Parking facilities and the built environment: Impacts on travel behaviour

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Parking facilities and the built environment: Impacts on travel behaviour

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A B S T R A C T

Car ownership and car use depend on numerous factors, among which are parking availability at destination and at home. While the former has attracted considerable research efforts for decades the latter, home parking, has recently become subject to increasing research interest.

We use evidence from the 2013/14 Norwegian National Travel Survey, and combine this with additional geographical context data. In this way, we analyse the impact of parking availability at home and at destination on car use, while controlling for different urban contexts like housing and job density, and population density.

The analysis is divided into three. The first part links car use to availability and payment arrangements of workplace parking. The second is concerned with the impact of home parking accessibility and car use. The third set of regressions looks at the combined effect of parking at trip start and the trip end on car use.

Reduced access to free workplace parking stands out as one of the most effective ways of reducing car use on work trips. Maximum parking standards are therefore important parts of an urban planner's toolbox. Workplace parking fees can be effective when parking capacity is abundant and especially so if payment is made on a daily basis. Car use is in fact almost doubled where employees can pay monthly instead of daily.

Limited access to parking at home also affects car use. The decision to drive decreases with increasing walking distance to the car park, especially in densely built-up areas.

Restricted parking both at home and at the trip destination add up to very low odds of car use. Parking restrictions will have the greatest effect in compact cities.

1. Introduction

Car-parking policy is significant in influencing transport, since almost all car trips start and end in a parking space. Parking charges have long been regarded as efficient means to reduce car-use, especially to work, but also on leisure and shopping trips, although there is a case for parking charges in order to increase circulation.

Policies that affect parking availability and the cost of parking have several effects. For instance, parking can influence mode choice, destination choice, trip timing, and car occupancy (Feeney, 1989), as well as car ownership (Guo, 2013a).

Traditionally, studies of car-parking's effect on car use have mainly dealt with how parking at the end destination influences travel behaviour (Inci, 2015). For work trips this would be the workplace parking arrangements and how they

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affect commuting mode choice. Home parking has in this literature often been assumed as given, or not dealt with at all. In line with this, residential parking supply has typically been regarded a result of parking norms, whose role has been to ensure sufficient off-street parking supply (Hanssen et al., 2014b; Litman, 2013).

In recent years, a growing body of research has concluded that residential parking might be just as important, since nearly all car trip chains either start or end at home and studies that analyse the interaction between on-street supply and off-street supply (Manville et al., 2013; Manville and Shoup, 2005, 2010; Weinberger, 2012).

The importance of residential parking for transport mode choice, trip frequency and car ownership must still be regarded as under-researched (Christiansen et al., forthcoming; Guo, 2013b; Marsden, 2006; Weinberger, 2012) and further, we are not aware of any published studies that look at the combined effect of parking availability at both the start and at the end of a trip on mode choice. These knowledge gaps need to be addressed if we are to gain a deeper understanding of how parking influences travel behaviour and car ownership.

A central challenge for empirical studies of parking and car use, is access to a sufficient amount of valid and reliable data. A lot of research in the field has depended on a limited number of case areas (Weinberger et al., 2008b; Transport for London, 2012), manual observations (Christiansen and Hanssen, 2014; Hanssen et al., 2014a), stated preference questionnaires (Guo and McDonnell, 2013), parking revenue data (Kobus et al., 2013), or even general common sense arguments of, e.g. how parking requirements affect the cost of car ownership. A few have combined different data sources, like property prices with residential parking zones (van Ommeren et al., 2011). A prominent example is Guo (2013b) who combined household travel data with parking information retrieved using Google Street View observations. In contrast to all this, our study benefits from the wealth and precision of National Travel Survey data, where parking resources at home and at work are among the data collected. We combine this with objective geographical data about parking zones, population, and registry of buildings.

In general, there are one or two significant differences in parking standards between residential parking and parking for other purposes. In Norway, as in most Western countries, residential parking supply is still largely a result of minimum standards (Christiansen et al., forthcoming). It has been argued by many that minimum standards are imprecise for calculating the demand for parking and therefore they contribute to over-supply, encourage car-use, increase the costs of building projects and make it more challenging to offer affordable housing (Litman, 2009; Shoup, 2005; Willson, 2013).

In Norway, most local municipalities use minimum parking standards for residential parking. The main goal is to ensure that developers set aside enough space for parking and consequently reduce the pressure for on-street parking. Use of maximum standards, or a combination of minimum and maximum standards, is the usual way of managing parking for other purposes, e.g. offices, shopping malls and services in the largest cities. In general, Norwegian municipalities use maximum standards in urban centres and minimum standards in areas outside the most central areas. The largest cities – Oslo, Bergen, Trondheim and Stavanger – have stricter parking standards than the smaller cities (Hanssen et al., 2014b). Smaller cities have traditionally not used maximum standards. While this set of policies is relatively commonplace, it forms an important contextual backdrop for the analyses performed in this paper.

