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ROAD PRICING AND ITS INDIVIDUAL RESPONSES WITHIN TRAVEL PATTERNS – LESSONS FROM THE AKTA STUDY

DRAFT

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Abstract:

While mobility pricing is discussed as a suitable tool for tackling urban traffic problems, its impact on the travel pattern of individuals is largely unexplored. Individual responses to pricing emerge as a number of different changes in attitude. As an example, it involves the reduction in actual trip making, more efficient route choice decisions, trip chaining, and change of destination choice. The analysis of reliable data seems necessary to gain a deeper insight into the personal motivations of behavioural adjustments to the new monetary constraints.

The AKTA Copenhagen study – which is part of the EU funded project Pricing ROad use for Greater Responsibility, Efficiency and Sustainability in cities (PROGRESS) – is a real life experiment of road pricing in the greater Copenhagen region (Nielsen and Jovicic, 2003; Nielsen, 2004). During 2001 and 2002, about 400 cars were equipped with GPS data loggers over a period of up to 24 weeks. The on-board systems monitored vehicle movement data for each second and were parallely used to simulate road pricing by displaying cost information for every trip driven. The experiment has already shown significant demand effects with a decrease in daily kilometrage between 0 and 40% depending on the location and the pricing scheme.

One of the appealing features of AKTA is the possibility to examine the differentiated pricing system applied against its impact on personal mobility. The paper goes into the question of how road pricing impacts destination choice by deeply analysing the rich GPS trip data set. The panel structure with multiple observations for single cars/drivers allows to investigate the diversity of individual activity repertoires and related travel patterns in both, the control and the pricing periods.

In particular, the analysis aims at describing how road pricing affects:
- the choice of destinations
- the size and structure of activity spaces (according to measures developed for longitudinal travel data by Schönfelder and Axhausen (2004))

1. NEW CHALLENGES FOR TRANSPORT POLICY

Most cities worldwide are facing severe traffic problems with high private and social costs. Environmental effects of increasing traffic, congestion as well as infrastructure investment insufficiency are major challenges for current transport policy. In the economic literature as well as in a growing part of the transport planning community, mobility pricing approaches of different types (cordon, distance) are widely agreed strategies to reduce the social costs of current travel patterns (see O'Sullivan, 2003; Huwer, 2005). The planned and already implemented introduction of charging schemes in several urban areas are believed to contribute considerably to a more sustainable and efficient urban policy.

In the wider literature, there is considerable attention to the question of spatial displacement, but little empirical evidence. This paper will report on such changes using the unique longitudinal dataset collected as part of the AKTA study in Copenhagen. The AKTA study simulated a number of road pricing schemes for the participating car drivers. The primary instrument for analysis is the concept of the activity space.

Individual GPS-trace enriched panel data sets such as the AKTA study allow to investigate the complexity of daily life and the diversity of individual activity repertoires and related travel patterns over time – including human activity spaces. Due to the availability of exact location data for GPS enhanced data sets, interesting opportunities arise for the analysis of spatial decision making and navigation.

The micro-geographical *activity space* concept captures the structures of realised locational choices for single travellers. The concept – which was developed in parallel with a range of related approaches to describe individual perception, knowledge and actual usage of space in the 1960s and 1970s (see Golledge and Stimson, 1997 for a discussion) – aims to represent the distribution of places visited and the space which contains those places frequented over a period of time. Activity spaces are geometric indicators of the *observed* or *realised* daily travel patterns (see also Axhausen, 2002).

The focus of the present study was to investigate how destination choice contributes to the reduction of travel observed in the AKTA experiment. The other dimensions of travel behaviour (route choice, mode choice, departure time choice, activity sequencing) are omitted at this place. If destination choice is believed to be one of the key dimensions, the AKTA GPS data with its great temporal and spatial exactness and its long-term character will provide important insights. However, the character of this paper is still preliminary – being descriptive for most part. It opens up the discussion on a range of issues important for travel behaviour analysis and its methodology (refer to the discussion at the end of this paper).

The hypotheses on the relationship between pricing and destination choice changes will be tested using an ad-hoc approach based on the enumeration of trips and destinations which was already applied to several other longitudinal data sets earlier (Schönfelder and Axhausen, 2004; Schönfelder, Li, Guensler, Ogle and Axhausen, 2005). The enumeration and listing of places visited over time is one of the methodologies to represent revealed human activity spaces – a concept which is introduced in more detail at the beginning of Chapter 5.

The paper is organised as follows: Chapter 2 reflects on the possible behavioural adaptations due to mobility charging. The next chapter provides a brief introduction to the AKTA survey design to give a background for this analysis. Chapter 4 provides details on the data base used for investigation - in particular on the post-processing and filtering of the raw GPS data available. The analysis is given in Chapter 5 before some conclusions are drawn for practice and research.

2. BEHAVIOURAL RESPONSES TO PRICING: ASSUMPTIONS

The activity space of an individual is defined as the locations visited over time. It is therefore a subset of the travellers' mental map, which locates all elements of the person's activity repertoire. The locations are defined completely as the combination of a geographical destination with an activity of a particular type undertaken there.

As a general hypothesis, we would expect the following assumptions to hold:

(1) Behavioural response to mobility pricing is believed to involve a range of adaptations in route choice, departure time choice, duration of activities, destination choice and trip chaining.

For individual destination choice decisions and revealed activity space in particular we expect:

(2) If there is a reduction in the average trip rate per person and day (by pricing period), there should be a visible decrease also in the number of locations visited as there is a direct connection between these two parameters (Schönfelder and Axhausen, 2004).

(3) If there is a reduction in the average daily travel distance, one would expect a smaller dispersion of the visited locations in space. This should affect non-obligatory destination or trips rather than destinations fixed in the short-run such as work place or school.

(4) A lower dispersion of places will have an impact on the distance of visited places from the home location as the major peg of daily travel.

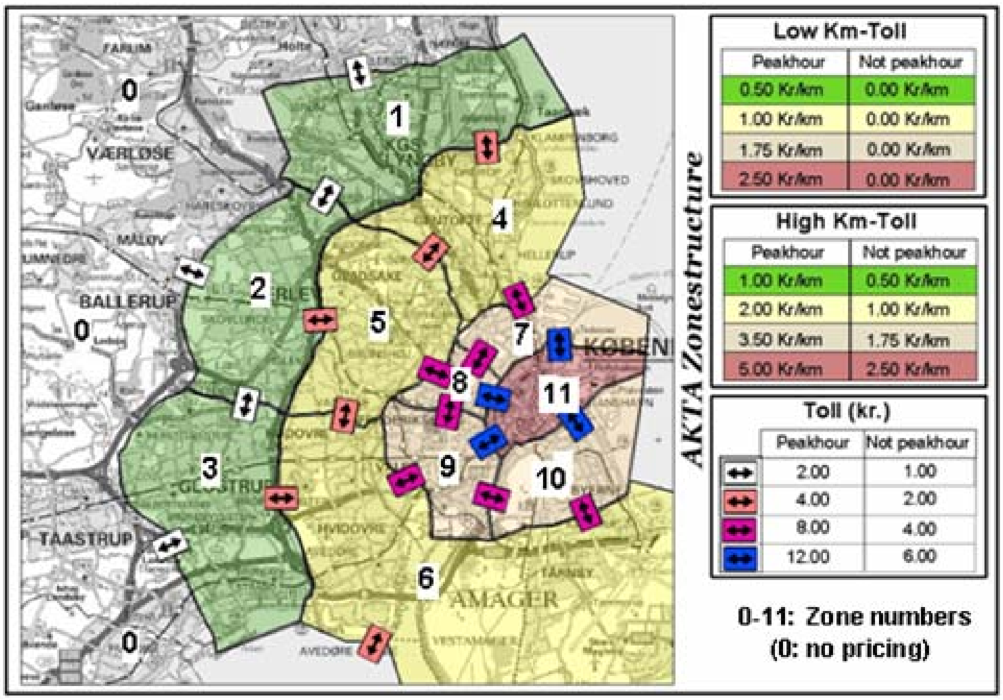
(5) The combination of destinations into tours and subtours will change. This is especially true for any cordon pricing scheme where destinations in "more expensive" zones get less attractive to the driver if there are alternatives in the same or less expensive zones. The same effect is possible for the kilometrage pricing schemes where places further away from the current location get less desirable due to budget considerations.

