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Residential location, workplace location and car driving in four Norwegian cities

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Abstract

Based on a study in four Norwegian cities (Oslo, Stavanger/Sandnes, Bergen and Trondheim) differing in size and center structure, this article illuminates how residential and workplace location, local-area density and transit accessibility influence different aspects of travel behavior. We find strong effects of residential and workplace distance to the city center on overall driving distances and commuting distances. We also find clear effects of local area densities around residences and workplaces on the choice of car as a travel mode, along with less pronounced effects of the distance from dwellings and workplaces to the city center. In the cities with the best developed transit provision, we also see clear effects of transit accessibility at the residence on the propensity of choosing the car as travel mode. The results provide strong support of Norwegian national policies of urban densification as a planning strategy to curb the growth in urban motoring. However, although the influences of urban structure on travel show many similarities across the four cities, there are also important differences reflecting variations in center structure (predominantly mono- or polycentric) and population size. The magnitude of the influences of various urban structural characteristics on travel behavior are thus highly context-dependent.

1. Introduction

Using data from the four largest cities in Norway (Oslo, Bergen, Stavanger/Sandnes and Trondheim), this article illuminates how the location of the residence relative to the main city center and lower order centers, local-area density, transit accessibility and (for commuting) workplace location influence the inhabitants' overall car driving distance, commuting distances and their propensity of choosing car driving as the dominant travel mode. By comparing the influences of urban structural characteristics on travel behavior in cities differing in their size and center structure, and investigating influences of both residential location and workplace location across these contexts, the article brings knowledge about hitherto under-researched aspects of the nexus between land use and travel. While statistical analysis of travel survey data is the main approach of this article, we also draw on qualitative interviews carried out as another part of the same research project (Næss et al., 2018). This qualitative material has enabled us to identify important causal mechanisms underlying the correlation patterns found in the statistical analysis.

The concept of 'city' as referred to in this article is the city as a morphological object, i.e. the continuous urban area, regardless of administrative borders. The city, as understood in this article, thus covers a smaller geographical area than the functional urban region but a larger area than the urban land within a single municipality in situations where the urban area extends across municipal borders. Our definition of the morphological city is in line with a common Nordic definition according to which the distance between buildings must normally not exceed 50 meters (except parks, graveyards, sports fields, water

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bodies, industrial sites, etc.). Demarcated this way, Oslo had 976,000 inhabitants, Bergen 253,000, Stavanger/Sandnes 213,000 and Trondheim 178,000 inhabitants in 2016. Oslo is the most densely developed of the cities with a population density in 2016 of 36.7 persons per hectare, compared to 29.2 in Bergen, 29.0 in Stavanger/Sandnes and 30.9 in Trondheim (Statistics Norway, 2017).

There are differences between urban areas as to how different functions are distributed over the urban area. Christiansen et al. (2016) have developed a so-called monocentric bias indicator. The aim of this indicator is to tell something about how concentrated or decentralized jobs and housing are distributed over the city landscape. If the respective functions are evenly distributed over the area, the indicator approaches 0, while a concentrated urban region has a bias indicator value closer to 1. Figure 1 shows that Stavanger/Sandnes differs from the three other cities, as it has a clearly polycentric structure³. The city is a conurbation of two previously separate cities (Stavanger and Sandnes), with a large suburban employment center (Forus) developed since the 1970s located in-between. The three other cities have a different distribution of housing and workplaces over the city area than Stavanger/Sandnes. However, these three are also different. However, it may be reasonable to characterize three of the regions as relatively monocentric, while Stavanger/Sandnes appears relatively polysentric.

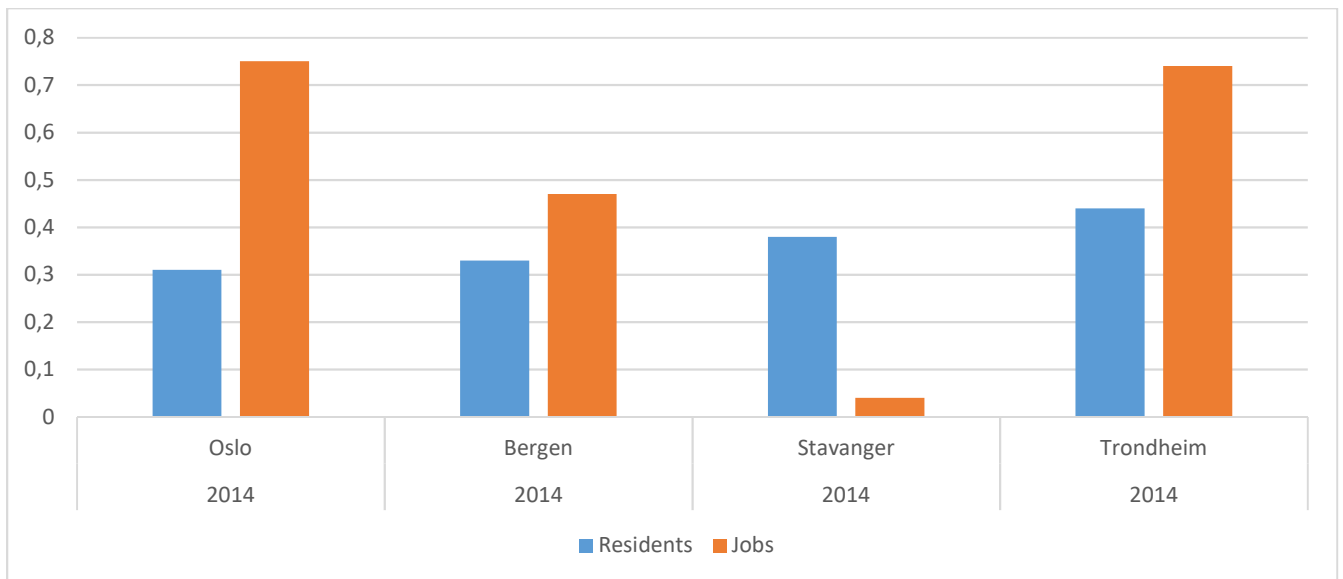


Figure 1: Monocentric bias indicators for dwellings and workplaces in the metropolitan areas Oslo, Stavanger/Sandnes, Bergen and Trondheim

Oslo and Bergen have clearly monocentric structures. Trondheim also has one dominating center but also a suburban 'relief center' developed from the late 1960s and onward.

As can be seen in Figure 2, the built-up area of Bergen takes a ribbon-like form, winding around a number of high mountains. Compared to Bergen, Oslo, Stavanger/Sandnes and Trondheim all have a more compact geometrical shape, although the urban areas of these cities also stretch out from the

³ This indicator might not in itself distinguish unambiguously between a polysentric and a sprawled urban structure. However, the large difference between Stavanger and the three other cities in employment distribution cannot be attributed merely to different degrees of sprawl. As mentioned above, there is great similarity in population densities between the three medium-sized cities (Stavanger, Bergen and Trondheim), ranging from 29 to 31 persons per hectare. Instead of representing sprawl, the low monocentric bias value for jobs in Stavanger thus reflects the strongly polycentric distribution of jobs over the urban area.

inner city in broad bands along the main transport arteries. Figure 2 also shows, as mentioned above, the much more polycentric distribution of jobs in Stavanger/Sandnes than in the other three cities.