The remainder of this paper is organised as follows. In Section 2, we review the literature on parking availability at home and at work, focusing especially on how travel habits and mode choice are influenced. We also highlight the state of art with respect to the relationship between urban structure and transport. In Section 3, we present the dataset and explain how we have integrated additional data on urban areas and parking availability with the 2013/14 National Travel Survey (NTS). In Section 4, we analyse how parking availability influences mode choice. We discuss findings and draw conclusions in Section 5.

2. Literature review

2.1. Parking and work trips

The importance of workplace parking for commuting mode choice, is well studied. Willson and Shoup (1990) refer for instance to four before-and-after studies analysing the effects of parking charges at the workplace. These studies were conducted in the 1970s and 1980s and all showed a clear reduction in car-use. Christiansen (2014) conducted the same type of study for employees at the Norwegian Public Roads Administration in Oslo, and showed that the introduction of a moderate parking fee led to a significant reduction in car use on work trips. Employees became more positive towards a charge after it was implemented, and the study showed that there were only limited signs of spill over parking to local streets. In addition, the parking fee increased the flexibility of car drivers, since it made it possible to arrive later and still be able to find a parking space. Peng et al. (1996) documented that a parking fee influenced mode choice on the journey to work and that it had different impacts depending on the public transport service and residential location. Hamre and Buehler (2014) showed that employer benefits for public transport, walking and cycling are not effective where employees enjoy free parking. According to Albert and Mahalel (2006), both congestion charging and parking fees reduce car-use, but congestion charging has stronger effect in influencing trip timing. Su and Zhou (2012) showed that employers can reduce the share of employers driving alone if they provide parking discounts for ride-sharers, reduce the number of parking spaces or increase parking charges for those who drive alone. Rye et al. (2006) showed that Controlled Parking Zones, in combination with other measures, can reduce the number of car trips to work. When conducting a literature review in connection with parking studies, Fearnley and Hanssen (2012) found that average price elasticity was −0.21 for work trips, which was in line with Marsden (2006). Compared with workplace parking charges, there is less evidence regarding the effect of reducing the number of parking spaces (Pandhe and March, 2012).

Taking the employers' view, Rye and Ison (2005) showed that they have weak incentives for implementing parking fees, arguing that it is only in specific circumstances that a parking fee is likely to be charged. Moreover, politicians can be reluctant to implement restrictive measures, since congestion pricing and parking fees are usually unpopular among their constituencies.

2.2. Residential parking

During most of the post-war period, local authorities required that new developments should have a parking ratio that met the (peak) demand for parking. However, several voices argue that a more flexible approach should be taken (Litman, 2009; Shoup, 2005; Melia, 2014; Millard-Ball, 2002). Shoup (2005), in particular, argues that market principles should would make property developers calculate the demand for parking. On the other hand, Barter (2010) sees several potential barriers for a market-based off-street parking system, such as spillover parking or cooperation problems between developers.

Knoflacher (2006) notes that the distance to the parking space is usually shorter than to the public transport stop. Therefore, parking policies promote car driving and discourage public transport use. He suggests that parking spaces should be located as far away as the closest public transport stop both at home and at the end destination (ibid). In fact, Christiansen et al. (forthcoming) document that longer distances between home and home parking location reduce the car's modal share significantly. They argue, on this background and in line with Knoflacher, that physical separation of the two would facilitate more efficient housing and reduce car use. The Norwegian city of Stavanger has in fact passed such a guideline in their land use regulation (Christiansen et al., 2015).

Weinberger et al. (2008a, 2008b, 2009) show that properties that are subject to minimum off-street parking requirements are populated with households with higher car ownership and car-use compared with residents within similar neighbourhoods but with less parking availability. In their literature review, Weinberger et al. (2009) pointed out, however, the scarce evidence that links home parking availability to car-use and car ownership. Since then, Guo (2013b, 2013a) documented that parking availability at home has a big impact on car ownership, and Weinberger (2012) showed a correlation between good home parking availability and car-use on work trips. Christiansen et al. (forthcoming) and Guo (2013c) identify similar effects. For example, Christiansen et al. (forthcoming) show that access to private or reserved home parking triples the likelihood of car ownership. Recent research evidence suggests, therefore, that maximum standards would be an effective way of influencing car ownership and use. However, maximum standards only work if parking is neither free nor freely available in nearby streets (Guo, 2013a; Melia, 2014).

2.3. Travel behaviour and built environment

Travel behaviour in urban areas is determined by people's daily activities, spatial organisation and the built environment (Cervero and Duncan, 2006; Krizek, 2003; Naess, 2011, 2012; Næss, 2005, 2006; Zhang, 2004; Miller and Ibrahim, 1998; Krizek, 2003; Zhang, 2004; Cervero and Duncan, 2006). Ewing and Cervero (2010) conducted a meta-analysis on the built-environment-travel literature and found that population and job density only have small effects on travel behaviour. However, Naess (2012) has surveyed the results from urban form and travel behaviour in a Nordic context and conclude that the Nordic studies show stronger effects of density on travel behaviour.