3. THE AKTA EXPERIMENT IN BRIEF

The AKTA[1] study (Nielsen and Jovicic, 2003; Nielsen, 2004) – which is part of the EU funded project Pricing ROad use for Greater Responsibility, Efficiency and Sustainability in cities (PROGRESS)[2] – is a real life experiment of road pricing in the greater Copenhagen region. In 2002 Copenhagen had 620.000 inhabitants in the municipality itself, about 1.800.000 in Greater Copenhagen (Koebenhavn kommun) and more than three million inhabitants in the Öresund region covering Greater Copenhagen and the neighbouring Swedish city region of Malmö.

Approximately 400 cars were equipped with a GPS-based device in three experimental rounds during a period of about two times 8-12 weeks in 2001/2002. Vehicle movement data was collected each second. An onboard system simulated road pricing by providing cost information for every trip within the City of Copenhagen, which was virtually divided by cordon rings defining prizing zones. After two monitoring periods which differed by the pricing scheme virtually applied (high kilometrage, low kilometrage or cordon), the AKTA test drivers were paid an amount of money according to their observed route choice behaviour. The GPS monitoring was accompanied by a telephone based before-and-after survey containing of attitude questions and SP instruments.

Figure 1 Pricing structure and zones



[1] Danish abbreviation for: Alternative Driving and Congestion Charging
[2] http://www.progress-project.org/ as of 27/9-2005

4. DATA POST PROCESSING AND AVAILABILITY

The analysis of the destination choice patterns is based on a sub-sample of the total AKTA movement data. The sub-sample contains about 100.000 trips (after post-processing) and covers all three combinations of a control period plus a pricing scheme (high and low kilometrage as well as cordon charging).

It is clear that such GPS data - obtained entirely by passive monitoring - lacks a range of essential information ordinary travel survey data sets usually provide. Apart from the systematic neglect of travelling by modes other than car - which may be taken into serious consideration by the drivers if the costs for using the car are raised - several data cleaning and imputation tasks would be necessary to match the comprehensiveness of ordinary travel survey data. This includes for example the exact identification of the driver, the detection of all trips and of aborted trips or the identification of trip purposes. However, given the objective of this study which is the demonstration of how the AKTA data could be used to test behavioural change in destination choice, the data was not fully cleaned as for example shown in Schönfelder and Samaga, 2003 and Wolf, Schönfelder, Samaga, Oliveira and Axhausen, 2004. Furthermore, neither an imputation of trip purposes nor the identification of the actual driver was implemented. These will be issues for further work based on the knowledge of underlying land use attributes and identified temporal regularities in trip and activity demands. However, to match minimal requirements for this investigation, the post-processing included initial filtering of the raw data as well as the identification of trip end positions.

The technical setup of the data collection led to a large number of monitored trips with unrealistic attributes such as too short trip durations or improbable speeds. Approaches to overcome these problems were already comprehensively discussed and encountered elsewhere (Wolf, 2000; Pearson, 2001; Wolf, Guensler and Bachman, 2001), especially by defining thresholds of (minimum/maximum) durations which parametrize elimination rules or by using knowledge about habitual behaviour of the driver. Such filtering of the data using an ad-hoc threshold approach does not systematically prevent that all erroneous trips are detected and erased. Especially if dealing with large data sets such as the AKTA data, it rather guarantees a minimum quality. Where more certainty about trip attributes is needed a sophisticated way of complementing and correcting the GPS traces is indispensable (Wolf *et al.*, 2004).

The strategy applied to clean the data used the following rules:

- Deleting trips with suspect speeds (average speed > 70 or = 0)
- Deleting trips with suspect stop / activity durations (<120 secs)
- Deleting trips with suspect trip durations (<30 secs.)
- Deleting trips with suspect travel distances (<100m) or with travel distances which exceed a definition of “daily life” travel or day-to-day activity space (>100km)

Weighting by length of observation period was another matter of particular concern for all the following analyses. As the particular lengths of the monitoring periods differ, the comparison of longitudinal phenomena in travel and especially the number of locations is non-trivial. While it makes sense to compare averages such as the mean daily trip rate or mean daily distance, it seems dangerous to compare for example the spatial distribution of destinations without any appropriate weighting by the length of observation period. The weighting applied in the following focused on the levelling of the two periods for single travellers which allowed a comparison of equally long observation periods capturing both, mobile and immobile days and therefore considering an eventual shift from travel to no-travel alternative (leave the car at home).

Finally the GPS data was grouped into regular and non-regular trips. To identify regular or routine trips, the data was clustered by departure time, day of week (Monday to Friday, Saturdays and Sundays) and stop duration using a suitable cluster methodology (SAS FASTCLUS; Anderberg, 1973). A trip was defined as regular when it belongs to a cluster with at least ten or 3% of all non-home directed trips by person. The percentage of regular trips was found to be approximately 75 % of all out-of-home trips.

The resulting data base includes trips with the following control-pricing combinations:

- Control – High kilometrage charge: 54.000 trips
- Control – Low kilometrage charge: 28.000 trips
- Control – Cordon based charge: 11.000 trips

The sampling within the AKTA study is described in more details in Nielsen (2004). In brief, the participants were recruited based on a factorial design by income groups, residence and work place location and pricing schemes. All drivers belonged to one-car families which is common in Danmark due to high car taxes. All households were located in the area of the pricing experiment. For all participants there was a requirement to travel daily (regular or even fulltime workers).

Some aspects of the socioeconomic structure of the used subsample are given in Table 1. This study makes use of about a half of the available total sample.

