km) to closest local center | --- | 0.92 (0.40) | --- | 0.053 | --- | 0.022 |
| Constant | 119.45 (1.75) | 60.72 (1.64) | | | 0.000 | 0.000 |
| *Factors influencing job densities* | | | | | | |
| Logarithm of the distance (in km) to the main city center | -16.550 (0.454) | -4.79 (0.37) | -0.632 | -0.321 | 0.000 | 0.000 |
| Logarithm of the distance (in km) to Forus second-order center | | -7.73 (0.45) | | -0.423 | | 0.000 |
| Logarithm of the distance (in km) to the closest second-order center | -6.578 (0.368) | --- | -0.290 | --- | 0.000 | --- |
| Logarithm of the distance (in km) to the closest local center | 2.116 (0.470) | n.s. | 0.073 | n.s. | 0.000 | n.s. |
| Constant | 64.25 (1.02) | 34.46 (1.28) | | | 0.000 | 0.000 |

# 5. Built environment influences on travel distances

This section shows results of analyses of effects of residential location and local built environment characteristics on commuting in the two metropolitan areas. Results of cross-sectional (Section 5.1) and longitudinal (Section 5.2) statistical analyses will first be presented. Section 5.2 also includes examples from  qualitative interviews concerning travel distances. Section 5.3 sheds light on causal mechanisms based on interpretations of the interview material .

## 5.1. Cross-sectional analyses

One of the key residential location variables influencing various aspects of travel behavior is the location of the dwelling relative to the city center. In a monocentric city region such as Oslo, a curve depicting the relationship between residential distance to the city center and the commuting distance could theoretically be expected to rise gently with increasing distances to the center in the beginning, then turn to a steeper slope, and then gradually become more gentle until reaching a turning point. Beyond this turning point, the curve would eventually start sloping gently downward. The reason why the curve could be expected to slope only gently in the beginning is that the dense inner city area covers a broader area than just the downtown. And the reason why the curve could be expected to become less steep again after a while and then flatten out and decline is that the attraction power of jobs in central Oslo will gradually be reduced when the distance from the dwelling to the city center increases beyond a certain level. A curve fitting with this description can be constructed by transforming the residential distance to the city center by means of a combination of a hyperbolic-tangential function and a quadratic function[5]. Based on a number of iterations, such a function actually turned out to yield a slightly better explanatory power for the bivariate relationship between residential distance from the city center and the commuting distance. Figure 5 to the left shows the resulting curve depicting the relationship between residential distance to the city center and commuting distance.

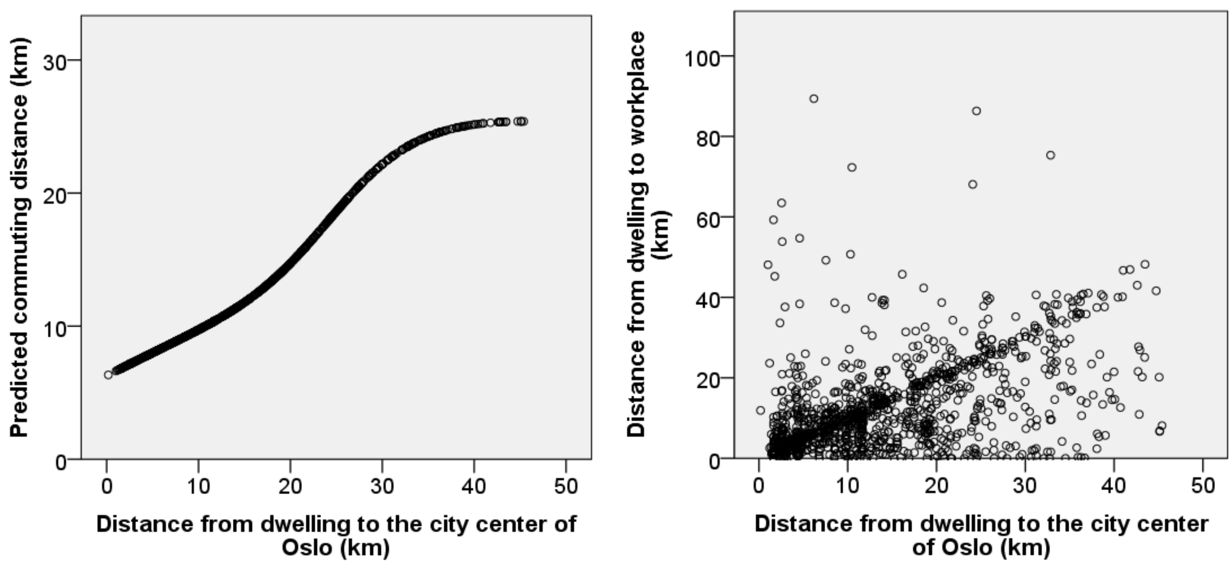


Figure 5. Curve depicting the relationship between residential distance to the city center and commuting distance (to the left) and scatterplot of commuting distances among workforce participants living at different distances from the city center of Oslo (to the right).

However, the improvement in Adjusted $R^2$ values is very small when applying this transformation (0.226 compared to 0.224 for non-transformed distance to the city center). A scatterplot (Figure 5 to the right) reveals that the commuting distances of a considerable number of respondents actually follow a nearly perfect linear relationship with the distance from the dwelling to the city center. Moreover, the shapes of curves for commuting distances by different modes (car, transit, non-motorized) and the shares of each of these modes for commuting would not necessarily be the same as for overall commuting distance, and we would then have to operate with different transformations for each mode. This would make the analyses very complicated and difficult to communicate[6].

Since the values of both the distance from the dwelling to the city centers of Oslo and Stavanger and the commuting distances deviate somewhat from a normal distribution[7], transformation of commuting distances and/or the distance from the dwelling to the three center categories into logarithmic values were tried out. However, these logarithmic transformations turned out to reduce the explanatory power of the regression models[8], and the shapes of the curves depicting the relationship between the distance from the dwelling to the city center and the commuting distance based on these transformations were also not theoretically plausible. None of the logarithmic transformations was therefore used in the final analyses of commuting. Instead, we decided to stick with non-transformed distances to the city center as well as to the closest second-order and local center in these analyses.

Distinct from the relationships between residential location and commuting, the relationships between residential location and non-work travel are depicted in a better way when distances from the dwelling to the city center, second-order centers and local centers are logarithmically transformed. Like for commuting, transformations of the residential distance to the city center by combinations of hyperbolic-tangential functions and quadratic functions could theoretically be expected to give better representations of the relationships between residential location and the investigated categories and aspects of non-work travel. However, the relevant transformations would be different for the various non-work travel variables, and the analyses would therefore be very complicated. For non-work travel, we therefore decided to stick with logarithmic transformations of the distances from the dwelling to the various center categories, bearing in mind that this is only a crude approximation of the theoretically most plausible relationships.

### 5.1.1. Commuting distances

In the analyses of commuting distances, only respondents who are workforce participants with one-way commuting distance less than 100 km in Oslo and 50 km in Stavanger are included in the analysis. The exclusion of commuting distances exceeding these limits makes sense conceptually based on the size of the metropolitan areas. Among the remaining respondents, the mean commuting distance is 12.5 km in Oslo and 7.8 km in Stavanger. The longer overall commuting distances in Oslo than in Stavanger reflect Oslo's larger population size, the deficit of jobs in outer parts of the region and facilitation for travel through motorways and high-frequency local trains, metro lines and express buses.

As already indicated in Figure 5, commuting distances in Oslo are considerably longer among suburbanites than among inner-city dwellers. The pattern is more nuanced in Stavanger, although outer-suburban respondents commute on average clearly longer than their inner-city counterparts. Figure 6 shows how average one-way commuting distances vary with the distance between the dwelling and the city centers of Oslo (to the left) and Stavanger (to the right).

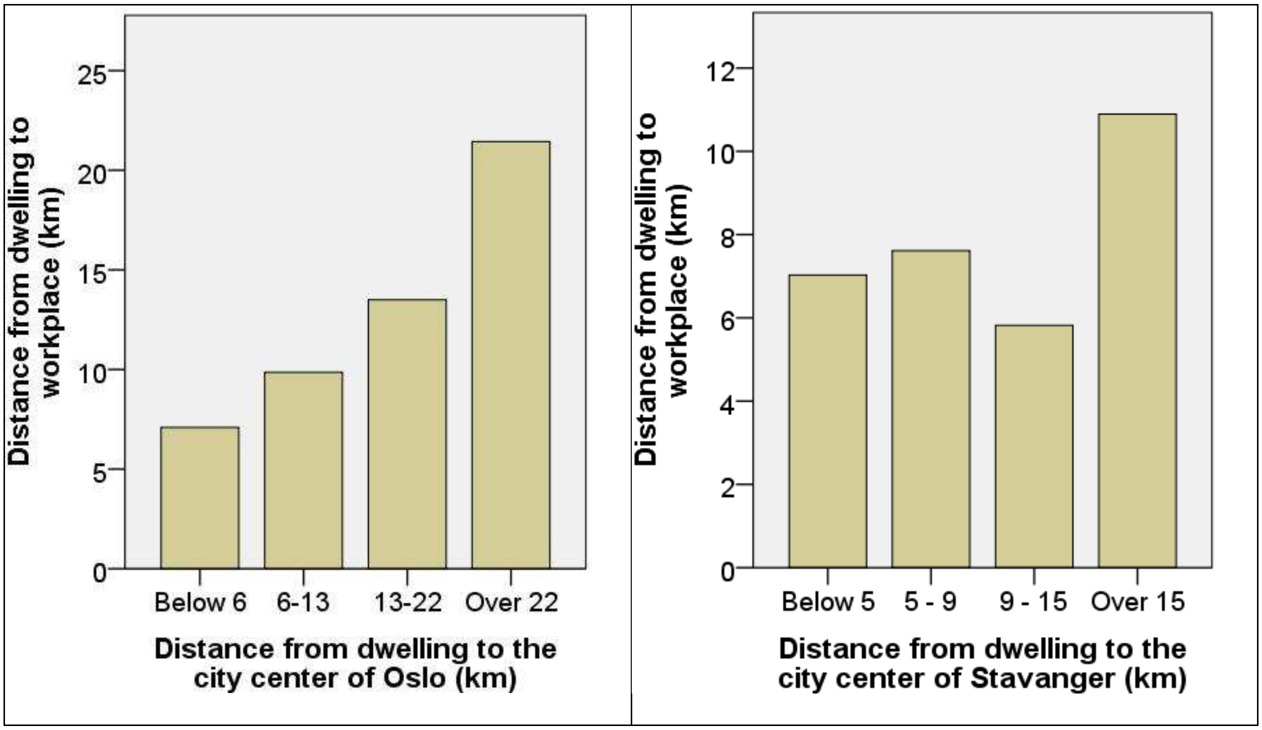


Figure 6: Mean one-way commuting distances among respondents living at different distances from the city centers of Oslo (N = 1160) and Stavanger (N = 788).

Commuting distances are generally longer in Oslo than in Stavanger, reflecting the larger geographical size of the former functional urban region. In Oslo, there is a steep center-periphery gradient in commuting distances, where respondents living far away from the city center of Oslo commute substantially longer distances than their counterparts living in the inner city of Oslo do. This is in line with findings in several other cities, cf. section 2. However, Stavanger displays a different pattern. Although respondents living furthest away from the city center of Stavanger make longer commutes than their inner Stavanger counterparts do, the shortest average commuting distances are found among the respondents living in the distance belt 9 to 15 km from the city center of Stavanger. Most of these respondents live at a short distance from the second-order center of Forus, reflected in a mean commuting distance considerably below the metropolitan average of 7.8 km, namely 5,7km.

In connection with each of the multivariate analyses presented in the remaining part of this article, we will pay most attentions to the effects of the residential location and local built environment variables, since the illumination of relationships between land use and travel is the main purpose of the paper. However, we also consider it important to comment on the effects of the demographic, socioeconomic and residential preference variables, both in order to show that each regression model yields overall plausible results and because it is in itself interesting to illuminate influential factors also beyond a land use perspective.

Table 2 shows the effects of various residential locational and sociodemographic variables on the respondents’ commuting distances in each of the two metropolitan areas. In this table, as well as in the remaining multivariate analysis tables of this article, only variables whose effects have a significance level (p-value) below 0.1 in at least one of the metropolitan areas are included.

Table 2: Factors influencing commuting distances among respondents living at different locations in the metropolitan areas of Oslo (N = 888) and Stavanger (N = 640). Adj. $R^2$ = 0.288 and 0.245, respectively.[9]

| | Unstandardized coefficient (standard error in parenthesis) | | Standardized coefficient (Beta) | | Level of significance (p value) | |
|---|---|---|---|---|---|---|
| Metropolitan area | Oslo | Stavanger | Oslo | Stavanger | Oslo | Stavanger |
| *Built environment characteristics* | | | | | | |
| Distance from dwelling to the main city center (km) | 0.510 (0.036) | 0.152 (0.035) | 0.461 | 0.164 | 0.000 | 0.000 |
| Distance from dwelling to the Forus second-order center (km) | --- | 0.437 (0.043) | --- | 0.355 | --- | 0.000 |
| Distance from workplace to the main city center (km) | 0.181 (0.029) | 0.154 (0.033) | 0.191 | 0.176 | 0.000 | 0.000 |
| *Demographic and socioeconomic characteristics* | | | | | | |
| Gender (female = 1, male = 0) | n.s. | -1.323 (0.607) | n.s. | -0.114 | n.s. | 0.001 |
| Personal annual income (NOK 1000) | 0.0058 (0.0014) | n.s. | 0.119 | n.s. | 0.000 | n.s. |
| Number of household members 18 years and older | n.s. | -0.470 (0.233) | n.s. | -0.070 | n.s. | 0.044 |
| Age | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| Number of household members below 7 years | 1.588 (0.563) | 0.607 (0.300) | 0.090 | 0.070 | 0.005 | 0.044 |
| *Residential preferences* | | | | | | |
| Preference factor “good for children” | -1.287 (0.485) | n.s. | -0.087 | n.s. | 0.008 | n.s. |
| Preference factor “physical exercise” | -0.794 (0.477) | n.s. | -0.048 | n.s. | 0.096 | n.s. |
| Preference factor “proximity to transit” | 0.770 (0.444) | n.s. | 0.051 | n.s. | 0.083 | n.s. |
| Constant | -1.017 (1.15) | 3.78 (0.91) | | | 0.376 | 0.000 |

In Oslo, the distance from the dwelling to the city center is the only residential location characteristic showing a significant effect on commuting distances. This influence is very strong, with a Beta value as high as 0.461. The dominance of the location of the dwelling relative to the city center over more local built environment characteristics is partly due to the overall more centralized location of jobs than dwellings in Oslo.

In Stavanger, two residential locations characteristics show significant effects on commuting distances: the distances from the dwelling to the second-order center of Forus and to the city center of Stavanger. The influence of the distance to Forus is the strongest one, with a Beta value of 0.338. The dominance of the location of the dwelling relative to the Forus second-order center over the distance to the city center of Stavanger is partly due to the polycentric location of jobs in Stavanger.

We also find quite strong effects in each metropolitan area of the distance from the workplace to the city center, where commuting distances in Oslo as well as in Stavanger tend to increase the further from the city center the workplace is located.

Both in Oslo and Stavanger, the effects of the built environment variables are very much stronger than those of the sociodemographic and attitudinal variables. While the Adjusted $R^2$ values for models including only the latter variables are 0.023 and 0.032, respectively, in Oslo and Stavanger, the corresponding values when the models also include the built environment variables are 0.288 and 0.245.

Among the demographic and socioeconomic characteristics, income and age are the only ones showing similar influences on commuting distances in both urban regions. Young workforce participants tend to commute longer distances than older workforce participants do, and respondents with a high income tend to make longer journeys to work than those with a low income do. The longer commutes among young respondents is a bit difficult to interpret but might reflect that young workers more often have temporary jobs and therefore are less prone than older respondents to move to a residence closer to the workplace. The tendency of longer commutes among high-income respondents probably reflects that high-income jobs tend to be more specialized, and that people working in these kinds of jobs therefore are less likely to find their job locally. Besides, since well-paid jobs are attractive, job seekers may be more willing to commute a longer distance if they can get such a job.

In Stavanger, respondents belonging to households with more than one adult member tend to work somewhat closer to home, possibly reflecting that single persons have less family commitments putting limitations to the time spent on commuting. Female respondents in Stavanger tend to work somewhat closer to home than men do, reflecting that women more often than men tend to choose local jobs in order to make the daily schedule of tasks hang together (Hjorthol, 1998; Næss, 2008). In Stavanger, we also find a tendency of shorter commuting distances among respondents who do not hold a driver's license. In Oslo, belonging to a household with children below 7 years contributes to slightly longer commutes. This is the opposite of what could be expected theoretically, since the daily schedule of commuting and bringing and picking up children at kindergarten may be too tight if the workplace is located too far from home.

We find influences of two of the residential preference characteristics in both urban regions. Hardly surprising, residential preference for proximity to workplace contributes to reduce commuting distances in both metropolitan areas. Respondents emphasizing this aspect of the dwelling tend to choose residential locations closer to their workplaces, and they are probably less inclined to seek jobs located very far from home. On the other hand, respondents emphasizing proximity to transit as residential preference tend to make somewhat longer commutes, which is plausible since good accessibility by transit makes it easier to overcome distances.

In Oslo, respondents emphasizing a good neighborhood for children tend to work closer to home than those who do not express such a preference. In Stavanger, respondents who emphasize the dwelling as an investment object tend to make somewhat longer commutes. These two effects are difficult to explain.

The remaining demographic, socioeconomic and residential preference variables do not show significant effects in any of the urban regions (see note xx).

### Working at home instead of commuting

One mechanism that could counteract the longer commuting distances among suburban and exurban residents is teleworking. Some authors have pointed at teleworking as a solution to the car dependency of suburban living (Martin, 1981; Irwin, 2004; Dwelly & Lake, 2008), and it has even been predicted that the core-oriented city may gradually vanish as virtual communication replaces corporeal travel (Berry, 1973). In the questionnaire, "working at home instead of going to the workplace" was one of the answer alternatives to questions about travel modes. In Oslo, 9 % of the employed respondents worked at home at least one day a week, and in Stavanger about 5 %.[10] In Stavanger, around 60 % of these respondents worked at home two or more days a week and in Oslo only around 40 %. In Oslo, working at home instead of going to the ordinary workplace reduced the total number of commutes among the employed respondents by less than 5 %. In Stavanger, the corresponding reduction was less than 4 %.

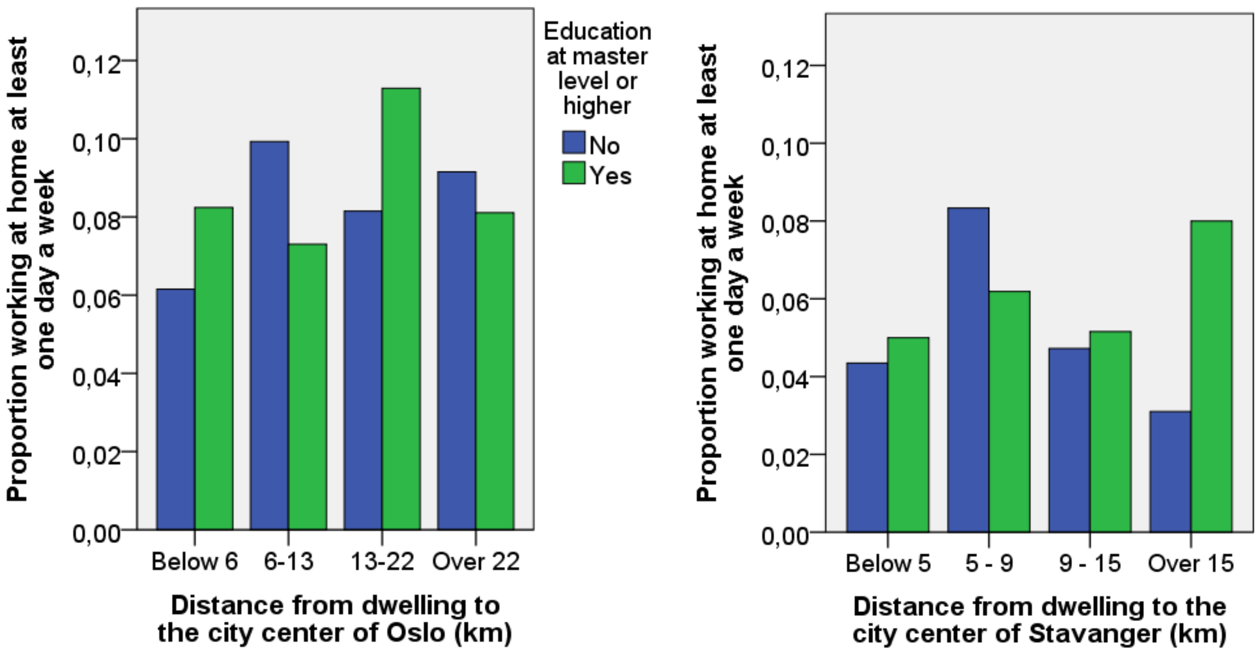


Figure 7: Proportions working at home at least one day a week among respondents living at different distances from the city centers of Oslo (N = 1198) and Stavanger (N = 869)

As indicated by Figure 7, there is no clear center-periphery variation in the frequency of working at home instead of commuting. This applies to both metropolitan areas and to respondents with education at master level or higher as well as the remaining employed respondents. In Oslo, suburban respondents telework slightly more frequently than inner-city respondents do, but this correlation is not statistically significant ($p = 0.424$). In Stavanger, there is no correlation at all between the frequency of telecommuting and the distance between the dwelling and the city center ($p = 0.925$) and not either with its distance to the Forus second-order center ($p = 0.531$). Given the low proportions telecommuting makes up of the respondents' overall workdays, we can conclude that any counteracting effect resulting from increased telecommuting among suburbanites in the two investigated metropolitan areas is negligible.

