

# HOW SPATIAL AND TRANSPORT PLANNING AFFECTS CAR OWNERSHIP AND COMMUTE MODE CHOICE

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## ABSTRACT SUMMARY

This paper discusses how far not only mode choice decisions are influenced by land use patterns and transport infrastructure, but also the household car ownership decisions. An integrated car ownership and commute mode choice model with state dependence is presented.

## ABSTRACT

Individual travel behaviour is decisively influenced by long term commitments due to the ownership of cars and public transport passes. However, most car ownership models ignore that planning strategies could influence car ownership decisions by reducing (or increasing) the need for (multiple) car ownership. In urban areas with good accessibility by alternative modes many households live with no or only one car even if they could afford a (2nd) vehicle.

This paper analyses the factors influencing household car ownership and commute mode choice, and the interactions between these medium-term mobility decisions. Joint conditional logit models are estimated using data from the German Socio-Economic Panel (GSOEP). The impact of socio-economic attributes, and the influence of different local and regional accessibility indicators on these decisions are evaluated.

As car ownership level and commute mode choice are decisions that are not revised frequently, state-dependence is analysed by including the car ownership level and the commute mode used 5 years ago.

To illustrate the effects of different location attributes and travel conditions upon car ownership and commute mode choice, the choice probabilities for typical households with identical socio-economic attributes at different locations and with different public transport accessibility are calculated. The results reveal, that improved public transport services effectuates not only a direct modal shift from car to public transport, but also reduces the probability for households to own (a 2<sup>nd</sup> or 3<sup>rd</sup>) car. This provokes additional indirect effects on car ownership, even if they might happen with a time lag of several years due to the state dependence. Neglecting these indirect effects might lead to a serious underestimation of the long-term effects of integrated planning options.

For new residential developments this means, that providing quality public transport and shopping facilities from the beginning might pay off in terms of lower car ownership, less parking demand, and higher public transport

ridership, because the new residents do not get accustomed to a car-dependent life style.

The model can be applied within a micro-simulation framework of travel demand, linking the long-term decisions of residential and workplace location choice to the short-term travel behaviour.

## 1 BACKGROUND AND OBJECTIVES OF THIS PAPER

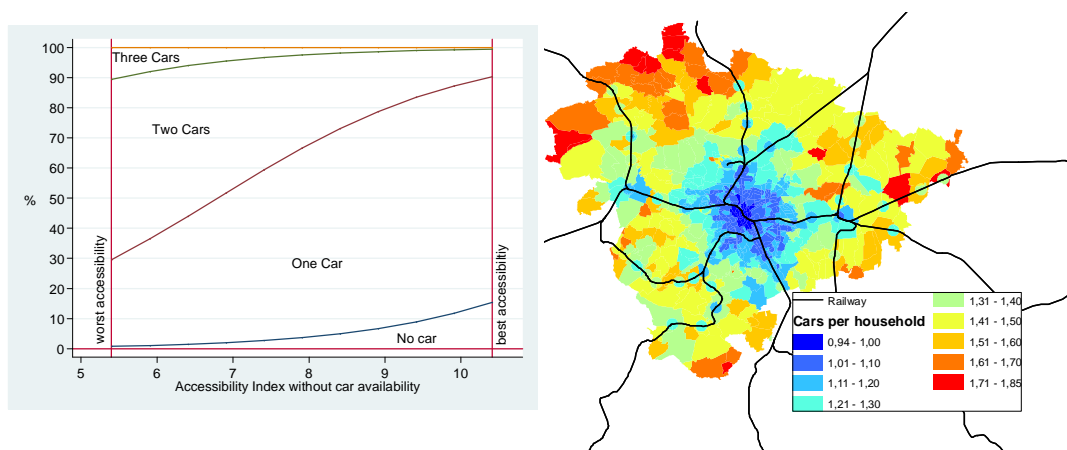
Car availability is one of the most important determinants of daily travel behaviour – for activity participation, destination choice, and particularly mode choice. In most macroscopic transportation demand models, this is incorporated by a segmentation of the population according to their car availability. Microscopic demand models use car availability as an explaining variable at the different stages of the model system.

However, car availability is treated exogenously in most travel demand models. Spatial differences in motorisation are taken often into account, but rarely modelled in a way that is sensitive to policy options:

Often land use policy favours monofunctional, low-density developments with poor access to shops, services and public transport. This could encourage or even force residents to acquire a (2<sup>nd</sup> or even 3<sup>rd</sup>) car. In contrast, an integrated planning strategy, that supports transit orientated development, improves public transport services, and offers attractive public transport passes would reduce the need for (multiple) car ownership.

A car ownership models for the Hanover Region using policy sensitive accessibility indicators (see Figure 1) revealed, that car ownership doubles for a typical household from the least to the best accessible areas within the metropolitan area (Bohnet, Gertz 2008).

FIGURE 1: Expected average number of cars per household for a 2-adult household with a net monthly household income of 1.850 € in the Hanover Region



Source: Bohnet, Gertz (2008)

Within the context of microscopic travel demand models there remains the problem, how to deal with household car ownership, individual car accessibility, and car allocation to household members within households with more than one driver, and how to integrate not only residential location choice but the location of work and education of household members.

To address these issues, this paper takes up an approach proposed by

(Lerman, Ben-Akiva 1976) and (Ben-Akiva, Lerman 1985): It estimates joint household car ownership and commute mode choice models using German Survey Data and extends it a) by integrating non-motorised modes, and b) by reflecting path dependence through lagged response variables.