Table 1 Socioeconomic structure of sub-sample: Selected variables

Variable	Control – High (Total: 91)	Control – Low (Total: 72)	Control – Cordon (Total: 39)
Male [%]	74	66	68
Age [%]			
Under 30	9	11	10
30-39	31	18	32
40-49	27	27	24
50-59	22	34	31
> 60	11	10	3
Income before tax / year in k DKK [%]			
< 300	5	1	15
300-599	59	40	38
600-899	29	52	41
>= 900	7	7	5
Distance HH location from city centre in km [%]			
< 7.5	21	17	45
7.5 – 15	59	38	37
15 – 30	13	34	13
> 30	7	11	5
Average distance to work [km] (Std.)	11 (10)	19 (13)	11 (8)
Average total kilometrage / year [kkm] (Std.)	16.1 (7.6)	19.8 (8.6)	16.8 (9.2)
Average amount paid [DKK] (Std.)	46 (197)	178 (328)	558 (724)
Median duration of monitoring – both periods (days)	164	107	80
Median number of mobile days – both periods	132	97	61

The main travel characteristics of the resulting data set are given in Table 2 and 3. They show that the virtual charging has a – partly statistically significant – impact on travel behaviour. The reduction in trip rates and daily travel distances are obvious for the high kilometrage scenario with a decrease of about 6 to 10 percent. For the two other pricing combinations the results are ambivalent – especially if turning to the weekday differentiation in Table 3.

Similar results were found in earlier studies of AKTA using a different subset of the data base for analysis (Nielsen and Jovicic, 2003; Nielsen, 2004). The differences between the pricing combinations for the daily travel distances are probably due to random variations and the socio-economic structure of the subsamples – with for example a larger share of households located further away from Copenhagen city centre in the low kilometrage scheme. This fact is presumably leading to generally longer travel distances.

Table 2 Movement data description

Combination of pricing periods	Mean number of trips/day		Mean daily distance [km]	
	Control	Pricing	Control	Pricing
Control – High	4.9	**4.6**	33.0	**30.4**
Morning peak	**0.7**	**0.6**	**6.2**	**5.3**
Afternoon peak	**1.0**	**0.9**	**6.6**	**6.0**
Weekday	2.0	1.9	**12.5**	**11.7**
Weekends	1.2	1.1	7.7	7.4
Control – Low	4.9	4.8	38.5	39.2
Morning peak	0.6	0.6	7.5	7.5
Afternoon peak	1.1	1.0	**8.0**	**9.0**
Weekday	2.0	2.0	14.5	14.5
Weekends	1.2	1.2	8.5	8.2
Control – Cordon	4.6	4.6	31.2	30.0
Morning peak	0.7	0.6	4.6	4.5
Afternoon peak	1.0	1.0	6.6	5.9
Weekday	1.8	1.9	12.3	12.6
Weekends	1.1	1.1	7.7	7.2

Means based on mobile days
In bold: Significant difference in means (T-Test); p = 0.05

Table 3 Movement data description by day of week

	Mo		Tu		We		Th		Fr		Sa		Su	
	Trip rate	Distance	Trip rate	Distance	Trip rate	Distance	Trip rate	Distance	Trip rate	Distance	Trip rate	Distance	Trip rate	Distance
Control – High														
Contr.	5.2	34.8	4.9	34.1	4.9	33.9	5.1	34.8	5.1	35.0	4.8	29.3	3.9	28.0
High	**4.8**	**31.5**	4.7	**30.7**	4.7	**31.5**	4.9	**31.7**	**4.8**	**32.8**	4.7	28.2	3.7	25.8
Control – Low														
Contr.	4.9	40.3	4.8	37.8	5.0	42.2	5.1	41.1	5.1	42.8	5.2	33.0	4.1	31.0
Low	4.8	40.5	4.9	**42.7**	4.8	42.1	4.9	43.2	5.4	43.4	4.9	31.0	4.0	29.9
Control – Cordon														
Contr.	4.8	31.2	4.9	32.8	4.4	29.6	5.0	33.2	4.5	32.9	4.5	28.8	3.7	29.3
Cordon	4.4	27.6	5.0	31.3	4.7	28.8	5.3	35.3	**5.1**	**34.2**	4.3	26.9	3.3	25.4

Means based on mobile days
In bold: Significant difference in means (T-Test); $p = 0.05$

An interesting observation is that there seem to be no significant substitution between weekdays and weekends. This underlies that daily transport are seriously restrained to scheduled activities that cannot be changed in the short to medium long run.

5. LOCATIONAL CHOICE AND ACTIVITY SPACES: ANALYSIS OF CHANGES DUE TO PRICING

The enumeration of trips and especially of the locations visited during the respective pricing periods is employed here as a straightforward way to reveal changes in the stability, innovation and variety seeking of locational choice and individual activity spaces. The exercise has been rarely done before (see Marble and Bowlby, 1968 for retail travel; Schönfelder and Axhausen, 2004; Schönfelder *et al.*, 2005).

In the following, we use the term activity space as a description of the daily (revealed) structures of human spatial behaviour. Activity spaces represent the places individuals have regular contact with over a prolonged period of time (Golledge and Stimson, 1997). Jakle, Brunn and Roseman (1976) describe the micro-geographical activity space approach as a manifestation of our everyday lives and a process through which we gain information and attach meaning to our environment.

A major methodological issue in the enumeration procedure is the concept of (*unique) locations* – especially when analysing GPS traces. A location is fully defined as the product of geocode and trip purpose (see also Schönfelder and Axhausen, 2004). This definition has to be adjusted for different sources of travel behaviour data given their different sets of available information and their geographical resolution of trip destinations. As the final positions of the cars differed between the various trips to the same destinations, locations had to be identified by grouping parking positions within a radius of 200m. This distance was found reasonable in studies using similar GPS track data such as the Swedish ISA Rättfart data (Wolf *et al.*, 2004) or the Commute Atlanta data (Schönfelder *et al.*, 2005). This way of identifying unique locations is without doubt debatable as – as mentioned earlier – no trip purpose information is linked to the generated point. Plus, it should be noted that the choice of this radius influences the number of locations and that a detailed sensitivity study is still outstanding.

5.1 Stability

The earlier analysis of long-duration data sets such as Mobi*drive* underpinned the hypothesis that the amount of travel has direct effects on the number of locations and their spatial distribution. In order to provide an initial impression of how much travel one can expect if people are observed over prolonged time periods, the observed trip rates are reported below.

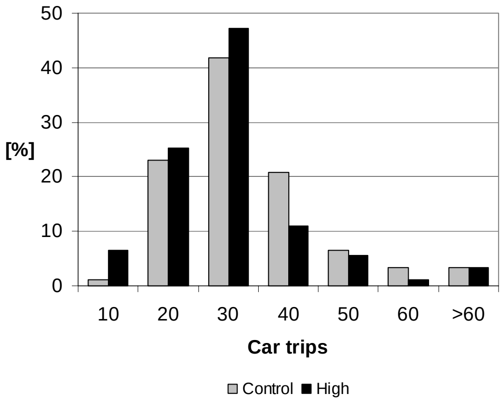
The trip rates (Figure 2) mainly follow a Gamma distribution with zero as the lower limit of the underlying random variable (non-negative trip rates possible only)[3]. The median is 24 to 26 trips per week which roughly corresponds to

[3] Gamma distribution obtains highest score in probability distribution fitting using XPERTFIT (Law and Kelton, 1999).