### 5.1.2 Intra-metropolitan non-work travel distances

This section shows results of analyses of effects of residential location on non-work travel in the metropolitan areas of Oslo and Stavanger. In the questionnaire survey, respondents were asked how far from home seven different non-work activities usually took place. The activities in question were: Visit to civic or religious building, such as library, church, mosque, etc.; visit to a service provider, such as bank or hairdresser; purchasing daily necessities; visit to restaurant or coffee place; visit to place for entertainment/culture; visit to place to exercise, e.g. a gym, a sports hall or a park; and visit to place where you pick up or drop off a passenger, e.g. a child to an activity, school/kindergarten, etc. Among these activities, daily necessities shopping is the one carried out most frequently[11] with averages of 14.3 and13.8 times a month, respectively, in Oslo and Stavanger. The second-most frequent out-of-home activity is physical exercise (7.6 times/month in Oslo and 11.0 in Stavanger), followed by escorting trips (4.9 times/month in both metropolitan areas), visits to restaurant/coffee place (4.2 times/month in Oslo and 3.3 in Stavanger), visits to service provider (3.2 and 2.8 times/month, respectively), visits to place for entertainment/culture (3.2 and 2.7 times/month, respectively), and visits to civic or religious building (2.0 times/month in each metropolitan area).

Distinct from choices of workplaces, where the workplace must be attractive for the job-seeker while the job-seeker must also be attractive for the employer, residents' choices of facilities for non-work activities are to a much greater extent a matter of their own choice. The geographical size of jobs-housing markets is therefore normally much larger than the areas within which people choose non-work intra-metropolitan facilities. This is reflected in the average distances respondents travel to reach their workplace compared to other facility types. Whereas the mean distance between home and workplace among Oslo respondents is 12.5 km (excluding respondents with commuting distances exceeding 100 km), six of the seven investigated non-work activities take place on average between 1.6 and 4.7 km from the dwelling and the seventh category (visits to cultural or entertainment events) takes place 6.3 km from home. Among Stavanger respondents, the mean distance between home and workplace is 7.8 km (excluding respondents with commuting distances exceeding 50 km), while five of the seven investigated non-work activities take place on average between 1.6 and 3.7 km from the dwelling and the remaining categories (visits to restaurants/coffee places and cultural or entertainment events) take place 4.7 and 4.9 km from home, respectively. Compared to commuting, the travel distances and modes for non-work intra-metropolitan trips are therefore likely to be influenced to a greater extent by local built environment characteristics.

Table 3 shows how the average distances from the respondents' dwellings to the normal locations of each activity type[12] varies with the location of the dwelling relative to the city centers of Oslo and Stavanger.

Table 3: Mean distances from the dwelling to the normal locations of various non-work activities among respondents living at different distances from the city centers of Oslo and Stavanger (km). P = 0.000 for all activities in both metropolitan areas except picking up/dropping passenger in Stavanger (p = 0.012).

| Metropolitan area | Oslo | | | | Stavanger | | | |
|---|---|---|---|---|---|---|---|---|
| Distance from the main city center (km) | Below 6 | 6-13 | 13-22 | Over 22 | Below 5 | 5-9 | 9-15 | Over 15 |
| Visit to civic or religious building (Oslo N = 920, Stavanger N = 733) | 2.25 | 3.30 | 3.25 | 3.83 | 2.61 | 4.18 | 4.60 | 3.71 |
| Visit to a service provider (Oslo N = 1680, Stavanger N = 1160) | 2.39 | 3.69 | 3.60 | 4.00 | 2.46 | 3.78 | 3.79 | 4.32 |
| Purchasing daily necessities (Oslo N = 1765, Stavanger N = 1213) | 1.09 | 1.41 | 1.61 | 2.23 | 1.25 | 1.55 | 1.72 | 2.11 |
| Visit to restaurant or coffee place (Oslo N = 1684, Stavanger N = 1142) | 2.51 | 5.33 | 5.04 | 6.14 | 2.61 | 4.82 | 6.66 | 5.58 |
| Visit to place for entertainment/culture (Oslo N = 1688, Stavanger N = 1158) | 3.39 | 7.48 | 6.32 | 8.21 | 3.20 | 6.58 | 7.94 | 6.01 |
| Visit to place to exercise (Oslo N = 1653, Stavanger N = 1123) | 1.76 | 2.52 | 2.77 | 3.38 | 1.78 | 2.95 | 3.33 | 2.83 |
| Visit to place where you pick up or drop off a passenger (Oslo N = 690, Stavanger N = 516) | 2.47 | 2.58 | 3.02 | 4.36 | 2.47 | 3.26 | 3.43 | 3.56 |

For all activity categories and in both metropolitan areas, distances from the dwelling to the places where the activities are normally carried out are shorter among inner-city dwellers than among respondents living at suburban locations. For most activities, this center-periphery gradient is quite pronounced.

Multivariate analyses will throw light on the influence of the distance from the dwelling to the city center as well as other built environment characteristics and a number of relevant demographic, socioeconomic and attitudinal factors on the distances traveled to non-work activities. Due to space constraints, we will only present analyses for two activity categories: daily necessities shopping, and visits to cultural or entertainment events, with the latter analysis presented first. The dependent variable in these analyses is whether the respondent normally carries out the activity in question more than 2 km away from home. Graphs showing how this variable varies with the location of the dwelling relative to the city centers of Oslo and Stavanger will also be presented. The independent variables included in each of the multivariate analyses are the same as in the analyses of commuting distances, with one exception. Since Sandnes is a more important center than Forus for non-work activities, the distance from the dwelling to the Sandnes second-order center has replaced distance to Forus in the analyses of non-work travel.

### *Distances to cultural and entertainment events*

Table 4 shows the effects of various residential locational and sociodemographic variables on the Oslo and Stavanger respondents' likelihood of normally visiting facilities more than 2 km from home when going to cultural or entertainment events.

Table 4: Factors influencing the likelihood of normally going to cultural and entertainment events more than 2 km away from home among respondents living at different locations in Oslo (N = 1496) and Stavanger (N = 1012). Nagelkerke $R^2$ = 0.314 and 0.319, respectively.[13]

| | B (standard error in parenthesis) | | Wald | | Level of significance (p value) | |
|---|---|---|---|---|---|---|
| Metropolitan area | Oslo | Stavanger | Oslo | Stavanger | Oslo | Stavanger |
| *Built environment characteristics* | | | | | | |
| Logarithm of the distance (in km) to the main city center | n.s. | 2.196 (0.179) | n.s. | 149.70 | n.s. | 0.000 |
| Logarithm of the distance (in km) to the Sandnes second-order center | --- | 1.655 (0.153) | --- | 116.73 | --- | 0.000 |
| Inhabitants per hectare within the 1 km² grid square of the dwelling | -0.033 (0.003) | | 121.43 | n.s. | 0.000 | n.s. |
| Logarithm of the distance (in km) to the closest second-order center | 0.513 (0.069) | --- | 54.72 | --- | 0.000 | --- |
| *Demographic and socioeconomic characteristics* | | | | | | |
| Education (master level = 1, otherwise 0) | n.s. | 0.471 (0.149) | n.s. | 9.97 | n.s. | 0.002 |
| Whether the respondent is a workforce participant | 0.376 (0.140) | n.s. | 7.26 | n.s. | 0.007 | n.s. |
| Age | -0.010 (0.004) | n.s. | 5.47 | n.s. | 0.019 | n.s. |
| Number of household members younger than 7 years | -0.177 (0.105) | n.s. | 2.84 | n.s. | 0.092 | n.s. |
| Number of household members 7-17 years | -0.211 (0.083) | n.s. | 6.54 | n.s. | 0.011 | n.s. |
| Number of household members 18 years or older | n.s. | 0.241 (0.084) | n.s. | 8.34 | n.s. | 0.004 |
| *Residential preferences* | | | | | | |
| Preference factor “shopping opportunities” | -0.168 (0.080) | n.s. | 4.41 | n.s. | 0.036 | n.s. |
| Preference factor “proximity to transit” | 0.206 (0.081) | 0.202 (0.089) | 6.42 | 5.18 | 0.011 | 0.023 |
| Preference factor “good for children” | n.s. | -0.169 (0.095) | n.s. | 3.20 | n.s. | 0.074 |
| Constant | 0.474 (0.305) | -8.58 (0.680) | 2.42 | 159.10 | 0.120 | 0.000 |

In Oslo, the likelihood of visiting facilities further than 2 km from home when going to cultural or entertainment events decreases the higher is the local-area density and the shorter the distance is from the dwelling to the closest second-order center. Both these effects are strong, and especially the local-area density exerts a substantial influence on the likelihood of choosing facilities not far from home when going to cultural/entertainment events. While not showing any direct effect, the location of the dwelling relative to the city center of Oslo has a considerable indirect effect through its influence on local-area densities, cf. Table 1. Proximity to the closest local center shows no significant effect, reflecting that few local centers include much-visited cultural or entertainment facilities. In Stavanger, the likelihood of choosing non-local facilities for cultural or entertainment events increases the further the dwelling is located from the city center of Stavanger as well as the second-order center of Sandnes. Both these effects are very strong.

A reason for the absence of any effect of local-area density in Stavanger could be that densities are quite moderate even in neighborhoods a couple of kilometers from the centers of Stavanger and Sandnes. Many of the respondents living in these neighborhoods can therefore reach downtown cultural facilities within 2 km from home even if the population density of their local area is not particularly high.

The effects of the demographic and socioeconomic variables differ between the two metropolitan areas but are in any case not very strong. In Stavanger, there is a slight tendency of more often choosing facilities further than 2 km from home among respondents with a high education, possibly reflecting a more specialized and "narrow" cultural taste within this group. In Oslo, old respondents tend to visit facilities closer to home than young respondents do. The same applies to respondents with young children or schoolchildren in the household and respondents who are not workforce participants, possibly reflecting a tight time budget among families with children.

In both metropolitan areas, respondents emphasizing accessibility by transit as a residential preference have higher likelihood of choosing facilities more than two km from home, reflecting a motivation for overcoming distance by means of good transit connections from the dwelling. In Oslo, respondents emphasizing shopping opportunities as a residential preference factor are somewhat more likely to make short trips when going to cultural/entertainment events, which may reflect that dwellings matching these preferences are often located in inner-city areas where many cultural/entertainment facilities are also concentrated. In Stavanger, respondents emphasizing a good environment for children as a residential preference tend to choose cultural/entertainment facilities closer to home. This is in line with the above-mentioned effects of having children in the household.

### *Distances to daily necessities shopping*

Table 5 shows the effects of various residential locational and sociodemographic variables on the respondents' likelihood of normally purchasing daily necessities more than 2 km away from home.

Table 5: Factors influencing the likelihood of normally purchasing their daily necessities more than 2 km away from home among respondents living at different locations in Oslo (N = 1562) and Stavanger (N = 1052). Nagelkerke $R^2$ = 0.258 and 0.215, respectively.[14]

| | B (standard error in parenthesis) | | Wald | | Level of significance (p value) | |
|---|---|---|---|---|---|---|
| Metropolitan area | Oslo | Stavanger | Oslo | Stavanger | Oslo | Stavanger |
| *Built environment characteristics* | | | | | | |
| Logarithm of the distance (in km) to the closest local center | 0.581 (0.102) | 0.712 (0.129) | 32.28 | 30.49 | 0.000 | 0.000 |
| Inhabitants per hectare within the 1 km² grid square of the dwelling | -0.032 (0.005) | -0.042 (0.008) | 39.23 | 26.17 | 0.000 | 0.000 |
| Logarithm of the distance (in km) to the closest second-order center | 0.316 (0.083) | --- | 14.53 | --- | 0.000 | --- |
| Logarithm of the distance (in km) to the main city center | n.s. | 0.365 (0.167) | n.s. | 4.77 | n.s. | 0.029 |
| *Demographic and socioeconomic characteristics* | | | | | | |
| Age | 0.022 (0.006) | n.s. | 15.48 | n.s. | 0.000 | n.s. |
| Personal gross annual income (1000 NOK) | -0.00145 (0.00037) | n.s. | 15.32 | n.s. | 0.000 | n.s. |
| Whether the respondent is a workforce participant | 0.834 (0.227) | n.s. | 13.51 | n.s. | 0.000 | n.s. |
| Gender (female = 1, male = 0) | -0.363 (0.164) | n.s. | 4.89 | n.s. | 0.027 | n.s. |
| *Residential preferences* | | | | | | |
| Preference factor “shopping opportunities” | -0.280 (0.103) | -0.368 (0.116) | 7.46 | 10.04 | 0.006 | 0.002 |
| Preference factor “physical exercise” | n.s. | -0.300 (0.118) | n.s. | 6.47 | n.s. | 0.011 |
| Preference factor “proximity to transit” | n.s. | 0.187 (0.103) | n.s. | 3.28 | n.s. | 0.070 |
| Constant | -2.25 (0.51) | -2.61 (0.646) | 19.27 | 16.38 | 0.000 | 0.000 |

In Oslo, the likelihood of purchasing daily necessities far from home increases the lower is the local-area density and the further the dwelling is located from the closest local center as well as from the closest second-order center. Among these variables, the effect of local-area density is the strongest and the effect of distance to the closest second-order center the weakest. The distance from the dwelling to the city center of Oslo shows no significant effect. In Stavanger, the likelihood of purchasing daily necessities far from home increases the further the dwelling is located from the closest local center and the city center of Stavanger, and the lower is the local-area density. Among these variables, the effects of the distance to the closest local center and local-area density are  the strongest, while the effect of distance to the city center of Stavanger is rather weak.

The stronger effects of local-scale variables reflect that opportunities for daily necessities shopping are distributed relatively evenly all over the metropolitan area, although the density of such stores is higher in the central parts of Oslo, Stavanger and Sandnes. As mentioned above, local area density and proximity to the closest local center are both strongly influenced by the location of the dwelling relative to the city centers of Oslo and Stavanger, and the latter variable thus exerts considerable indirect influences via the two local-scale variables.

*Effects of residential location and local built environment variables on the likelihood of choosing non-local facilities for the remaining non-work travel purposes*

Table 6 shows effects of residential location and local built environment variables on the likelihood of choosing non-local facilities for the non-work travel purposes not included in tables 10 and 11. The effects of residential location and local built environment variables shown in the table are controlled for the same demographic, socioeconomic and residential preference variables as in the previous tables. Due to space constraints, we only show Wald statistics and significance levels. The effects of local-area density and distance to the second-order center of Forus are negative, i.e. the likelihood of choosing non-local facilities decreases with higher densities and with longer distance to the Forus second-order center. All the remaining effects are positive, i.e. the likelihood of choosing non-local facilities increases with higher values on the variable in question.

Table 6: Effects of residential location and local built environment variables on the likelihood of normally going to various non-work activities more than 2 km away from home. Wald values, levels of significance (p values) in parentheses. All effects of residential location and local built environment variables shown in the table are controlled for the same demographic, socioeconomic and residential preference variables as in the previous tables.

| Trip purpose | Visit to civic or religious building | | Visit to a service provider | | Visit to restaurant or coffee place | | Visit to place to exercise | | Visit to place where you pick up or drop off a passenger | |
|---|---|---|---|---|---|---|---|---|---|---|
| Metropolitan area | Oslo N=805 | Sta-vanger N=639 | Oslo N=1489 | Sta-vanger N=1012 | Oslo N=1493 | Sta-vanger N=995 | Oslo N=1464 | Sta-vanger N=976 | Oslo N=608 | Sta-vanger N=457 |
| Logarithm of the distance (in km) to the main city center | n.s. | n.s. | n.s. | 17.55 (0.000) | n.s. | 116.66 (0.000) | n.s. | 25.90 (0.000) | n.s. | 10.02 (0.002) |
| Logarithm of the distance (in km) to the closest second-order center | 13.11 (0.000) | --- | 34.05 (0.000) | --- | 36.35 (0.000) | --- | 10.74 (0.001) | --- | n.s. | --- |
| Logarithm of the distance (in km) to the Sandnes second-order center | --- | n.s. | --- | n.s. | --- | 97.47 (0.000) | --- | 12.32 (0.000) | --- | n.s. |
| Inhabitants per hectare within the 1 km$^2$ grid square of the dwelling | 10.62 (0.001) | 33.63 (0.000) | 22.11 (0.000) | 12.91 (0.001) | 54.26 (0.000) | n.s. | 44.20 (0.058 | n.s. | 4.75 (0.029) | n.s. |
| Logarithm of the distance (in km) to the closest local center | 8.14 (0.004) | n.s. | 22.58 (0.000) | 15.80 (0.000) | 9.22 (0.002) | 7.91 (0.005) | n.s. | 7.94 (0.005) | 10.82 (0.001) | n.s.) |

There are some clear differences between the two metropolitan areas in the way that residential location and local built environment variables influence the respondents' likelihood of choosing non-work activity facilities more than 2 km from home. In Oslo, respondents are more prone to choose non-local facilities if they live far away from the closest second-order center, if the local-area density is low, and if they live far away from the closest local center. We find no effects of the distance to Oslo's main city center for any of the trip purposes. In contrast, the distance from the dwelling to the main city center of Stavanger exerts the strongest influences on respondents' likelihood of using facilities more than 2 km from home. The only exception is visits to civic or religious buildings, where low local-area density increases the likelihood of using non-local facilities. A similar effect is found for visits to service providers. Moreover, living far away from the Sandnes second-order center increases the likelihood of using restaurants/coffee places and places for physical exercise more than 2 km from home.

The lack of any separate effect of the Oslo respondents' distance to the main city center implies that the center-periphery gradient shown in table 3 mainly reflects the different densities in the inner and outer parts of the urban region. The high-density areas in the inner city make up a large population base for various services, and residents of these areas can therefore often find suitable facilities for intra-urban non-work activities close to where they live. In Stavanger, the inner city is less dense, and the cluster of non-work facilities covers a much smaller area. The area within 2 km from the city center includes low-density neighborhoods dominated by duplexes and single-family houses. In Stavanger, the access to non-work activity facilities close to home therefore depends more on the distance from the dwelling to the central parts of Stavanger than on local-area densities.

### 5.1.3 Frequencies of non-work activity participation

Apart from escorting trips (both metropolitan areas), visits to civic or religious buildings (Oslo) and trips to places for physical exercise (Stavanger), respondents living in the inner districts of Oslo and Stavanger tend to carry out the activities in question more frequently than do their counterparts living in the three remaining distance belts (Table 7). This reflects the generally longer distances that suburban residents need to travel in order to reach the relevant facilities compared to inner-city dwellers who generally have such facilities in closer proximity to their dwellings, cf. above. The opposite tendency for escorting trips partly reflects the greater need for suburbanites to drive children to leisure activities and maybe also to school, since these activities more often take place beyond walking or biking distance when living in a peripheral than in a central part of the urban region. In Oslo, the lower frequency of escorting trips among inner-city dwellers probably also reflects a lower number of respondents with children in the household in the inner distance belt. In Stavanger, the frequency of trips to places for physical exercise is quite stable across the distance belts. The overall frequency of trips to places for exercise is generally very high in Stavanger (on average 11 times a month, compared to 7.6 in Oslo). Possibly, Stavanger respondents make more frequent, but shorter-duration exercise activities in indoor facilities and smaller green areas than Oslo respondents, who have greater opportunities for long-duration walking, jogging and skiing in the large forest areas surrounding the city.