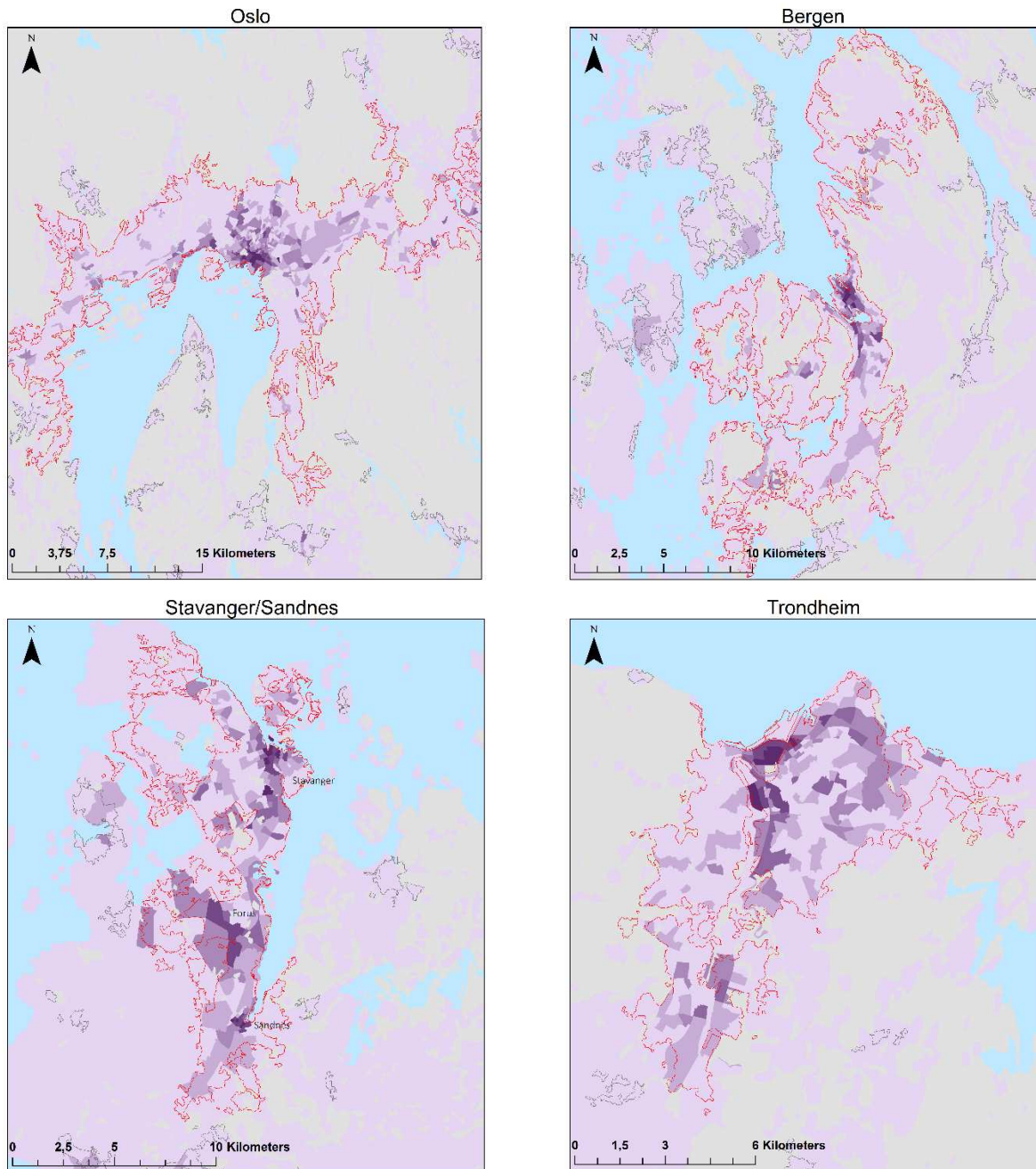


Figure 2: Urban area demarcations and job densities within different parts of the urban areas of Oslo (upper left), Bergen (upper right), and Stavanger/Sandnes (lower left) and Trondheim (lower right). Dark colors signify high densities. In order to highlight variation within each city, the color scales differ between the four cities, reflecting the generally higher densities in Oslo. Maps by Anja Fleten Nielsen, Institute of Transport Economics.

The strong concentration of jobs to areas close to the city centers of Oslo, Bergen and Trondheim and the clearly more polycentric job location pattern in Stavanger/Sandnes is also evident from Figure 3.

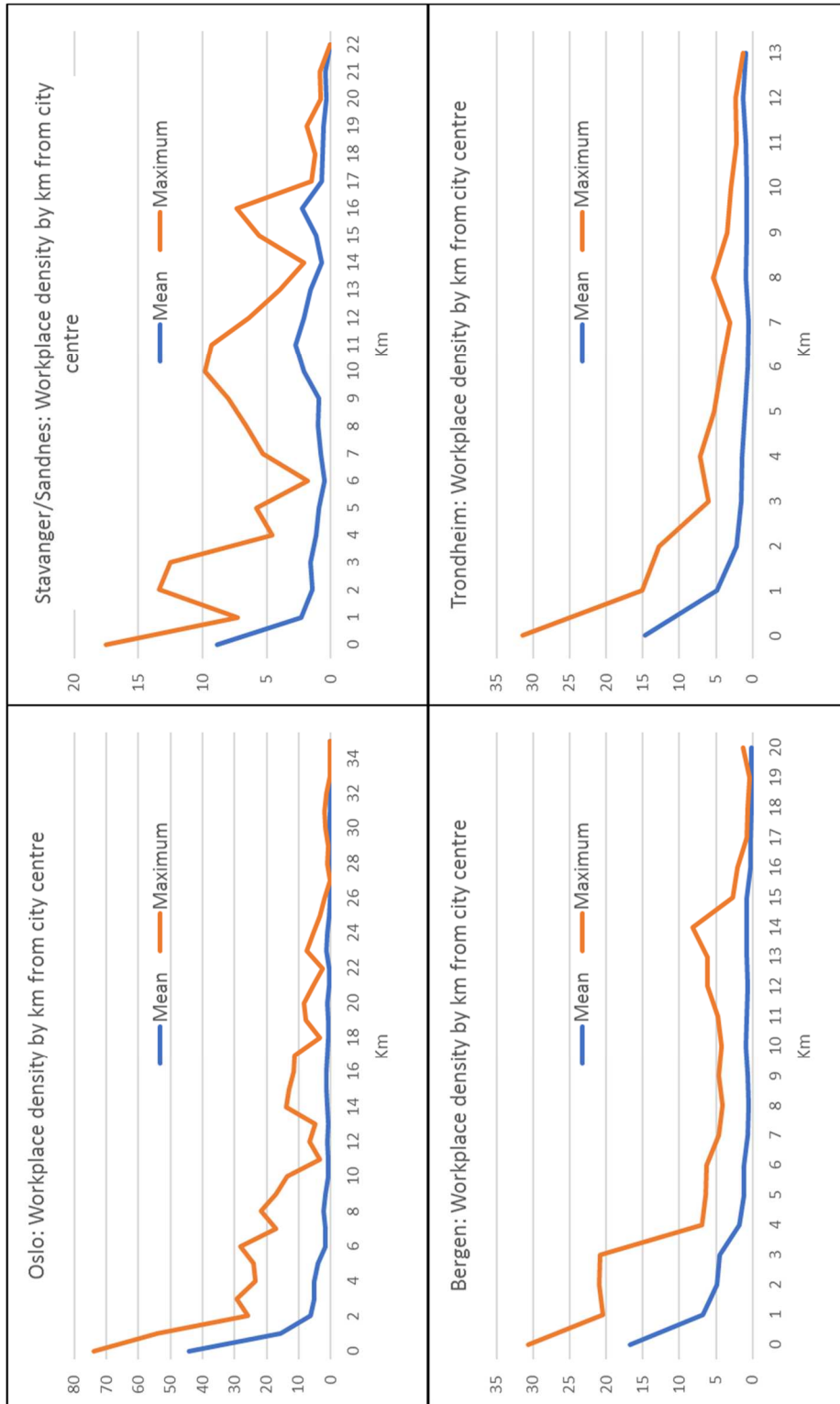


Figure 3: Job densities at different distances from the city centers of Oslo, Stavanger/Sandnes, Bergen and Trondheim. Thousands of employed persons per square kilometer.