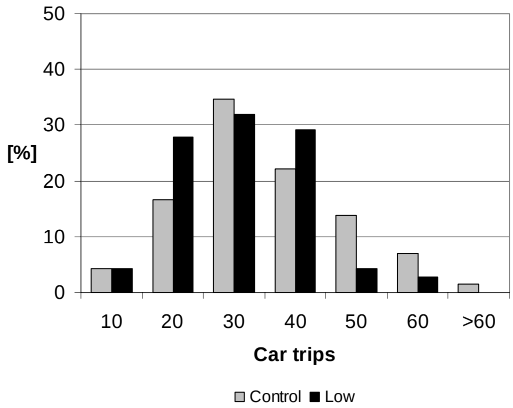
cross-sectional results of 3 to 4 trips per day per traveller[4]. An analysis of a comparative GPS data source from Atlanta yielded similar figures which is interesting given the rather different metropolitan contexts (see Schönfelder *et al.*, 2005).

Figure 2 Mean number of trips per week and vehicle

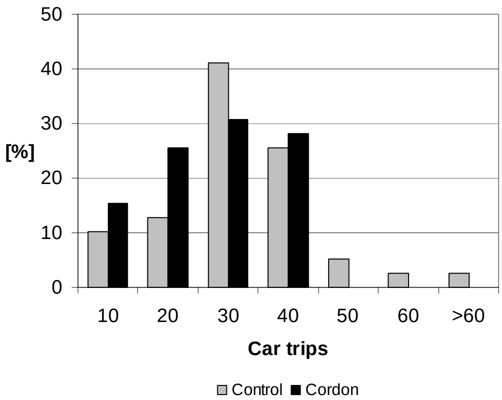
Control – High
Control: Mean = 28.0 Std. = 11.9
High: Mean = 24.8 Std. = 11.7



Control – Low
Control: Mean = 30.5 Std. = 14.4
Low: Mean = 26.1 Std. = 10.1



Control – Cordon
Control: Mean = 27.5 Std.= 13.3
Cordon: Mean= 22.2 Std.= 10.6



The actual analysis of behavioural change starts with the question whether the (virtual) introduction of mobility pricing changes the variability or better stability in travel behaviour. In previous studies, we have been able to identify a stable ratio between the number of trips made and the number of locations – at least if observing behaviour over suitably long periods of time. Consequently, if the number of unique locations grows consistently with the

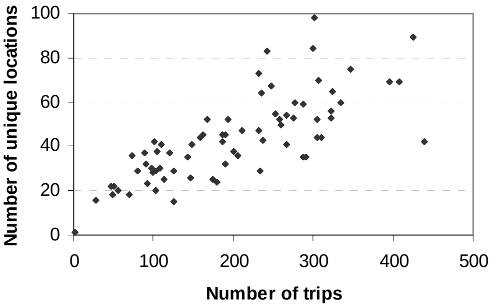
[4] If one wishes to compare with cross-sectional results, note that the figures shown here capture mobile days as well as immobile days.

number of trips, then variety seeking, for its own sake, becomes a credible explanation of these choices. This ratio was previously unknowable, as cross-sectional surveys cannot provide such estimate of this parameter.

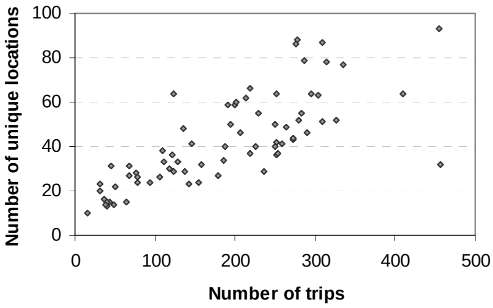
Figure 3 represents an example of such ratio for the AKTA data set. It is interesting that the corresponding ratio for control as well as for the pricing period is almost identical. The ratio varies in a narrow band, approaching about five trips to one location over time.

Figure 3 Number of unique locations by number of trips for the drivers in the control-low kilometrage group

Control period



Low kilometrage pricing



The following table shows the differences in this ratio considering the different pricing schemes. For both, the ratio for locations by trips made and the locations by mobile days, the mean figures are close or even identical and do not have statistically significant differences. However, the locations to trips respectively days ratios (1 to 5 and 1:1) are in line with earlier findings.

Table 4 Mean ratio between number of locations and trips monitored (Std.)

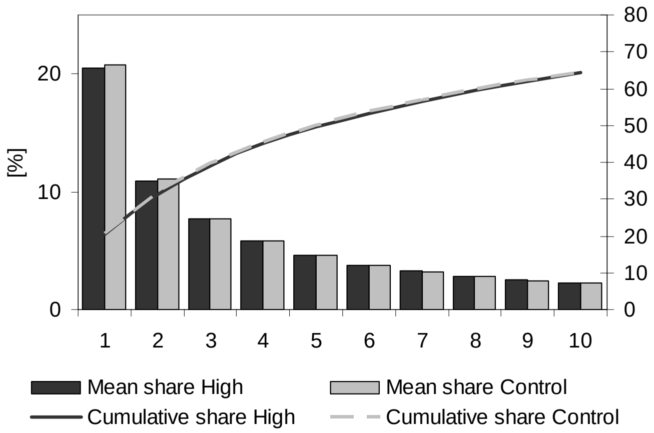
	Locations by trips		Locations by mobile days	
Combination of pricing periods	Control	Pricing	Control	Pricing
Control – High	0.20 (0.08)	0.22 (0.10)	0.93 (0.34)	0.95 (0.36)
Control – Low	0.26 (0.13)	0.28 (0.13)	1.12 (0.40)	1.23 (0.54)
Control – Cordon	0.28 (0.15)	0.31 (0.17)	1.14 (0.46)	1.26 (0.64)

Another way of describing the stability of destination choice behaviour is its concentration on a few important places. Recent analysis with other longitudinal travel data has shown that locational choice is reasonably routinized with the dominance of a few locations – in particular home and one second important core.

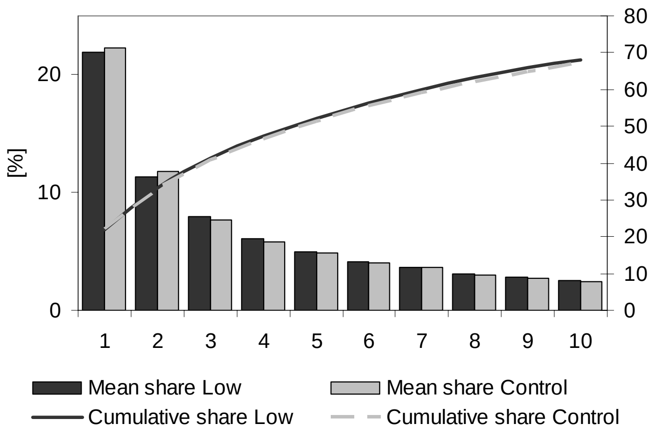
Similar results can be presented for the AKTA data: Figure 4 shows the average shares of non-home trips which are directed to the 10 most important locations identified. The cumulative share for these first ten locations is about 70% for all control-pricing combinations. Given the fact, that in total about 40% of all trips are home-directed, this proves that over longer periods daily life is notably concentrated. For the fulltime-workers recruited for the AKTA experiment, it becomes clear that the work location – which is likely the second most important location - attracts a dominant share of trips with about 20-25% of the total non-home directed travel.