Table 7: Frequencies of participation in various non-work activities among respondents living at different distances (km) from the city centers of Oslo and Stavanger. Mean times per month. N = 1739 (Oslo) and 1196 (Stavanger)

| Metropolitan area | Oslo | | | | Stavanger | | | |
|---|---|---|---|---|---|---|---|---|
| Distance from the main city center (km) | Below 6 | 6-13 | 13-22 | Over 22 | Below 5 | 5-9 | 9-15 | Over 15 |
| Visit to civic or religious building (Oslo p = 0.313, Stavanger p = 0.594) | 2.17 | 2.01 | 1.62 | 1.99 | 2.53 | 1.72 | 1.74 | 1.93 |
| Visit to a service provider (Oslo p = 0.002, Stavanger p = 0.573) | 3.60 | 3.63 | 2.75 | 2.85 | 3.24 | 2.71 | 2.51 | 2.78 |
| Purchasing daily necessities (Oslo p = 0.000, Stavanger p = 0.044) | 15.59 | 14.51 | 13.98 | 13.12 | 15.33 | 13.52 | 13.13 | 13.33 |
| Visit to restaurant or coffee place (Oslo p = 0.000, Stavanger p = 0.114) | 6.39 | 4.29 | 3.24 | 2.87 | 3.74 | 3.25 | 3.07 | 2.97 |
| Visit to place for entertainment/culture (Oslo p = 0.000, Stavanger p = 0.067) | 4.37 | 3.28 | 2.60 | 2.42 | 3.06 | 2.71 | 2.42 | 2.48 |
| Visit to place to exercise (Oslo p = 0.000, Stavanger p = 0.669) | 7.70 | 7.92 | 7.40 | 7.24 | 11.10 | 11.43 | 10.54 | 11.12 |
| Visit to place where you pick up or drop off a passenger (Oslo p = 0.013, Stavanger p = 0.081) | 3.76 | 5.11 | 5.28 | 5.65 | 4.37 | 4.35 | 5.67 | 5.12 |

Table 7 indicates a tendency for the use of a service or facility to decrease with the distance from its location. Such 'distance decay' (Maddison et al., 1996) implies a counteracting mechanism reducing some of the transport-reducing effects of living in central and dense neighborhoods. Still, our material indicates that overall traveling distances tend to increase not only for commuting, but also for intra-metropolitan non-work purposes, the more peripherally the dwelling is located and the lower is the local-area density.

## 5.2. Longitudinal analyses

The questionnaire asked the respondents to state how long they had lived in their present dwelling and to write their previous home address.

### 5.2.1. Stated changes in overall weekly travel distances due to moving

We asked the respondents who had moved to their present dwelling less than two years ago whether the move had caused any changes in their overall weekly travel distance. About a half of the recent movers in each city region (56% in Oslo and 47% in Stavanger) who answered this question[15] stated that they had increased or reduced their weekly travel distance due to the move. The remaining respondents had either not experienced any change in travel distance or had changed their travel distance for other reasons than the change in residential location. Among the respondents whose weekly travel distance had changed due to moving, those who had *increased* their travel distance had on average moved 4.4 km farther away from the city center of Oslo as well as Stavanger. Conversely, those who had *reduced* their travel distance had on average moved 3.8 km closer to the city center of Oslo and 1.6 km closer to the city center of Stavanger (p = 0.000 for outward as well as inward movers in both cities). In each city, those who had not changed their weekly travel distance had moved on average 0.2 km further away from the city center of Oslo and 0.8 km from the city center of Stavanger. These differences between the cities are plausible since many of the outward movers in Stavanger decreased their distance to the main employment center of Forus, cf. the above cross-sectional analysis of commuting distances.

A logistic regression analysis including only those respondents who had changed their weekly travel distance due to moving sheds additional light on the impacts of moving outward or inward (Table 8). Here, we investigated changes in the residential distance not only to the main city center but also to the closest second-order center.

Table 8: Effects on stated weekly travel distance (increase = 1; decrease = 0) of having changed residential locations in Oslo (N = 245, Nagelkerke $R^2$ = 0.265) and Stavanger (N = 238, Nagelkerke $R^2$ = 0.344).

| Metropolitan area | Unstandardized coefficient (standard error in parenthesis) | | Wald | | Level of significance (p value) | |
|---|---|---|---|---|---|---|
| | Oslo | Stavanger | Oslo | Stavanger | Oslo | Stavanger |
| Change in distance from the dwelling to the main city center (km) | 0.094 (0.021) | 0.134 (0.026) | 19.92 | 27.51 | 0.000 | 0.000 |
| Change in distance to the closest second-order center (km) | 0.102 (0.036) | 0.131 (0.040) | 7.90 | 10.92 | 0.005 | 0.001 |
| Constant | 0.117 (0.150) | 0.191 (0.160) | | | 0.432 | 0.234 |

As can be seen, the likelihood that recent movers consider their weekly travel distance to have increased due to the move is greater the farther away they have moved from the main city center as well as from the closest second-order center. Conversely, the likelihood that they consider their travel distance to have decreased is higher when the increase in residential distance to the two kinds of centers is negative, i.e. that they have moved closer to the main center or the closest second-order center. In both cities, the effect of changing the distance to the main city center is stronger than that of changing the distance to the closest second-order center.

### 5.2.2. Changes in commuting distances after moving

Table 9 shows how changes in residential location have influenced the commuting distances of Oslo and Stavanger respondents. Only workforce participants who had lived in their present dwelling less than five years and whose present commuting distance is less than 100 km in Oslo and 50 km in Stavanger are included in the analysis. Moreover, reflecting the geographical sizes of the two metropolitan areas, only respondents who have changed the distance between the dwelling and the city center by less than 50 km in Oslo and 30 km in Stavanger have been included. Because changes in commuting distances are also influenced by any changes in workplace location, we have controlled for whether or not the respondents changed their job location during the last three years.

Table 9: Effects on commuting distances of having changed residential locations in Oslo (N = 450, Adj. $R^2$ = 0.440) and Stavanger (N = 279, Adj. $R^2$ = 0.167).

| Metropolitan area | Unstandardized coefficient (standard error in parenthesis) | | Standardized coefficient (Beta) | | Level of significance (p value) | |
|---|---|---|---|---|---|---|
| | Oslo | Stavanger | Oslo | Stavanger | Oslo | Stavanger |
| Change in distance from the dwelling to the main city center (km) | 0.616 (0.045) | 0.134 (0.048) | 0.533 | 0.160 | 0.000 | 0.006 |
| Change in distance to Forus second-order center (km) | --- | 0.425 (0.072) | --- | 0.340 | --- | 0.000 |
| Change in distance to the closest second-order center (km) | 0.506 (0.069) | --- | 0.233 | --- | 0.000 | --- |
| Changed workplace less than 3 years ago | 1.721 (0.650) | 0.516 (0.638) | 0.094 | 0.044 | 0.008 | 0.419 |
| Constant | -4.06 (1.11) | -1.97 (1.09) | | | 0.000 | 0.071 |

The results substantiate the results of the cross-sectional analysis of commuting distances. In Oslo, changes in the distance from the dwelling to the main city center shows the strongest effect. One km change in the distance between the dwelling and the city center is associated with about 0.6 km change in one-way commuting distance. This is similar to the effect found in the cross-sectional analysis (cf. Table 2). Distinct from the cross-sectional analysis, the analysis of recent movers also shows a clear effect among Oslo respondents of changing the distance between the dwelling and the closest second-order center.

In Stavanger , changing the distance from the dwelling to the Forus second-order center shows the clearly strongest effect, reflecting the status of the Forus area as the major workplace concentration in Stavanger. One km change in the distance between the dwelling and the Forus second-order center is associated with about 0.4 km change in one-way commuting distance, which is slightly more than the corresponding effect found in the cross-sectional analysis (Table 2). In line with the cross-sectional analysis, we also find an effect of changing the residential distance to the city center of Stavanger, but the standardized coefficient is only about half as high as for changing the distance to Forus.

Since the effects of moving outward from the major workplace concentrations and inward toward them may not necessarily be the same, we have carried out separate analyses for inward and outward movers (Table 10). In these analyses, we have only looked at impacts of increasing or decreasing the residential distance from the main workplace concentration in each urban region, i.e. moves toward or away from the city center of Oslo and the Forus second-order center, respectively.

Table 10: Effects on commuting distances from having moved closer to or further away from the city center of Oslo and the Forus second-order center, respectively. Unstandardized regression coefficients (above), standardized coefficients (in the middle, in italics); p-values in parentheses (below).

| | Moving outward | Moving inward |
|---|---|---|
| Oslo (N = outward = 247, N inward = 193)):<br>Change in distance from the dwelling to the city center of Oslo (km) | 0.578<br>*0.414*<br>(0.000) | -1.039<br>*-0.755*<br>(0.000) |
| Stavanger (N = away from Forus = 117, N closer to Forus = 161)<br>Change in distance from the dwelling to the Forus second-order center (km) | 0.148<br>*0.443*<br>(0.151) | -0.563<br>*-0.416*<br>(0.000) |

In both urban regions, we find stronger transport-reducing effects of moving inward toward the main employment centers than the corresponding increases in commuting distances resulting from outward moves. In Oslo, moving inward tends to result in a very substantial reduction in commuting distance, but there is also a considerable transport-increasing effect of moving outward. In Stavanger, moving closer to the Forus second-order center shows a considerable transport-reducing effect on commuting distances, whereas moving further away from Forus tends to increase commuting distances only slightly, and this effect is rather uncertain.

The differences between inward and outward moving suggest that both inward and outward movers are concerned about commuting distances and would like to avoid too long commutes. Whereas inward moving usually reduces commuting distance as well as brings the residents closer to several other facilities, outward moving often realizes the mover's wishes for more green areas and a more spacious dwelling. Residents who would for the latter reasons like to move outward, may in some cases decide against it because commuting would then become too cumbersome. If this is the case, outward commuters would to a greater extent be workers whose jobs are not located in the main workplace concentrations of the two urban regions. In Stavanger, several among the respondents who have moved further away from Forus have found their new dwelling close to the city centers of Stavanger and Sandnes, and many of them have thereby reduced their commuting distances. This may explain the weak and uncertain effect on commuting distances from moving further away from the Forus second-order center, and says something about the positive effects of a polycentric urban structure.

### 5.2.3. Changes in non-work travel distances after moving

Respondents who had moved to their present dwelling less than 2 years ago were asked to state how far from home different activities were carried out when they lived at their previous residential address. Table 11 shows how changes in the distance from the dwelling to the city centers of Oslo and Stavanger have contributed to changes in the distances to the normal locations of the investigated non-work activities. Although the cross-sectional analyses showed that trip distances to many non-work activities, especially in Oslo, were influenced to a great extent by local-area densities and residential distance to second-order or local centers, we have chosen to focus here on the changes in the distance from the dwelling to the main city center. The distance to the city center also exerts considerable influence on local-area densities (cf. Table 1). Moreover, because there are more second-order and local centers in the inner parts of the metropolitan area, dwellings in the metropolitan periphery are typically also located further away from the closest lower-order centers. The distance from the dwelling to the city center thus exerts indirect influences on trip distance via the latter variables.

Since the effects of moving outward and inward do not differ much, we do not show separate influences of inward and outward movers. Reflecting the geographical sizes of the two metropolitan areas, only respondents who have changed the distance between the dwelling and the city center by less than 50 km in Oslo and 30 km in Stavanger have been included in the analysis.

Table 11: Effects on having changed the distance between the dwelling and the city centers of Oslo and Stavanger on the distance from the dwelling to various non-work activities. Unstandardized regression coefficients (above), standardized coefficients (in the middle, in italics); p-values in parentheses (below).

| | Oslo | Stavanger |
|---|---|---|
| Visit to civic or religious building (N = 195 in Oslo and 114 in Stavanger; Adj. R2 = 0.051 and 0.048, respectively.) | 0.110<br>*0.236*<br>(0.001) | 0.209<br>*0.391*<br>(0.000) |
| Visit to a service provider (N = 422 in Oslo and 216 in Stavanger; Adj. R2 = 0.044 and 0.094, respectively.) | 0.091<br>*0.216*<br>(0.000) | 0.157<br>*0.314*<br>(0.000) |
| Purchasing daily necessities (N = 440 in Oslo and 225 in Stavanger; Adj. R2 = 0.071 and 0.031, respectively.) | 0.067<br>*0.271*<br>(0.000) | 0.053<br>*0.188*<br>(0.005) |
| Visit to restaurant or coffee place (N = 426 in Oslo and 212 in Stavanger; Adj. R2 = 0.153 and 0.467, respectively.) | 0.208<br>*0.393*<br>(0.000) | 0.418<br>*0.685*<br>(0.000) |
| Visit to place for entertainment/culture (N = 424 in Oslo and 209 in Stavanger; Adj. R2 = 0.204 and 0.422, respectively.) | 0.255<br>*0.454*<br>(0.000) | 0.421<br>*0.652*<br>(0.000) |
| Visit to place to exercise (N = 413 in Oslo and 209 in Stavanger; Adj. R2 = 0.054 and 0.108, respectively.) | 0.089<br>*0.239*<br>(0.000) | 0.167<br>*0.336*<br>(0.000) |
| Visit to place where you pick up or drop off a passenger (N = 134 in Oslo and 73 in Stavanger; Adj. R2 = 0.024 and 0.150, respectively.) | 0.091<br>*0.175*<br>(0.044) | 0.188<br>*0.402*<br>(0.000) |

The analysis of recent movers consistently shows that moving further away from the city centers of Oslo and Stavanger contributes to increasing the traveling distances to non-work activities, whereas moving closer to the city center has opposite effects. The cross-sectional analyses and the analyses of changes after moving point in the same direction: Living close to the city center contributes to shorter trip distances for all the seven investigated intra-metropolitan non-work trip purposes.

Generally, the influences of proximity to the city center on non-work trip distances are stronger in Stavanger than in the Oslo. In Stavanger, the city center is mainly an attractor of trips to cultural/entertainment facilities, restaurants, coffee places, shops and other non-work activities and to a lesser extent an attractor of commuting trips (cf. Section 5.1). In Oslo, the districts close to the main city center contain a large number of workplaces and thus attract many commuting trips, but the inner city is not as dominant an attractor of non-work trips as in Stavanger. In Oslo, facilities for a number of non-work activities exist also in a number of lower-order centers, while in Stavanger this is largely the case only in the downtown area of Sandnes.

### 5.2.4. Examples from the qualitative interviews

Our qualitative interviews show several examples of interviewees whose travel distances had increased due to outward moving or decreased as a result of having moved from suburban to central locations. Among the 33 interviewees altogether for both metropolitan areas, fourteen had moved during recent years to residential locations differing clearly in their urban structural situation from their previous residential location. The remaining interviewees had either lived in their present dwelling for a long time, moved from an urban structural situation similar to their present neighborhood, or moved from a different country with no available information enabling a comparison between the urban structural situations before and after the move.

In Oslo, an inner-city interviewee household that had moved from a single-family house 19 km from the city center (ID 50136 and her husband, a retired couple) now traveled much shorter distances than they did before the move. Two other interviewees, who had moved from inner-suburban residential locations (IDs 10078 and 12137) had experienced less pronounced changes due to their moves. 10078 had reduced her traveling distances as well as travel time for commuting, shopping and leisure trips, but none of these changes was very big. 12137 had increased her commuting distance, since her previous dwelling was located only 200 m from the workplace she had by then and to which she had now returned after having other jobs for some years. Apart from this, the move itself does not seem to have caused any changes worth mentioning in her travel behavior. Another Oslo interviewee, ID 51899, had moved with his family to a less peripheral, but still suburban location. Because of the move, he had reduced his travel distances especially for commuting, but also for leisure activities. On the other hand, his wife had increased her commuting distance, but she would soon change her workplace to a suburban location somewhat closer to the present than to the previous dwelling, yet quite far away from both.

In Stavanger, both the two interviewees who had moved from less central locations to the inner city of Stavanger (IDs 37424 and 53787) had changed their travel behavior due to the moves. After moving from a single-family house 10.5 km from the city center to an apartment only 0.8 km from the city center, 54466 had reduced his travel distances for most trip purposes (journeys to work, political meetings, cultural events, sport and other leisure activities). Moving had also reduced his and his spouse's amount of travel from their cabin in the nearby countryside (where they used to live most of the time during the summer half-year) to and from cultural events and restaurants, since they could now use their apartment as overnight place in the city. For the pensioner 37424, moving from a suburb outside the second-order center town Sandnes to downtown Stavanger has reduced his travel distances to cultural events, and in addition, for visits to his partner, who is now his close neighbor.

All the four interviewees who had moved from central to non-central residential locations (two in each metropolitan area) told that they had increased their amount of travel due to the move. In Oslo, IDs 16030 and 51437, who both had moved to locations further away from the city center of Oslo as well as from the closest second-order center, had increased their travel distances especially for commuting. In Stavanger, ID 35894 had increased her travel distances for daily purposes after moving from the inner city to a suburban single-family house neighborhood. ID 39693, who had moved from central Stavanger to a new apartment in a transformed industrial area in a suburb, had increased her travel distances to most destinations. The move had also increased her son's distance to his temporary job. On the other hand, moving had reduced her husband's commuting distance to his job in the suburban second-order center of Forus.

The two suburban interviewees who have moved only very short distances have not made noticeable travel behavioral changes due to moving. For TGE 52803 as well as EF 54466, travel distances as well as modes have remained practically unchanged. BM 40880, who also moved only a short distance, says that any changes that have occurred in his travel behavior are not due to his change of place of residence.

## 5.3. Why do residential location and local built environment characteristics influence travel distances the way they do?

In this section, we will draw on the qualitative interview material to shed light on the underlying causal mechanisms that produce the statistical patterns shown in the preceding sections. Our interviewees' *rationales* for location of activities make up important links in the mechanisms by which built environment characteristics influence commuting distances. Transport rationales are here understood as the backgrounds, motivations and justifications that agents draw on when they make transport-relevant decisions (Næss and Jensen 2005: 165; Næss, 2005, 2013; see also Scheiner, 2014 on mobility biographies).

The rationales were normally not something that the interviewees stated explicitly in the interviews. They were inferred by us, the researchers, based on what the interviewees told about their present and previous workplaces, acceptable commuting distances if they were to find a new job, location of outdoor recreation activities, choices of stores, restaurants, cultural facilities etc., and their statements about whether their activity pattern and/or travel behavior would change if they lived at a different kind of residential location. In addition to the information given in the qualitative interviews, we also drew on the interviewees' as well as the general respondents' answers to questionnaire questions about acceptable distances to jobs and other facilities as well as their stated tradeoffs between commuting time, job content and salary.

Among the 33 interviewees, the following rationales for activity locations were encountered in the interviews: Minimizing the friction of distance, with a related rationale of limiting other travel-related expenses; and choosing the best facility, with related rationales of maintaining social contacts and variety seeking. The two latter of these rationales are mainly relevant for non-work travel purpose and of quite limited importance to the interviewees' choices of workplace locations. For workplaces, what is considered the 'best facility' is usually conceived in terms of salary level, the content of the job, work conditions, colleagues and work environment. The rationale of minimizing the friction of distance implies that interviewees would, other things being equal, prefer a workplace where the perceived time consumption, inconvenience, undesired physical efforts, frustration and travel expenses associated with commuting are low. The 'limiting other travel-related expenses' rationale refers to monetary expenditures that are not linked to the distance itself, notably road toll and parking fees.

For choice of workplace, the 'best facility' rationale clearly dominates over distance minimizing, where the interviewees choose the best job they can get within wide limits for acceptable commuting time. This is also reflected in the long distances that the survey respondents on average travel to reach their workplaces, cf. the introduction of Section 5. The respondents' answers to questions about how they would prioritize between on the one hand salary and job content and on the other hand commuting time also illustrates this. As can be seen in Figure 8, more than half of the Oslo respondents (52 %) would rather prefer to spend 45 minutes instead of 30 minutes on their journey to work if they could then increase their salary by 10 %. In Stavanger, the proportion who would prefer this is lower (43 %), reflecting that commuting distances and times are generally shorter in Stavanger region and that only a small proportion of the workforce participants actually need to spend as long time as 45 minutes on their journey to work. There is a gender difference, where women, especially in Stavanger, are less inclined than men to prioritize higher salary over short commuting time. This is in line with the effects of gender found in Table 2.