Oslo has a comprehensive public transportation system including metros, streetcars, high-frequency commuter trains, express commuter buses, ordinary city buses. Transit provision in the other three cities is less extensive, consisting mainly of buses but with a high-frequency commuter train line in Stavanger, a major light rail line in Bergen and a less important light rail line in Trondheim. Compared to 'bike cities' such as Copenhagen and Amsterdam, the provision of bike paths and cycling facilities more generally is more modest in all four cities. Stavanger has maybe somewhat better conditions for cycling since the terrain is not as hilly as in the other three cities. Winters in Stavanger and Bergen are also mild with little snow. Toll rings around the inner districts have existed in Oslo, Bergen and Trondheim since around 30 years ago and in Stavanger since 2001.

Theoretically, residential location in central and dense parts of a city could be expected to lead to shorter travel distances and a lower proportion of trips by car, since many potential trip destinations will be available within a short distance from home, often within acceptable walking or biking distance. With a high density, the passenger base for a high level of mass transit service will also be better, while driving may be more cumbersome due to frequent crossings, narrow streets and scarcity of parking opportunities. These attributes are likely to be particularly important to commuting mode choice, since most journeys to work take place in the peak period when the accessibility by public transit to the dense inner-city areas is at its best while the accessibility by car is at its worst due to congestion. Arguing along the same lines, it is to expect that the polycentric city region will give better conditions for commuting by car.

Whereas most research into influences of land use on travel behavior (especially in the USA) has focused on neighborhood-scale built environment characteristics, the main focus of this article is on the influence of the location of the dwelling within the overall spatial structure of the city (although we also investigate impacts of local densities). Since most daily-life trips in modern cities have destinations outside the confines of the residential neighborhood, overall travel distances are likely to be influenced more by the location of the dwelling relative to the main clusters or potential trip destinations than by the internal characteristics of the residential neighborhood. Such clusters of potential trip destinations are normally closely aligned with the center structure of the city, with the largest cluster in and adjacent to the main city center. This does not mean that local built environment characteristics do not also influence travel behavior. The density of a local neighborhood influences the population base for public transport and hence the average walking distance to transit stops and the frequency of departures. However, local-area densities (and built form characteristics associated with density such as transit level of service, parking availability and availability of local grocery stores) are heavily influenced by the location of the neighborhood within the urban structure. In all our four investigated cities, there is a clear center-periphery gradient in neighborhood densities, with the highest densities in the inner city and the lowest densities in the outer suburbs.

At least in Norway, the decision about where to build comes before the decision about how to build⁴. For economic (Alonso, 1960) and cultural (Fishman, 1996) reasons, higher densities are more accepted at central than at peripheral locations. Deciding whether to densify or expand the city outward also

⁴ In Norway, the location of new development is decided first in the municipal master land use plan differentiating between developmental areas and areas where no construction is to take place. The density and design of the planned development is decided in subsequent, more detailed local development plans before final building permits are given based on architectural drawings. The local development plans must be in accordance with the municipal master land use plans, and although exemptions are sometimes given, there is normally conformance between the two tiers of planning.

largely decides whether to build apartments or single-family houses. The distance of a residential neighborhood to the city center therefore has an indirect influence on travel behavior via the neighborhood-scale characteristics, in addition to its direct effect (see Figure 4).

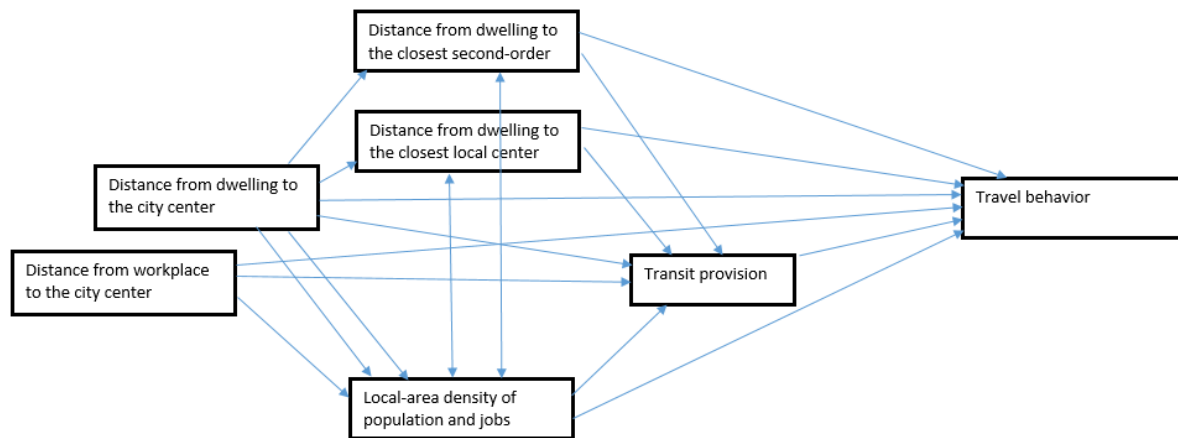


Figure 4: Assumed causal relationships between different built environment characteristics and travel behavior.

In the next section, we review the literature on the influences of residential location, neighborhood density and workplace location on travel behavior. Section 3 presents the analytical framework, data and methods of the study. Section 4 presents the empirical results, whereas section 5 discusses the underlying causal mechanisms and compares the results across the four city contexts and with the international literature. Section 6 brings some concluding remarks.

2. Literature review

Since the early 1980s, a large number of studies have attempted to identify and estimate the effects of built environment characteristics on travel behavior (for overviews, see Saelens & Handy, 2008; Ewing & Cervero, 2010; Næss, 2012; Stevens, 2017). These studies differ in terms of geographic scale, the built environment characteristics focused on, as well as the aspects of travel behavior investigated. Most commonly, the built environment characteristics are investigated with the urban structural situation of the dwelling as the point of departure. As mentioned in the introductory section, many studies have focused mainly on local built environment characteristics, especially in the USA, addressing four of the D's often referred to in research on land use and transportation (Cervero & Kockelman, 1997; Ewing & Cervero, 2010): (land use) Diversity, (street) Design, (local-area) Density, and Distance to transit. Besides local-area density and transit accessibility, the present study focuses on the fifth D: Destination accessibility, which may refer to the local scale as well as at a city-wide scale ("regional destination accessibility"). Two residential location variables of the present study belong to the latter category (distance from the dwelling to the city center and to the closest second-order center), whereas one variable (distance to the closest local center) falls within the "local destination accessibility" category. The analysis of commuting distances includes one regional destination accessibility variable (distance from the workplace to the city center) and local-area density at the workplace. In the following, we will review the literature addressing the influences of the built environment characteristics investigated in the present study.