Figure 4 Mean shares of trips to the ten most frequent locations (excluding home)

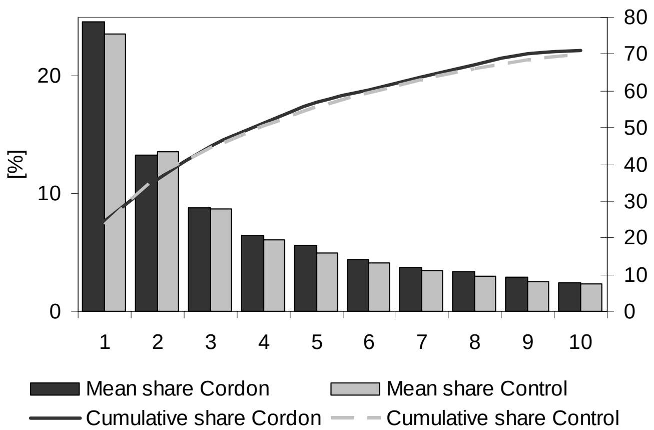
Control – High



Control – Low



Control – Cordon



Again, differences between the pricing and the control period are not visible for any pricing combinations. Stability in destination choice does not seem to be affected by pricing considerations. This may be explained by the dominance of behavioural routines in daily travel which are based on personal resistence to change but mainly by the requirements to match individual and societal spatio-temporal constraints (Hägerstrand, 1970).

5.2 Order of destinations

As a second step, we want to show how the individual hierarchy of important destinations might potentially change due to congestion charging. Table 5 represents how many places within the regular repertoire of destinations are substituted by others in the pricing period. An average number equal or near zero would mean total stability of behaviour and no change between the respective periods at all.

Here, a substitution rate of about a third can be observed for the repertoires of most important destinations. Although this is a considerable change given the broad routinisation of spatio-temporal behaviour, the figures do not deviate considerably from the analysis of equivalent GPS data such Atlanta or Borlänge/Sweden[5].

If one applies a *rank correlation* similar results can be found: The average Spearman Rho describing the monotonous connection between the two rank series "hierarchy of unique locations in the control and pricing periods" varies between 0.69 (high kilometrage) and 0.77 (cordon)[6] which may not be described as a perfect rank correlation.

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[5] The mean substitution rate for Atlanta – if for example considering two consecutive 12 weeks periods – is 2.1, 4.6 and 9.5 for the first five, ten or twenty most important destinations respectively.

[6] Spearman's rank correlation coefficient is a non-parametric measure of correlation – that is, it assesses how well an arbitrary monotonic function could describe the relationship between two variables. It does not require the assumption that the relationship between the variables is linear, nor does it require the variables to be measured on interval scales. It can be used for variables measured at the ordinal level. In principle, the coefficient is simply a special case of the Pearson product-moment coefficient in which the data are converted to ranks before calculating the coefficient. It may take values between -1 (perfect negative rank correlation) and 1 (perfect positive rank correlation).

Table 5 Shifts in destination choice hierarchy: Average number of important destinations substituted (base: first N most important destinations without home)

Combination of pricing periods	N	First 5		First 10		First 20	
		Med.	Mean (Std.)	Med.	Mean (Std.)	Med.	Mean (Std.)
Control – High	91	2	1.6 (1.0)	3	3.2 (1.3)	6	6.6 (2.6)
Control – Low	72	2	1.8 (1.4)	3.5	3.6 (1.8)	9	9.0 (5.7)
Control – Cordon	39	2	1.9 (1.1)	3.5	3.6 (1.8)	7.5	8.2 (3.4)

5.3 Dispersion of destinations: Extent of the activity space

Another issue of interest is the spatial distribution of destinations visited. As a straightforward indicator of dispersion, we choose the average (crow-line) distance of the locations from home. Home is by far, most important centre of daily life and acts for most travellers as the hub for obligatory as well as discretionary travel (see e.g. Ellegård and Villhelmson, 2004). By calculating the individual mean distance of places from home, one gets an impression about the approximate extent of individual activity spaces.

Table 6 shows the results for the mean home distance for all places visited – unweighted and weighted by frequency of visit. This differentiation makes sense as outliers visited only once or twice may heavily distort the averages. Another division is made by the periodic character of trips, i.e. if a trip belongs to regular daily travel or not (see above).

The figures follow our intuitive assumptions with slightly lower distances for the destinations weighted by frequency of contact and greater distances for those places linked to trips defined as non-regular. However, there is no clear trend evident for differences between control and pricing periods. Comparisons remain fuzzy with neither statistical significance (at the 90% level) nor a general tendency to decreased average distances in the charging periods.

The result is surprising at first glance as one could expect strategies to minimise travel distances from home as daily base. That would eventually lead to a preference of shopping or leisure destinations close(r) to the home location. Conversely, complex trip chaining and commitments which do not allow switching destinations make it difficult to decide more consciously on distances. In addition to that it remains open if the activity space is an outcome of mid-term decision making. Finally, since the zoning of the pricing scheme has a great geographical variation, one could expect even increasing trip lengths in some cases. Trips to shopping facilities at destinations of no or low kilometrage charging further away in the suburban area could have been more attractive than places in the city center eventually closer to home. Large regional shopping malls such as the Lyngby Storcenter are located in the lowest pricing level zone. Substitution to trips in the no-charging area around Copenhagen are to be expected as well.

As a final note it should be pointed out that, the fact that longer trips tend to be less elastic to a kilometre tax than shorter trips, seems to have some support in the literature. At least it conforms well to a number of findings in the literature showing severe non-linearities as a function of the trip length. It is an empirical fact, even though not well explained by economic theory, that the value-of-time increases with trip length. Clearly, this would cause a less elastic behaviour for longer trips.

Table 6 Average distance of visited locations from home location [km] (Std.)

	All				Weighted by frequency of visit			
	All		Non-regular trips		All		Non-regular trips	
	Control.	Pricing.	Control.	Pricing.	Control.	Pricing.	Control.	Pricing.
Control – High	15.1 (14.7)	18.0 (18.0)	17.6 (18.9)	18.3 (17.0)	11.0 (11.5)	12.5 (11.8)	17.1 (22.3)	17.5 (18.9)
Control – Low	23.2 (37.5)	25.5 (34.0)	23.6 (35.3)	28.3 (36.6)	19.0 (36.1)	22.6 (33.0)	23.2 (35.7)	29.7 (39.7)
Control – Cordon	23.0 (28.1)	22.6 (31.6)	25.3 (30.5)	22.6 (31.6)	18.3 (24.4)	20.9 (35.2)	25.0 (31.6)	28.0 (42.5)

In contrast to the calculation of averages which capture the pricing periods as a whole, it is appealing to use the longitudinal character of the data to represent the development of such activity space indicators over time.

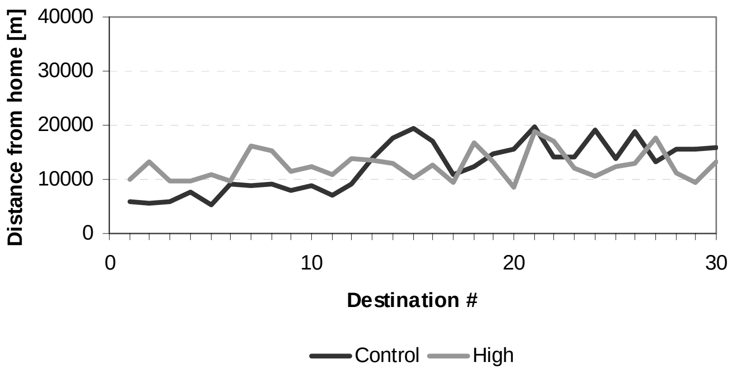
The hypothesis behind this is that new locations tend to be chosen further away from home than those the traveller has regularly been in contact with. It may be assumed that variety seeking aspirations in spatial choice values closer locations less than those further away from one's centre of life.