The rest of the paper is organised as follows

Section 2 describes the data used and discusses the methodology. Section 3 presents the estimates results for the household car ownership model and the the commute mode choice models for primary and secondary workers.

Section 4 illustrates the results by estimating the impact of different spatial attributes on car ownership and mode choice for typical households.

Finally, in section 5, some conclusions are drawn and further research need formulated.

## **2 METHODOLOGY AND DATA USED**

Section 2.1 describes the data used and provides an overview on the variables used in this analysis. Section 2.2 discusses the methodology within the framework of a microscopic travel demand model.

### **2.1 Data used**

For these analysis, data from the German Socio-Economic Panel (GSOEP) is used. The GSOEP (Wagner et al. 2007) is a large-scale multi-purpose household panel survey. The same households are asked every year on topics such as family and work biography, income, health, education, housing, neighbourhood, life satisfaction, and car and driving licence availability. In 1998 and 2003 there was a focus on environmental and travel behaviour. About 14.000 household interviews of households with commuters from these panel waves were used in this analysis.

TABLE 1 Descriptive Statistics of the GSOEP data from 1998 and 2003

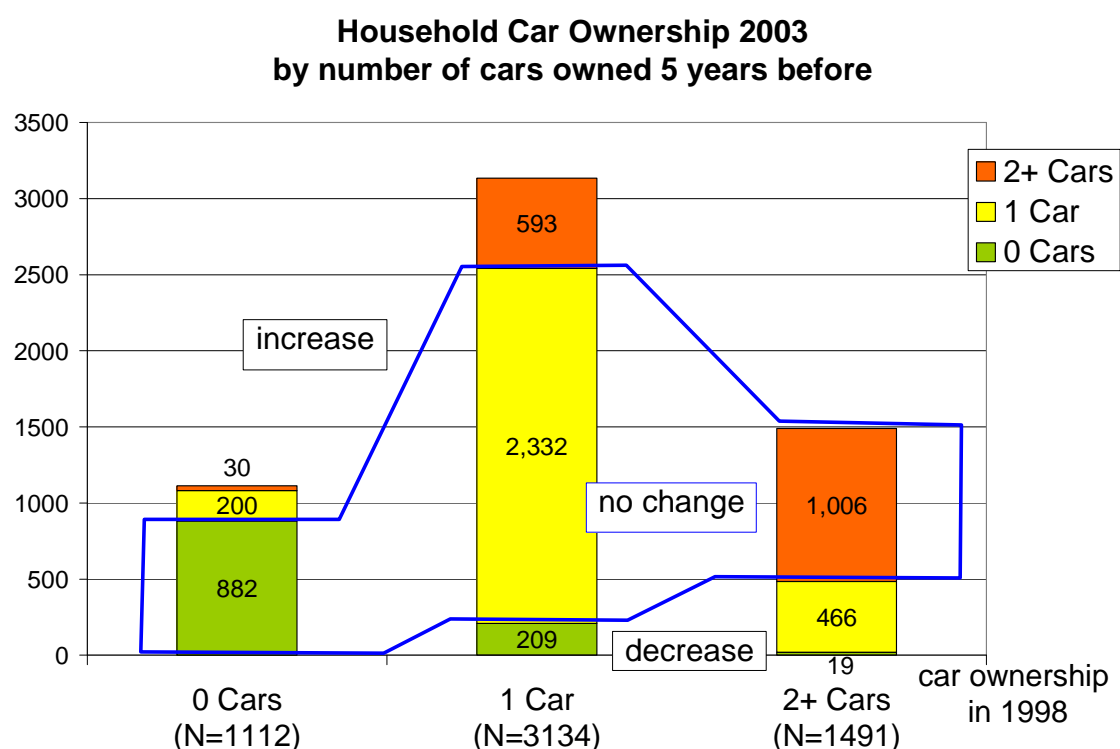
Sample Size	N	Households without commuters	5436
		Households with commuters	14124
		Responding persons >= 18 years	35870
		Persons with commute trips	23488
			Share in % or Mean (Std.Dev.)
Cars	Number of cars per household	0	20%
		1	52%
		2	24%
		3	4%
Socio-Economic Household Variables	number of licenced drivers in household	0	20%
		1	33%
		2	39%
		3	6%
		4	2%
	children in household	no children children < 18 years	71% 29%
Income	net monthly household income, deflated to prices of 2007 [€]	1978 € (1125 €)	
Socio-Economic Person Variables	age	age at interview [years]	45.4 (16.4)
	occupation	fulltime job	45%
		parttime job	12%
		apprentice/military/civil service	3%
		university/college student	3%
		not employed	38%
	transit pass	Transit Pass owner	12%
driving licence	driving licence at time of interview	81%	
car availability	never available	26%	
	occasionally available	12%	
	always available	62%	
Spatial/ Accessibility Variables	mixed neighbourhood	mixed-used neighbourhood	24%
		residential neighbourhood	76%
	type of house	rural farm	3%
		detached 1-2 fam. house	32%
		terraced house	16%
		multifamily 3-8 app.	32%
		multifamily, 9+ app.	17%
	distance to big city	urban centre	12%
		less than 10 km	26%
		10-25 km	27%
		25-40 km	14%
	walking distance to shops	more than 40 km	21%
		shops in 0-10 minutes by foot	59%
		shops in 10-20 minutes by foot	28%
Accessibility gains of a car on access to	no shops in walking distance	12%	
	High-Level Centre	3.6 (2.3)	
	Middle-Level Centre	1.5 (1.5)	
Waiting Time	Average Transit Waiting Time on trip to next middle-level centre	14.6 (11.0)	

The data was retrieved using the PanelWhiz v2.0 (Nov 2007) Tool for Stata written by Haisken-DeNew and Hahn (2006), extended by PanelWhiz plugins written by Haisken-DeNew/Hahn and Max Bohnet. Additional information on public transport frequency and the accessibility by car and other modes to the next middle- and high level centres could be joined to the data for the zip code area in which the households resided during a guest stay at the DIW Berlin. Thanks to John Haisken-DeNew and Markus Hahn for PanelWhiz, Jan Goebel for his support at the DIW and Thomas Weiner for his support generating the accessibility indicators. All code (Stata do-files and plugins) are available upon request.