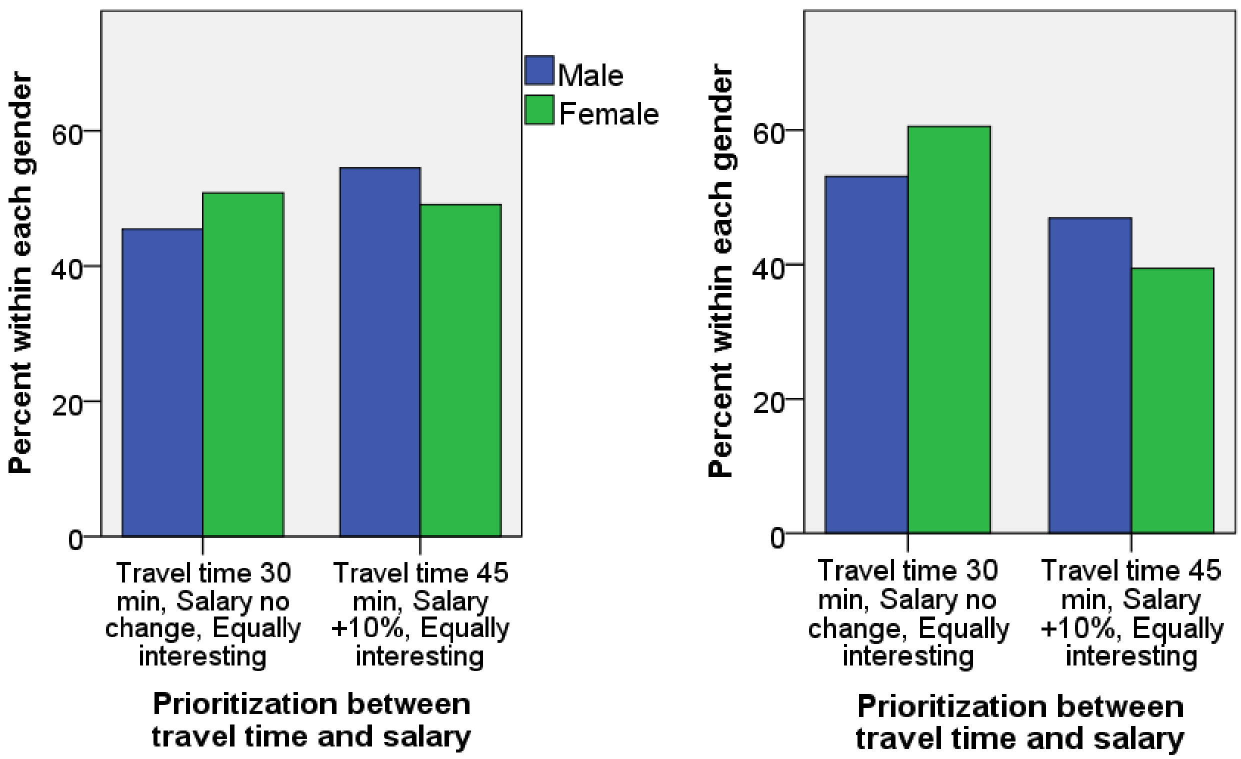


Figure 8: Prioritization between travel time and salary among respondents in the metropolitan areas of Oslo (N = 1344, to the left) and Stavanger (N = 974, to the right)

Considerable proportions of the respondents in both metropolitan areas (42-43 %) would prefer to spend as much as 90 minutes on their journey to work if they could then have a more interesting job than today and 10% higher salary, rather than having a commute of only 15 minutes, a less interesting job and 10 % lower salary. Again, there are gender differences, similar to those shown in Figure 8.

The proportions of respondents in both regions who are willing to commute longer if they can have higher salary suggest a high general tendency to give priority to the 'best facility' above distance minimizing within quite wide thresholds for acceptable commuting distances. It should be noted that job location is of course not only a matter of the worker's choice – the job applicant must also be chosen by the employer for the job. This double selection process is part of the explanation why interviewees are prepared to search for jobs within wider geographical areas than they do for most other facility categories. For example, the likelihood that a vacant job in a randomly selected office building close to where you live is suitable for you and will be offered to you if you apply is much lower than the likelihood that you will find a randomly selected grocery store close to where you live acceptable as a place for buying daily necessities.

Table 12 summarizes the contributions of the various rationales for activity location to the relationships between residential location and travel distances.

Table 12: Rationales for activity location encountered among the 33 interviewees living in the metropolitan areas of Oslo and Stavanger, and the contribution of these rationales to relationships between residential location and intra-metropolitan travel distances.

| Rationales | Contribution to the influence of proximity of the dwelling to the ***main city center*** on intra-metropolitan non-work travel distances | Contribution to the influence of proximity to ***lower-order centers*** on intra-metropolitan non-work travel distances |
|---|---|---|
| Minimizing the friction of distance (all interviews) | Some strengthening | Substantial strengthening |
| Choosing the best facility (all interviews) | Substantial strengthening | Some weakening |
| Maintaining social contacts (nearly half of the interviews) | Strengthening | Strengthening |
| Limiting other travel-related expenses (a few interviews) | Slight strengthening | Strengthening |
| Variety seeking (several interviews) | Hardly any effect | Hardly any effect |

The first four rationales contribute to varying degrees to build up the tendencies of longer travel distances the further away from the main city center the interviewees live. Three of these rationales also contribute to tendencies of longer travel distances the further the interviewees live from local centers, but one rationale (choosing the best facility) contributes to a certain weakening of these relationships. The fifth rationale, variety seeking, hardly affects the influence on traveling distances from the residential distance either to the main city center or to more local centers. Together, the five rationales imply that travel distances tend to depend more on how far from the main city center a person lives than on how far the dwelling is located from lower-order centers.

The rationale of ***minimizing the friction of distance*** contributes to strengthen the influence of living close to local centers on travel distances, since it increases the likelihood of choosing local jobs and non-work facilities, if available, rather than more distant ones. However, this rationale also contributes somewhat to the dependence of travel distances on the distance from the residence to the main centers of the metropolitan area (inner Oslo, central Stavanger and, for commuting, the Forus employment center). This is both because the facilities in these centers are the closest opportunities for residents of adjacent neighborhoods, and because of the shortage of facilities, particularly job opportunities, in the periphery.

The rationale of ***choosing the best facility*** contributes strongly to the influence of residential proximity to the main centers of the metropolitan areas on commuting distances, since it increases the likelihood of commuting to the large job concentrations found in inner Oslo, Forus and the inner part of Stavanger. Because the availability close to the dwelling of facilities for more specialized and culturally differentiated non-work activities is usually greater in the inner city than in lower-order centers, the rationale of choosing the best facility also contributes strongly to the influence of residential proximity to the main city center on non-work travel distances. On the other hand, this rationale contributes to a certain weakening of the relationship between residential proximity to local centers and travel distances, since it increases the likelihood of choosing distant facilities rather than those available locally.

Inner-city residents can, for example, find many specialized as well as non-specialized cultural facilities within a moderate distance from the dwelling. In Oslo, some suburban residents also have specialized and/or non-specialized cultural facilities (such as the Henie Onstad art exhibition center in Bærum, the Lillestrøm cultural center, various local cinemas, etc.) close to where they live, but on average for all suburban respondents, few such facilities are available within moderate distance from the dwelling. The distances that suburban residents travel from their dwelling to visit cultural facilities thus tend to be longer than the distances that inner-city residents travel to reach such facilities. This is reinforced by the prevailing tendency found among interviewees of choosing the 'best' (i.e. the one matching the interviewee's cultural taste and interests) rather than the closest cultural facility. Those who live close to a suburban cultural facility therefore also tend to visit other cultural facilities located in the inner city or in other suburbs. In Stavanger, the main concentrations of cultural facilities (theaters, cinemas, concert arenas, museums, art exhibitions, etc.) are located in Stavanger's downtown area. In addition, there are some such facilities in the central part of Sandnes, but these are considerably fewer than in downtown Stavanger. Given the strong emphasis that the interviewees place on the 'best facility' rationale compared to 'distance minimizing' for this activity group, culture-interested residents would be likely not to just go to the closest cultural event taking place but rather go to events matching their specific cultural taste even if this requires more travel. Apart from the facilities themselves, the 'urban atmosphere' in their surroundings also play a role and tend to increase the attractiveness of downtown cultural facilities (and also restaurants, special commodity stores, etc.) (Stefansdottir, 2018). Culture-interested residents of suburban neighborhoods as well as residents in the central parts of Sandnes therefore tend to make longer trips to cultural facilities than their culture-interested counterparts living close to the city center of Stavanger.

For service facilities such as special commodity stores and restaurants/cafes, the situation and resulting mechanisms leading to differences in travel distances are in many ways similar to those concerning cultural facilities. Inner-city residents have many non-specialized as well as specialized shops and restaurants/cafes within a moderate distance from the dwelling, while most suburbanites have fewer and less specialized such facilities within a moderate travel distance. For grocery stores, the situation is different. Although differences exist between discount stores and stores offering a wider assortment, both categories are usually available in most local centers. For this facility category, most interviewees usually differentiate between different stores of a given assortment category within a quite narrow threshold distance.

However, since areas offering opportunities for recreational walks, jogging, etc. exist close to most of the residential neighborhoods in the metropolitan areas, the distances that residents travel to reach such areas tend to vary less between different parts of the urban region. And since the density of facilities for indoor exercise is generally higher in the inner and central parts of the metropolitan areas, inner-city dwellers tend to have shorter overall distances than suburbanites to the exercise opportunities, despite the greater proximity of suburban neighborhoods to areas for long-duration outdoor activities.

The rationale of ***maintaining social contacts*** guides the location of common non-work activities such as going to restaurants, cafes or bars and common outdoor recreation trips. Since the central part of the metropolitan area is usually easier accessible for a group of people going out together than suburban locations (unless all group members live in the same suburb), the inner city is often preferred as a meeting place. The high concentration of facilities in the downtown area also makes it more likely for a group of friends to find a facility they like there than in more peripheral parts of the urban region. Facilities close to the city center are therefore more likely to be chosen when a group of friends or colleagues go out together. Especially for the kinds of social contacts taking place at public spaces such as restaurants, cafes and bars, the rationale of maintaining social contacts tends to produce shorter travel distances among inner-city dwellers than among suburbanites. For other types of common social activities, such as common exercise activities, facilities are less concentrated to the central parts of the metropolitan area. For such activities, the social contacts rationale is less likely to produce great center-periphery differences in travel distances.

The rationale of ***variety-seeking*** is encountered among interviewees independent of their residential location, and there are no indications in the interviews of any mechanisms that might lead variety-seeking people to locate in particular parts of the urban region. Among the interviewees, this rationale appears mainly for outdoor recreation, but in a few cases also for shopping. The variety-seeking rationale probably increases the distances the interviewees travel in order to reach relevant non-work facilities, but it does not seem plausible that this rationale has much influence on the differences between residents living in different parts of the metropolitan area on travel distances.

The different rationales for choices of ***workplace location*** can also to a great extent be fulfilled simultaneously for the inner city interviewees in Oslo and to some extent also in Stavanger. In the latter metropolitan area, workplaces are concentrated even more to the Forus area than to the inner city of Stavanger, so the advantage for inner-city dwellers over suburbanites in the possibility of finding employment close to home is lower in Stavanger than in Oslo. Because many different job opportunities are often available within a short distance from the dwelling, it is possible for inner-city residents in Oslo to be quite selective about the quality of the job (in terms of salary, job content, working conditions, etc.) without needing to commute a long distance. In Stavanger, the same applies to workers living close to the Forus area or to the inner part of Stavanger. Typical for many interviewees living close to these center formations is that their prioritization between ‘best facility’ and ‘distance minimizing’ rationales is not put to the test since ‘best facility’ jobs can be found within short distances from the dwelling.

Apart from outdoor recreation, the different rationales for ***non-work activity location*** can to a great extent be fulfilled simultaneously for the inner city interviewees in both metropolitan areas. Because many potential facilities within each category are often available within a short distance from the dwelling, it is possible for inner-city residents to be quite selective about the quality of the facility without needing to travel a long distance to reach the facility in question. The inner-city interviewees therefore generally do not feel that they have to compromise on facility quality although they are keeping most of their destinations within a short distance from home. For interviewees living close to a second-order center, the possibility of fulfilling the different rationales for non-work activity location simultaneously is lower than for inner-city dwellers but still higher than for those living far away from the main center of the metropolitan area. For the interviewees living at non-central locations, the possibilities of combining the 'best facility' and the 'distance minimizing' rationales are much more constrained, especially for those interested in attending cultural events.

# 6. Built environment influences on travel modes

This section shows results of analyses of the effects of residential location and local built environment characteristics on choice of travel modes in the two metropolitan areas. Results of cross-sectional and longitudinal statistical analyses and interpretations of qualitative interview data concerning travel modes will be presented.

## 6.1. Cross-sectional analyses

### 6.1.1. Travel modes for commuting

Tables 13 and 14 show the proportions commuting regularly by car, transit and non-motorized modes among respondents living at different distances from the city centers of Oslo and Stavanger, respectively. For car commuting and commuting by non-motorized modes, we see a clear center-periphery gradient in Oslo, with higher proportions of regular car commuters and lower shares of commuters regularly using non-motorized modes the farther from the city center the respondents live. In Stavanger too, a similar tendency can be seen, but here, the distance belt 9-15 km from the city center is an exception. As mentioned earlier, the second-order center of Sandnes and the Forus employment center are both located at this distance from the city center of Stavanger. Respondents living close to Forus have on average shorter commuting distance and greater likelihood of living within walking or biking distance from their workplace, and respondents living close to Sandnes have relatively good access to transit. There is no clear center-periphery gradient in any of the city regions in the shares of regular transit commuting. The multivariate analyses presented in the following will shed more light on how travel modes for commuting are associated with different residential location and built environment characteristics.

Table 13: Proportions commuting by car, transit and non-motorized modes four or more days during the week among respondents living at different distances from the city center of Oslo. Percent. N = 1156-1157, p = 0.000 for all modes.

| | Distance from the city center of Oslo (km) | | | |
|---|---|---|---|---|
| | Below 6 | 6-13 | 13-22 | Over 22 |
| Car | 12.5 | 29.0 | 45.2 | 51.0 |
| Transit | 35.0 | 30.2 | 29.5 | 28.9 |
| Walking or biking | 30.0 | 20.0 | 13.7 | 9.1 |

Table 14: Proportions commuting by car, transit and non-motorized modes four or more days during the week among respondents living at different distances from the city center of Stavanger. Percent. N = 791.

| | Distance from the city center of Stavanger (km) | | | |
|---|---|---|---|---|
| | Below 5 | 5-9 | 9-15 | Over 15 |
| Car (p = 0.000) | 38.9 | 48.5 | 44.4 | 62.2 |
| Transit (p = 0.916) | 7.2 | 7.1 | 5.6 | 6.7 |
| Walking or biking (p = 0.000) | 37.5 | 22.5 | 27.3 | 15.0 |

### *Car commuting*

Table 15 shows the effects of various residential locational and sociodemographic variables[16] and residential preferences on the likelihood of commuting regularly by car.

Table 15: Factors influencing the likelihood of commuting by car at least four days during the week among respondents living at different locations in Oslo (N = 890) and Stavanger (N = 641). Nagelkerke $R^2$ = 0.345 and 0.206, respectively.[17]

| | B (standard error in parenthesis) | | Wald | | Level of significance (p value) | |
|---|---|---|---|---|---|---|
| Metropolitan area | Oslo | Stavanger | Oslo | Stavanger | Oslo | Stavanger |
| *Built environment characteristics* | | | | | | |
| Distance from dwelling to the main city center (km) | 0.030 (0.011) | 0.043 (0.018) | 7.85 | 5.74 | 0.005 | 0.017 |
| Inhabitants per hectare within the 1 $km^2$ grid square of the dwelling | -0.012 (0.0035) | n.s. | 12.33 | n.s. | 0.000 | n.s. |
| Distance from dwelling to the Sandnes second-order center (km) | --- | 0.031 (0.018) | --- | 2.87 | --- | 0.090 |
| Distance from workplace to the main city center (km) | 0.059 (0.009) | 0.046 (0.015) | 48.73 | 9.42 | 0.000 | 0.002 |
| *Demographic and socioeconomic characteristics* | | | | | | |
| Age | -0.019 (0.008) | -0.022 (0.008) | 5.41 | 7.53 | 0.020 | 0.006 |
| Education (master level or above = 1, otherwise 0) | -0.784 (0.183) | -0.703 (0.183) | 18.41 | 14.08 | 0.000 | 0.000 |
| Personal gross income (1000 NOK) | 0.0015 (0.0004) | 0.0011 (0.0004) | 14.71 | 6.79 | 0.000 | 0.009 |
| Number of household members 7-17 years of age | n.s. | -0.229 (0.103) | n.s. | 4.93 | n.s. | 0.026 |
| *Residential preferences* | | | | | | |
| Preference factor “proximity to transit” | -0.582 (0.112) | -0.476 (0.111) | 26.89 | 18.31 | 0.000 | 0.000 |
| Preference factor “local amenities” | n.s. | 0.212 (0.128) | n.s. | 2.74 | n.s. | 0.098 |
| Preference factor “favorable investment” | 0.261 (0.117) | 0.444 (0.121) | 5.00 | 13.42 | 0.025 | 0.000 |
| Preference factor “physical exercise” | -0.304 | -0.295 | 5.74 | 5.05 | 0.017 | 0.025 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | (0.127) | (0.131) | | | | |
| Constant | -1.152<br>(0.479) | -0.724<br>(0.529) | 5.79 | 1.87 | 0.016 | 0.172 |

In each metropolitan area, three built environment characteristics show effects on the likelihood of commuting by car at least four days a week. In both Oslo and Stavanger, the distance from the dwelling to the main city center has the strongest effect among the residential location variables, with higher likelihood of regular car commuting the further from the city center the dwelling is located. However, the built environment variable clearly showing the strongest effect in both cities is the distance from the workplace to the city center. The likelihood of being a regular car commuter is lower the closer to the center the workplace is located. This reflects that centrally located workplaces are normally both easily accessible by transit and more difficult to access by car due to narrower streets, more frequent crossings, lower and more expensive parking opportunities and (in the case of Oslo) toll fees on the roads leading to the inner city.

In Oslo, the likelihood of car commuting increases the lower is the local-area density. The effects of proximity to the city center and density reflect the generally better transit in the inner than in the outer parts of the metropolitan area, with local variations at a given distance from the city center reflecting the population base provided by the local density. In addition, the generally shorter commuting distances among respondents living close to the city center of Oslo (cf. Figure 6 and Table 2) make walking and biking attractive alternatives to car commuting.

Apart from the effect of living close to the main city center,, Stavanger respondents are somewhat less likely to commute by car if the distance from the dwelling to the Sandnes second-order center is short. These two effects reflect the prevalence of better transit provision in the inner part of Stavanger generally and in the corridor between Stavanger and Sandnes, and the more favorable conditions for non-motorized travel particularly in the inner city of Stavanger. The tendency of shorter commuting distances among respondents living close to the Forus second-order center (cf. Table 2) does not translate in any tendency of reduced likelihood of car commuting among these respondents. The Forus area is not particularly well served by transit connections, and the local built environment is rather car-oriented in terms of parking availability, street design and width, and no good facilitation for non-motorized travel modes.

Distinct from Oslo, we do not find any effect of local-area density on the likelihood of being a regular car commuter among the Stavanger respondents.

Four sociodemographic control variables show effects in both metropolitan areas on the likelihood of car commuting. The likelihood of being a regular car commuter tends to decrease if the respondent has high education, possibly reflecting a somewhat more centralized location of the jobs requiring this education level. In line with findings in many previous studies, high income increases the likelihood of car commuting in both case regions. In both metropolitan areas, the likelihood of being a regular car commuter is also higher among young respondents, possibly reflecting their tendency to work at a longer distance from home (cf. Table 2). In Stavanger, the likelihood of being a regular car commuter also decreases with schoolchildren in the household. The reasons for the latter effect, and why it appears only in Stavanger, are a bit difficult to interpret.

Three residential preference variables also show effects in both metropolitan area on the likelihood of car commuting. Residential preferences emphasizing transit accessibility and physical exercise reduce the likelihood of commuting by car in both Oslo and Stavanger. This is hardly surprising, since the former of these variables indicates a preference for a travel mode different from the private car, whereas the effect of the latter variable reflects the exercise benefit from biking or walking (including walking to and from transit stops) instead of driving. In both metropolitan areas, the likelihood of being a regular car commuter also increases among respondents who emphasize the dwelling as an investment object. The reasons for this is more difficult to interpret. Residential preferences emphasizing local amenities also increase the likelihood of car commuting among Stavanger respondents. The local amenities included in this variable are usually associated with suburban neighborhoods, where car travel is more common than in central districts.

### *Commuting by transit*

The variables showing effects on the likelihood of being a regular transit commuter (table not shown) in many ways mirror the analysis of regular car commuting. The built environment characteristic showing the strongest effect is the location of the workplace. The likelihood of being a regular transit commuter decreases the further from the main city center the workplace is located, for the same reasons as for the opposite effect on regular car commuting. This effect is particularly strong in Oslo.

The effects of the residential location variables illustrate that the need for motorized transportation, including travel by transit, is higher when living far away from relevant destinations. In both metropolitan areas, the likelihood of being a regular transit commuter increases the farther from the main city center the dwelling is located. In Stavanger, the likelihood of transit commuting also increases somewhat with increasing residential distance to the second-order center Sandnes. On the other hand, living in a low-density area decreases the likelihood for Stavanger respondents of being a regular transit commuter. In Oslo, we find a corresponding slight tendency of increased likelihood of transit commuting when living close to a local center, reflecting their generally better transit accessibility than in surrounding suburban areas. Despite the high density of transit lines and high frequency of departures in the high-density inner districts of Oslo, we find no effect on the likelihood of being a regular transit commuter from the local-area density.

In both metropolitan areas, holding a driver’s license reduces the likelihood of commuting by transit, whereas holding a master’s degree has the opposite effect. In Oslo, we also find a tendency of more frequent transit commuting among low-income respondents. A pro-transit attitude, measured as residential preference for proximity to transit, contributes strongly in both metropolitan areas to increase the likelihood of being a regular transit commuter. In Stavanger, we also see a slight tendency of reduced transit commuting among respondents emphasizing opportunities for physical activity as a residential preference, probably reflecting a predilection among such respondents for choosing non-motorized travel rather than transit.