The aggregate results confirm these assumptions with an obvious increase in distance over time. Figure 5 shows the average home distance of all destinations ordered by date / time of first visit. All curves are clearly rising with the linear trends underpinning the findings.

However, it is again difficult to evaluate if pricing has an impact on this activity space indicator. Whereas the linear trends for the low kilometrage and cordon schemes are either too close to the control periods or statistically insignificant. There is some difference for the high kilometrage – with a low R^2 for the pricing scheme trend, though. The increase in home distance over time is lower for all so “new” destinations in the pricing scheme than in the control period.

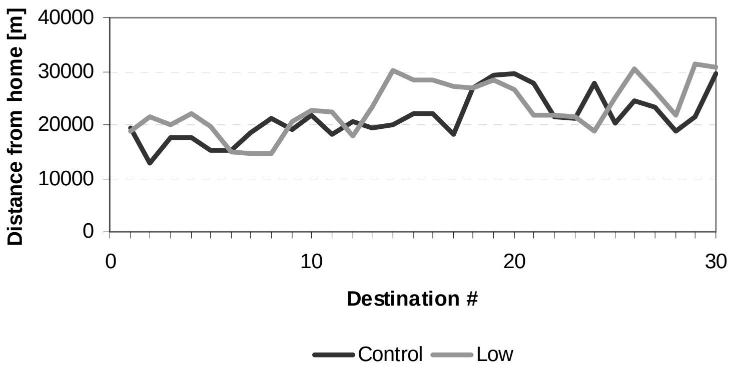
Figure 5 Destinations ordered by sequence of first visit: Mean distance from home [m]

Control – High



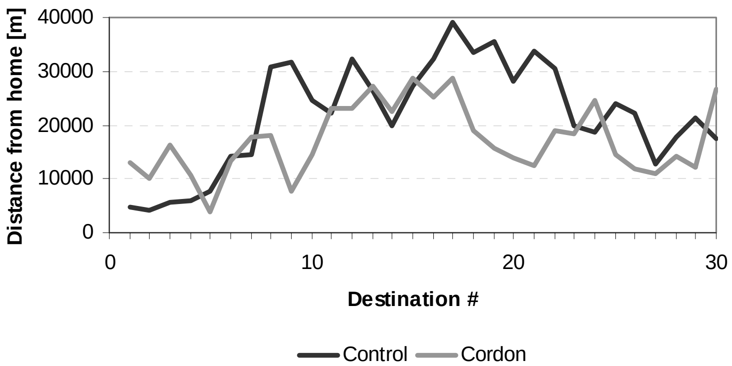
Linear trends: Control: y=409x+5626; R^2=0.62;
High: y=64x+11505; R^2=0.04

Control – Low



Linear trends: Control: y=317x+16171; R^2=0.41
Low: y=327x+17890; R^2=0.35

Control – Cordon



Linear trends: Control: y=432x+14828; R^2=0.15
Cordon: y=150x+14772; R^2=0.04

Clearly, this analysis provokes the question if so far unfrequented locations are added to the personal standard destination repertoire, i.e. destinations which belong to one's activity space in a narrow sense. This cannot be answered explicitly as the drivers have not been asked to provide such information, but a further analysis offers some explanation: Table 7 shows the number of locations which were visited only once in the long run ("dropped places"). One could assume that under pricing conditions, there is less flexibility and therefore a stronger behavioural concentration on known or regular visited places.

This assumption cannot be confirmed. A comparison of this indicator between control and pricing (T-test) yielded no statistical significance which implies no behavioural adaptation. About the half of all visited places are not visited on a repetitive base – at least within the limits of the observation period. This remains stable for the pricing period, too.

Table 7 Mean share of number of places visited only once (dropped) of number of all places (without home location) (Std.) [%]

Combination of pricing period	N	Control	Pricing
Control – High	91	55 (9)	56 (11)
Control – Low	72	59 (11)	60 (11)
Control – Cordon	39	61 (12)	60 (13)

5.4 Destinations by zones and crossing of zonal borders

One of the likely changes of main interest for transport planning and policy is certainly the distribution of destinations by sub-region or zones. As the central parts of urban agglomerations are affected by congestion most severely, a relief from traffic for those areas is welcome.

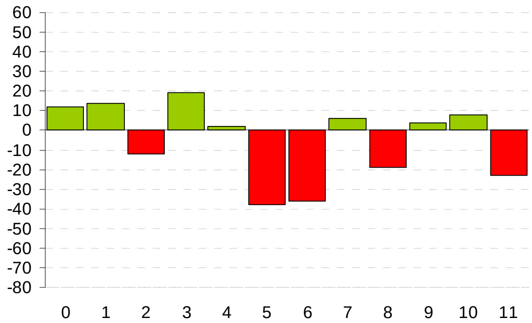
The results shown in Figure 6 provide a first impression of how behavioural change is taking place – providing an aggregate picture for the non-regular travel. The figure represents the percentage change of trips and unique locations between the period of charging and the respective control period by zone (zonal structure in Figure 1).

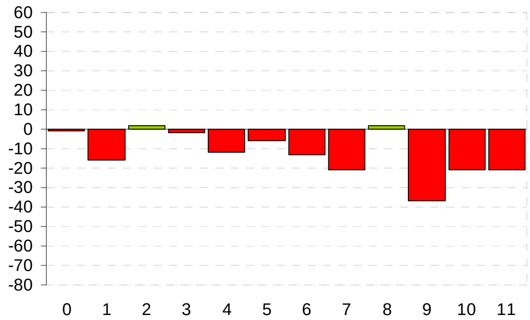
A trend is especially visible for the cordon based pricing. The high kilometre pricing scheme shows an ambivalent picture without a trend towards a reduction in the inner-city zones. What can be seen is the general tendency of a reduction in travel for the pricing period. Some change towards avoiding more expensive zones is evident for the cordon based pricing. The pricing obviously causes reductions in the first ring around the city centre and in the city centre cordon itself (zones 8, 9, 10 and 11).