Regional residential destination accessibility. A large number of studies, mainly in Europe, but also in America, Australia and Asia, have found that residents of suburban neighborhoods far away from the city center travel longer overall distances, longer distances by car and make a higher proportion of their travel by car, compared to their inner-city counterparts. With a few exceptions, most of these studies have used monocentric cities or city regions as cases. Apart from the Nordic countries, effects of residential distance to the city center on at least one of the above-mentioned travel behavior variables have been found in London and Paris (Mogridge, 1985), New York and Melbourne (Newman & Kenworthy, 1989), Austin (Zhou & Kockelman, 2008), Athens (Milakis et al., 2008), Hangzhou (Næss, 2010), and Santiago de Chile (Zegras, 2010). In the Nordic countries, such effects have been found in Bergen (Duun et al., 1994), earlier studies in Oslo (Næss et al., 1995; Røe, 2001), Frederikshavn (Næss & Jensen, 2004), Aalborg (Nielsen, 2002), Copenhagen (Næss, 2005, 2009 and 2011), Gothenburg (Eldér, 2014, 2017), as well as in Oslo and Stavanger/Sandnes (Næss et al., 2017 a and b, based on a different data set than that of the present study).

Local residential destination accessibility. Internationally, studies investigating local residential destination accessibility have usually not at the same time controlled for regional residential destination accessibility. Such studies have also normally focused on the frequency of walking trips (e.g. Handy, 1993; Handy & Clifton, 2001). A few studies have investigated effects of the distance to medium-level (second-order) urban centers on overall travel distances or driving distance. Some of these studies (e.g. Nielsen, 2002; Næss, 2005) show somewhat longer overall travel distance and distance traveled by car as a result of living far from the closest second-order urban center, but these effects are smaller than those of the distance to the main city center. Other studies show no significant effects (e.g. Eldér, 2017). In one study, investigating the polycentric Greater Oporto area, the effect of the distance to the closest retail center was still found to be larger than that of the distance to the main city center (Næss, 2015).

Density of residential neighborhoods. Several studies internationally have investigated travel behavioral impacts of local-area density. Ewing & Cervero's (2010) identified nine studies investigating population densities and six addressing job densities, and found that the average effects of population density were very small and that of job density practically non-existing. On the other hand, a study by Lee et al. (2011) of the four largest Californian metropolitan areas showed a tendency, albeit not very strong, of higher shares of transit and lower car shares among commuters living in dense neighborhoods. In the Nordic countries, studies in Copenhagen (Næss, 2005), Frederikshavn (Næss & Jensen, 2004) and earlier studies in Oslo (Næss et al., 1995; Holden & Norland, 2004), found no effect of residential neighborhood density on travel distances when accounting for the distance from the residences to the city center. One of the studies in Oslo did, however, find a tendency of a higher share of travel by public transit in neighborhoods with a high density of dwellings (Næss et al. 1995).

Workplace destination accessibility. Although the influence of workplace location on travel behavior has been subject to considerably less attention than impact of residential location, several studies around the world have investigated how workplace location influences commuting distances and travel modes. Most often, these studies have shown moderate effects on commuting distances from moving workplaces closer to or farther away from the main center of the city region. Whether intra-regional decentralization leads to longer or shorter commutes seems to depend much on the specific geographical and socio-economic context of the city. However, while the impacts on commuting distances are mixed, research shows a clearer pattern for the impacts of workplace location on

commuting travel modes, where workers at suburban workplaces tend to commute more often by car and less often by mass transit than their counterparts working at inner-city workplaces do. Such patterns have been found, among others, in the San Francisco Bay area (Cervero & Landis, 1992), Oslo (Næss & Sandberg, 1996), Copenhagen (Hartoft-Nielsen, 2001), the Dutch Randstadt area (Schwanen et al. 2001), Trondheim (Strømmen, 2002), Atlanta and Boston (Yang 2005), Lisbon (Vale, 2013) and Kunming (Yang et al., 2016). On the other hand, studies in Beijing indicate little or no effect of job decentralization on the proportion of car commuting (Yang et al., 2012; Lin et al., 2015).

Density of workplace neighborhood. Fewer studies have investigated the specific impact of the density of the workplace neighborhood on commuting travel modes. These studies show quite consistently higher shares of car commuting and lower shares of transit commuting to jobs located in a low-density than in a high-density neighborhood. Examples of this include Oslo (Næss & Sandberg, 1996), the San Francisco bay area (Cervero & Wu, 1997), the four largest Californian metropolitan areas (Lee et al., 2011) and respondents from a nation-wide travel survey in the USA (Chatman, 2003).

Diverging claims exist. Despite the above-mentioned evidence, some authors still maintain that effects of built environment characteristics on travel are small or even non-existing (e.g. Bruegmann, 2005; Echenique et al., 2012; Van Wee, 2013; Woods & Ferguson, 2014). However, studies showing non-existing or modest influences of built environment characteristics on travel are rather uncommon. Such studies are sometimes based on model simulations where the results inevitably depend on the assumptions fed into the model (e.g. Echenique et al. 2012), or they investigate other aspects of the built environment than those addressed in the present paper. Sometimes, authors denying the influence of land use on travel rely on old secondary sources that have later been refuted (e.g. Bruegmann, 2005).

Many of the more recent studies on land use influences on travel have been concerned about residential self-selection based on travel attitudes as a source of bias. The present study does not include attitudinal variables and may thus be a target of criticism for not taking such bias into due consideration. However, in the contemporary Norwegian urban context, where the demand for inner-city housing is higher than the supply of such dwellings, it does not seem plausible that travel-related residential self-selection will lead to exaggerated estimates of the effects of residential location on travel behavior. Results from earlier Nordic studies show that the estimates of the effects of residential distance to the city center and the other built environment characteristics investigated in this article are very similar regardless of whether or not control is made for residential preferences (Næss, 2009), and that a number of other concerns are more important than travel attitudes when people choose where to live (Wolday et al., 2018). More fundamentally, the fact that people to some extent self-select into areas matching their transport attitudes is in itself a demonstration of the influence of residential location on travel behavior. If there were no such effect, people who prefer to travel short distances and/or by non-motorized modes might as well choose to live in the outer suburbs at a long distance from the clusters of workplaces and service facilities of the inner city (Næss, 2014).

Very few studies have simultaneously investigated how residential and workplace built environment characteristics influence commuting behavior (Lee et al, 2011 is one of these few studies). Given the very different spatial distribution of workplaces in our four case cities, investigating the interplay between residential and workplace location on commuting distances and modes will be of particular relevance to the comparison of built effects across metropolitan contexts.

Based on the literature review and the above considerations, the present article aims to bring new knowledge by investigating the following research questions:

- Which residential location and density characteristics are most influential on overall traveling distances, driving distances and the share of travel distance carried out by car?
- What are the relative influences of residential location and workplace location, respectively, on commuting distances?
- How do the effects of residential location and local-area density vary across cities of different size, with different center structures and with differing transportation infrastructure?

3. Analytical framework

In line with the above-mentioned research questions, the dependent variables of our statistical analyses will be the following aspects of travel behavior: Total daily car driving distance, whether or not car driving accounts for at least 90% of daily travel distance, one-way commuting distance, and whether or not commuting is carried out by car (see Figure 5). In order to illuminate the research questions, six different multivariate analyses have been carried out, focusing on:

- effects of residential urban structural attributes on overall car driving distance
- effects of residential urban structural attributes on the likelihood of traveling predominantly as a car driver
- effects of residential urban structural attributes on commuting distances
- effects of workplace urban structural attributes on commuting distances
- effects of residential urban structural attributes on the likelihood of commuting by car
- effects of workplace urban structural attributes on the likelihood of commuting by car.

Since the dependent variables of the second, fifth and sixth models are dichotomous, we use binary logistic regression in these models, whereas ordinary linear regression is used in the remaining models.