### Household Car Ownership in the GSOEP-Sample

Table 1 displays some descriptive variables of the sample used. 1/5 of all respondents have no car, about one half has one car and 28%. This figure did not differ significantly between 1998 and 2003. Among those 5.500 households which responded both in 1998 and 2003, a significant share of households changed the car ownership level (Figure 2):

FIGURE 2 Changes in Car ownership between 1998 and 2003



One fifth of the households without car in 1998 acquired one or more cars until 2003. One third of all households, who had 2 or more cars in 1998, had disposed of one or both of their cars 5 years later. This shows that a significant share of households adapt their car ownership within a 5-year-period to changing possibilities and needs. In total, every 14% of all households bought an (additional) car, 12% of the household disposed of at least one car and 74% remained their car ownership level stable. Regarding the 12-year period from 1991 – 2003, every fourth household increased and 17% decreased their car ownership levels.

In 1998 and 2003, the the commute distance and the mode chosen for the (work or education) commute trip was asked. In addition, the respondents were asked to estimate the it would take them to commute by car and public transport. So also information on the not-chosen alternatives were available which facilitated the estimation of the contitional logit models.

The spatial attributes, which were expected to influence car ownerhsip, that were found in the survey data or could be joined to the data, included:

- housing and neighbourhood type (in neighbourhoods with denser housing types local accessibility to different activity opportunities tend to be better)
- shopping facilities within walking distance
- accessibility benefits of a car to the next middle- and higher level centre (calculated for the zip-code-area): The more time a household saves using the car to reach the next centre compared to using other modes, the higher the utility to own an additional car might be.
- public transport frequency (the lower the waiting time, the more flexible public transport is and the more likely it might serve as an alternative to private car ownership)

The workplace accessibility of the household members by car and by alternative modes is captured through the mode choice models.

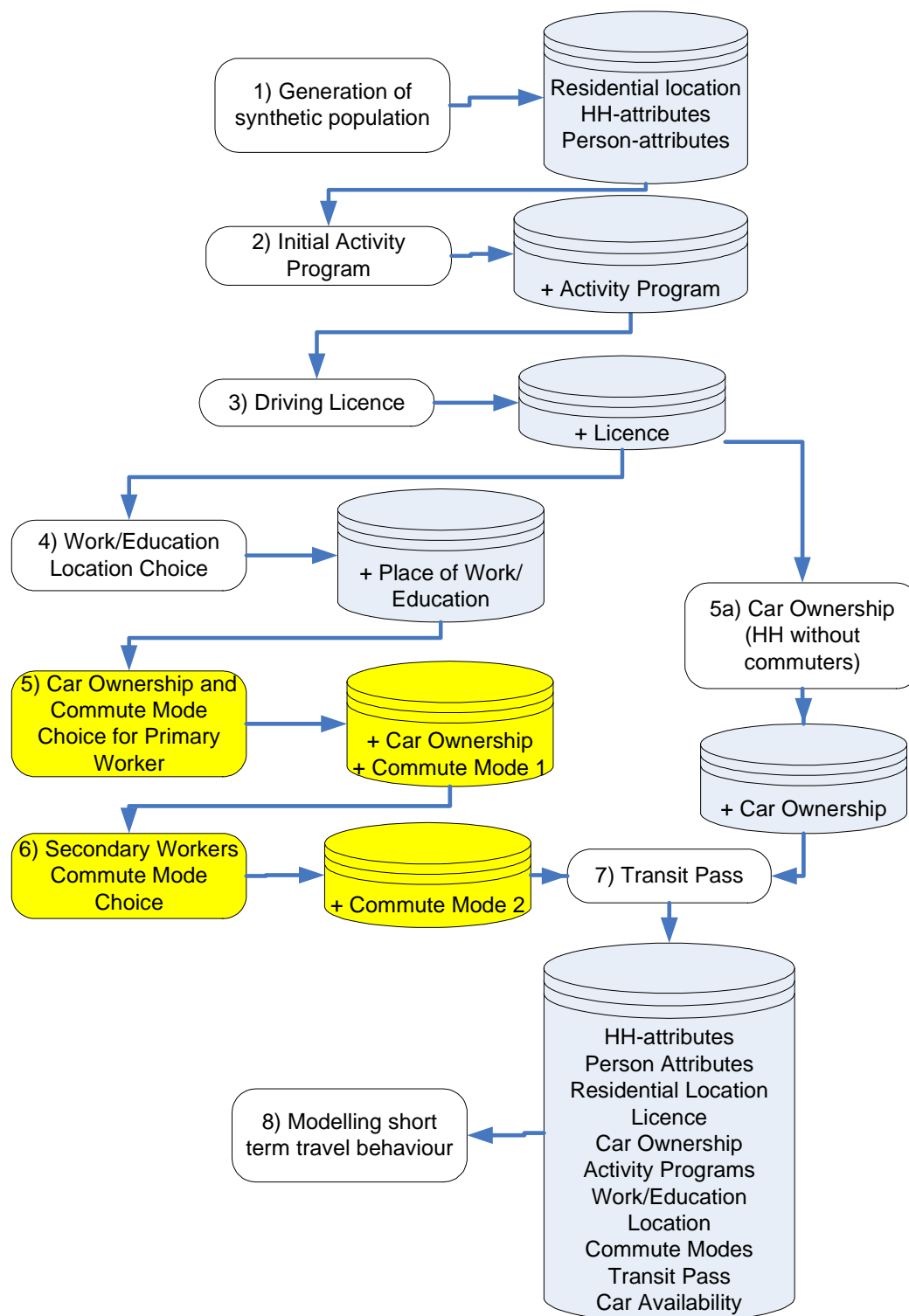
## **2.2 household car ownership and commute mode choice within microscopic travel demand models**