Figure 6 Percentage changes of amount of trips and locations in the different zones*: "Non-regular" travel (comparison with control period)

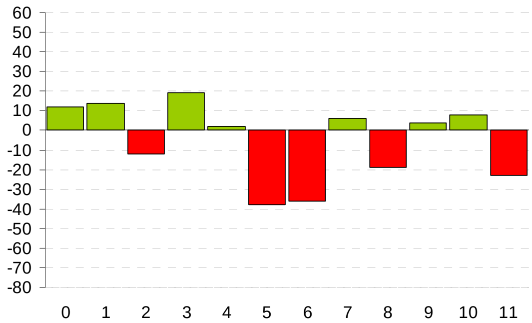
Trips	Locations

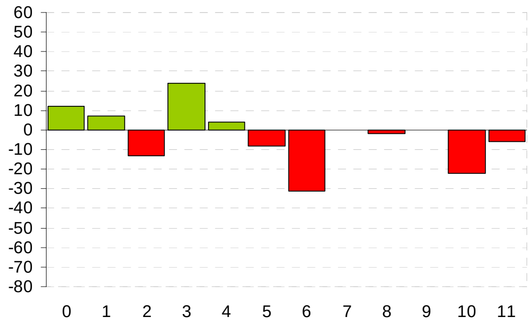
Control – High N = 4364/3888 trips N = 2021/1843 locations



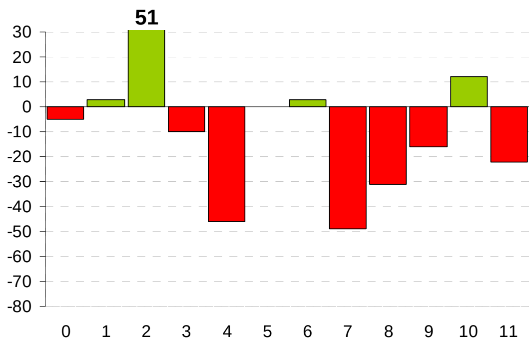


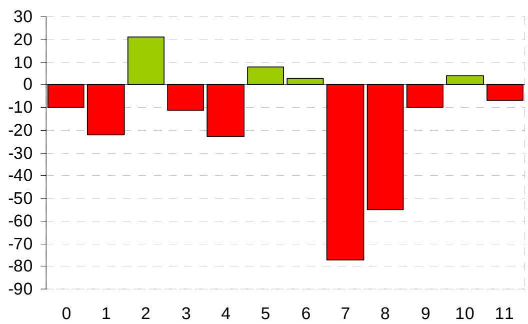
Control – Low N = 2672/2650 trips N = 1262/1284 locations





Control – Cord. N = 1205/1156 trips N = 580/528 locations





* Zone 0: out of pricing charging area

The analysis of destinations by zones leads to another question which was already touched above: Is the home zone a preferred destination if mobility pricing is introduced? Table 8 gives percentage share of trips and destinations in the home zone of the respondents. Again, no clear trend is visible. The shares between the control period and the pricing are almost identical and do not deviate statistically.

Table 8 Share of trips and unique locations in the household location zone (global averages without trips to home location) [%] (Std.)

	Trips				Unique locations			
	All trips		Non-regular trips		All trips		Non-regular trips	
	Control	Pricing	Control	Pricing	Control	Pricing	Control	Pricing
Control – High (N=91)	32.2 (16.4)	32.8 (16.5)	30.8 (16.8)	29.7 (16.3)	26.4 (14.3)	26.9 (14.1)	10.5 (7.1)	10.3 (7.4)
Control – Low (N=72)	44.7 (20.7)	55.5 (20.5)	41.6 (20.1)	42.4 (20.3)	30.7 (14.3)	30.9 (16.6)	14.9 (9.4)	15.9 (11.7)
Control – Cordon (N=39)	33.5 (19.0)	33.1 (18.2)	30.5 (17.5)	27.1 (16.2)	26.7 (15.3)	27.0 (15.5)	12.6 (8.8)	11.9 (7.8)

Apart from the distribution of destinations by zones, it is interesting to analyse if the number of trips entering or leaving zones – which is charged in the cordon based pricing scheme – is altering the respondents' travel behaviour. As crossing the zonal boundary is "punished" (leading to a deduction of the pre-paid amount of money), travellers eventually try to avoid choosing destinations which require crossing the cordon or a sub-zone within the cordon.

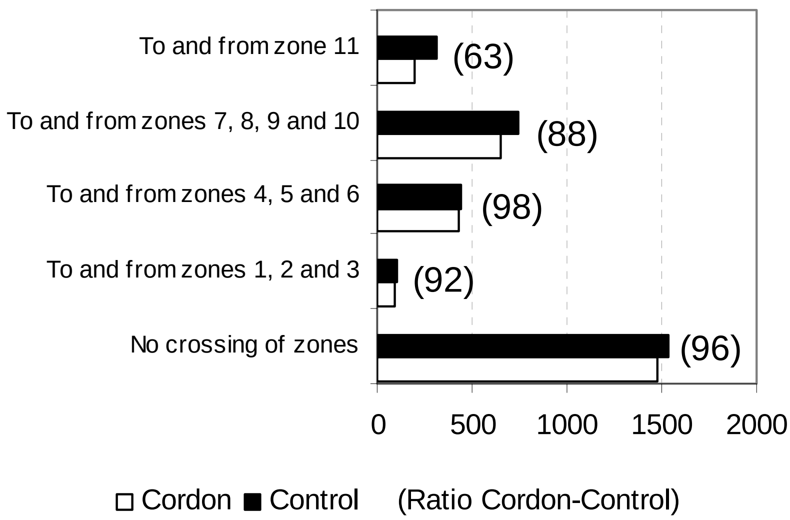
The following figure gives the total number of origin-destination relations by zones (or cordons which are constituted by single zones) and the ratio of these numbers for the control period to cordon based pricing. As one can easily see, most of the travel observed is inner-zonal with about 50% of origin – destination linkages in one zone.

The interesting but certainly not unexpected result here is a behavioural change especially for the Copenhagen inner city cordon. This cordon consists of zone 7 to 11 with the oldest part of the town as well as the main shopping area in zone 11. The reduction between the pricing and the control period is considerable with about 20 to 30 percent in OD-relations. Slightly ambiguous is the fact that the reduction is less obvious for trips predefined as non-regular. For those trips the potential for choosing an alternative destination outside the expensive zones may be assumed to be greater. However, the results are not clear due to the small sub-sample used here.

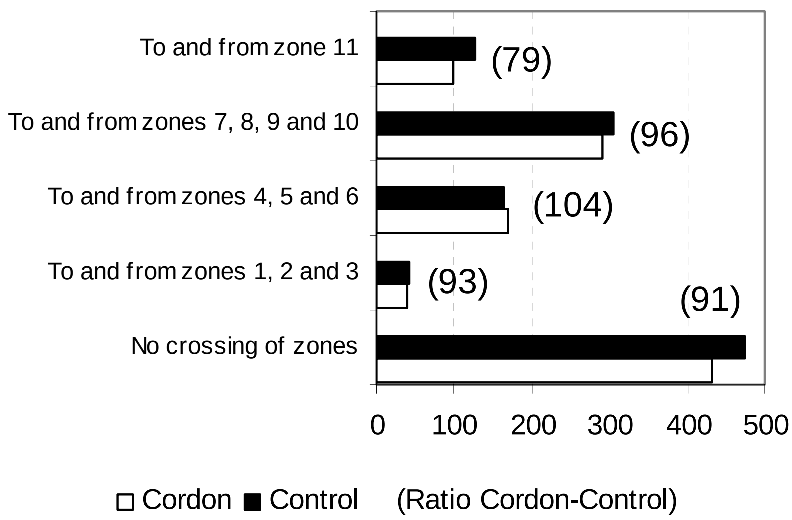
Both findings show that the cordon pricing might be successful for charging strategies which aim to reduce traffic and congestion locally – especially in the sensitive inner-city areas. This general finding is in line with the real-life experiences made in cities such as London or Oslo where the inner-city area was charged.