Built environment is a term that potentially can consist of a multitude of different aspects. Especially, residential location has received much attention. For instance, people living in the outer parts of a city travel significantly more by motorised transport compared to people living in the city centre (Engebretsen and Christiansen, 2011). Also location of workplaces and retail is regarded as a key factors. People working in the central parts of the city have lower car use and higher share of people travelling by foot, cycle or public transport compared to people working in less central areas (Christiansen et al., 2015). Also, most studies have focused on density at the local scale (Naess, 2012), but also the population density at the city scale has been analysed (Newman and Kenworthy, 1989). In summary, car use is lowest in densely built-up large urban areas, areas close to city centres, and areas in which a high number of people work. In addition, public transport services and the use of restrictive measures influence mode choice. In a Norwegian context, Engebretsen and Christiansen (2011) documented that car use is greatest in small and medium sized urban areas, particularly if they are less self-sufficient in terms of jobs, shopping and services.

Also other factors influence travel behaviour. Sex, age, household structure and income have significant impacts on mode of travel (Dieleman et al., 2002). Families with children, higher income and age are factors that are associated with higher car use.

3. Data

The 2013–14 Norwegian National Travel Survey (NTS; documented in Hjorthol et al., 2014) comprises a total of 60,000 individuals aged 13 and above. The survey covers a broad set of aspects, of which the following are relevant for this study:

access to transport resources, residential address and workplace address, socio-economic data, personal travel of all types with information about mode, travel time, distance and purpose. NTS covers all transport modes, including walking and cycling, and long and short trips.

In regard to parking, NTS respondents state whether they have a dedicated own parking space at home and, if that is the case, the distance, in metres, between residence and home parking space. If respondents do not have dedicated home parking, they are asked about possibilities to park in nearby areas and whether it is easy or difficult to find parking space there. NTS also records respondents' workplace parking availability: whether it is offered, whether it is easy to find a vacant parking space, whether there is a parking fee to be paid and, if so, how much and whether it is paid per hour, per day or per month. Those who do not have access to workplace parking, and those who have difficulties finding a parking space or are charged for their parking, are asked about the possibility of parking in nearby areas and whether that parking is charged.

The fact that NTS records start and end addresses for all trips enables us to link relevant geographical explanatory variables to NTS. In this way, we capture aspects that are important for understanding travel behaviour in different urban contexts. Main explanatory variables are land-use density, distance to city centre, zones of parking restrictions, and city size. The NTS and the geographical data are spatially joined using coordinates for the start and end of the trip, home address and workplace. For each of the NTS points there is information about which city, number of inhabitants in the urban area and the average population density of the urban area.

Local land-use density is measured as the total floor space of residential and commercial buildings divided by the area within 250 × 250 m cells (*Registry of Buildings*, The Norwegian Mapping Authority). In addition, crow flow distance to the city centre (kilometres) is measured for each of the NTS points.

The public transport service is defined by categorising the number of public transport departures between 7 and 9 a.m. at the residence and distance to the nearest public transport stop.

Limited parking availability is a dichotomous variable which suggests it is difficult to park in the area where the trip starts or ends. This variable equals 1 if the location is in a CBD, in other areas where parking is charged, or if the location is subject to residential parking zoning.

Table 1 provides descriptive characteristics of key NTS variables.

4. Analysis

The analysis is divided into three different parts. In the first, we analyse how parking at work influences whether or not the car is used for the journey to work. We then move on to analyse how distance to parking at the residence influences

Table 1
Sample characteristics of variables used for analysis.

Variables	N	Mean, %
Car share all trips	199,567	54%
Car share work trips	37,803	61%
Gender (percentage female)	60,733	49%
Age	60,813	45
Education (1 = primary school, 4 = higher university degree)	60,297	2.53
Household income (6 levels)	60,813	4.8
Public transport services (1 = Excellent, 5 = Poor)	47,933	2.45
Number of inhabitants in urban area (trips)	157,187	275,911
Local density (250 × 250 m cells - trip start)	199,583	19,669
Local density (250 × 250 metres cells - trip end)	199,583	19,527
Distance all trips, km	199,583	14
Commuting distance, km	37,783	16.6
Distance to city centre (trip start), km	92,012	5
Distance to city centre (trip end), km	89,543	4.9
Parking at residence	41,277	
No dedicated parking space		10.7%
Parking at own yard		74.5%
Parking distance less than 100 m		12.5%
Parking distance 100–200 m		1.8%
Parking distance more than 200 m		0.5%
Parking at work	32,180	
No parking option		16.4%
Easy to find parking space and it is free		71.6%
Easy to find parking space and it is charged		4.8%
Difficult to find parking space and it is free		5.5%
Difficult to find parking space and it is charged		1.7%
Limited parking availability trip start	199,583	26.4
Limited parking availability trip end	199,583	26.2