### *Commuting by non-motorized modes*

Table 16 shows the effects of various residential locational, sociodemographic and residential preference variables on the likelihood of commuting by non-motorized modes at least four of the days during the week.

Table 16: Factors influencing the likelihood of commuting regularly by non-motorized modes among respondents living at different locations in the metropolitan areas of Oslo (N = 889) and Stavanger (N = 641). Nagelkerke $R^2$ = 0.133 and 0.097, respectively.[18]

| | B (standard error in parenthesis) | | Wald | | Level of significance (p value) | |
|---|---|---|---|---|---|---|
| Metropolitan area | Oslo | Stavanger | Oslo | Stavanger | Oslo | Stavanger |
| *Built environment characteristics* | | | | | | |
| Distance from dwelling to the main city center (km) | -0.072 (0.012) | -0.102 (0.025) | 36.37 | 16.13 | 0.000 | 0.000 |
| Distance from dwelling to the Sandnes second-order center (km) | --- | -0.058 (0.025) | --- | 5.39 | --- | 0.020 |
| Distance from workplace to the main city center (km) | n.s. | -0.039 (0.017) | n.s. | 4.90 | n.s. | 0.027 |
| *Demographic and socioeconomic characteristics* | | | | | | |
| Education (master level or above = 1, otherwise 0) | 0.629 (0.189) | n.s. | 11.09 | n.s. | 0.001 | n.s. |
| Number of household members younger than 7 years | -0.431 (0.166) | n.s. | 6.80 | n.s. | 0.009 | n.s. |
| Gender (female = 1, male = 0) | -0.366 (0.185) | n.s. | 3.92 | n.s. | 0.048 | n.s. |
| Number of household members 18 years and older | n.s. | 0.198 (0.103) | n.s. | 3.72 | n.s. | 0.054 |
| *Residential preferences* | | | | | | |
| Preference factor "physical exercise" | 0.297 (0.133) | 0.263 (0.134) | 4.95 | 3.89 | 0.026 | 0.049 |
| Preference factor "good for children" | 0.305 (0.131) | n.s. | 5.41 | n.s. | 0.020 | n.s. |
| Constant | 0.20 (0.45) | 0.49 (0.49) | 0.19 | 1.02 | 0.661 | 0.312 |

In both metropolitan areas, the distance from the dwelling to the main city center is the built environment characteristic showing the strongest effect on the likelihood of being a regular commuter by non-motorized modes. The closer to the city centers of Oslo and Stavanger the dwelling is located, the higher is the likelihood of traveling to work by bike or on foot four or more days a week. In Oslo, this reflects the generally shorter commuting distances among inner-city dwellers (cf. Figure 6 and Table 2) and the resulting higher number of jobs within acceptable walking or biking distance. Despite the longer average commuting distances among inner-city dwellers in Stavanger than among respondents living near the Forus area, other urban structural characteristics, such as narrower roads and better facilitation for non-motorized travel in the inner city areas, evidently outweigh the large number of jobs within biking or walking distance for respondents living close to Forus. In Stavanger, we also find a slightly increased likelihood of being a regular commuter by non-motorized modes among respondents living close to the Sandnes second-order center.

The absence of any significant effects of more local built environment characteristics in any of the metropolitan areas reflects that respondents' workplaces (except those of inner-city dwellers) are usually located outside their residential neighborhoods, regardless of variations in local-area density.

In Stavanger, respondents whose workplace is located close to the city center are somewhat more likely to be a regular commuter by non-motorized modes than those living farther away from the city center. Distinct from the analyses of commuting by car and by transit, we do not find any effect of the distance between the workplace and the city center in Oslo.

The effects of the demographic, socioeconomic and residential preference variables are largely in line with theoretical expectations. In both metropolitan areas, the likelihood of being a regular commuter by non-motorized modes is higher for respondents with high education and among those with residential preferences emphasizing physical exercise. In Oslo, regular commuting by bike or on foot is also more likely among respondents emphasizing a good neighborhood for children as a residential preference criterion. On the other hand, Oslo respondents with small children in the household are less likely to commute by non-motorized modes, possibly because they find it inconvenient to bring children to and from kindergarten by bike or on foot when facing the "time bind" set by the combined demands of work life and family life (Hochschild, 1997). A lower likelihood for female Oslo respondents to commute by non-motorized modes may reflect some of the same circumstances. In Stavanger, the likelihood of commuting by non-motorized modes is higher if there is more than one adult household member, possibly because one of the spouses will then not have a car available for commuting if the household has only one car.

### 6.1.2. Non-work travel modes

The travel modes for intra-metropolitan non-work purposes are influenced considerably by built environment characteristics of the dwelling. Due to space constraints, detailed results will only be shown for trips to two activity categories: visits to cultural events and daily necessities shopping, and only for one travel mode: car travel.

Tables 17 and 18 show how the mean modal shares for trips to cultural/entertainment events vary between respondents living within different distance belts from the city centers of Oslo and Stavanger, respectively. The modal shares for car trips are consistently higher in both metropolitan areas, the further away from the city center the dwelling is located. In Oslo we also find consistently lower shares of non-motorized trips with increasing residential distance from the city center. In Stavanger too, the share of non-motorized trips to cultural/entertainment events is highest in the most central distance belt (below 6 km from the city center), but there is no further decrease across the three outer distance belts. Instead, the share of non-motorized trips to cultural/entertainment events is somewhat higher in the outermost distance belt (over 15 km from the city center) than in the second (5-9 km) and third (9-15 km). This reflects that the second-order center of Sandnes is located in the outermost distance belt, and that several respondents living at this distance from the city center of Stavanger can easily reach the cultural facilities in the Sandnes downtown area by foot or by bike.

Table 17: Mean modal shares for trips to cultural and entertainment events among respondents living at different distances from the city center of Oslo. Percent. N = 1612-1617, p = 0.000 for all modes.

| | Distance from the city center of Oslo (km) | | | |
|---|---|---|---|---|
| | Below 6 | 6-13 | 13-22 | Over 22 |
| Car | 11.3 | 31.6 | 44.0 | 56.8 |
| Transit | 40.0 | 45.3 | 30.0 | 21.2 |
| Walking or biking | 48.8 | 22.7 | 25.8 | 21.8 |

Table 18: Mean modal shares for trips to cultural and entertainment events among respondents living at different distances from the city center of Stavanger. Percent.

| | Distance from the city center of Stavanger (km) | | | |
|---|---|---|---|---|
| | Below 5 | 5-9 | 9-15 | Over 15 |
| Car (N = 1096, p = 0.000) | 31.8 | 54.9 | 58.7 | 61.9 |
| Transit (N = 1096, p = 0.001) | 21.1 | 25.9 | 21.7 | 14.2 |
| Walking or biking (N = 1101, p = 0.000) | 46.8 | 19.0 | 19.6 | 23.8 |

Tables 19 and 20 show how the mean modal shares for trips to grocery stores vary between respondents living within different distance belts from the city centers of Oslo and Stavanger, respectively. In both metropolitan areas, the modal shares for car trips are consistently higher the further away from the city center the dwelling is located, whereas the opposite is the case for trips by non-motorized modes. The shares of trips by transit to grocery stores are low in both metropolitan areas. In Oslo, this share is somewhat higher in the two inner distance belts than in the two outer. In Stavanger, respondents living in the inner suburbs of Stavanger (5-9 km from the city center) travel more frequently by transit than the remaining respondents do.

Table 19: Mean modal shares for trips to stores for daily necessity shopping among respondents living at different distances from the city center of Oslo. Percent. N = 1734-1738, p = 0.000 for all modes.

| | Distance from the city center of Oslo (km) | | | |
|---|---|---|---|---|
| | Below 6 | 6-13 | 13-22 | Over 22 |
| Car | 14.3 | 41.7 | 54.0 | 65.1 |
| Transit | 5.4 | 6.0 | 3.2 | 1.9 |
| Walking or biking | 80.4 | 52.0 | 42.5 | 32.9 |

Table 20: Mean modal shares for trips to stores for daily necessity shopping among respondents living at different distances from the city center of Stavanger. Percent.

| | Distance from the city center of Stavanger (km) | | | |
|---|---|---|---|---|
| | Below 5 | 5-9 | 9-15 | Over 15 |
| Car (N = 1188, p = 0.000) | 36.5 | 54.4 | 61.9 | 66.2 |
| Transit (N = 1188, p = 0.425) | 1.7 | 3.0 | 2.2 | 1.6 |
| Walking or biking (N = 1191, p = 0.000) | 61.6 | 42.5 | 35.9 | 32.2 |

Tables 21 and 22 show the effects of various built environment, sociodemographic and residential preference characteristics on the modal share of car travel for trips to cultural/entertainment events and grocery stores, respectively, in each of the two metropolitan areas.

Table 21: Factors influencing the modal share of car travel for trips to cultural/entertainment events among respondents living at different locations in the metropolitan areas of Oslo (N = 1452) and Stavanger (N = 974). Adj. $R^2$ = 0.358 and 0.255, respectively.[19]

| | Unstandardized coefficient (standard error in parenthesis) | | Standardized coefficient (Beta) | | Level of significance (p value) | |
|---|---|---|---|---|---|---|
| Metropolitan area | Oslo | Stavanger | Oslo | Stavanger | Oslo | Stavanger |
| *Built environment characteristics* | | | | | | |
| Logarithm of the distance (in km) to the main city center | 0.110 (0.014) | 0.164 (0.019) | 0.234 | 0.368 | 0.000 | 0.000 |
| Inhabitants per hectare within the 1 km² grid square of the dwelling | -0.0008 (0.0003) | -0.0032 (0.0009) | -0.129 | -0.120 | 0.004 | 0.000 |
| Logarithm of the distance (in km) to the closest second-order center | 0.056 (0.008) | --- | 0.141 | ---- | 0.000 | --- |
| Logarithm of the distance (in km) to the closest local center | 0.056 (0.010) | n.s. | 0.107 | n.s. | 0.000 | n.s. |
| Logarithm of the distance (in km) to the Sandnes second-order center | --- | 0.068 (0.016) | --- | 0.157 | --- | 0.000 |
| *Demographic and socioeconomic characteristics* | | | | | | |
| Driver's license for car | 0.174 (0.027) | 0.182 (0.039) | 0.152 | 0.133 | 0.000 | 0.000 |
| Age | -0.0015 (0.0005) | n.s. | -0.069 | n.s. | 0.006 | n.s. |
| Personal gross annual income (1000 NOK) | 0.00008 (0.00003) | n.s. | 0.059 | n.s. | 0.018 | n.s. |
| Number of household members 7-17 years | 0.027 (0.011) | n.s. | 0.057 | n.s. | 0.015 | n.s. |
| Education (master level = 1, otherwise 0) | -0.035 (0.016) | n.s. | -0.050 | n.s. | 0.029 | n.s. |
| *Residential preferences* | | | | | | |
| Preference factor "proximity to transit" | -0.058 (0.010) | -0.087 (0.012) | -0.127 | -0.209 | 0.000 | 0.000 |
| Preference factor "good for children" | 0.020 (0.011) | 0.045 (0.012) | 0.046 | 0.102 | 0.069 | 0.000 |
| Preference factor "favorable investment" | 0.025 (0.010) | n.s. | 0.055 | n.s. | 0.013 | n.s. |
| Preference factor "shopping opportunities" | 0.024 (0.010) | n.s. | 0.054 | n.s. | 0.018 | n.s. |
| Preference factor "physical exercise" | -0.026 (0.011) | n.s. | -0.053 | n.s. | 0.015 | n.s. |
| Constant | -0.099 (0.051) | -0.084 (0.084) | | | 0.052 | 0.321 |

Table 22: Factors influencing the modal share of car travel for trips to grocery stores among respondents living at different locations in the metropolitan areas of Oslo (N = 1558) and Stavanger (N = 1074). Adj. $R^2$ = 0.402 and 0.248, respectively.[20]

| | Unstandardized coefficient (standard error in parenthesis) | | Standardized coefficient (Beta) | | Level of significance (p value) | |
|---|---|---|---|---|---|---|
| Metropolitan area | Oslo | Stavanger | Oslo | Stavanger | Oslo | Stavanger |
| *Built environment characteristics* | | | | | | |
| Logarithm of the distance (in km) to the main city center | 0.100 (0.014) | 0.103 (0.014) | 0.234 | 0.230 | 0.000 | 0.000 |
| Logarithm of the distance (in km) to the closest second-order center | 0.053 (0.008) | --- | 0.141 | --- | 0.000 | --- |
| Logarithm of the distance (in km) to the closest local center | 0.052 (0.010) | 0.028 (0.013) | 0.107 | 0.060 | 0.000 | 0.032 |
| Inhabitants per hectare within the 1 $km^2$ grid square of the dwelling | -0.0012 (0.0003) | -0.0038 (0.0008) | -0.129 | -0.141 | 0.000 | 0.000 |
| *Demographic and socioeconomic characteristics* | | | | | | |
| Driver's license for car | 0.202 (0.027) | 0.216 (0.039) | 0.160 | 0.161 | 0.000 | 0.000 |
| Personal gross annual income (1000 NOK) | 0.00019 (0.00003) | 0.00019 (0.00004) | 0.135 | 0.155 | 0.000 | 0.000 |
| Number of household members 7-17 years | 0.038 (0.011) | n.s. | 0.073 | n.s. | 0.001 | n.s. |
| Number of household members 18 years and older | n.s. | 0.029 (0.011) | n.s. | 0.070 | n.s. | 0.010 |
| Education (master level = 1, otherwise 0) | -0.054 (0.016) | -0.050 (0.022) | -0.072 | -0.069 | 0.001 | 0.021 |
| Gender (female = 1, male = 0) | 0.028 (0.016) | 0.036 (0.021) | 0.038 | 0.052 | 0.075 | 0.081 |
| *Residential preferences* | | | | | | |
| Preference factor "proximity to transit" | -0.050 (0.010) | -0.050 (0.012) | -0.102 | -0.120 | 0.000 | 0.000 |
| Preference factor "good for children" | 0.044 (0.011) | 0.035 (0.012) | 0.091 | 0.080 | 0.000 | 0.004 |
| Preference factor "physical exercise" | -0.036 (0.011) | -0.042 (0.013) | -0.067 | -0.087 | 0.001 | 0.002 |
| Preference factor "favorable investment" | 0.022 (0.010) | 0.033 (0.013) | 0.045 | 0.071 | 0.025 | 0.012 |
| Preference factor "local amenities" | 0.036 (0.011) | n.s. | 0.071 | n.s. | 0.001 | n.s. |
| Preference factor "shopping opportunities" | n.s. | -0.022 (0.013) | n.s. | -0.46 | n.s. | 0.099 |
| Constant | -0.174 (0.057) | -0.012 (0.070) | | | 0.002 | 0.870 |

Most of the built environment variables in both metropolitan areas show quite strong effects on the modal share of car travel for trips to grocery stores as well as to cultural or entertainment events. The distances from the dwelling to the city centers of Oslo and Stavanger have the strongest effects. The closer to the center of each metropolitan area the respondents live, the lower do their shares of car travel tend to be, particularly for trips to cultural/entertainment events. In both metropolitan areas, high local-area population density also contributes to lower proportions of car travel when purchasing daily necessities as well as when going to cultural or entertainment events. In Oslo, living close to a second-order center also contributes quite strongly to reduce the share of car travel for both trip purposes. Corresponding to this, living close to the Sandnes second-order center has a strong reducing effect on car travel to cultural/entertainment events (but no effect on trips to grocery stores). Proximity to the closest local center shows effects, albeit not very strong, in terms of reducing car travel for daily necessities shopping in both metropolitan areas, and in Oslo also for trips to cultural or entertainment events. Consistent with the effects on traveling distances found in tables 11 and 14, we find strong tendencies for respondents in Stavanger living close to the Forus second-order center of relying more on car travel to grocery stores as well as to cultural/entertainment facilities. This reflects the car-oriented urban structure of this part of the metropolitan area and the location of Forus in-between the central parts of Stavanger and Sandnes, with long distances to the cultural, entertainment and shopping opportunities in either of these downtown areas.

The effects of the demographic and socioeconomic variables are mostly in line with theoretical expectations, where holding a driver's license, high income, and education lower than master level contribute to increase the share of car travel for both trip purposes in both metropolitan areas. The effect of education may reflect car-driving habits engendered by the more decentralized location of 'blue-collar' jobs than of jobs requiring master-level education. For one trip purpose each, young age and being male also increases the share of car travel in Oslo as well as in Stavanger.

Residential preferences emphasizing a good neighborhood for children, favorable investment, and (weakly) local amenities, tend to contribute to somewhat higher shares of car travel, whereas the opposite is the case for emphasis on proximity to transit and physical exercise. The effects of the former and latter residential preferences probably reflect that these criteria are often considered to be met the best in suburban neighborhoods, where car dependency is larger than in inner-city contexts. The effect of the favorable investment variable may indicate a kind of materialism also associated with positive attitudes to car driving.

### *Effects of residential location and local built environment variables on the shares of car travel for the remaining non-work travel purposes*

Table 23 shows the effects of residential location and local built environment variables on car travel for the non-work travel purposes not included in tables 19 and 20. The effects of residential location and local built environment variables shown in the table are controlled for the same demographic, socioeconomic and residential preference variables as in the previous tables.

Table 23: Effects of residential location and local built environment variables on regular car travel for five non-work travel purposes. Standardized regression coefficients, levels of significance (p values) in parentheses. All effects of residential location and local built environment variables shown in the table are controlled for the same demographic, socioeconomic and residential preference variables as in the previous tables.

| Trip purpose | Visit to civic or religious building | | Visit to a service provider | | Visit to restaurant or coffee place | | Visit to place to exercise | | Visit to place where you pick up or drop off a passenger | |
|---|---|---|---|---|---|---|---|---|---|---|
| Metropolitan area | Oslo N=750 | Sta-vanger N=578 | Oslo N=1463 | Sta-vanger N=984 | Oslo N=1458 | Sta-vanger N=970 | Oslo N=1563 | Sta-vanger N=938 | Oslo N=573 | Sta-vanger N=397 |
| Logarithm of the distance (in km) to the main city center | 0.169 (0.001) | 0.264 (0.000) | 0.233 (0.000) | 0.261 (0.000) | 0.300 (0.000) | 0.336 (0.000) | 0.135 (0.000) | 0.157 (0.000) | 0.360 (0.000) | 0.210 (0.000) |
| Logarithm of the distance (in km) to the closest second-order center | 0.170 (0.000) | --- | 0.147 (0.000) | --- | 0.183 (0.000) | --- | 0.057 (0.030) | --- | n.s. | --- |
| Logarithm of the distance (in km) to the Sandnes second-order center | --- | 0.111 (0.023) | --- | 0.103 (0.006) | --- | 0.155 (0.000) | --- | n.s. | --- | n.s. |
| Inhabitants per hectare within the 1 $km^2$ grid square of the dwelling | -0.132 (0.005) | -0.195 (0.000) | -0.077 (0.019) | -0.125 (0.000) | n.s. | -0.127 (0.000) | -0.071 (0.058 | -0.070 (0.049) | n.s. | n.s. |
| Logarithm of the distance (in km) to the closest local center | 0.120 (0.001) | n.s. | 0.140 (0.000) | 0.077 (0.008) | 0.119 (0.000) | 0.057 (0.054) | 0.061 (0.020) | n.s.) | n.s. | n.s.) |

For all the five travel purposes, except visits to civic or religious buildings in Oslo, and in both metropolitan areas, the location of the dwelling relative to the main city center exerts the clearly strongest influence on the proportion of car travel. The further away from the city center the respondents live, the higher their share of car travel for non-work purposes tends to be. For Oslo case respondents' visits to civic or religious buildings, the distance to the city center and to the closest second-order center show equally strong influences on the share of car travel. In Oslo, living far away from the closest second-order center, living in a low-density local-area and living far from the closest local center also contribute to increase the share of car travel for most of the non-work travel purposes, but these effects are generally not as strong as those of the distance from the dwelling to the main city center. In Stavanger metropolitan area, we find effects of the distance from the dwelling to the second-order center of Sandnes, the local-area density and the distance to the closest local center similar to those in Oslo. In addition, we find a consistent tendency across all travel purposes except escorting trips of higher shares of car travel the closer to the second-order center of Forus the respondents live. As mentioned earlier, the local urban structure in and around the Forus area is very car-oriented, and this is probably a main reason for the observed higher shares of car travel among respondents living in its vicinity.

## 6.2. Longitudinal analyses

Our questionnaire data do not include information suitable for assessing changes in the shares of different travel modes due to moving. This section therefore draws only on the qualitative interview material. As mentioned earlier, we asked interviewees who had moved to a different kind of residential location (closer to or farther away from the city center and/or the closest lower-order center) about any changes in travel behavior due to moving. We also asked hypothetical questions about any expected changes in travel behavior if the interviewees were to live in a kind of residential location different from where they lived now.