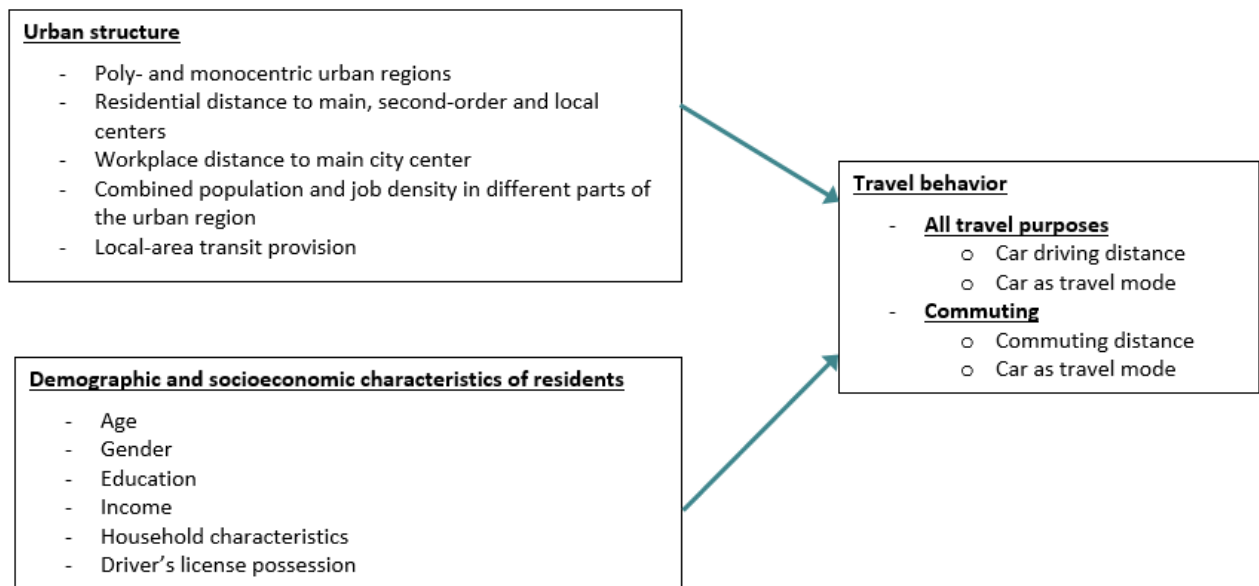


Figure 5: Key aspects investigated in the study.

The following urban structural variables are included in the multivariate analyses:

- Distance⁵ from the dwelling to the main city center
- Distance from the dwelling to the closest second-order center (except in Trondheim, where such centers only exist at a long distance from the city)⁶.
- Distance from the dwelling to the closest third-order center
- Distance from the workplace to the main city center
- Local-area combined job and population density⁷
- Transit accessibility at the residence⁸

Besides the urban structural variables, the multivariate analyses include the following demographic, socioeconomic and attitudinal control variables: education level, annual personal income, possession of driver's license, number of children in household (0-17 years), gender, and age.

The analyses of travel for all purposes include all trips ≤ 50 km starting and/or ending within the morphological city, excluding respondents who did not make any journey on the day of investigation. The analysis of total car driving distance includes only trips carried out as car driver. The analyses of the likelihood of traveling predominantly as a car driver distinguishes between persons who have or have not traveled at least 90% of the distance on the day of investigation as car driver. The analyses of commuting includes one-way journeys to work of ≤ 50 km starting or ending within the morphological city.

Data on travel behavior were obtained from the Norwegian National Travel Survey 2013/2014. Table 1 shows descriptive statistics for the variables used in the study.

Table 1: Descriptive statistics of the variables of the study.

Variables	Mean, percent			
	Oslo	Stavanger/ Sandnes	Bergen	Trondheim
Distance residence to city centre <u>(km)</u>	10.2	8.7	8.1	5.6
Distance residence to 2nd order centre <u>(km)</u>	5.1	8.1	4.3	33.4
Distance residence to 3rd order centre <u>(km)</u>	1.9	2.5	2.8	2.2
Distance workplace to city centre <u>(km)</u> ^{a)}	7.8	9.2	6.7	4.7
Local density (residence)	8.8	4.2	5.3	5.0
Local density (work place) ^{a)}	19.9	6.7	10.3	9.5
Public transport services (residence)	5.8	3.6	4.6	4.9

⁵ Distances to the various categories of centers are measured as the fastest driving route along the road network. This also applies to commuting distances as dependent variables.

⁶ In the city region of Trondheim, the closest second-order centres comparable to those in Oslo, Bergen and Stavanger (Stjørdalshalsen and Orkanger) are located 34 km and 42 km, respectively, away from the city centre of Trondheim.

⁷ Measured within a 750 x 750 m square centered on the 250 x 250 m square to which the address belongs.

⁸ Departures per hour within 1.5 km from the dwelling between 07 and 09 on weekdays.

University degree (percentage)	62.9 %	56.0 %	56.2 %	56.9 %
Income (NOK 100,000 / year)	4.4	4.7	4.1	3.8
Driver's license (percentage)	80.4 %	84.1 %	80.7 %	84.4 %
Number of children in the household	0.6	0.8	0.6	0.6
Gender (percentage of women)	50.6 %	47.3 %	51.9 %	49.6 %
Age	43.4	43.1	43.5	42.9
Km as driver per day	8.9	13.2	10.6	8.0
At least 90 % of the distance as car driver (percentage)	28.1 %	43.2 %	33.1 %	30.3 %
Distance residence to workplace ^{a)}	9.5	7.9	8.2	6.3
Percentage using car to work (driver) ^{a)}	37.3 %	59.8 %	46.1 %	41.1 %
Transport mode single trips (percentage):				
Walk	28.2 %	21.1 %	28.8 %	29.1 %
Bicycle	4.9 %	7.7 %	3.6 %	9.6 %
Car driver	39.0 %	56.8 %	44.1 %	42.5 %
Car passenger	5.9 %	7.3 %	7.9 %	7.0 %
Public transport	21.4 %	6.3 %	14.7 %	11.0 %

^{a)} Mean for commuters.

4. Results

4.1. Travel for all purposes

Daily car-driving distance

Table 2 shows the effects of the various built environment, demographic and socioeconomic variables on the daily distance traveled as car driver. In all four cities, respondents living far from the city center tend to drive considerably longer daily distances than their inner-city counterparts. Controlling for the other variables, Oslo respondents living in an outer suburb (about 20 km from the city center) drive on average 4 km longer daily distance than the respondents living closest to the city center. In Stavanger/Sandnes, Bergen and Trondheim, the difference between outer suburbanites and inner-city dwellers is of a similar magnitude (4-5 km in each city), but since these cities are considerably smaller than Oslo and cover a smaller area each, the urban fringe is closer to the city center than in Oslo (typically around 10 km from the city center in Bergen and Trondheim). The center-periphery gradient in driving distance shown in Table 2 (as well as in other aspects of travel behavior presented in the subsequent five tables) is therefore steeper in Stavanger/Sandnes, Bergen and Trondheim than in Oslo.

Table 2: Daily distance traveled as car driver. Standardized regression coefficients (Beta).