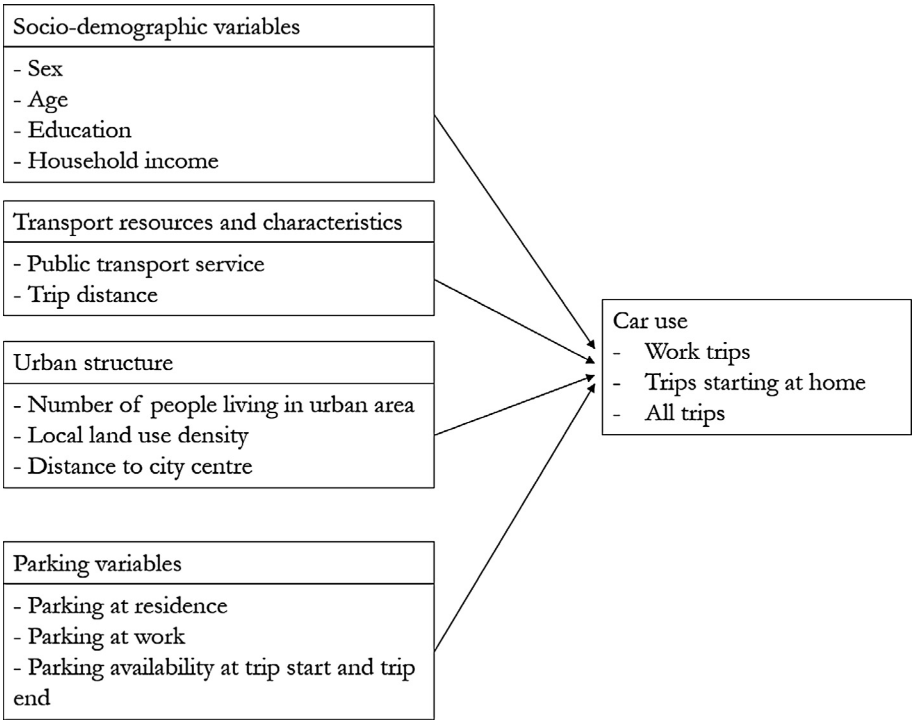

Fig. 1. Model for analysis.

car-use. Finally, we analyse how parking both at the start *and* at the end of the trip influences car-use. Additionally, the analyses include the effects of socio-economic variations, urban structure and transport options. In this way we conduct a broad analysis of how parking influences mode of travel, while controlling for the effects of structural and context factors.

The data is analysed with logistic regressions in SPSS. Based on the literature review we have constructed a model (Fig. 1) for analysing how parking influence mode choice. Socio-demographic variables, transport resources and urban structure are factors that are included in all models. The use of parking variables varies depending on whether we analyse parking at residence, parking at work or parking availability at trip start and trip end. In the models, we have analysed data for collinearity (Tol) and multicollinearity (VIF). A tolerance value of 0.10 can be used as the minimum level of tolerance (Tabachnick et al., 2001) while multicollinearity level above a value of 10 has been regarded as the maximum level of VIF (Hair et al., 2009). The results did not indicate problems with neither collinearity nor multicollinearity.

4.1. Workplace parking and car use

Workplace parking availability is categorised such that it takes into account both how easy it is to find a parking space and whether parking is being charged for. The reference category is employees with no possibility of parking at a parking facility managed by the employer. If these employees drive to work, they need to find a free space on nearby streets or to use other parking facilities.

Table 2 presents the results of a logistic regression where mode choice is analysed for work trips. The odds for driving are greater if the public transport service is poor at home. The causality is unclear, however, as we come back to in the discussion chapter. Women are associated with lower odds of being a car driver to work. The built environment influence mode choice, both at home and at the workplace. Increased distance from the city centre also increases the odds for driving.

The association between parking regulations at the workplace and commuting mode choice is significant. The model estimates suggest that no parking availability at work is the most effective way of reducing the odds on using the car on work trips. Compared with such a situation, free and generous parking availability quadruples the odds of driving a car to work. The introduction of a parking fee hardly changes this picture when parking spaces are abundant. In contrast, free but limited availability of workplace parking halves the odds of car use compared with free and easy to find parking.

However, it is almost equally effective to combine a limited number of parking spaces with a parking fee.

Among those who are charged for parking at work, 70% pay by the month, which is then by far the most common way of organising the parking fee. Norwegian employers are usually free to choose whether to impose parking fees on their premises and how it should be organised. We therefore analysed whether the arrangement of the fee has any effect on the odds of the car being used on work travel. Table 3 shows the effect of whether the parking fee is paid by month, day or hour. The

Table 2
Use of a car on work trips (driver). Trips from home to work. N = 4764. Logistic regression model.

Independent variables	B	S.E.	Sig.	Exp(B)
Gender (1 = male 2 = female)	−0.452	0.068	0.000	0.637
Age	0.008	0.003	0.003	1.009
Education	−0.146	0.042	0.000	0.864
Household income	0.122	0.025	0.000	1.130
Public transport service at residence (1 = Excellent, 5 = Poor)	0.144	0.039	0.000	1.155
Trip distance	0.009	0.003	0.002	1.009
Number of people living in urban area	−0.003	0.001	0.012	0.997
Local density around residence	−0.015	0.002	0.000	0.985
Local density around workplace	−0.007	0.001	0.000	0.993
Distance to city centre (residence)	0.016	0.010	0.126	1.016
Distance to city centre (workplace)	0.041	0.010	0.000	1.041
Easy to find a parking space and it is free (reference category – no parking options)	1.402	0.106	0.000	4.063
Easy to find parking space and it is charged (reference category – no parking options)	1.289	0.140	0.000	3.628
Difficult to find parking space and it is free (reference category – no parking options)	0.587	0.154	0.000	1.798
Difficult to find parking space and it is charged (reference category – no parking options)	0.233	0.224	0.299	1.262
Limited parking availability around workplace	−0.205	0.090	0.022	0.814
Constant	−0.598	0.268	0.026	0.550

Cox & Snell R^2 = 0.235, Nagelkerke R^2 = 0.314.