### Changes in travel modes after moving

In Oslo, the interviewee household that had moved to the city center from a single-family house at the urban fringe (JR 50136 and her husband) told that they now travel much less by car than they did before the move. In Stavanger, ID 53787, who had also moved to the city center from a suburban single-family house, had changed from car to walking or biking for journeys to work, political meetings, cultural events, sport and other leisure activities. For ID 37424 too, after moving to downtown Stavanger walking had become his most common travel mode to cultural events and for visits to his partner, who is now his close neighbor. Previously, he made most of such trips by car or, in some cases, by transit. ID 53940, who moved to the inner city of Stavanger from a suburb of Trondheim, said that moving had resulted in more biking, partly because of the milder winter climate in Stavanger but also because more trip destinations were within a short distance from his new, centrally located dwelling. For the same reasons, his driving on weekdays has also been reduced.

Only two of the interviewees who have moved closer to a second-order center (one in Oslo and one in Stavanger) said that they had changed their travel modes due to the move. In Oslo, ID 52271 had recently moved from the outskirts of a second-order center town to the very core of this town. As a result, she had increased her use of transit (including journeys to work on the days when she did not have to pick up children) and reduced her use of car, reflecting that she now lived only 50 meters from the railroad station. Moreover, her trips for daily necessities shopping and other local facilities now took place on foot, which they probably did not do before. In Stavanger, the EU 52703 household (a retired couple) had replaced driving with walking when buying daily necessities as a result of moving to the downtown area of the second-order center town Sandnes. They now also traveled by train on their regular trips to visit relatives in Stavanger.

The four interviewees who had moved from central to non-central residential locations (two in each metropolitan area) had increased their motorized travel due to the move. In Oslo, ID 51437, who had moved to a neighborhood further away from the city center of Oslo as well as the closest second-order center, had shifted from walking to driving to work and from city-bike and streetcar to car travel for some other trip purposes. In Stavanger, ID 35894 had changed from walking to driving for trips to virtually all intra-metropolitan activities after moving from the inner city to a suburban neighborhood. ID 39693, who had moved from the inner city to a densified suburban neighborhood, first increased her travel by car but shifted to predominantly going by transit for journeys to work and cultural events after realizing that the transit connections from her new dwelling were quite good. When living in her previous inner-city dwelling, she used to walk to these destinations. For her son, the move had led to a higher dependence on car travel, while her husband continued to commute by car despite having moved closer to his job in the suburban Forus second-order center.

FV 51899, who had moved to a less peripheral location within Oslo than his previous dwelling, had changed travel modes to walking and biking to work, kindergarten, shops and leisure activities. His wife continued to drive to her workplace, as she did before they moved.

Although not all moving interviewees had experienced changes worth mentioning in their modes of travel, the changes that did occur were generally in line with what could be expected from theoretical considerations. ID 39693's increased use of transit after having moved from the inner city of Stavanger to a suburb might seem to run contrary to this. However, her shift to bus and train is in accordance with the 'transit-oriented' character of her new local neighborhood, which is located close to a train station and bus stop in the major transit corridor of the region.

### Expected changes due to hypothetical residential location changes

Asked about likely travel behavioral changes of a hypothetical change of place of residence to a different part of the metropolitan area, most inner-city interviewees in both cities wo reflected on this thought they would be driving more if they were to live at a suburban location. This was stated by four Oslo interviewees (IDs 10749, 11404, 50136 and ALH 50711) and the only inner-city Stavanger interviewee who talked about hypothetical changes in travel behavior (ID 53940). They all indicated that they would travel more by car, be more dependent on car travel and/or consider it more important to acquire a car if they lived in a suburb. IDs 10749 and 50711 would use transit less if living in a suburb, while IDs 11404 and 50136 would walk less. Similarly, Stavanger ID 53940 said that he would travel more by car if living in a suburb such as the one near the airport.

Five interviewees living close to a second-order center (two in Oslo and three in Stavanger) discussed hypothetical travel behavioral impacts of living in a different urban structural situation. Both the two Oslo interviewees said that moving to the downtown area would likely reduce their car travel. ID 17095 thought he would go by transit instead of by car to the large outdoor recreation forest surrounding Oslo if he lived in the inner city. ID 52271 believed that she would drive a lot no matter where she lived except in inner Oslo, where alternative transport options are good. In Stavanger, ID 40363, who had her office at home, thought her travel modes would generally not be very much affected by moving to downtown from her present dwelling close to the Forus second-order center, apart from trips to Monday morning swimming, which she would no longer need to make by car since the distance from home would be shorter. She also thought that she might no longer need to drive her daughter to swimming exercises since the swimming hall in question could be reached by a direct bus from the downtown area. The two Stavanger interviewees now living close to a second-order center and with out-of-home workplaces (IDs 33352 and 40880) believed that moving to the downtown area would entail increased car commuting, since their workplaces were both located at considerable distance from the city center. On the other hand, they considered that they would probably reduce their driving for non-work travel purposes if they moved to inner-city Stavanger.

Two Oslo interviewees living at non-central locations (IDs 16030 and 20398) thought they would travel more by transit and non-motorized modes and less by car if they lived in the inner city of Oslo, and 20398 said that she would then not bother to buy a car, which she was otherwise intending to do. In Stavanger, ID 52803 thought he would generally travel less if living in a central area such as the district immediately east of the downtown area. He thought he and his wife would then maybe need only one car, compared to their present two. Conversely, ID 32356 (who would need to drive their children to a number of activities that the kids could now reach by foot or by bike) and ID 35196 thought they would drive more if they moved to an even more peripheral part of Stavanger. Similarly, the Oslo interviewee 51437 thought his family would use their car more if they were to move to a more peripheral suburb. On the other hand, a retired suburban Oslo interviewee (ID 13896) thought he would need to make additional car trips to escort grandchildren if living centrally.

Some of the interviewees anticipated that moving to a differently located neighborhood would not entail any changes in their travel modes. This reflects that there may be considerable inertia in travel mode choice, reflecting ingrained habits, attitudes as well as particular obligations such as caretaking of old relatives or bringing children to leisure activities associated with a particular sports club, brass band or other organization. However, among the interviewees who did think their travel behavior might be affected if their residential location were to change, the anticipated travel mode changes were all in line with what could be expected from theoretical considerations.

## 6.3. Why do residential location and local built environment characteristics influence travel modes the way they do?

In order to illustrate underlying causal mechanisms that produce the statistical patterns shown in the preceding sections, we will draw on further analyses of the qualitative interview material. Among the Oslo and Stavanger interviewees, three main and seven secondary rationales (cf. section 5.3) for travel mode choice were encountered. The following three rationales were the main ones: Convenience and comfort; time saving; and frustration aversion (see below). The seven secondary rationales were physical exercise; long-lasting habits; limiting travel expenses; safety; social contact and caretaking; esthetics; and environmental concerns.

The secondary rationales are weaker than the main rationales in the sense that they are of lower importance across all interviewees, or are rationales that appear only in combination with the main rationales. However, even though they appear less frequently this does not mean that they cannot be of high importance to individual interviewees (and in these cases override the 'main' rationales). This may be the case for e.g. habit or caretaking.

Table 24 shows how the rationales influencing the interviewees' choices of transport modes contribute to strengthen or weaken the relationships between residential location and travel modes.

Table 24: Rationales for travel mode choice encountered among the 33 interviewees living in Oslo and Stavanger, and the contribution of these rationales to relationships between residential location and travel modes.

| Rationales | Contribution to the influence of proximity of the dwelling to the ***main city center*** on travel modes | Contribution to the influence of proximity to ***lower-order centers*** on travel modes |
|---|---|---|
| Main rationales | | |
| Convenience and comfort | Can give some strengthening as well as some weakening | Can give some strengthening as well as some weakening |
| Time saving | Considerable strengthening | Slight strengthening |
| Frustration aversion | Strengthening | Slight strengthening |
| Secondary rationales | | |
| Wish for physical exercise | Mostly strengthening but can also weaken | Mostly strengthening, but can also weaken |
| Long-lasting habits | Possibly slight weakening | Possibly slight weakening |
| Limiting travel expenses | Mostly strengthening but can also weaken | Slight strengthening |
| Safety | Slight weakening | Slight weakening |
| Social contact and caretaking | Slight weakening | Slight weakening |
| Esthetics | Strengthening | Strengthening |
| Environmental concerns | Can give some strengthening as well as some weakening | Can give some strengthening as well as some weakening |

Only a few of the rationales substantially affect the influences of residential location on travel modes for commuting. The tendencies of higher shares of non-motorized modes and lower share of car travel for commuting trips when living close to the main city center (cf. tables 6 and 7) are considerably strengthened by the rationale of time saving, and partly also by the rationale of frustration aversion. Most of the remaining rationales affect this tendency in a less clear way; some can strengthen as well as weaken this relationship, depending on the specific context, and a few rationales contribute to a slight weakening.

Almost none of the rationales contributes to any strong influence on commuting travel modes from living close to lower-order centers. Many of the rationales affect these relationships ambiguously, depending on the context, and the remaining ones contribute only slightly to strengthening or weakening.

The rationale of ***convenience and comfort*** includes avoiding too much physical efforts and obtaining mobile simplicity. This rationale seems to occur independently of whether the interviewees live in the inner city, in a suburb close to a lower-order center or in a non-central area. Convenience is always important and has much to say for travel mode choice. Yet, this rationale does not seem to favor any particular travel mode. For example, there are no indications that car driving is generally the most convenient mode to choose. On the contrary, the different stories interviewees tell show that it is more convenient for many of them to walk, bicycle or use transit. This rationale also includes what one may call a wish for simplicity, which is maybe the opposite rationale of frustration aversion. For the inner-city interviewees, particularly in Oslo, this rationale discourages car travel for short trips since parking is cumbersome. The transit functionality (as a combination of good access and service) of the inner city is also so convenient that car driving is often not considered. For inner-city dwellers, the convenience and comfort rationale thus encourages travel by transit, bike or on foot.

Emphasis on avoiding too much physical efforts (which is also part of this rationale) reduces the acceptable walking and biking distances and tends to make non-motorized travel likely only for those who live very close to their destinations. In this way, the convenience and comfort rationale strengthens tendencies of higher shares of walking and biking travel among inner-city dwellers and, to some extent, also among those living close to a lower-order center. However, the convenience and comfort rationale can also make some inner-city residents and residents living close to a lower-order center choose car instead of walking, biking or going by transit. It can thereby weaken the influence on travel modes of residential proximity to the main city center as well as to lower-order centers.

The ***time-saving*** rationale plays a role among all interviewees, but it impacts on travel mode choice mainly for interviewees living at suburban locations. Many of these interviewees need to overcome long distances to reach daily destinations. In order not to spend too much time, they need fast means of transportation, and they therefore consider themselves as more car-dependent. This is also evident from the questionnaire survey, where the proportions considering themselves highly dependent on car travel to reach daily destinations are 12 % and 18 %, respectively, among residents of the inner distance belt in Oslo and Stavanger, compared to 52 % and 37 % in the outer distance belts of the two metropolitan areas. Apparently, the time-saving rationale plays a less important role for inner-city residents' choices of travel modes. For these interviewees, distances are often so short that the time consumption will anyway be moderate (independent of the transport mode choice), and the time-saving rationale thus gains less weight. However, one might argue that a time-saving rationale is still at play when deciding not to use a car for inner city travel, because using a car in congested traffic, searching for a parking place and possibly needing to walk long distances from and to parking may take a considerable amount of time.

Due to the usually greater need for overcoming long distances when living far from the city center than when living in the inner city and the ensuing greater need for fast modes of transport among suburbanites, the time-saving rationale contributes strongly to the higher share of motorized transport (especially car) among suburbanites than among inner-city residents. Combined with the need to avoid too much physical efforts (cf. the convenience and comfort rationale), this makes trip distance an important condition for whether or not to travel by non-motorized modes. As can be seen in Figure 9, the likelihood of commuting by non-motorized modes is around 55 % in each metropolitan area if the commuting distance is 1 km, compared to only 5-10 % if the commuting distance is 10 km. The time-saving rationale and limitation of physical efforts therefore contribute strongly to the tendency of higher shares of non-motorized travel among those who live centrally, especially inner-city dwellers but to some extent also those living close to a lower-order center. Since there are several lower-order centers, most residents can reach such centers within a relatively moderate distance, and the time and physical efforts saved by driving instead of biking or walking is therefore less than for suburbanites' trips to the inner city.

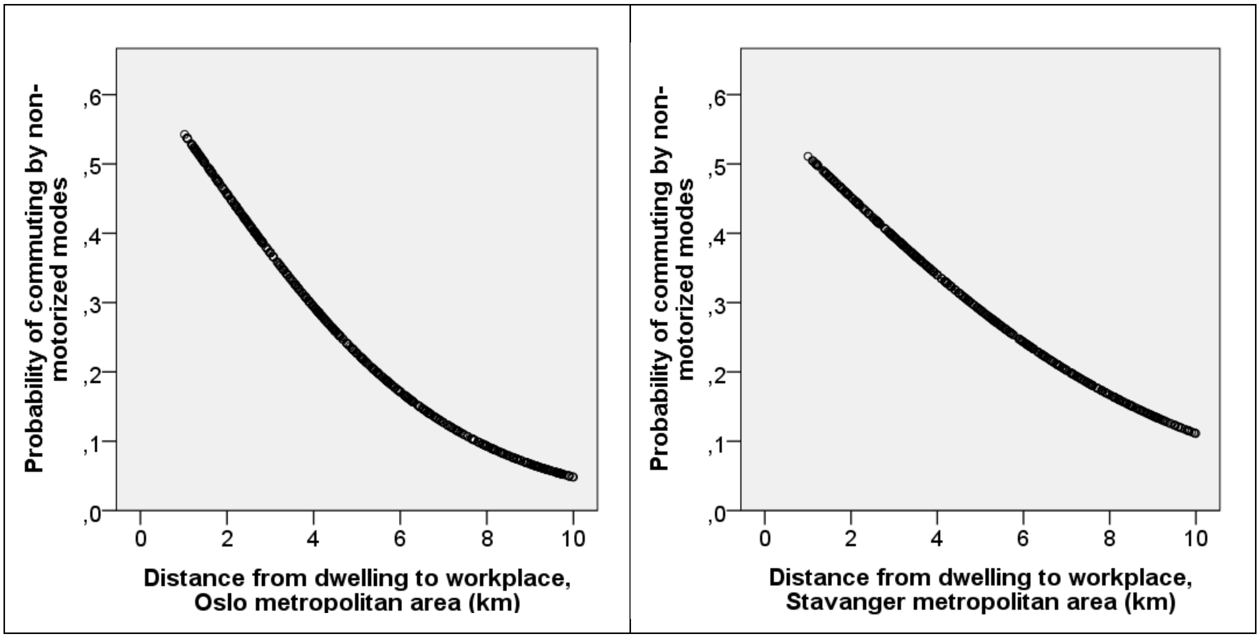


Figure 9: Likelihood of commuting by non-motorized modes among respondents working at different distances from their residence. N = 551 (Oslo, to the left) and 495 (Stavanger, to the right) workforce participants whose commuting distances range between 1 and 10 km.

The ***frustration aversion*** rationale is mainly encountered in connection with car travel and (apart from inner city cases) public transportation. Biking and walking do not seem to be experienced as frustrating. Again, there is a difference between the geographical conditions regarding this rationale. For inner city Oslo, frustration linked to mode choice has to do with driving (and owning, maintaining) a car. For interviewees living close to a lower-order center or at non-central locations, transit also seems to be a cause of frustration in some cases.

The frustration aversion rationale contributes to prevent inner-city residents from traveling by car for local trips and thus contributes to the tendency of lower shares of car travel among inner-city dwellers. A similar effect exists for residential proximity to lower-order centers, but this effect is weaker since the levels of congestion, scarcity of parking and parking costs are usually lower in these centers than in the inner city. For interviewees living at non-central locations, travel by transit is sometimes a cause of frustration, motivating these residents to travel by car rather than transit.

Among the secondary rationales, the rationale of ***physical exercise*** has similar, but opposite effects of the limiting physical efforts component of the convenience rationale. It can therefore contribute to strengthen as well as weaken the influences of residential location on travel mode choice. The same applies to the ***environmental concerns*** rationale, which can make some inner-city residents who would otherwise find walking or biking a bit too time-consuming or uncomfortable still choose these modes for environmental reasons if the destinations are not too far away. On the other hand, this rationale can also activate a potential for commuting by bike among physically fit suburbanites who would otherwise choose motorized travel modes.

***Long-lasting habits*** tend to weaken the influence on travel modes of residential proximity to the main city center as well as to lower-order centers, since such habits can make residents stick to their old travel mode habits more or less regardless of the urban-structural situation in which they live. The rationales of ***safety*** and ***caretaking/social contact*** have similar effects on the relationships between residential location and travel mode choice. Among our interviewees, these two rationales support choosing the car as travel mode instead of non-motorized modes, since the car is often perceived as more safe (especially in the inner city) and offers better conditions for private conversations than in a transit vehicle. It is also convenient when escorting small children or old, physically impaired persons. By promoting car travel regardless of residential location, the safety and social contact/caretaking rationales reduce the differences between inner-city dwellers and suburbanites in travel mode choice.

Among the interviewees, there are indications that an ***esthetical*** perspective – in the sense that travel has a recreational value – is important to some people, mainly linked to the experience of walking, be it in built environment or in nature. This can enhance non-motorized travel if the conditions for using such modes are otherwise acceptable. Since the latter is usually the case mostly in central areas, the esthetics rationale can strengthen the tendencies of higher shares of non-motorized travel among inner-city residents and (to a lesser extent) those living close to a lower-order center.

Finally, the rationale of ***limiting travel expenses*** can trigger some additional inner-city dwellers to use non-motorized modes, in a way similar to the effect of the physical exercise and environmental rationales. On the other hand, the travel expenses rationale can make some suburban residents who would otherwise pay toll fees for driving to their workplace in the inner city choose transit instead. The rationale of limiting travel expenses can also, in some cases, make residents who are not much in need for car travel in their daily life sell their car, or one of the cars if there are more than one car in the household. Since the conditions enabling this typically exist more often in the inner city than in the suburbs (cf. Cao et al., 2017), the travel expenses rationale strengthens the tendency of lower shares of car commuting among inner-city residents also through its influence on car ownership levels.

Overall, most of the rationales contribute to strengthen tendencies of lower shares of car travel and higher shares of non-motorized (and partly transit) travel among inner-city dwellers than among suburbanites. Some rationales can sometimes strengthen and sometimes weaken the influences on travel mode choice from living close to the city center, depending on the context. A few rationales tend to weaken slightly, although not directly counteract, the main effects on travel modes of the distance from the dwelling to the city center. The contributions of the rationales to travel mode effects of living close to lower-order centers are less pronounced. These contributions partly counteract each other, resulting in small overall influences on commuting travel modes from living close to a lower-order center.

Some of the rationales can also explain why car travel plays a more important role for intra-metropolitan travel in Stavanger than in Oslo. In Oslo, there is higher overall congestion level on the roads, better transit provision, toll fees on the roads leading to the inner city and lower and more expensive parking opportunities than in Stavanger. Rationales of time-saving, comfort/convenience as well as money-saving therefore make up greater incentives against car driving in Oslo than in Stavanger. These circumstances may in their turn contribute to the development of different 'transport cultures' in the two regions which, among others, give rise to the formation of different kinds of travel habits among young people growing up in each region.

# 7. Comparison across travel purposes and metropolitan cases

In the preceding sections, we have examined the importance to the amount of transport and the proportions accounted for by different transport modes of 1) the location of the dwelling relative to the main center and other centers within a metropolitan area, 2) characteristics of the local residential neighborhood, and 3) individual characteristics of the residents.

The two investigated metropolitan areas have different numbers of inhabitants. The continuous urban area of Oslo (i.e. the morphological city) has about one million inhabitants, while the continuous urban area of Stavanger comprises barely a quarter as many - about 215,000 inhabitants. The morphological city of Oslo settlement thus has significantly larger area-wise extent than the morphological city of Stavanger, and similar differences exist in the sizes of the two functional urban regions. Population density is also higher in Oslo than in Stavanger - respectively 36.7 and 29.0 inhabitants per hectare within the continuous urban areas. Moreover, Stavanger has a more weak developed transport infrastructure - especially when it comes to public transit.

## Metropolitan size is important to travel distances and modal split

The above-mentioned differences imply that inhabitants of the Oslo region commute on average farther than Stavanger region inhabitants do. For non-work trips, there are only small differences in average in travel distances (see Table 25). Partly because transit provision is normally higher in bigger than in smaller cities,  the proportions of travel accounted for by different transport modes are also substantially more car-oriented in Stavanger region than in the Oslo region (see Table 26). The greatest difference between the two cities in travel modes occur among residents living near the city center. The difference in modal shares is smaller at medium distances from the center, and the proportion of car travel is nearly identical at distances far from the city center.