Within the framework of an integrated simulation of long- and short-term mobility decisions (see Figure 3), car ownership and commute mode choice can be regarded as a medium-term decision, which shapes decisively the short term travel behaviour and is determined by long term residential and workplace location decisions. These long-, medium- and short-term decisions can be captured within a microscopic travel demand simulation (see for example: Kuhnimhof 2007, Ciari et al. 2007).

This requires a synthetic population, which is set up for a base year with initial socio-economic attributes and initial residential locations. In further simulation steps, additional attributes such as activity programs, driving licence, place of work or education, car ownership, commute mode and public transport pass ownerhsip can be modelled using monte-carlo-simulation techniques.

This paper focusses on the highlighted steps of household car ownership and commute mode choice.

FIGURE 3: Household Car Ownership and Commute Mode Choice within a microscopic simulation of mobility decisions



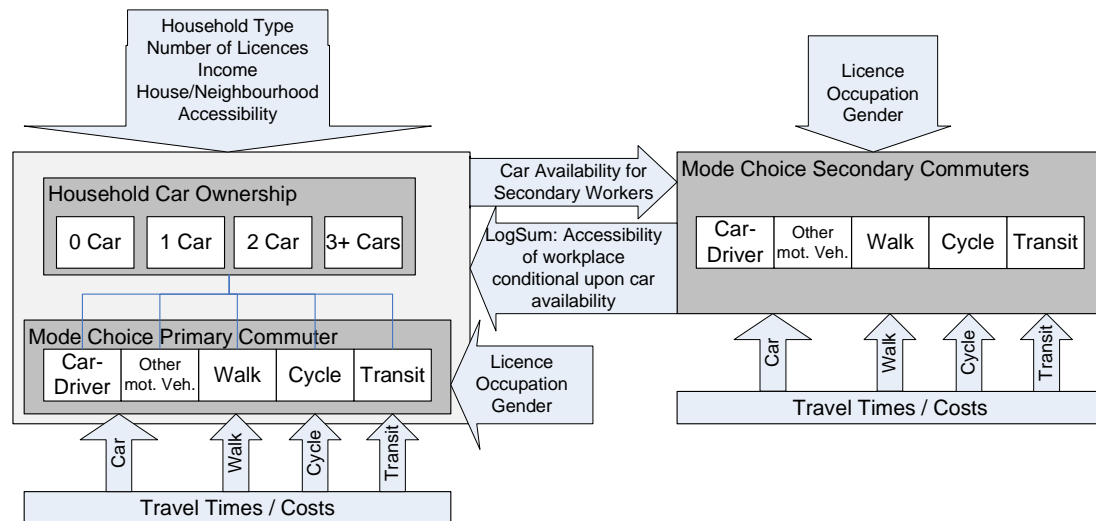
Models for commute mode choice and household car ownership are estimated for households with at least one commuter (a person with regular trips to work or education) (Figure 4).

For the primary commuter (here defined as the person with the largest commute distance) household car ownership and commute mode choice is modelled simultaneously in order to capture the interactions between these mobility decisions. There are  $5 \cdot 4 - 1 = 19$  alternatives in the choice set (4 car

ownership levels [0, 1, 2, 3+ cars] \* 5 modes [public transport, walk, cycle, drive own car, car passenger/other motorised vehicle]). The alternative “no cars and drive own car” is excluded as infeasible as well as the “drive own car” for commuters without a driving licence. Alternatives which are not available are marked in Tables 2 and 3 with a cross.

For the other (secondary) commuters, a mode choice model conditional upon car availability is estimated. There are 5 modes in the choice set (4 if no car is available for the secondary commuters).

FIGURE 4: Models of Household Car Ownership, and Commute Mode Choice for the primary and secondary workers.



### Controlling for Socio-economic variables

For the mode choice decision, type of occupation, gender, and the travel and waiting times by the corresponding mode are taken into account as explaining variables.

For the household car ownership decision, socio-demographic household characteristics (number of driving licences, children) are used. To include the monetary aspects into the model, we pick up the approach proposed by (Lerman, Ben-Akiva 1976, p. 40f.) and adopt it to German conditions of the year 2003:

For each alternative, the remaining income is calculated by deducing from the monthly net household income a fixed amount for basic needs (400 € per household plus 230 € for each household member), by deducing the monthly fixed car ownership costs (200 € for each car, which corresponds to the fixed costs for a small car, see ADAC 2008), and by deducing the monthly variable commute costs for each mode (calculated based upon commute distance). As the marginal utility of 1 € decreases with rising income, the log of this remaining income  $rincl_{c,m}$  is used as explaining variable. Before taking the logarithm of the remaining income, a constant value has to be added to ensure that the resulting value is always positive – 1.700 € was found to fit the data best.