Table 3
Use of a car on work trips (driver). Trips from home to work for employees with parking fee at work. N = 454.[a]

Independent variables	B	S.E.	Sig.	Exp(B)
Gender (1 = male 2 = female)	−0.492	0.216	0.023	0.612
Age	0.002	0.010	0.865	1.002
Education	−0.067	0.150	0.654	0.935
Household income	0.141	0.084	0.093	1.151
Public transport service at residence (1 = Excellent, 5 = Poor)	0.271	0.129	0.035	1.311
Trip distance	−0.003	0.009	0.720	0.997
Number of people living in urban area	0.003	0.004	0.499	1.003
Local density around residence	−0.002	0.001	0.001	0.998
Local density around workplace	0.000	0.000	0.176	1.000
Distance to city centre (residence)	0.011	0.031	0.724	1.011
Distance to city centre (workplace)	0.084	0.038	0.028	1.088
Pay by day (reference category – pay by month)	−1.212	0.299	0.000	0.298
Pay by hour (reference category – pay by month)	−1.667	0.483	0.001	0.189
Limited parking availability around workplace	−0.170	0.874	0.846	0.844
Constant	0.355	1.238	0.775	1.426

Cox & Snell R^2 = 0.177, Nagelkerke R^2 = 0.237.
[a] This model has significant fewer cases since it only includes trips for employees that have charged parking at work.

model documents the significant impact on mode choice of how the fee is paid despite a considerably lower N compared to the other models. The odds on using a car are significantly lower if employers pay daily and even lower if the payment is made per hour.

Higher density around the residence is associated with lower odds on using the car, while owning more cars increase the odds.

4.2. Parking availability at home and car use

In this section, we analyse how parking availability at home affects the probability of choosing the car for daily travel that starts at home, while at the same time controlling for a range of other structural and socio-economic factors. The distance between residence and home parking location can be interpreted as an indicator of the convenience of parking (cf. Guo, 2013a). Residents are secured a parking space at home but increased walking distance to it can reduce any incentive for using the car.

Table 4 presents the model results. The odds of using a car increase if residents have poor public transport services and with increasing household income. Women have lower odds on using the car on a daily basis. The built environment also influences the odds of using the car. Higher density around the residence and the end destination reduces the odds. The odds also decrease when the end destination is closer to the city centre. The largest urban areas, i.e. higher number of inhabitants, are characterised by lower car-use.

Table 4
Use of car (driver) on all trips that start at home. Persons 18 years or older. N = 21,790.

Independent variables	B	S.E.	Sig.	Exp(B)
Gender (1 = male 2 = female)	−0.549	0.029	0.000	0.578
Age	0.002	0.001	0.054	1.002
Education	−0.039	0.018	0.025	0.961
Household income	0.152	0.010	0.000	1.165
Public transport service at residence (1 = Excellent, 5 = Poor)	0.120	0.017	0.000	1.127
Trip distance	0.000	0.000	0.410	1.000
Number of people living in urban area	−0.004	0.001	0.000	0.996
Local density around residence	−0.015	0.001	0.000	0.989
Local density at trip end	−0.004	0.000	0.000	0.996
Distance to city centre (residence)	0.000	0.006	0.977	1.000
Distance to city centre (trip end)	0.035	0.006	0.000	1.036
Not having own dedicated parking space (parking at own yard -reference category	−0.787	0.067	0.000	0.455
Walking distance to parking (parking at own yard – reference category)	−0.106	0.044	0.016	0.899
Limited parking availability around end destination	−0.072	0.033	0.029	0.930
Constant	0.354	0.103	0.000	1.425

Cox & Snell R^2 = 0.127, Nagelkerke R^2 = 0.169.

Table 5
Use of a car on all trips for persons 18 years or older. N = 52,681.[a]

Independent variables	B	S.E.	Sig.	Exp(B)
Gender (1 = male 2 = female)	−0.596	0.019	0.000	0.551
Age	0.006	0.001	0.000	1.006
Education	−0.057	0.012	0.000	0.945
Household income	0.192	0.007	0.000	1.211
Public transport service at residence (1 = Excellent, 5 = Poor)	0.173	0.010	0.000	1.189
Trip distance	−0.001	0.000	0.003	0.999
Number of people living in urban area	−0.007	0.000	0.000	0.993
Local density around residence	−0.001	0.000	0.000	0.999
Local density at trip end	−0.001	0.000	0.000	0.999
Distance to city centre (residence)	0.028	0.003	0.000	1.028
Distance to city centre (trip end)	0.024	0.003	0.000	1.024
Limited parking availability around start destination	−0.191	0.024	0.000	0.826
Limited parking availability around end destination	−0.198	0.024	0.000	0.820
Constant	0.236	0.064	0.000	1.266

Cox & Snell R^2 = 0.164, Nagelkerke R^2 = 0.219.
[a] This model has the most cases since it does not require that a trip start at home.