	Oslo	Stavanger/Sandnes	Bergen	Trondheim
Distance residence to city center	0.082***	0.127***	0.123***	0.109***
Distance residence to 2nd order center	0.068***	0.094***	0.010	---
Distance residence to 3rd order center	0.011	0.036	0.025	0.037*
Density of population and jobs (residence)	-0.066***	-0.042*	-0.066***	-0.062**
Public transport services (residence)	-0.055***	0.000	-0.009	-0.039*
University degree (dichotomy)	0.031***	0.003	0.041**	0.019
Annual personal income	0.058***	0.106***	0.097***	0.069***
Driver's license (dichotomy)	0.208***	0.278***	0.212***	0.184***
Number of children in the household	0.054***	0.029	0.026	0.062***
Gender (female = 1, male = 0)	-0.108***	-0.091***	-0.112***	-0.084***
Age	-0.022**	-0.053**	-0.020	0.021
N / R ² (adjusted)	7315 / 0.115	2415 / 0.127	2669 / 0.133	3057 / 0.097

* p<0.10. ** p<0.05. *** p<0.01

We also find a tendency in all four cities of shorter driving distance the higher is the combined population and job density of the local area. This effect is fairly strong in Oslo, Bergen and Trondheim, but not as strong as the effect of the distance from the dwelling to the city center. An effect of density can also be seen in Stavanger/Sandnes, albeit weaker and less certain than in the other cities.

In Oslo and especially in Stavanger/Sandnes, respondents living close to a second-order center also tend to drive shorter daily distances. No similar effects are apparent in Bergen or Trondheim. In Oslo and to some extent also in Trondheim, respondents living in an area with a high level of transit service tend to drive shorter distances by car. Transit provision does, however, not show any effect on driving distance in Bergen or Stavanger/Sandnes.

As one might expect, we find a strong effect across the cities of possession of driver's license. Female respondents also tend to drive less than males in all four cities, while respondents with a high income tend to drive more. We also see tendencies in some of the cities of longer driving distances among respondents who belong to a household with children (Oslo and Trondheim), hold a university degree (Oslo and Bergen), or are young (Oslo and Stavanger/Sandnes).

Traveling predominantly as a car driver

Table 3 shows the effects of the investigated built environment, demographic and socioeconomic variables on the likelihood of traveling at least 90% of the daily distance as car driver. Residential distance to the city center shows significant and fairly strong effects in all four cities and especially in Oslo. However, local-area density shows even more pronounced effects in all cities except Stavanger/Sandnes, and in Oslo and Trondheim the local level of transit service is the variable showing the strongest effect among the urban structural characteristic.

In Oslo, we find a tendency of increased likelihood of traveling predominantly as a car driver also among respondents living far away from the closest second-order center. None of the other cities shows any effect of residential proximity to either second- or third-order centers.

Among the demographic and socioeconomic variables, we notice similar effects of driver's license possession, gender, income and children in the household as in the analysis of daily driving distance. Distinct from the latter analysis, where being young was associated with shorter driving distance, high

age is associated with higher likelihood of traveling predominantly as a car driver among Oslo and Trondheim respondents. In Oslo we also find a lower propensity of traveling predominantly as a car driver among respondents who hold a university degree. This probably reflects the concentration of public and private sector administrative jobs at inner-city locations with high transit and low car accessibility.

Table 3: Travel mode of at least 90 % of the distance as car driver. Wald values. Negative effects are indicated by a minus sign in parenthesis before the Wald value.

	Oslo	Stavanger/Sandnes	Bergen	Trondheim
Distance residence to city center	41.4***	9.4***	17.4***	7.5***
Distance residence to 2nd order center	21.8***	1.6	(-) 0.3	---
Distance residence to 3rd order center	(-) 3.6*	0.1	0.2	3.3*
Density of population and jobs (residence)	(-) 52.0***	(-) 0.7	(-) 26.1***	(-) 9.6***
Public transport services (residence)	(-) 90.2***	(-) 0.0	(-) 3.0*	(-) 9.6***
University degree (dichotomy)	(-) 17.2***	(-) 2.5	(-) 0.0	(-) 0.6
Annual personal income	12.2***	10.1***	19.6***	2.0
Driver's license (dichotomy)	358.0***	90.7***	92.7***	47.5***
Number of children in the household	45.1***	1.1	3.8*	9.0***
Gender (female = 1, male = 0)	(-) 143.9***	(-) 37.9***	(-) 38.1***	(-) 25.0***
Age	14.5***	0.0	0.0	8.3***
Constant	(-) 203.3***	(-) 48.4***	(-) 55.4***	(-) 42.2***
N / R ² (Nagelkerke)	6149 / 0.291	2114 / 0.264	2303 / 0.323	2607 / 0.234

* p<0.10. ** p<0.05. *** p<0.01

4.2. Commuting

Commuting distance

Below, we will first present the results of analyses with urban structural variables related to the residential location as the built environment variables of the models. Thereupon, the results of another set of analyses will be presented, where the built environment variables of the models are urban structural variables related to the location of the workplace.

Tables 4 and 5 show the effects of the investigated variables on employed respondents' one-way commuting distance, with urban structural characteristics of the residential location and the workplace location, respectively, as the built environment variables.

Table 4: Distance from residence to workplace (with residential location variables). Standardized regression coefficients (Beta).

	Oslo	Stavanger/Sandnes	Bergen	Trondheim
Distance residence to city centre	0.344***	0.402***	0.315***	0.245***
Distance residence to 2nd order centre	0.128***	0.338***	0.008	-
Distance residence to 3rd order centre	0.026	0.070*	0.117***	0.029
Density of population and jobs (residence)	-0.009	0.060	-0.069	-0.007
Public transport services (residence)	0.027	-0.032	0.004	-0.063
University degree (dichotomy)	0.059***	0.027	0.027	0.066
Annual personal income	0.030*	0.069*	0.015	0.002
Driver's license (dichotomy)	0.043***	0.113***	0.051	0.084*
Number of children in the household	-0.032*	-0.113***	-0.022	-0.017
Gender (female = 1, male = 0)	-0.081***	-0.121***	-0.112***	-0.009
Age	-0.031*	-0.144***	-0.005	-0.062
N / R ² (adjusted)	2153 / 0.166	751 / 0.134	742 / 0.148	845 / 0.060

* p<0.10, ** p<0.05, *** p<0.01

Table 5: Distance from residence to workplace (with workplace location variables). Standardized regression coefficients (Beta).

	Oslo	Stavanger/Sandnes	Bergen	Trondheim
Distance workplace to city centre	0.495***	0.429***	0.520***	0.780***
Density of population and jobs (workplace)	0.144***	0.011	0.114***	0.161***
University degree (dichotomy)	0.034**	0.003	0.005	0.033
Annual personal income	0.042**	0.101***	-0.014	0.001
Driver's license (dichotomy)	0.031*	0.066*	0.049	0.047
Number of children in the household	0.039**	-0.066**	0.078**	0.045
Gender (female = 1, male = 0)	-0.064***	-0.083**	-0.084***	-0.022
Age	0.049***	-0.081**	0.129***	0.030
N / R ² (adjusted)	2153 / 0.198	751 / 0.215	742 / 0.230	845 / 0.510

* p<0.10, ** p<0.05, *** p<0.01

For both dwellings and workplaces, a location close to the city center contributes to reduce the commuting distance between home and workplace. These effects are evident in all four cities and are strong for residential location as well as for workplace location. Controlling for the other investigated variables, Oslo residents living 20 km from the city center have on average a one-way commuting distance 8 km longer than their counterparts living closest to the city center. In Stavanger/Sandnes, Bergen and Trondheim, respondents living in the outer suburbs 10 km from the city center have one-way commuting distances on average 4-5 km longer than their downtown counterparts. Regarding workplace location, employees of Oslo workplaces located 20 km from the city center commute on average 9 km longer than those working in the city center. In the Stavanger/Sandnes and Bergen other cities, employees at outer-suburban (10 km from the city center) workplaces commute on average 3.5-

5.5 km longer in each direction from their home, while the corresponding difference in Trondheim is nearly 8 km.