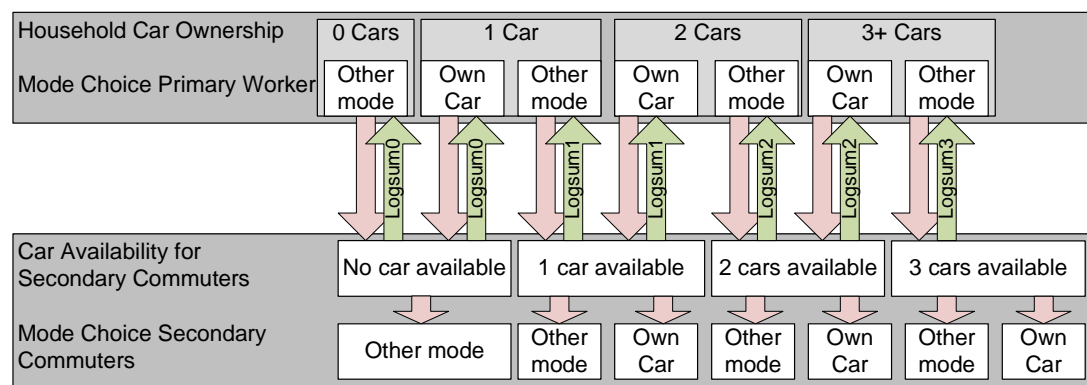
$$rincl_{p,m} = \ln(hhinc - 400€ - 230€ * (hhsz) - 200€ * hhcars - co_m + 1700€) \quad (1)$$

### Linking the primary and secondary commuter mode choice model

For households with more than one commuter, the household-car-

ownership/primary-commuter-mode-choice-model is linked to the secondary-worker-mode-choice-model in both directions:

FIGURE 5: Link between household car ownership and secondary workers mode choice model through car availability and LogSum variables.



The available cars for the secondary workers is the number of household cars minus 1, if the primary worker uses the car to drive to work, so that during the day, no other household member can use this car.

The secondary commuter mode choice model is estimated conditional upon car availability. Then, the LogSum (log of the denominator) of the mode choice model is calculated for all levels of car availability. These LogSum-values can be interpreted as the accessibility, the secondary workers gain if they have one (or 2 or 3) cars available compared to the case, where they have no car available.

Including these LogSum indicators to the corresponding alternatives in the car ownership model makes the model sensitive to changes of travel times for the secondary commuters: If the accessibility gains of a car decreases to the secondary commuters because of better public transport services, then the primary worker is more likely to drive to work with the car, which is less required by the secondary worker. On the other hand, the household is more likely to own only one instead of 2 cars, if the second car is less needed by the the secondary commuters.

### 3 RESULTS

The conditional logit models have been estimated using the maximum likelihood procedure of the Stata 10 *clogit* model (Long, Freese 2006). Only parameters that were significantly (at least at the 10%-level) different between the different alternatives (or different from 0 in case of alternative specific variables) are displayed. The household car-ownership/primary worker performed quite well with a McFadden-Pseudo-R<sup>2</sup> of about 0.5. The secondary worker model had a Pseudo-R<sup>2</sup> of 0.42.

#### 3.1 commute mode choice

The parameters for the different groups (Table 2) indicate, that utility is influenced by the type of main occupation: Pupils are more likely to walk, university students prefer cycling, part- and full-time workers tend to use the car. Women are more likely to walk and use public transport than men.

TABLE 2 Estimated Parameters for the Mode Choice Models

	constant	occupation					female	waiting time [min]	travel time [min]	ln(remaining income)	remaining cars available					other licenced drivers in household	State dependence: Same mode 5 years ago
		full time	part time	apprentice	univ. student	other (pupils)					no car	1 car	2 cars	3 cars			
Mode Choice of Primary Commuter																	
public transport	0.20	-1.23	-1.15	-0.38	0.60	0.00	0.36	-0.06	-0.04	14							
bicycle	-1.97	0.99	0.78	0.38	2.26	0.00	-0.24		-0.11	14							
walk	2.70	-1.62	-1.69	-1.58	-1.28	0.00	0.49		-0.12	14							
other car	-3.02	-0.04	-0.99	0.45	0.54	0.00	-0.17		-0.06	14							
drives own car	0.00	0.00	0.00	0.00	0.00	0.00	0.00		-0.06	14							
Mode Choice of Secondary Commuters																	
public transport	-0.39	-2.08	-1.97	-0.79	0.15	0.00	0.59	-0.05	-0.03	14					1.38		
bicycle	1.05	-1.88	-1.56	-1.26	-0.25	0.00	-0.05		-0.11	14					1.87		
walk	0.53	-1.36	-1.49	-0.63	-0.60	0.00	0.52		-0.11	14					1.17		
other car	-2.23	-0.33	-0.52	0.19	0.02	0.00	0.07		-0.07	14					0.90		
drives own car	0.00	0.00	0.00	0.00	0.00	0.00	0.00		-0.07	14	0.00	0.33	0.79	-0.68	1.24		

For the mode choice decision of the primary worker, very similar travel time parameters are found. One minute of physical movement (walking or cycling) seems to be evaluated more negative than one minute of physically 'passive' movements: (car), and particularly travel time in public transport, where time can be used for reading, working etc.