Controlling for these factors, walk distance between home and home parking location significantly reduces the probability of choosing the car. Not having own dedicated parking space reduces the odds the most.

4.3. Parking availability at trip start and trip end

We now turn to the combined influence on mode choice of parking availability both at home and at destination. This combined effect is important, because almost every car trip starts and ends in a parking space.

A pattern similar to the logistic regressions presented above can be seen in Table 5. The odds of driving increase with poor public transport service at home. Males also have higher odds of driving, while the odds decrease with increasing density at city and local levels. The closer the destination to the city centre, the fewer cars there are. This can be linked to the fact that the public transport service is usually best in these cases and that provision for car parking is usually less available than for trips that end outside the city centre. In general, car use is low in areas with high densities of businesses, services or residents.

Controlling for these socio-economic and contextual factors, our model shows that reduced parking availability at both trip start and trip end significantly reduces the odds on driving.

5. Discussion

Parking availability significantly affects the probability of choosing car. We have analysed National Travel Survey data that was merged with geographical and contextual data and shown that this is the case for workplace parking, home parking and indeed for the combined effect of parking availability at origin and destination of any daily trip. Our study has documented the overall effect of various parking measures and how they can enhance the effect of urban land-use and transport planning.

The results from this study have several implications that are relevant for practitioners and policymakers alike. One main conclusion is that parking restrictions at the workplace can be very effective in reducing car-use on work trips. This is certainly in line with the research literature in general. Based on our analysis, it is evident that workplace parking capacity restrictions are considerably more effective than regulation through parking fees in affecting commuting mode choice.

The restriction in number of workplace parking places, together with a parking fee, add up to an effective and efficient package. The limited number of places restricts the overall possibility of car use, while a parking fee helps secure efficient allocation of the scarce parking resources.

As a stand-alone instrument, workplace parking charges have negligible impact on car-use on the journey to work. However, in theory, the payment mechanism can influence trip timing and as such help spread the peak, since it reduces the need to race for parking spaces that are otherwise allocated on a first come first served basis (Christiansen et al., 2015). Nevertheless, workplace parking fees are more effective when parking capacity is reduced.

The policy-relevant implication of this is that maximum parking standards, at least in the long run, significantly reduce car-use on journeys to work. By imposing (strict) maximum standards, cities can reduce congestion and pollution and also reduce the need for large investments in road capacity (cf. Marsden, 2006). This effect of restrictive parking standards is further increased when combined with parking fees.

The majority of workers in the largest cities in Norway are able to park free and it is easy to find a space (Christiansen et al., 2015). This means that even modest move in the direction of fewer and paid-for parking spaces can have a significant impact on trips to work if the ambition is to influence mode choice.

We have brought in a new aspect of workplace parking fees; namely the question of how it is paid. Our results show that car-use on work trips is considerably lower if employees pay each time they drive to work (daily payment) and even less if parking is paid per hour. Compared with payment per day, car-use is almost twice as high if employees can pay the parking fee on a monthly basis, which can be linked to the fact that monthly payments do not induce incentives for reducing the number of car trips at the margin. On the contrary, for each trip the average cost of parking falls. On average, the monthly payment also turns out to be cheaper compared with daily fees.

As for residential parking, our results show that the probability of driving decreases with increasing distance between the home and the home parking space. This holds true when controlling for a range of geographical and socio-economic factors. The results coincide with recent literature analysing whether residential parking influences car-use and car ownership (Guo, 2013a, 2013b, 2013c). It is worth noting that a longer distance between home and home parking does not reduce the number of trips being made, it only affects mode choice (Christiansen et al., 2015) The distance effect is especially strong in dense urban areas, where distances to shopping, restaurants and services are shorter. A long walking distance to the car therefore reduces its advantage for local travel purposes. This finding is therefore of particular relevance for urban policy-makers. Stavanger municipality guidelines state, for example, that the distance between parking and the home should be at least as far as the distance between the home and the nearest public transport stop. A guideline like this can lead to reduced car use. Parking limitations at both home and end destination add up to very low odds on using the car.

Like almost every empirical study of parking and car use, also ours is plagued with the potential of self-selection bias and endogeneity (cf. Inci, 2015). Residents are aware of parking availability when they decide to rent or buy a house or a flat and also when they decide where to work. It is therefore reasonable to assume that people with lower car use or car ownership are more likely to choose to live with reduced parking availability at home and thus also choose to work in places where parking availability is restricted.

The effect of parking regulations must also be seen in a larger context, one in which urban form, urban structure, land-use and public transport are all taken into account. Our results document that a city's structure affects the extent of car use in that city, and this is consistent with results from a number of previous studies (Naess, 2012; Engebretsen and Christiansen, 2011). As for urban form and parking, our results show that the effect of parking restrictions decreases with increasing distance from the city centre. In other words, parking restrictions will have the greatest effect in compact cities. Access to high standard public transport reduces the odds on the decision to drive. However, our study shows that the effect of high standard public transport becomes much greater if it is combined with parking restrictions. High land-use density usually results in shorter average distances to various destinations, thus leading to less need for motorised transport on daily travel. As for urban form and public transport, our conclusion is that the effects of high densities are amplified through parking restrictions. Overall, this means that parking policy should be implemented as part of overall city and transport planning which aims to limit or reduce car traffic.