Table 25: Average distances from home to different trip destinations among respondents from Oslo and Stavanger (km).

| | Oslo | Stavanger |
|---|---|---|
| Average distance between dwelling and workplace | 12.5 | 7.8 |
| Average distance to a number of non-work facilities visited | 1.6 – 6.3 | 1.6 – 8.9 |

Table 26: Proportions of journeys to grocery stores traveled by car among Oslo and Stavanger respondents living at different distances from the main centers (km)

| Distance from dwelling to the main center of Oslo (km) | Oslo | Stavanger | Distance from dwelling to the main center of Stavanger (km) |
|---|---|---|---|
| <6 | 14.3 | 36.5 | <5 |
| 6-13 | 41.7 | 54.4 | 5-9 |
| 13-22 | 54.0 | 61.9 | 9-15 |
| 22+ | 65.1 | 66.2 | 15+ |

## Urban structures are important to travel distances

The different urban structures of the two regions have given rise to large and interesting variations in daily traveling distances among the inhabitants. As mentioned in section 2, a large number of studies within the field of land use and transport have found that metropolitan residents travel on average longer daily distances the further away from the city center they live. Our respondents from Oslo comply with this pattern. Residents of the inner zone (0-6 km from the city center) commute less than a third as long distance to their workplace as residents do who live in the metropolitan periphery (more than 22 km from the city center). This pattern is less clear in Stavanger. In Stavanger, the average commuting distance of inner-zone residents is similar to the distance that inner-zone Oslo respondents travel to reach their workplace (about 7 km), while residents in the outermost zone of Stavanger have an average commute distance only 50 percent longer than their inner-zone counterparts. And while commuting distances increase steadily as the distance between the residence and the city center of Oslo increases, commuting distances are stable or declining as the distance from the dwelling to the city center of Stavanger increases up to 15 km (see Table 27 and Figure 10). On average, the shortest commutes occur among workforce participants living in the zone 9-15 km from the city center of Stavanger. Most of these respondents live within easy reach of the Forus area and its major concentration of jobs. Their commuting distance of 5.8 kilometers on average is significantly lower than the mean commuting distance for Stavanger metropolitan respondents as a whole (7.8 km), see Table 25.

Table 27: Average commuting distance among workforce participants in Oslo and Stavanger living at different distances from the main centers (km).

| Distance from dwelling to the main center of Oslo (km) | Oslo | Stavanger | Distance from dwelling to the main center of Stavanger (km) |
|---|---|---|---|
| <6 | 7 | 7 | <5 |
| 6-13 | 10 | 7.5 | 5-9 |
| 13-22 | 14 | 5.8 | 9-15 |
| 22+ | 21.5 | 10.5 | 15+ |

The trips for non-work purposes exhibit to some degree the same pattern in both regions as observed for commuting in the Oslo region. It appears, however, from Table 28 that the variation in journey length is substantially smaller for these purposes than for commuting. Urban structure shows its importance, but it is not as strongly involved in determining the length of the shopping and service trips as it is for journeys to work.

Table 28: Average length of trips to grocery stores and service providers in Oslo and Stavanger.

| Distance from dwelling to the main center of Oslo (km) | Purchasing daily necessities | | Visiting service provider | | Distance from dwelling to the main center of Stavanger (km) |
|---|---|---|---|---|---|
| | Oslo | Stavanger | Oslo | Stavanger | |
| <6 | 1.09 | 1.25 | 2.39 | 2.46 | <5 |
| 6-13 | 1.41 | 1.55 | 3.69 | 3.78 | 5-9 |
| 13-22 | 1.61 | 1.72 | 3.60 | 3.79 | 9-15 |
| 22+ | 2.23 | 2.11 | 4.00 | 4.32 | 15+ |

Residential location exerts greater influence in Oslo than in Stavanger on the distances traveled to purchase daily necessities. In Oslo, we find a significant increase in the frequency of purchasing groceries more than 2 km away from the home with increasing residential distance from the city center. In Stavanger, the influence of the distance to the main center is far weaker (see Table 29). Closer analysis shows that this is largely due to the relatively greater access to other larger and smaller local centers outside the main center in Stavanger region than in the Oslo region.

Table 29: Percentages of respondents living at different distances from the city centers of Oslo and Stavanger who normally do their grocery shopping more than 2 km from home

| Distance from dwelling to the main center of Oslo (km) | Oslo | Stavanger | Distance from dwelling to the main center of Stavanger (km) |
|---|---|---|---|
| <6 | 7 | 7.5 | <5 |
| 6-13 | 18 | 19 | 5-9 |
| 13-22 | 21 | 28 | 9-15 |
| 22+ | 40 | 24 | 15+ |

## Urban structures are also important for modal choice

Transport mode choice varies depending on where in the metropolitan urban structure the individual lives both for work trips and when traveling to non-work activities (see Table 31). The closer to the main city center respondents live, the less frequently they travel by car to reach the relevant facilities. As shown in table 30, there are different effects in the two metropolitan areas of residential location on the proportions of car trips both for commuting and when traveling to non-work activities - as was also registered for travel distances (see above).

Table 30: Car share on commuting and travel for grocery shopping in Oslo and Stavanger (percent).

| Distance from dwelling to the main center of Oslo (km) | Car share commuting | | Car share grocery shopping | | Distance from dwelling to the main center of Stavanger (km) |
|---|---|---|---|---|---|
| | Oslo | Stavanger | Oslo | Stavanger | |
| <6 | 12 | 39 | 14 | 37 | <5 |
| 6-13 | 29 | 49 | 42 | 54 | 5-9 |
| 13-22 | 45 | 44 | 54 | 62 | 9-15 |
| 22+ | 52 | 62 | 65 | 66 | 15+ |

## Urban structural characteristics mostly show greater effects than individual characteristics of respondents on traveling distances and mode choice

Of course, it is not just the urban structure (spatial context) that determines how far respondents travel and with which modes. Individual characteristics of the residents also contribute considerably to the variation in travel behavior. However, for most of the investigated aspects of travel behavior, residential location and local area built environment characteristics show greater effects than the investigated demographic, socioeconomic and residential preference variables. For some aspects of travel behavior, particularly in Stavanger region, the latter variables still turn out with greater effects, but in these cases too, the residential location and local built environment variables show considerable effects.

## Overall travel distances are longer, and travel distances and modes show greater variation with residential location in Oslo than in Stavanger

Both for commuting (Figure 10) and the seven investigated non-work purposes (Figure 11), respondents living in the periphery of the metropolitan area travel longer distances than their inner-city counterparts, but this gradient is considerably less steep and consistent in Stavanger than in Oslo, as noted above.

Although the non-motorized shares of the distance traveled are higher among inner-city residents than among suburbanites, the actual number of kilometers that respondents travel on foot or by bicycle varies little with the distance between the dwelling and the city center. There is also little variation in non-motorized travel distances between the two regions. In Oslo, those who live in the central parts of the region commute the fewest km by non-motorized modes per week, while in Stavanger those who live farthest from the center of Stavanger commute on average the longest distances on foot or by bike (see Figure 10). For non-work purposes, those who live in central parts of each of the metropolitan areas produce the longest total weekly distance traveled by bicycle and on foot. The weekly trip length on foot and by bicycle decreases with increasing distance from the main center in the two regions, but mostly in Oslo (see Figure 11). In Oslo, non-motorized travel distances for non-work travel thus show a center-periphery gradient opposite to the one found for commuting.

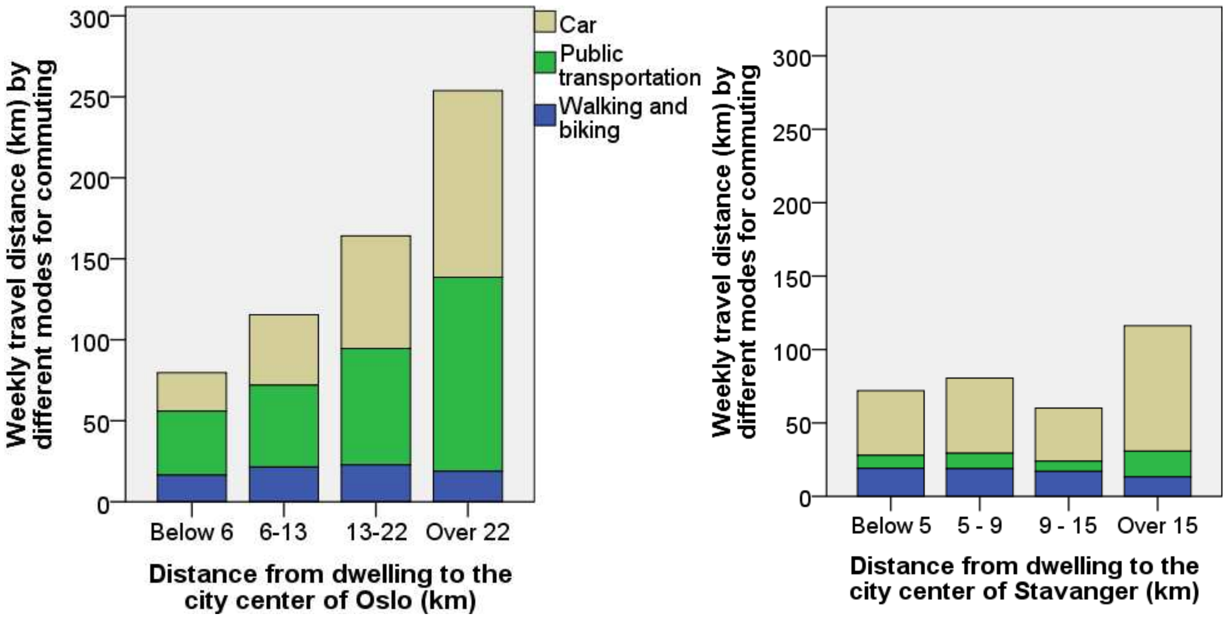


Figure 10: Weekly commuting distances by different modes[21] among respondents living at different distances form the city centers of Oslo (to the left, N = 1156) and Stavanger (to the right, N = 787).

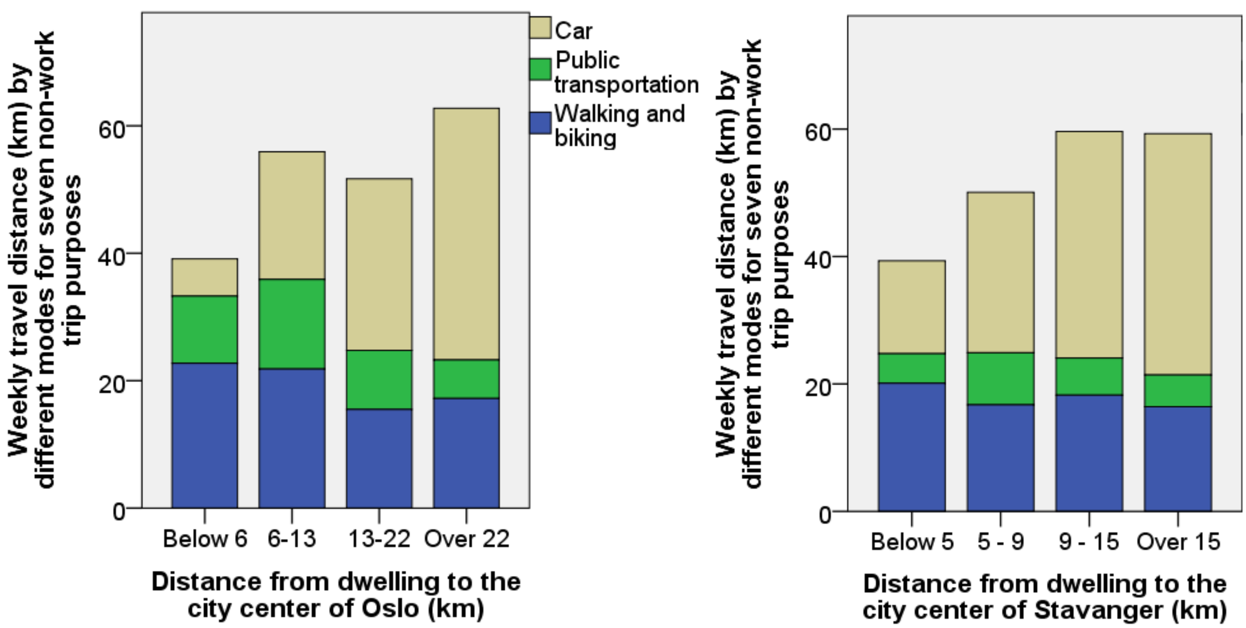


Figure 11: Weekly travel distances by different modes for seven non-work purposes among respondents living at different distances form the city centers of Oslo (to the left, N = 1639) and Stavanger (to the right, N = 1119).

Travel distances by transit show some interesting variations that are not visible when looking only at the shares of trips by transit. In Oslo, distances traveled by transit for commuting increase substantially with increasing residential distance from the city center. A similar pattern appears in Stavanger, yet with an exception among respondents living in the distance belt closest to the Forus area. These tendencies reflect the greater need for motorized travel when living far away from the main workplace concentrations. However, for trips to non-work activities, the center-periphery gradient for travel distances by transit is reversed for the three outer distance belts in both regions. Respondents living in the second-innermost zone travel the longest distances by transit for non-work purposes, with declining distances traveled by transit the further away from the city centers the dwellings are located. In both metropolitan areas, the distances traveled by transit are still lower in the central zone than in the inner suburbs, reflecting shorter overall travel distances as well as higher shares of non-motorized travel among these respondents.

Travel distances by car depend heavily on residential location in Oslo. Both for travel to work and for non-work purposes, the proportion of the distance traveled by car increases substantially with increasing residential distance from the main city center. In Stavanger too, such a center-periphery gradient appears for non-work purposes, although not as steep as in Oslo. Travel distances for car commuting do, however, vary little with distance from the center of Stavanger for residents up to 15 km and even drop a bit in the distance belt 9-15 km where the Forus employment center is located (Figure 10). Among residents of the outermost parts of the region, car commuting is still more extensive than in the remaining three distance belts.

When commuting and the seven investigated non-work trip purposes are seen together (Figure 12), travel distances by car show very clear differences depending on how centrally or peripherally the residence is located, especially in Oslo. Suburban Oslo residents living more than 22 km from the city center travel on average nearly six times as long distances by car for commuting and seven intra-metropolitan non-work purposes as their counterparts living less than 6 km from the city center do. In Stavanger, travel distances by car are about two and a half times longer on average among respondents living more than 15 km from the city center than among respondents living closer to the city center than 5 km.

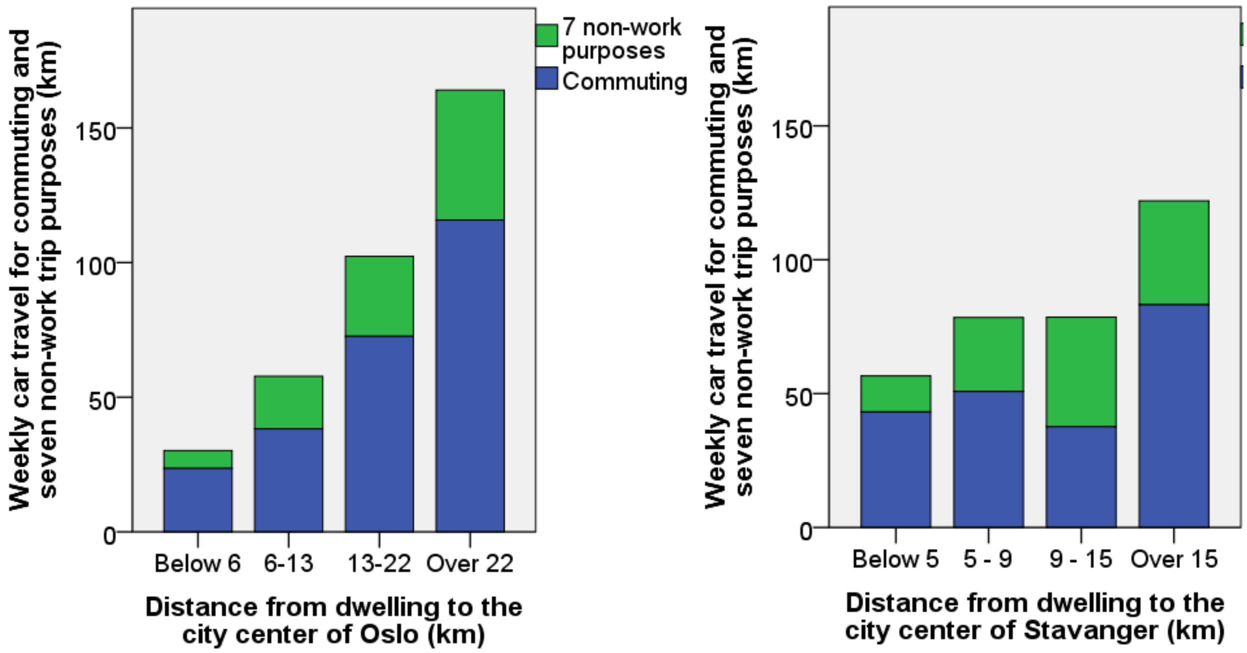


Figure 12: Weekly travel distances by car for commuting and seven non-work purposes among workforce participants living at different distances form the city centers of Oslo (to the left, N = 1061) and Stavanger (to the right, N = 718).

These differences are practically the same when controlling statistically for differences in income, gender, household structure, residential preferences and the other investigated demographic and socioeconomic variables. Table 31 shows such controlled effects of different residential location and local built environment characteristics on different aspect of travel behavior in each region: total travel distance by car for commuting and seven non-work trip purposes, and the shares of car and non-motorized modes, respectively, of this traveled distance. The distance between the dwelling and the main city center showed considerable effects on all these aspects of travel behavior in both metropolitan areas. Local-area density showed effects on all travel behavior variables except the total travel distance by car in Oslo. The distance to the closest second-order center showed effects on car travel distance in both metropolitan areas (with a particularly strong effect in Stavanger) and a moderate effect on the share of non-motorized travel in Oslo. Finally, we see a slight and rather uncertain tendency of increased share of non-motorized travel among Oslo respondents living at a distance from the closest local center, probably because the walking or cycling trips of these respondents to local destinations are longer than if they lived close to the local center. Apart from this, the distance to the closest local center shows no effects on any of the travel behavior variables in either of the two metropolitan areas.

Table 31: Effects of residential location and local built environment characteristics[22] on different aspects of travel behavior among respondents from Oslo and Stavanger. Unstandardized and standardized (in bold italics) regression coefficients, levels of significance (p-values) in parentheses.

| Aspect of travel behavior | Weekly distance traveled by car for commuting and seven non-work purposes | | Car share of distance traveled by car for commuting and seven non-work purposes | | Walk/bike share of distance traveled by car for commuting and seven non-work purposes | |
|---|---|---|---|---|---|---|
| Metropolitan area | Oslo N=991 | Sta-vanger N=667 | Oslo N=956 | Sta-vanger N=648 | Oslo N=958 | Sta-vanger N=653 |
| Distance to the main city center (km) | 4.72 ***0.401*** (0.000) | 4.39 ***0.324*** (0.000) | 0.0087 ***0.234*** (0.000) | 0.0095 ***0.175*** (0.000) | -0.0069 ***-0.255*** (0.000) | -0.0093 ***-0.192*** (0.000) |
| Distance to the closest second-order center (km) | 1.35 ***0.058*** (0.063) | 4.92 ***0.282*** (0.000) | n.s. | n.s. | -0.0047 ***-0.087*** (0.009) | n.s. |
| Inhabitants per hectare within the 1 km² grid square of the dwelling | n.s. | -0.475 ***-0.072*** (0.064) | -0.0010 ***-0.112*** (0.001) | -0.0024 ***-0.092*** (0.018) | 0.0017 ***0.253*** (0.000) | 0.0022 ***0.092*** (0.026) |
| Distance to the closest local center | n.s. | n.s. | n.s. | n.s. | 0.0056 ***0.058*** (0.096) | n.s. |

## Transport rationales are largely similar across regions and residential locations

Our qualitative interviews aimed at enabling us to say something about why location of the dwellings in the urban structure and local density are significant for how far people travel when commuting and for non-work trips. Based on the interviews, we identified seven rationales for the interviewees' location of their activities. Three of these – minimizing the friction of distance, limiting other travel-related expenses and choosing the best facility - appear as important to choices of workplace locations. The rationale of choosing the best facility emerges as most important, and more important for men than for women. Most workforce participants seek employment that is interesting, well-paid and with a good working environment. If there are opportunities to choose between different satisfactory job opportunities, the rationale of minimizing the friction of distance will be activated, and with expenditure savings as a subsidiary condition. We find no differences between the metropolitan areas in the importance attached to different transport rationales.

Overall, we find that commuting distances, due to active rationales, depend more on how far the individual lives from the main workplace concentrations of the regions than how close to or distant from various other centers the dwelling is located. In predominantly monocentric Oslo, there is high likelihood that inner-city residents will be able to satisfy the rationale of choosing the best facility as well as minimizing the friction of distance and expense savings at the same time. For Oslo suburbanites, these concerns have to be traded off against each other. In Stavanger region, the conflict between 'best facility' and 'distance minimizing' is less tough. Residents on the metropolitan periphery live much closer to the main employment centers in Stavanger than in Oslo, both because the urban region covers a smaller geographical area and because the employment centers exist at different locations across the region.