Figure 7 Amount and ratio [%] of O-D (D-O) relationships:
Cordon based pricing compared to control period (totals)*

All trips



"Non-regular" trips



* The term "crossing" does not capture the entering / leaving of several zones but only the origin – destination relation

5.6 Socio-economic differentiations - a starting point

Finally, the analysis will link selected measurements of activity space indicators to socio-demographic and life-style variables describing the respondents. As mentioned above, the AKTA study was accompanied by a comprehensive debriefing of the drivers which allows a description of the respondents in great socioeconomic detail. Only part of the available rich information is used here.

Table 9 summarizes the socioeconomic differences for two selected measures of destination choice patterns. These are the concentration of trips in the five most visited destinations and the average distance of destinations from home.

In general, there are only few differences salient for the several groups. Obvious differences – but in no way significant in the means – can be found for sex, age, household income location of household . Men tend to have a slightly more stable or concentrated daily life with a higher share of trips directed to few unique locations. The same can be found for older respondents (50 years and above) with potentially less flexible daily life structures. Contrarily, drivers of households with higher income have a more flexible life-style than those of lower income. There is a statistically significant correlation in the control – high and control – low pricing combination, respectively. Finally, the location of households mirrors the general commuting and mobility patterns – with less central households having a larger dispersion of destinations. In summary, common trends of trip and activity demand can be reproduced.

Concerning the behavioural change due to pricing a valid assessment of the results is again difficult. Where the group size is acceptably large, the differences between the pricing periods are marginal. Statistical significance is not existent as already shown in most of the analysis above without stratification. Some results differ (e.g. for income), but those underlie heavy random variation and non-representativeness due to small group sizes (less than ten respondents).

Table 9 Activity space indicator by socioeconomic characteristics: Selected means*

	Share of trips in 5 most visited locations (without home) [%]						Average distance of visited locations from home location [km]**					
	Control	High	Control	Low	Control	Cordon	Control	High	Control	Low	Control	Cordon
Sex												
Female	51	50	49	51	53	51	7	12	30	13	19	17
Male	50	49	53	53	56	60	13	13	30	19	18	23
Age												
Under 30	50	49	48	52	52	54	10	12	15	9	24	26
30-39	50	51	51	51	53	52	12	17	15	31	17	21
40-49	48	47	49	49	53	62	12	10	27	22	21	30
50-59	53	52	56	57	59	58	10	8	17	25	17	14
> 60	51	47	50	48	70	67	10	16	16	17	9	5
Income before tax / year in k DKK [%]* **												
< 300	60	57	65	56	56	55	7	19	9	43	10	17
300-599	51	51	54	54	55	52	11	14	22	22	16	21
600-899	48	47	50	51	55	59	8	9	16	21	25	25
>= 900	45	43	47	54	58	78	18	18	28	31	8	7
Distance HH location from city centre [km]												
< 7.5	50	49	54	55	52	54	12	20	19	23	24	22
7.5 – 15	49	49	50	52	57	58	9	9	11	19	10	20
15 – 30	52	53	53	53	60	65	11	11	17	15	11	11
> 30	53	54	49	46	53	55	31	18	52	56	42	43

* For number of cases see

Table 1 Socioeconomic structure of sub-sample: Selected variables

** Weighted by frequency of visit
*** Control – Low kilometrage: only 1 case for income < 300!

6. CONCLUSIONS

The descriptive analysis of travel patterns based on the AKTA GPS data revealed interesting structures of longitudinal mobility demand and provided insight into activity space characteristics never shown before. The enumeration of trips and destinations raises important issues for future travel demand analysis and modelling, in particular the stability and variability of spatial behaviour, the definition of more realistic choice sets in destination choice and the development of individual activity space sizes over time.

The investigation has also shown that mobility pricing will have an impact on spatial choice decisions. This is especially true for the distribution of trips and destinations by zonal order. However, the level of analytical resolution applied yielded also partly ambivalent results which have their reasons in actual behavioural obstacles for change as well as in the methodological approach of the study. Methodologically, the assessment of behavioural changes for activity spaces and destination choice remains a challenge for travel behaviour research (see below).

Nevertheless, the analysis clearly shows that road pricing dependent on pricing scheme will affect travel behaviour in a non-trivial way. This includes among other things:

- The average number of trips and kilometres driven are clearly affected by road pricing. More over, there are substitution effects in the departure time: travellers tend to some extent shift the departure of their trips to less costly periods.

- People do not to a significant degree substitute from weekdays to weekends.

- Generally, destination choice is not uncoupled from commitments and constraints of daily life which reduces the degree of freedom for alternative choices. This imposes inelasticity due to road pricing in the destination choice for the most frequent destinations.

- The order of destinations change. The hierarchy of most important destinations show that, within the regular repertoire of destinations, there is a substitution rate of approximately 1/3. This rate could be confirmed elsewhere.

- The number of new locations are unchanged. The hypothesis that pricing will tend to narrow the search spectrum and make people focus on known places cannot be accepted.

- Different charging schemes affect the OD pattern very differently. The cordon based charging reduces very efficiently the traffic across cordons, but will tend to leave internal traffic unchanged. Kilometre based charging will impose a more uniform geographical reduction, which clearly follows the level of the charging.

- The initial analysis of socioeconomic effects mirrors general trends in travel demand and activity space structure. A joint effect with mobility pricing is not visible.

Turning to the limitations of the analysis and the opportunities for further work, the following points should be mentioned:

- First of all, the sample size does certainly affect the strength of the results shown. The analysis of the destination choice patterns was based on about a half of the recruited drivers and even a smaller share of the trips made. This has especially implications for the stratification of the analysis by socio-economics as group sizes become rather small to capture appropriate bandwidths.

- As in every descriptive analysis of choice behaviour the question may be raised if the aggregation of individual responses is adequate. A wider differentiation by socio-economics will be an issue in further work on destination choice using the AKTA data – in particular by using explorative methods such as choice models.

- As mentioned above, data structure and processing issues considerations should be taken into account if interpreting the outcome. In addition to that, there is a bias to be expected due the initial character of the post-processing with the rough threshold approach to eliminate suspect or the missing identification of the actual driver. One further main field of prospective work is the linkage of activity purposes to destinations and trips – imputed by suitable approaches such as the joining of land-use information. This would support the differentiation of unique locations by the actual motive of travel.

- The analysis did not make any difference between the behavioural changes in the rounds which were found to show differences due to the experiment's design (Nielsen, 2004). Round 3 was planned – based on the partly ambivalent experiences in the first two rounds – more sensible in terms of the general structure of the experiment (just high kilometrage pricing following a control period), the length of the monitoring / pricing periods and the payment procedure. This undifferentiated treatment of the data was accepted in order to test the effects of low kilometrage and especially cordon pricing as well.

- Finally, the analysis remains descriptive at this stage and uses a selective set of indicators. Especially the analysis of elasticities by socioeconomics – as shown for the same data in the field of value of travel time saving (VTTS) (Nielsen, 2004) – needs to be elaborated for the destination choice matter in greater detail.

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