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References

Albert, Gila, Mahalel, David, 2006. Congestion tolls and parking fees: a comparison of the potential effect on travel behavior. Transp. Policy 13 (6), 496–502.

Barter, Paul A., 2010. Off-Street parking policy without parking requirements: a need for market fostering and regulation. Transp. Rev. 30 (5), 571–588.
Cervero, Robert, Duncan, Michael, 2006. 'Which reduces vehicle travel more: jobs-housing balance or retail-housing mixing? J. Am. Plan. Assoc. 72 (4), 475–490.
Christiansen, Petter, 2014. A case study of parking charges at work places – effects on travel behaviour and acceptance. In: Selected Proceedings from the Annual Transport Conference at Aalborg University.
Christiansen Petter, Engebretsen Øystein, Hanssen Jan Usterud, 2015. Parkeringstilbud ved bolig og arbeidsplass. Fordelingsffekter på bilbruk og bilhold i byer og bydeler. TØI-rapport 1439/2015.
Christiansen, Petter, Fearnley, Nils, Hanssen, Jan Usterud, Skollerud, Kåre H., 2016. Household parking facilities: relationship on travel behavior and car ownership. Transp. Res. Procedia (forthcoming).
Christiansen Petter, Hanssen Jan Usterud, 2014. Park and Ride - Results From Surveys Among Users. TOI-report 1367/2014.
Dieleman, Frans M., Dijst, Martin, Burghouwt, Guillaume, 2002. Urban form and travel behaviour: micro-level household attributes and residential context. Urban Stud. 39 (3), 507–527.
Engebretsen Øystein, Christiansen Petter, 2011. Bystruktur og transport. En studie av personreiser i byer og tettsteder. TØI-rapport 1178/2011.
Ewing, R., Cervero, R., 2010. Travel and the built environment. J. Am. Plan. Assoc. 76 (3), 265–294.
Fearnley Nils, Hanssen Jan Usterud, 2012. Basic Data about Urban Parking and Parking Price Elasticity. TOI Report 1206/2012.
Feeney, Bernard P., 1989. A review of the impact of parking policy measures on travel demand. Transport. Plan. Technol. 13 (4), 229–244.
Guo, Zhan, 2013a. Does residential parking supply affect household car ownership? The case of New York City. J. Transp. Geogr. 26, 18–28.
Guo, Zhan, 2013b. Home parking convenience, household car usage, and implications to residential parking policies. Transp. Policy 29, 97–106.
Guo, Zhan, 2013c. Residential street parking and car ownership. J. Am. Plan. Assoc. 79 (1), 32–48.
Guo, Zhan, McDonnell, Simon, 2013. Curb parking pricing for local residents: an exploration in New York City based on willingness to pay. Transp. Policy 30, 186–198.
Hair, Joseph F., Black, William C., Babin, Barry J., Anderson, Rolph E., 2009. Multivariate Data Analysis: A Global Perspective, seventh ed. Prentice Hall, Upper Saddle River.
Hamre, Andrea, Buehler, Ralph, 2014. Commuter mode choice and free car parking, public transportation benefits, showers/lockers, and bike parking at work: evidence from the Washington, DC Region. J. Pub. Transport. 17 (2), 4.
Hanssen Jan Usterud, Tennøy Aud, Christiansen Petter, Øksenholt Kjersti Visnes, 2014a. Which Kinds of P&R Can Contribute to Reduced Greenhouse Gas Emissions? TOi-report 1366/2014.
Hanssen Jan Usterud, Åretun Åsa, Fearnley Nils, Hrelja Robert, Christiansen Petter, 2014b. Parkeringsnormer i utvalgte norske og svenske byer. Status og effekter på bilinnehav, adferd og økonomi. TØI-rapport 1311/2014.
Hjorthol, R., Engebretsen, Ø., Uteng, T.P., 2014. 2013/14 National travel survey - key results. TØI report 1383/2014. Available on: <www.toi.no>.
Inci, Eren, 2015. A review of the economics of parking. Econ. Transport. 4 (1–2), 50–63.
Knoflacher, Hermann, 2006. A new way to organize parking: the key to a successful sustainable transport system for the future. Environ. Urban. 18 (2), 387–400.
Kobus, Martijn B.W., Gutiérrez-i-Puigarnau, Eva, Rietveld, Piet, Van Ommeren, Jos N., 2013. The on-street parking premium and car drivers' choice between street and garage parking. Reg. Sci. Urban Econ. 43 (2), 395–403.
Krizek, Kevin J., 2003. Residential relocation and changes in urban travel: does neighborhood-scale urban form matter? J. Am. Plan. Assoc. 69 (3), 265–281.
Litman, Todd, 2009. Parking Requirement Impacts on Housing Affordability. Victoria Transport Policy Institute, Victoria, Canada.
Litman Todd, (2013). Understanding Transport Demands and Elasticities, How Prices and Other Factors Affect Travel Behavior. Victoria Transport Policy Institute, Litman <http://www.vtpi.org/elasticities.pdf> (verified 22 November 2013).