Apart from the distance to the city center, residential proximity to the closest second-order center tends to reduce commuting distances in Oslo and especially in Stavanger/Sandnes, but not in Bergen or Trondheim. In Bergen, we instead see a distance-reducing effect for commuters living close to a third-order center. Such an effect, but relatively weak, can also be identified in Stavanger/Sandnes. For workplaces, high local-area density of population and jobs tends to reduce commuting distances in Oslo, Bergen and Trondheim, but not in Stavanger/Sandnes.

Individual characteristics of the respondents are generally more weakly associated than the urban structural variables with commuting distances, and several socio-demographic variables only show significant effects in one or two of the cities. The strongest and most stable effects of socio-demographic characteristics are those of gender and children in the household, where respondents who are female and/or belong to a household with children tend to commute shorter distances.

Commuting as car driver

Tables 6 and 7 show the effects of the investigated variables on employed respondents' propensity to commute as a car driver, with urban structural characteristics of the residential location and the workplace location, respectively, as the built environment variables.

Table 6: Travel mode for commuting as car driver (with residential location variables). Wald values. Negative effects are indicated by a minus sign in parenthesis before the Wald value.

	Oslo	Stavanger/Sandnes	Bergen	Trondheim
Distance residence to city centre	5.6**	0.2	8.4***	3.6*
Distance residence to 2nd order centre	0.8	(-) 0.0	1.2	-
Distance residence to 3rd order centre	(-) 3.5*	0.6	(-) 0.1	0.5
Density of population and jobs (residence)	(-) 62.5***	(-) 2.8*	(-) 12.2***	(-) 7.8***
Public transport services (residence)	(-) 58.0***	(-) 0.0	(-) 1.0	(-) 5.9**
University degree (dichotomy)	(-) 29.0***	(-) 14.1***	(-) 1.8	(-) 4.1**
Annual personal income	6.8***	10.1***	6.9***	0
Driver's license (dichotomy)	0.0	21.2***	0.0	0
Number of children in the household	7.6***	0.2	0.0	1.3
Gender (female = 1, male = 0)	(-) 23.7***	(-) 1.7	(-) 0.3	(-) 3.1*
Age	(-) 1.9	(-) 2.6	0.0	0.5
Constant	(-) 0.0	(-) 6.5**	(-) 0.0	(-) 0
N / R ² (Nagelkerke)	2153 / 0.304	751 / 0.212	742 / 0.275	845 / 0.235

* p<0.10, ** p<0.05, *** p<0.01

Table 7: Travel mode for commuting as car driver (with workplace location variables). Wald values. Negative effects are indicated by a minus sign in parenthesis before the Wald value.

	Oslo	Stavanger/Sandnes	Bergen	Trondheim
Distance workplace to city centre	75.2***	4.9**	14.2***	1.6
Density of population and jobs (workplace)	(-) 143.2***	(-) 19.5***	(-) 7.7***	(-) 36.2***
University degree (dichotomy)	(-) 25.0***	(-) 13.3***	(-) 2.2	(-) 6.8***
Annual personal income	16.7***	12.5***	6.2**	0.3
Driver's license (dichotomy)	0.0	22.4***	0.0	0.0
Number of children in the household	59.0***	0.8	3.2*	8.4***
Gender (female = 1, male = 0)	(-) 22.8***	(-) 0.2	0.3	(-) 1.0
Age	14.8***	(-) 1.3	6.8***	4.2**
Constant	(-) 0.0	(-) 9.4***	(-) 0.0	(-) 0.0
N / R ² (Nagelkerke)	2153 / 0.410	751 / 0.276	742 / 0.267	845 / 0.312

* p<0.10, ** p<0.05, *** p<0.01

For both residences and workplaces, the local-area density of population and jobs is the urban structural characteristics showing the overall strongest effects on respondents' propensity to commute by car. In all four cities, respondents living in high-density areas are less prone to commute by car, and the same applies to respondents working in high-density local areas. The strength of these effects vary between the cities, with the strongest effects found in Oslo. It should still be noted that the high Wald values for Oslo are partly due to larger samples sizes.

Living close to the city center is also associated with less likelihood of car commuting in Oslo, Bergen and Trondheim, but these tendencies are rather weak. In Oslo and Trondheim, high level of transit service at the residence also tends to reduce respondents' propensity to commute by car, and particularly in Oslo this tendency is strong. However, no effects of the level of transit service are evident in Stavanger/Sandnes or Bergen. Residential distance to the closest second-order center does not show significant effect on the likelihood of car commuting in any of the cities. In Oslo, we find a weak tendency of lower propensity of car commuting when living close to a third-order center.

Also for workplaces, a location close to the city center tends to reduce the employees' likelihood of commuting by car, and in Bergen this effect is stronger than that of density in the local area of the workplace.

Among the individual characteristics of the respondents, income and education are the variables most clearly associated with the use of car for commuting, each showing significant effects in three of the four cities in the residential as well as workplace attribute analyses. Respondents with holding a master degree are less prone to commute by car, while high income has the opposite effect. In the analysis of workplace attributes, we find tendencies in three cities of higher propensity of car commuting among older respondents, but no similar effects are found in the analysis of residential attributes. Gender and number of children in the household generally show clear effects in Oslo (less likelihood of car commuting among women and respondents with children in the household), but the effects of these variables are weaker and unstable in the other three cities.

5. Discussion

5.1. Causality and transport rationales

The results are in line with the rationales for activity location and travel mode choice identified in the qualitative part of the research project (Næss et al., 2017 and 2018). The location and neighborhood densities of residential areas influence travel through their interaction with time-geographical constraints and the residents' rationales for location of activities and choices of travel modes. For commuting and trips to specialized non-work activities, interviewees often do not choose the closest facility. Instead, they often travel a bit farther if they can then find a better facility. For less specialized activities, interviewees more often tend to use local facilities, but such trips normally make up a minor part of the total daily travel distance. Traveling distances, especially for commuting, therefore tend to depend primarily on how far the residence is located from the largest concentrations of jobs and other specialized facilities. Rationales for travel mode choice such as time saving and frustration aversion contribute, in combination with time-geographical constraints and suburbanites' usually longer trip distances, to make driving an attractive option for many of those who live far from the city center and for commuters to suburban workplaces. Inner-city narrow streets with frequent crossings, traffic lights, congestion and the necessity to pass toll cordons in some of the cities to access the inner center by car also contribute to this, along with scarce and/or expensive parking. In addition, transit provision is poorer and parking easier in the suburbs than in the city center.

5.2. Comparison across the four city contexts

For overall car-driving distances (regardless of trip purpose) as well as for commuting distances, locations close to the city center contribute to shorter distances traveled by car for all intra-metropolitan purposes jointly as well as shorter commuting distances. These tendencies are clear both for residential location and workplace location and are evident in all four cities. In the polycentric city of Stavanger/Sandnes, total car-driving distances and especially commuting distances are also influenced considerably by residential distance to the closest second-order center. This reflects the high concentration of workplaces in the suburban second-order center of Forus in this city (see Næss et al., 2017b). In Bergen and Trondheim, no effects of proximity to second- or third-order centers can be found on either total car-driving distances or commuting distances. Both these cities have predominantly monocentric center structures and are not sufficiently large to support second-order centers strong enough to affect overall travel behavior patterns significantly. Distinct from this, Oslo, although predominantly monocentric, has a size large enough to support several second-order centers of a certain magnitude offering employment opportunities as well as various service facilities. In Oslo, we therefore find significant effects of residential proximity to second-order centers, yet clearly weaker than those of proximity to the main city center.