These results should be handled carefully, because there might be large measurement errors (travel time for walking and cycling, evaluation of travel times for the means of transport not used).

As at least one household car is required for the secondary worker to drive in a (household)-car to work, .

We find a significant 'competition for household car' parameters in Tables 2 and 3. Additional licenced drivers reduce the probability to use the car for primary and secondary commuters. Larger accessibility gains by car for the secondary workers (measured as LogSum-Difference)

- decrease the probability, that the primary worker takes the household car to drive to work, and
- increases the probability, that the household acquires an additional car.

If there are children under 18 years in the household, it is less likely for a household to own no car, but not significantly more likely to buy a second or third car.

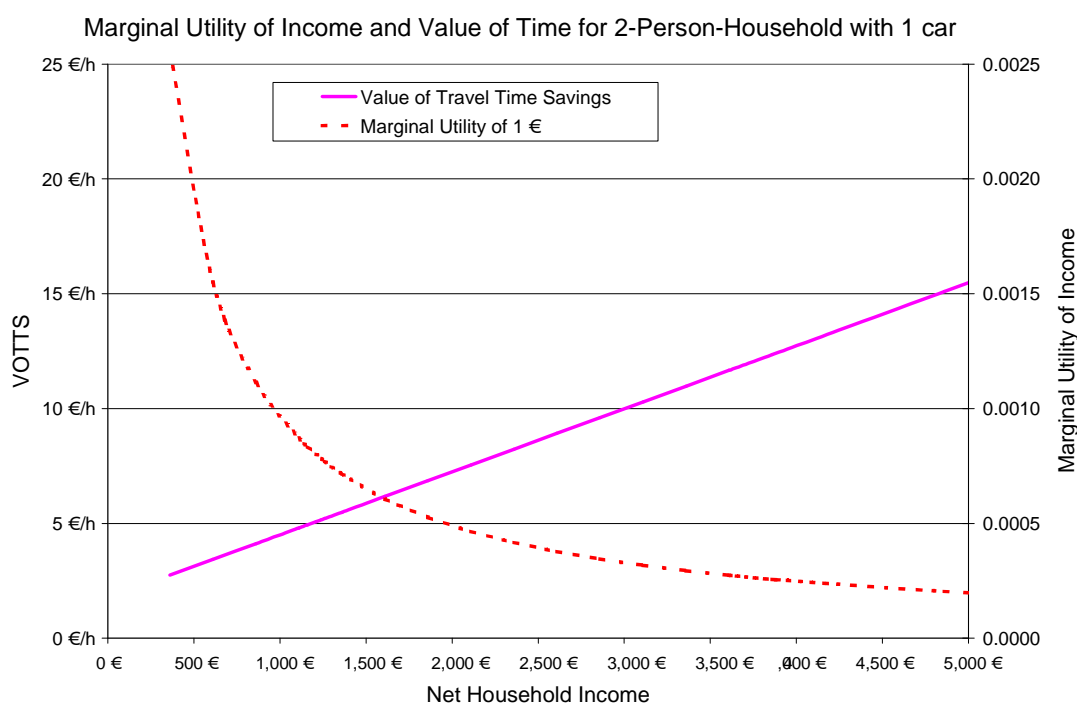
The 'log(remaining household income)' parameter reflects that the marginal utility for an household for each Euro, that a household has left (by *not buying* an additional car or *not spending* money on variable commute costs) decreases with rising income. The logarithmic specification implies a value of travel time, that increase lineary with income, if one relates this parameter to the travel time parameters (Figure 6).

- The location specific parameters indicate, that car ownership decreases with
- mixed-used neighbourhoods and housing density, which might reflecting density of activity opportunities in the neighbourhood, or parking conditions and costs
  - shopping facilities within walking distance
  - lower regional accessibility gains by car on trips to the next to middle-, and higher level-centres
  - frequent public transport services

TABLE 3 Estimated Parameters for the Household Car Ownership Model

	no car	1 car	2 cars	3+ cars
ln(Remaining income)	14.71			
Licences in Household				
No Licence	3.70	0.00		
1 Licence	-1.70	0.00	-2.26	
2 Licences	-2.96	0.00	-0.39	-2.65
3 Licences	-3.04	0.00	0.89	0.79
4 Licences		0.00	1.31	2.30
Drives own car, 1 licence		0.00	1.21	
Drives own car, 2 licences		<b>-0.55</b>	0.80	0.74
Drives own car, 3 licences		<b>-0.59</b>	0.17	0.53
Drives own car, 4 licences		<b>-1.04</b>	-0.15	0.41
Accessibility gains of cars for secondary commuters	0.36			
Children in Household	<b>-0.42</b>	0.00	0.14	0.14
Shopping facilities in walking distance	0.06	0.00	-0.25	-0.79
Mixed neighbourhood	0.11	0.00	-0.08	-0.30
Housing type				
rural house	-0.47	0.00	0.92	1.19
detached single family home	-1.30	0.00	0.54	0.97
terreced houses	-0.65	0.00	0.55	0.68
multi-family house with 3-8 appartm	-0.30	0.00	0.09	0.15
multi-family house with 9+ appartm	0.00	0.00	0.00	0.00
accessibility benefit of a car on trips to				
next middle level centre	-0.21	0.00	0.09	0.13
next high level centre	-0.14	0.00	0.02	0.04
Public transport waiting time	-0.02	0.00	0.01	0.03
State Dependence: 5 years ago				
no car	0.48	0.00	-0.13	-0.17
1 car	-0.78	0.00	-0.41	-1.15
2+ car	-0.73	0.00	0.43	0.26

FIGURE 6: Marginal Utility of remaining income and Value of Car Travel Time



### State dependence in car ownership and commute mode choice

In addition to the socio-economic and spatial variables, a model has been estimated that included the car ownership level, and the mode used in 1998 as explaining variables for the car ownership and commute mode choice in 2003. The sample-size was lower, because only part of all households have been interviewed in both years. Including the state-dependence variables did not alter the other parameters significantly (with exception of some parameters for occupation), so in Tables 2 and 3 only the additional state dependence parameters are displayed in italics. They reveal, that the car ownership and mode choice decisions are influenced by the decisions taken 5 years ago. This emphasises, that these decisions have long-term impacts. However, they also might reflect some unobserved attributes of the households and persons and their residential locations, which might not have changed during these 5 years.