Manville, Michael, Beata, Alex, Shoup, Donald, 2013. Turning housing into driving: parking requirements and density in Los Angeles and New York. Hous. Policy Debate 23 (2), 350–375.
Manville, Michael, Shoup, Donald, 2005. Parking, people, and cities. J. Urban Plan. Develop. 131 (4), 233–245.
Manville, Michael, Shoup, Donald C., 2010. Parking Requirements as a Barrier to Housing Development: Regulation and Reform in Los Angeles. University of California Transportation Center.
Marsden, Greg, 2006. The evidence base for parking policies—a review. Transp. Policy 13 (6), 447–457.
Melia, Steven, 2014. Carfree and Low-Car Development. Parking Issues and Policies (Transport and Sustainability), vol. 5. Emerald Group Publishing Limited, pp. 213–233.
Millard-Ball, Adam, 2002. Putting on their parking caps. Planning 68 (4), 16–21.
Miller, Erik J., Ibrahim, Amal, 1998. Urban form and vehicular travel: some empirical findings. Transport. Res. Rec. 1617, 18–27.
Naess, Petter, 2011. 'New urbanism'or metropolitan-level centralization? A comparison of the influences of metropolitan-level and neighborhood-level urban form characteristics on travel behavior. J. Transp. Land Use 4 (1), 25–44.
Naess, Petter, 2012. Urban form and travel behavior: experience from a Nordic context. J. Transp. Land Use 5 (2), 21–45.
Newman, Peter G., Kenworthy, Jeffrey R., 1989. Cities and automobile dependence: an international sourcebook. Gower, Aldershot.
Næss, Petter, 2005. Residential location affects travel behavior—but how and why? The case of Copenhagen metropolitan area. Prog. Plan. 63 (2), 167–257.
Næss, Petter, 2006. Urban Structure Matters: Residential Location, Car Dependence and Travel Behaviour. Routledge.
Pandhe, Amruta, March, Alan, 2012. Parking availability influences on travel mode: Melbourne CBD offices. Austral. Plan. 49 (2), 161–171.
Peng, Zhongren, Dueker, Kenneth, Strathman, James, 1996. Residential location, employment location, and commuter responses to parking charges. Transport. Res. Rec.: J. Transport. Res. Board 1556, 109–118.
Rye, Tom, Cowan, Tom, Ison, Stephen, 2006. Expansion of a Controlled Parking Zone (CPZ) and its influence on modal split: the case of Edinburgh. Transport. Plan. Technol. 29 (1), 75–89.
Rye, Tom, Ison, Stephen, 2005. Overcoming barriers to the implementation of car parking charges at UK workplaces. Transp. Policy 12 (1), 57–64.
Shoup, Donald C., 2005. The High Cost of Free Parking. Planners Press, Chicago.
Su, Qing, Zhou, Liren, 2012. Parking management, financial subsidies to alternatives to drive alone and commute mode choices in Seattle. Reg. Sci. Urban Econ. 42 (1–2), 88–97.
Tabachnick, Barbara G., Fidell, Linda S., Osterlind, Steven J., 2001. Using Multivariate Statistics, fifth ed. Haper and Row, New York.
Transport for London, 2012. Residential Parking Provision in New Developments. Travel in London Research Report.
van Ommeren, Jos, Wentink, Derk, Dekkers, Jasper, 2011. The real price of parking policy. J. Urban Econ. 70 (1), 25–31.
Weinberger, Rachel, 2012. Death by a thousand curb-cuts: evidence on the effect of minimum parking requirements on the choice to drive. Transp. Policy 20, 93–102.
Weinberger Rachel, Seaman Mark, Johnson Carolyn, 2008a. Suburbanizing the city: how New York City parking requirements lead to more driving. Transportation Alternatives, New York.
Weinberger, Rachel., Seaman, Mark., Johnson, Carolyn., Kaehny, John., 2008b. Guaranteed Parking–Guaranteed Driving: Comparing Jackson Heights, Queens And Park Slope, Brooklyn Shows That A Guaranteed Parking Spot At Home Leads To More Driving To Work. University of Pennsylvania for Transportation Alternatives.
Weinberger, Rachel, Seaman, Mark, Johnson, Carolyn, 2009. Residential off-street parking impacts on car ownership, vehicle miles traveled, and related carbon emissions: New York City case study. Transport. Res. Record: J. Transport. Res. Board 2118, 24–30.
Willson, Richard W., 2013. Parking Reform Made Easy. Island Press.
Willson, Richard W., Shoup, Donald C., 1990. Parking subsidies and travel choices: assessing the evidence. Transportation 17 (2), 141–157.
Zhang, Ming, 2004. The role of land use in travel mode choice: evidence from Boston and Hong Kong. J. Am. Plan.ing Assoc. 70 (3), 344–360.