High population density in the residential neighborhood shows influences on overall car-driving distances in all cities except Stavanger/Sandnes, but not on commuting distances. The latter reflects that most residents commute out of their local area (cf. above about rationales for activity location), and the density of population and jobs in the narrow local area therefore does not affect the average commuting distances much. In Stavanger/Sandnes, density variations between different parts of the city, and hence also in the availability of local facilities, are smaller (cf. Figure 3) than in the other cities, especially Oslo, which may explain why we do not find any effect of density on overall driving distances in Stavanger/Sandnes.

For travel mode choice, local-area density mostly shows stronger effects than proximity to the city center. This applies to the propensity of traveling predominantly as car driver when considering all trip purposes as well as the likelihood of commuting as a car driver. Choosing whether to drive or use other travel modes thus seems to be influenced mainly by characteristics of the residential or workplace neighborhood influenced by its density. These characteristics include the availability of residential neighborhood facilities such as grocery stores and kindergartens (important for choices between car and non-motorized trips for several non-work purposes), driving conditions and transit provision in the residential neighborhood (important to travel mode choice for non-work purposes as well as commuting) and especially transit accessibility, driving conditions and parking opportunities at the workplace (important to travel mode choice for commuting). Apart from Stavanger/Sandnes, where transit accessibility is generally not very high, high transit provision in the residential neighborhood also tends to reduce the likelihood of choosing car driving as travel mode in all cities.

We do find effects across the four cities on the likelihood of traveling as car driver also from residential and workplace proximity to the city center, with lower propensity for driving when living or working close to the main city center. These effects are, however, weaker than those of local-area density. Here, it should be borne in mind that local-area density and transit provision in the neighborhood are strongly influenced by how far from the city center the residence or workplace is located (cf. Figures 3 and 4). In addition to their direct effects, residential and workplace distance to the city center thus exert important influences on travel mode choices through their influences on local-area density and transit provision.

Interestingly, the effects of the urban structural variables (indicated by their standardized regression coefficients and Wald values) are generally more prominent than those of the investigated demographic and socioeconomic variables (except driver's license possession, which shows strong effects on the overall propensity of traveling as a car driver in all cities but still only shows significant effect on car commuting in Stavanger/Sandnes).

5.3. Our results compared to the international literature.

The findings in all four studies show considerable impacts of urban structural characteristics on the investigated aspects of travel behavior, in accordance with most of the literature reviewed in Section 2 but in contradiction to those authors (e.g. Echenique et al., 2012; Van Wee, 2013; Woods & Ferguson, 2014) who have claimed that the built environment exerts only small influences on travel. In relation to the D taxonomy coined by Cervero and his colleagues (Cervero & Kockelman, 1997; Ewing & Cervero, 2010), car driving distances as well as commuting distances are most strongly influenced by 'destination accessibility', or more precisely the so-called 'regional destination accessibility' often defined in the literature as distance to downtown. Our results are thus in line with earlier findings by, among others, Zhou & Kockelman (2008), Zegras (2009), Elldér (2014) regarding residential location and by Cervero & Landis, (1992), Hartoft-Nielsen (2001), Schwanen et al. (2001) and (Yang (2005) regarding workplaces. In Stavanger/Sandnes, the only predominantly polycentric city among the investigated ones, residential proximity to a large suburban employment center also shows a considerable effect on commuting distances – in fact even stronger than proximity to the main city center. Destination accessibility at a more local level shows little effect on either driving distances or commuting distances in any of the cities. Distinct from several other studies (including some of our own), we also find effects on overall car driving distances of residential local-area density, yet weaker than those of proximity to the city center.

However, local area density, in the vicinity of both the residence and the workplace, shows strong effects on whether or not the respondents travel as car drivers. This is in line with earlier studies in Oslo (Næss et al., 1995; Næss & Sandberg, 1996) as well as in an international context (Cervero & Wu, 1997; Lee et al., 2011; Chatman, 2003). We also find a clear effect of transit provision, measured in a more sophisticated way than Ewing & Cervero's rather simplistic D-variable 'distance to transit'.

Our study did not investigate the D-variable 'diversity', but the lack of significant effects of residential distance to third-order centers suggests that local-area diversity is of lesser importance to traveling distances than the location of the neighborhood within the urban structure of the city as a whole. The investigation included a large number of third-order centers in each city, and apart from the areas close to the main city center and second-order centers, the mix of dwellings and service facilities is higher in the areas close to the third-order centers than in the remaining parts of the cities. Moreover, the fact that commuting distances increase sharply the further from the city center dwellings as well as workplaces are located contradicts the idea promoted in some professional guidelines (e.g. Planning for Sustainable Travel, 2018) and underpinned by some studies (e. g. Cervero & Duncan, 2006)⁹ that local jobs-housing balance in the suburbs would contribute to reduce driving.

We also did not investigate the D-variable (street) 'design' separately. In a Nordic context, this does not appear as important to the aspects of travel behavior discussed in the present study. In the qualitative interviewee this was not at all mentioned as a built environment characteristic that matters to travel, and in the few earlier Nordic studies where street design has been investigated, any effect on car driving distance or car mode choice has vanished when controlling for the location and density of the investigated neighborhoods (see, for example, Næss, 2011).

The results conform well to the results of another recent study comprising two of the investigated cities (Oslo and Stavanger/Sandnes), where respondents were recruited from the whole metropolitan area instead of within the demarcations of the morphological city (Næss et al., 2017a). However, in the metropolitan-scale study, we found somewhat stronger effects of residential location than workplace location on commuting distances. The stronger centralization of workplaces than residences within the metropolitan area, with a pronounced shortage of jobs outside the morphological city especially in Oslo, is a possible explanation. The relative strength of local-area density compared to distance to the city center on the choice of car as travel mode was also smaller in the metropolitan-scale investigation than in the present study. This may reflect that density variations are relatively small outside the morphological cities and that the effect of low local-area density on car driving is overshadowed by the car-travel-inducing effect of long distances to jobs and non-local service facilities.

6. Concluding remarks

Our study of urban structure and travel behavior in the four largest Norwegian cities shows strong effects of residential and workplace distance to the city center on overall driving distances and commuting distances. We also find strong effects of local area densities around residences and workplaces on the choice of car as a travel mode, along with less pronounced effects of the distance from dwellings and workplaces to the city center. In the cities with the best developed transit provision, we also see clear effects of transit accessibility at the residence on the propensity of choosing the car as

⁹ The study by Cervero & Duncan (2006) investigated jobs-housing balance at a relatively large geographical scale (within 4 km from the dwelling) but did not control for distance to metropolitan city center.

travel mode. The results provide strong support of Norwegian national policies of urban densification as a planning strategy to curb the growth in urban motoring.

Although the influences of urban structure on travel show many similarities across the cities, there are also differences reflecting variations in center structure (Stavanger/Sandnes is predominantly polycentric while Oslo, Bergen and Trondheim are predominantly monocentric) and population size (Oslo is a large city while the other three cities are of medium size). In Stavanger/Sandnes, commuting distances depend more on residential distance to a suburban second-order center than on the distance to the main city center, which is the dominant residential variable influencing commuting distances in the other cities. In predominantly monocentric Oslo too, residential distance to second-order centers play some role in influencing commuting distances as well as overall driving distances, but not in Bergen and Trondheim, which are also predominantly monocentric but with smaller and less important second-order centers. Finally, the influence of local-area density on travel modes is less evident in Stavanger/Sandnes than in the other three cities, reflecting that density variations across the urban area are smaller in Stavanger/Sandnes than in Oslo, Bergen and Trondheim.

Showing that the magnitude of the influences of various urban structural characteristics on travel behavior 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. The strength of the impact of each urban structural characteristic will obviously vary with the specific city context, as we also observe when comparing the findings in Oslo, Stavanger/Sandnes, Bergen and Trondheim.

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