In order to illustrate the impact of policy measures for a typical household, the effects on car ownership and commute mode choice are presented in the next section.

## 4 EFFECTS OF TRANSPORT AND LAND USE SCHEMES ON CAR OWNERSHIP AND COMMUTE MODE CHOICE FOR A TYPICAL HOUSEHOLD

This section illustrates the effects of different locations and travel conditions on upon car ownership and commute mode choice by calculating the corresponding choice probabilities for two households with identical socio-economic attributes:

The household consists of 3 persons (1 full time worker, 1 part time worker, 1 pupil of 19 years, all with driving licence) with a net household income of 1.800 €. The pupil walks to a school nearby, the workers both work in the city centre. One household is living in a peripheral location in a detached single family home about 30 km from the city centre. Public transport services to the city centre and the next middle-level-centre are poor. The other household lives in an apartment in a mixed-used neighbourhood 2 km from the city centre with frequent public transport services.

FIGURE 7: Car Ownership and primary workers commute mode choice for two households (3 licenced drivers, 1.800 € net monthly income, workplace in the city centre) at different locations.

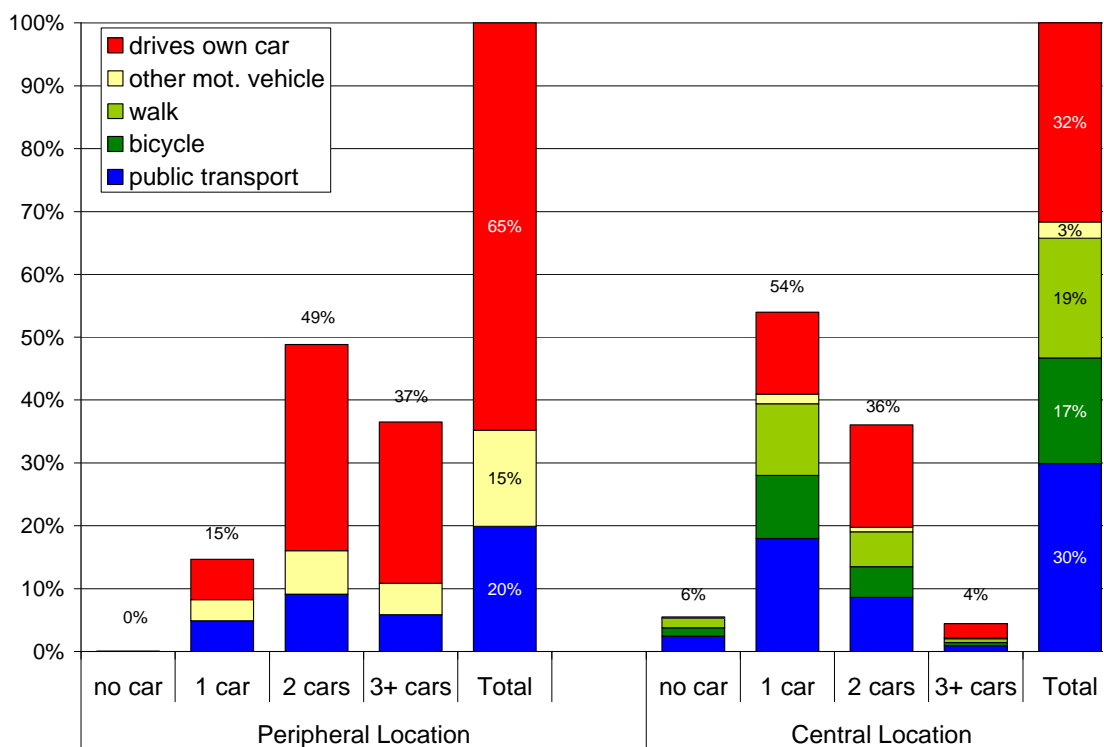


Figure 7 displays the choice probability for the 2 households: The probability for the peripheral household to own 2 or even 3 cars is 85%. The car (driver or passenger) is the dominant commute mode for the primary worker with 80% of all trips, while 20% use public transport. For the household at the central location the probability to own 2 or even 3 cars is much lower (40%). 6 % own no car at all. Due to the short commute distance, a significant share of commute trips (36%) will be made walking or cycling, while the the car accounts for only 35% and public transport for 30 % of all commute trips.