When choosing locations for non-work activities, some rationales apply in addition to those operating when choosing workplace location: maintaining social contacts, variety seeking, place attachment and caretaking. However, we do not find any difference between the two metropolitan contexts in the influences of the various rationales.

We examined changes in travel patterns among residents who had moved from one dwelling to another within each of the two regions. Moving away from the center leads to increased traveling distances for commuting as well as non-work activities, while moving towards the center has the opposite effects. No regional differences appear here. Neither does propensity of working at home now and then (a day or three a week) show any correlation with the type of region or the location of the residence within the metropolitan area.

# 8. Discussion

In the literature on impacts of built environment characteristics on travel behavior, it has repeatedly been claimed that residential location exerts only a weak influence on travel (Kitamura et al., 1997; Bagley & Mokhtarian, 2002; Van Wee, 2013; Woods & Ferguson, 2014) or that the status of knowledge is inconclusive due to difficulties in disentangling the true effect of residential location from that of residential self-selection (Van Wee, 2013; Mohktarian &Cao, 2008; Coevring et al., 2015). By applying a sophisticated mixed-methods approach, our research finds strong evidence of substantial influences of residential location and local built environment characteristics on travel behavior. Although the knowledge drawn from the questionnaire survey as well as from the interviews is necessarily fallible (see Næss, 2017 for a discussion of the latter), we maintain that our mixed-methods approach provides a better base for drawing conclusions about our research topic than what would have been with a traditional approach relying only on statistical analyses. This is especially so because questionnaire answers, narratives of the interviewees and analytical models could be judged not only against what might logically or theoretically seem plausible, but also against other empirical evidence from the same geographical context and time.

Our qualitative interviews have disclosed residents' rationales for activity locations and travel mode choice, and have thereby illuminated important causal mechanisms through which residential location influences travel behavior. By including of a number of residential preference variables in the statistical analyses, we have shown that there are strong influences of residential location on travel behavior when controlling for residential self-selection. Those who live close to the main city center tend to travel shorter distances and use the car the least, while those living in the outer parts of the city region tend to travel longer distances and make significantly more car trips.  This is particularly the case for commuting. For non-work travel purposes, we also find considerable influences on some aspects of travel from the local-area density (but the density of local areas is in itself heavily influenced by how far from the city center the neighborhood is located). Our analyses of respondents who have moved show consistently that moving outward from the city center leads to longer traveling distances and higher shares of car travel for commuting as well as non-work purposes, whereas moving inward toward the city center has opposite effects.

The study counters claims that the influences of compact development features on driving are small (Stevens, 2017). It also directs attention to urban form characteristics at the city or metropolitan scale as generally more important than neighborhood-scale built environment to travel distances and modes, in line with earlier studies by Mogridge (1985), Newman & Kenworthy (1989b), Martamo (1995), Headicar (2000), Hartoft-Nielsen (2001), Zegras (2010), Zhou & Kockelman (2008), Milakis et al. (2008), Ewing & Cervero (2010), Elldér (2015) as well as our own studies in Danish, Chinese and Portuguese cities. For a given city, our findings therefore points at densification close to the main urban center as a more favorable strategy in a sustainable mobility perspective than 'decentralized concentration' (Holden, 2007) and 'new urbanism' (Ellis, 2010; Piatkowski & Marshall, 2014). In a polycentric urban region, the travel-reducing effect of living close to the city center is reduced compared to a more monocentric urban region. A polycentric urban structure also tends to generate higher shares of car travel since jobs will then be generally easier to access by car. Our comparison between Oslo and Stavanger as well as the effects of workplace location on modal split for commuting found in each city region underpins this.

Our findings in polycentric Stavanger that commuting distances are more influenced by the location of the dwelling relative to a suburban main employment center than to the historical city center is theoretically plausible and supported by the interviewees' rationales for choosing where to work. The Stavanger findings about residential location and commuting distances also resonate with the results from a study of Greater Oporto, Portugal, where travel distance by car was influenced primarily by the distance from the dwelling to the closest main regional retail center, which is a kind of second-order commercial and employment center (Næss, 2015b). Proponents of polycentric urban development might argue on this ground that travel distances among suburbanites could be reduced if more workplaces and service facilities were decentralized. While it is true that non-specialized facilities such as grocery stores, primary schools and kindergartens should preferably be located close to the residential neighborhoods they are intended to serve, decentralization of specialized facilities will only lead to longer travel distances. This is especially so for specialized workplaces. Decentralizing of workplaces to a suburban sub-center may reduce commuting distances among the *local* residents, but most companies recruit their employees from a much larger geographic area than the local neighborhood. As shown in Table 2, commuting distances in both city regions tend to increase the farther from the main city center the workplace is located. Moreover, a polycentric structure such as exemplified by Stavanger appears to facilitate car travel to a greater extent than in a city where the historical urban core is the dominant center. At least this is the case if the additional centers are considerably easier accessible by car (like the Forus area in Stavanger) than the historical center.

The overall longer commuting distances in Oslo than in Stavanger illustrate that there is no advantage from a sustainable mobility perspective in centralizing a large part of a country's population in the largest city regions. Although a high population size can provide the passenger base for better transit provision, the spatial extension of large cities and the wider catchment areas of their workplaces counteract the gains in terms of lower shares of car travel. Thus, while centralization appears favorable at an intra-metropolitan scale, national-scale centralization from medium-sized to large metropolitan areas does not[23].

As mentioned in Section 2, much of the literature on built environment and travel frames the relevant urban structural variables in a scheme of a number of D's, originating from Cervero & Kockelman's (1997) concept of the three D's and later expanded to five D's (Cervero, 2009) and even seven D's

(Ewing & Cervero, 2010). We think this is not a very fruitful taxonomy as it tends to direct the research interest toward local-scale rather than city- or metropolitan-scale built environment characteristics. In our opinion, future research on the built environment and travel should not adhere to the 'D' agenda. The most relevant factors of influence found in the present study as well as in other Nordic studies are within one of the Ds, namely destination accessibility, which operates at different geographic levels but is reduced into one D, and density. In the D terminology, the latter variable is confined to neighborhood-scale density although density for the city as a whole is theoretically a more important variable. Other neighborhood characteristics whose names do not happen to start with a D may also be relevant, such as atmosphere (Stefansdottir, 2018) and variety of detail.

In our study, we find that the local-area population density is significant in both metropolitan areas for transport mode choice, but not for daily travel distances. Another D-word emphasized in much of the literature on built environment and travel is diversity (Ewing & Cervero, 2010; Stevens, 2017). Diversity, or land use mix, can obviously reduce trip distances, but for this to happen there needs to be a critical mass of facilities. This is especially crucial for workplaces. In the metropolitan areas of Oslo and Stavanger, the reason for the shorter traveling distances and less car usage among inner-city dwellers is that these residents have access to a wide range of jobs, education institutions, stores, service facilities, cultural arenas and exercise opportunities in their immediate environment. Especially for less specialized functions, such as grocery stores, interspersion with residential buildings facilitates short trip distances from the dwellings. However, if the critical mass of facilities is too small, it is unlikely that local residents will necessarily use the local facilities. Particularly, this is so for workplaces, due to the high degree of specialization of professions as well as enterprises and the fact that being employed in a particular job depends on the double requirement that the employee must find the workplace attractive while at the same time the employer must find the job-seeker to be the best qualified applicant. Diversity in the form of jobs-housing balance in suburban centers where the number of jobs does not reach the necessary critical mass is therefore likely to result in considerable crisscross travel by commuters living in other parts of the metropolitan area. Our qualitative interviews as well as the statistical material clearly indicates this.

Yet another D-word receiving much attention in the American literature in general as well as in the meta-analyses by Ewing & Cervero (2010) and Stevens (2017) is design, which in this context refers to the design of the street network. Characteristics of local street patterns were not included as a variable in the statistical part of our investigation. We have argued earlier (Næss, 2011) that it is implausible that variations in local street designs (for example between grid patterns versus non-grid patterns of street networks) would exert much influence on daily or weekly vehicle kilometers traveled. Street network design and connectivity could theoretically be expected to exert some influence on the choice of travel modes for short trips such as trips to the local grocery store, but it appears much less plausible that local street design would have much bearing on commuting distances or the amount of car travel for commuting. In line with this, none of the participants of our qualitative interviews indicated that the local street pattern was important to their travel behavior – this feature of the built environment was hardly mentioned at all.

# 9. Concluding remarks

This paper set out to investigate influences of residential location on commuting and non-work travel across the different metropolitan contexts of predominantly monocentric Oslo and predominantly polycentric Stavanger. Applying a combination of quantitative and qualitative research methods and conducting cross-sectional as well as longitudinal analyses, the study offers stronger evidence of causal influences than in most previous studies on the built environment and travel. Through the qualitative work, we have identified motivations, justifications and considerations that interviewees draw on when they decide where to carry out different kinds of activities and which travel modes to use. These transport rationales make up important links in the causal mechanisms through which the built environment influences travel. The qualitative interviews have also illustrated processes where residents who have moved from one kind of residential neighborhood to a different one have often changed their travel behavior due to the changed urban structural situation of the dwelling.

In both metropolitan areas, commuting distances tend to increase the further the respondents live from the region's main job concentrations. In Oslo, where a large part of the jobs is concentrated in its inner parts, the length of journeys to work tends to increase sharply with increasing distance between the residence and the city center. In Stavanger, commuting distances depend primarily on the distance from the dwelling to the suburban employment center Forus and only secondarily on its distance from the city center of Stavanger. For non-work intra-metropolitan trip purposes, traveling distances in both metropolitan areas depend mainly on the distance from the residence to the main city center and on the density of the local area.

In both metropolitan areas, residents living close to the city center make a higher proportion of trips by non-motorized modes and a lower proportion of car trips than their suburban counterparts do. This applies to commuting as well as non-work travel. This reflects inner-city dwellers' usually shorter trip distances and more difficult driving conditions in the central than in the peripheral parts of the metropolitan areas. Although transit provision is considerably better in the central parts of the metropolitan areas, the shares of travel by transit do not show great differences between inner-city and suburban residents, since those living in the central parts of the regions often prefer non-motorized modes to transit. However, despite their frequently short commuting distances, residents living close to the Forus employment center in Stavanger do not make fewer commutes by car than those who live further away from Forus. This reflects the very car-oriented local urban structure of the Forus area, which was developed mainly in the 1970s and 1980s.

Commuting and intra-metropolitan non-work trips seen together, travel distances by car in both metropolitan areas tend to increase the further from the main city center the dwelling is located. There is no tendency of intra-metropolitan non-work trips counteracting or outweighing the differences between inner-city dwellers and suburbanites in car travel for commuting. On the contrary, car travel for intra-metropolitan non-work trips is also considerably higher among suburbanites. This gradient is sharper in Oslo than in Stavanger. Overall travel distances, especially for commuting, are also longer in Oslo than in Stavanger, reflecting Oslo's larger population size and larger urbanized area, the deficit of jobs in outer parts of the region and facilitation for car travel through motorways and high-frequency local trains, metro lines and express buses.

Although the different population and area sizes of the two metropolitan areas obviously play an important role, monocentricity versus polycentricity also seems to foster different travel behavioral patterns. Monocentric structures are associated with longer traveling distances but lower proportions of car travel than in a polycentric structure.

We consider the main results of the study as relevant in particular to a Nordic context (Scandinavia, Finland and Iceland), but also to Northern and Western Europe more generally. This study and our earlier studies have shown high similarity in individuals' rationales for activity location and travel mode choice across quite different European and Asian contexts. This suggests high generality in the basic mechanisms through which urban form influences travel behavior, at least in cities above a certain level of affluence and job specialization. The strength of the impact of each built environment characteristic will obviously vary with the specific city context, as we also observe when comparing the findings in Oslo with those in Stavanger.

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## Notes

[1] For example, the response rate is similar to a much-cited American study (Kitamura et al., 1997), where a net response rate of 11% was achieved.
[2] Due to high multicollinearity, the distance to Sandnes and the distance to Forus could not be included in the same regression model.
[3] We considered including ‘proximity to workplace’ among the residential preference variables of commuting distances and modes. If this had been a workplace preference variable, such an inclusion might make sense since a high score on this variable would indicate that the respondent emphasized distance minimizing above finding the optimal (in terms of salary, job content etc.) job. But as a residential preference variable it just signifies that the respondent prefers to live close to the actual or potential workplace, which on average implies a residential location close to the city center of Oslo or close to the Forus area in Stavanger. In our opinion, the fact that residents living close to these employment concentrations appreciate their shorter commuting distance is not a valid reason for subtracting the effect of this appreciation from the effect of residential location otherwise estimated. If included in the regression model, the ‘proximity to workplace’ residential preference variable comes out with implausibly strong effects for commuting distances as well as the modal shares of transit and walk/bike. However, the effects of the residential location variables remain about equally as strong as, or only slightly weaker than without the inclusion of the ‘proximity to workplace’ residential preference variable.
[4] As mentioned earlier, distance to Forus and distance to Sandnes could not both be included in the same regression model. In the analysis of population densities, we included distance to Sandnes and in the analysis of job densities the distance to Forus. If we had instead made the opposite choices, Adjusted $R^2$ values of each model would drop substantially.
[5] The transformation that gives the highest Adjusted R2 value was made by means of the following function: centdisttransformed=(EXP(centdist * 0.11 - 2.7) - EXP( -(centdist * 0.11 - 2.7))) / (EXP(centdist * 0.11 - 2.7) + EXP( -(centdist * 0.11 - 2.7))) - (0.00068 * (centdist - 42) * (centdist - 42) - 2.8).

[6] The transformations that give the best fit for the relationships between residential location and commuting when controlling for demographic, socioeconomic and attitudinal variables may also be different from the transformations that give the best fit for the bivariate relationships.
[7] In the Oslo case, mean values of the distance from the dwelling to the city center were 24 % and 35 % higher, respectively, than their median values. In the Stavanger case, the corresponding mean values were 10 % and 17 % higher, respectively, than the median values.
[8] In the Oslo case, Adjusted $R^2$ values for the analysis with commuting distance as the dependent variable were 0.098, 0.209 and 0.120, respectively, when commuting distances, the built environment variables, and both commuting distances and built environment variables were logarithmically transformed. For comparison, Adjusted $R^2$ is 0.288 when neither commuting distances nor distances to centers are transformed. In the Stavanger case, the corresponding Adjusted $R^2$ values were 0.087, 0.201 and 0.085, respectively, when commuting distances, distances from residence to the four center categories and both commuting distances and distances to centers were logarithmically transformed. When neither commuting distances nor distances to centers are transformed, Adjusted R2 is 0.245.
[9] N.s = not significant at the 0.1 level. The following variables showed effects not meeting the required significance level in any of the metropolitan areas and were therefore excluded from the final regression model in each city region: distance from the dwelling to the closest local center; distance from the dwelling to the closest second-order center (in Oslo); local-area population density; number of household members 7-17 years of age; education level; possession of driver’s license for car; and residential preference factors “favorable investment”, “shopping opportunities” and “local amenities”.
[10] In these figures, 24 respondents in Oslo and 17 in Stavanger who have their permanent workplace at home are excluded.
[11] Frequencies of trips to non-work out-of-home activities were calculated from the respondents’ answers to questions of how often they traveled to the locations for each of the seven activity categories by non-motorized modes, car, and public transport, respectively. For each activity and mode, the answer alternatives were: Not at all, less than 1 day a month, 1-3 days a month, one day a week, 2-3 days a week, and 4 or more days a week. When

calculating frequencies of activities and travel modes, the answers were recoded using the median of each interval into the following number of times per month: 0, 0.5, 2, 4.33, 10.83 and 21.66, respectively.

[12] These distances were calculated from the respondents' answers to questions about how far away from home the various activities usually take place. For each activity, the answer alternatives were: Activity not relevant, less than 2 km, 2-5 km, 5-10 km, and over 10 km. "Activity not relevant" was recoded into "system missing". The remaining answers were recoded into a new variable with the following values: 1 km, 3.5 km, 7.5 km and 15 km. Because of the crudeness and uncertainty about the representativeness of these values with the ranges given in the original answer alternatives, especially for the highest category which has no upper limit, we have in the cross-sectional statistical analyses of travel modes used a dichotomous dependent variable, where the distance to the activity in question has been recoded into 'less than 2 km' and '2 km or above'. In the longitudinal analyses and in the analyses of travel distances by different modes in Section 7, modal shares calculated from the above-mentioned recoding have still been used.

[14] N.s = not significant at the 0.1 level. The following variables showed effects not meeting the required significance level in any of the metropolitan areas and were therefore excluded from the final regression model in each city region: distance from the dwelling to the closest local center; gender; possession of driver's license for car; and residential preference factors "local amenities", "physical exercise" and "favorable investment".

[15] N.s = not significant at the 0.1 level. The following variables showed effects not meeting the required significance level in any of the metropolitan areas and were therefore excluded from the final regression model in each city region: distance from the dwelling to the Sandnes second-order center (in Stavanger); possession of driver's license for car; education level; number of household members below 7 years of age; number of household members 7-17 years of age; number of household members 18 years or older; and residential preference factors "local amenities", "physical exercise" and "favorable investment".

[15] Only around 40 % of Oslo respondents and around 60% of Stavanger respondents answered the questions about changes in travel behavior due to moving. We have no reason to assume that those not answering differ substantially from the remaining recent movers in the ways in which travel distances have changed due to changes in residential location, although respondents experiencing only small or no changes in travel behavior due to moving might be overrepresented among the non-answerers.

[16] All regular car commuters in Oslo apart from one respondent had a driver's license for car. Including driver's license for car in the analysis caused inconsistent parameter estimates for this variable. It was therefore omitted in the analysis of regular car commuting.

[17] N.s = not significant at the 0.1 level. The following variables showed effects not meeting the required significance level in any of the metropolitan areas and were therefore excluded from the final regression model in each city region: distance from the dwelling to the closest local center; distance from the dwelling to the closest second-order center (in Oslo); gender; number of household members younger than 7 years; number of household members 18 years or older; and residential preference factors "shopping opportunities" and "good for children".

[18] N.s = not significant at the 0.1 level. The following variables showed effects not meeting the required significance level in any of the metropolitan areas and were therefore excluded from the final regression model in each city region: distance from the dwelling to the closest local center; distance from the dwelling to the closest second-order center (in Oslo); local-area population density; age; personal gross income; number of household members 7-17 years; driver's license for car; and residential preference factors "local amenities, "shopping opportunities", "favorable investment" and "proximity to transit".

[19] N.s = not significant at the 0.1 level. The following variables showed effects not meeting the required significance level in any of the metropolitan areas and were therefore excluded from the final regression model in each city region: gender; number of household members younger than 7 years of age; number of household members 18 years or older; workforce participation; and residential preference factor "local amenities".

[20] N.s = not significant at the 0.1 level. The following variables showed effects not meeting the required significance level in any of the metropolitan areas and were therefore excluded from the final regression model in each city region: logarithm of distance from the dwelling to the Sandnes second-order center (in Stavanger); age; number of household members younger than 7 years of age; and workforce participation.

[21] In figures 10, 11 and 12, data about frequencies of different travel modes have been transformed by recoding the original frequency values (not at all, less than 1 day a month, 1-3 days a month, one day a week, 2-3 days a week, and 4 or more days a week) into the following number of times per month: 0, 0.5, 2, 4.33, 10.83 and 21.66,

respectively. Similarly, the original values for distances from home to non-work activities (activity not relevant, less than 2 km, 2-5 km, 5-10 km, and over 10 km) were recoded into system-missing, 1 km, 3.5 km, 7.5 km and 15 km, respectively. This way of calculating travel distances to non-work activities ignores that different trip purposes may be chained into one tour. For example, many respondents probably sometimes purchase daily necessities on their way home from work, and following children to kindergarten (but usually not to leisure activities) usually takes place in connection with the journey to and from work. Such trip-chaining is probably less common among inner-city than among suburban residents. On the other hand, the recoding of 'less than 2 km' into 1 km as the lowest distance value for non-work activities probably tends to overestimate distances to non-work activities somewhat for inner-city respondents, since the stores, kindergartens and other non-work facilities used by inner-city residents are more often than for suburban residents located closer to home than 1 km.

[22] N.s. = not significant at the 0.1 level. The effects are controlled for the following demographic, socioeconomic and residential preference variables (Cao et al., 2017): gender; age; education level; personal gross income; number of household members below 7 years of age; number of household members 7-17 years; number of household members 18 years or older, possession of driver's license for car, and six residential preference indices: "shopping opportunities", "good for children", "favorable investment", "public transportation", "local amenities" and "physical exercise".

[23] Finnish commuting statistics illustrate this. While median commuting distances are 7-15 km in the municipalities of Helsinki metropolitan area, the median is typically 2.5-4.5 km in the most peripheral parts of Finland (Piela, 2013).