Relocating all families from peripheral single family homes to central apartments is not a very realistic policy option. Therefore in a second example we compare the situation of a couple living in a detached single family home in a suburban location at about 10 km from the city centre. Both have a driving licence and are working in the centre of a middle-level-centre. In the base scenario there are only poor public transport connections to the workplace in middle- and to the next high-level centre. Shopping facilities are

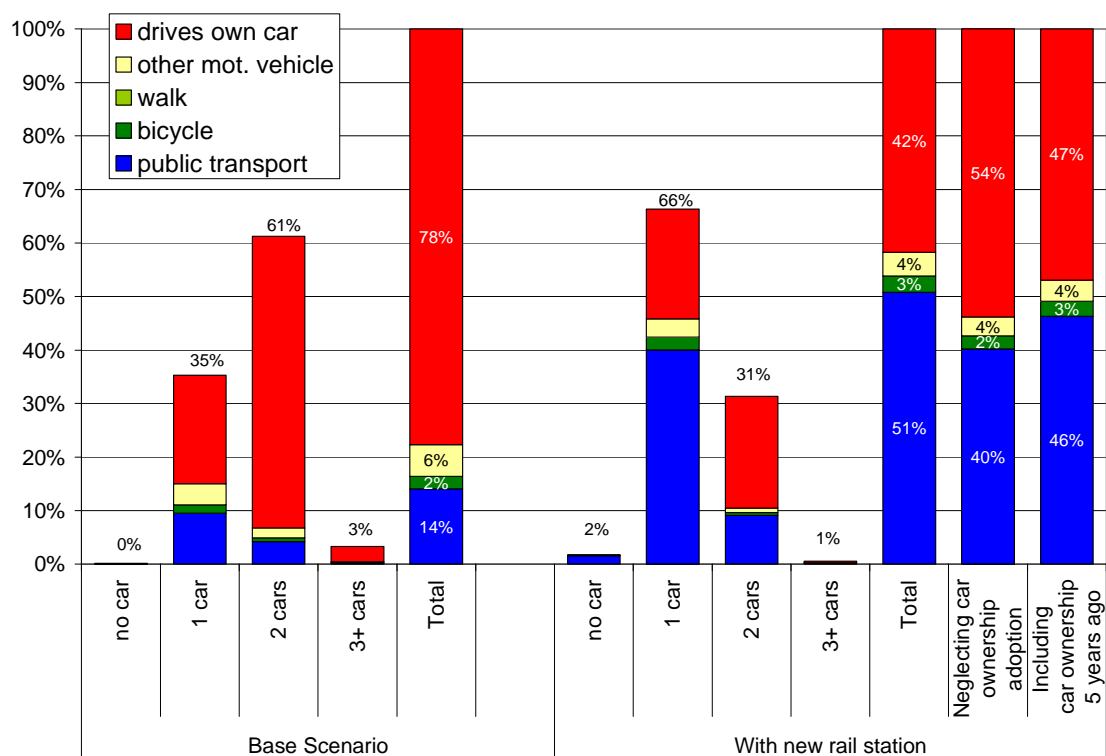
lacking.

In the second scenario a new station of a fast light-rail line is opened some 500 m from their house. The local accessibility is improved by new mixed-used transit-oriented development in the neighbourhood, including some shops.

Whereas in the base scenario the probability to own 2 or 3 cars is 64% and the car (driver or passenger) accounts for 84% of all commute trips, the new rail station and the improved local accessibility reduces the multiple car ownership probability to 32% and the car mode share to 42%. The expected average number of cars per household decreases from 1.68 to 1.31.

If one neglect the effects of the reduced car ownership on the mode choice decisions, the modal shift generated by the new rail station development is underestimated by 12 %.

FIGURE 8: Car Ownership and primary workers commute mode choice for two households in the base scenario and in the “new rail station” scenario.



If one includes the state dependence variables (5 years ago), then the average number of cars is slightly higher (1.34) than in the scenario without state dependence (1.31), but still much lower than in the base scenario. Public transport mode choice increases from 14% in the base scenario to 46% instead of 51% in the “new-rail-station-scenario”. This indicates, that within a period of 5 years, car ownership and travel behaviour adopts to a large extent to new travel conditions, but that still after 5 years some further adoption might be expected due to the long-term-state dependence of car ownership and commute mode choice.

## 5 CONCLUSIONS AND FURTHER RESEARCH NEEDS

The results show that car ownership is not only determined by socio-economic

factors, but also depends on spatial characteristics. Urban and transport planning can reduce the need for (multiple) car ownership by quality public transport services, integrated and transit orientated development and avoiding monofunctional low-density settlements. By this means, a competitive accessibility by walking, cycling, and public transport might serve for many households as an alternative to (multiple) car ownership.

To assess the impact of integrated land use and transport strategies on travel behaviour, transport models can be applied. Disaggregate, microscopic activity-based models offer a promising way to simulate the long- and short-term impacts of policy options. However, in many models, the medium-term car ownership decision, which decisively shapes the short term travel behaviour, is not endogenously modelled. The approach proposed in this paper demonstrates, how mode choice models can be integrated with household car ownership models in a way that is sensitive to urban and transport planning impacts. Neglecting the indirect effects of interventions via car ownership on mode choice might seriously underestimate the long-term impact of integrated planning options.

Further research needs are seen in the examination of the effects of reduced or free public transport passes, such as students- and job-tickets, on car ownership and commute mode decisions.

The estimated state-dependence models indicate, that households slowly adopt mode choice decisions or car ownership levels to changing conditions. For new residential developments this means, that providing quality public transport and shopping facilities from the beginning might pay off in terms of lower car ownership, less parking demand, and higher public transport ridership, because the new residents do not get accustomed to a car-dependent life style. On the other hand, after 5 years, a large share of households have adopted their car ownership and commute mode to changing conditions. How to better integrate these dynamic aspects of long term mobility decisions – in connection to the residential- and workplace location choice – remains subject to further research.

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