The AKTA road pricing experiment in Copenhagen

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Abstract

The paper presents the main results from the AKTA road pricing experiment in Copenhagen. The experiment followed 2x200 cars equipped with a GPS-based device during two experimental rounds. The participants' normal travel patterns were estimated on observations from a control period over 8-10 weeks. Pricing schemes were then implemented over 8-10 weeks. Since realistic and planned levels of road pricing were tested, the experiment is as close as possible to a real scheme. The GPS-device locked the coordinates each second, whereby routes and speed could be tracked. Data could be aggregated to trips, trip chains, and daily travel patterns. The participants completed questionnaires before and after the experiment. A group of 300 users followed a Stated Preference (SP) experiment before the field experiment. Furthermore, selected participants participated in qualitative focus group interviews.

Conclusions are made on the behavioural impacts of the different pricing schemes, road users' attitudes, and the accuracy of different survey and modelling techniques. The Revealed Preference data from the experiment is analysed, including within and between person variations. It appeared that about 2/3 of the participants acted utility maximising with little non-explained variation, while each of the rest showed very varying preferences. The SP-data showed some differences from the RP, as well as between different tested SP-design. However, both the RP and SP showed large heterogeneities in preferences between participants, higher value of time under congestion than free flow time, and some income effect. Error component models improved the fit to the SP-data significantly compared to a MNL model, and the RP-data clearly showed heterogenities on VoT across participants. The responses on road pricing were somewhat surprising, e.g. that changes in the RP experiment are slightly higher than if pricing were considered as marginal cost, while the SP showed the opposite. One would expect that it is easier to state than change behaviour, but the opposite seems to be the case.

Keywords

Road Pricing, GPS, RP, SP, Route Choice Models, Discrete Choices, Time of Day Choice, International Conference on Travel Behaviour Research, IATBR

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1. Introduction

The paper presents the design and some initial findings from the AKTA road pricing experiment in Copenhagen[1]. The main experiment encompassed 2x200 car-drivers being exposed to different road pricing schemes using a GPS-based technique by which all trips are charged and logged. The participants were paid the difference between their expected road pricing, if they did not change behaviour, and their actual behaviour. Since realistic and planned levels of road pricing were tested, the experiment is close to a real scheme. However, a third experimental round was applied, where the participants were paid money according to their measured driving pattern in a control period. They were then invoiced after the period of pricing. The amount of savings lied between zero (if negative, payment was ignored) and 8,000 Danish Kroner (DKK) per participant for the maximum scheme (0-1,100 Euro).

The data from the main experiment was supplemented by SP-analyses, questionnaires, modelling exercises, focus-group interviews and telephone interviews. The project accordingly provides a thorough knowledge on the impact of road pricing, as well as an empirical basis for comparison of different survey- and modelling techniques.

The paper describes in section 2 the experimental design of AKTA, and in section 3 experiences and problems of carrying out the experiment. Section 4 presents the results, and section 5 discusses the findings and methodological issues raised by the experiment. The paper is pretty long due to the large quantity of information in the AKTA experiment. Further information on the focus group interviews are provided in Nielsen & Herslund (2002), the estimation on utility functions based on the GPS-data in Nielsen (2003) and the models estimated on the SP in Nielsen & Jovicic (2003). The similar sections in the present paper build to some extent on these references.

2. Experimental design

AKTA makes a real life test of whether road user taxes will change travel behaviour. Hence, the city of Copenhagen was equipped with virtual cordon rings and prizing zones. 2x200 voluntary test drivers were equipped with a vehicle position system, making it possible for them to read the virtual prizing systems on a display. The cars' movements were logged in the system, and a payment calculated for every trip. A different pricing scheme – or control period – was followed

[1] AKTA (http://www.akta-kbh.dk/) is the Danish part study of the PROGRESS project (www.progress-project.org), which again is part of EU's 5th. Framework programme, "The Growth Programme on Sustainable Mobility and Intermodality", that support several projects concerning pricing (http://www.transport-pricing.net/). In PROGRESS, eight European cities assess in different ways impacts of different urban pricing schemes. The cities are Bristol and Edinburgh (UK), Genoa and Rome (I), Helsinki (SF), Trondheim (N), Gothenburg (S) and Copenhagen (DK). AKTA runs for three and a half year with at total budget of about 13.5 Mio. DKK (1.8 Mio. Euro).

in a first and second 8-week period in the first round (the first 200 participants), and 10-week periods in the second round (the last 200). At the end of each round, the test drivers were paid according to an estimate based on the difference in behaviour between the two periods they followed.

2.1 Survey design

The participants were distributed after a factorial design among income groups, commuting patterns (residence of home and work) and pricing schemes. All participants belonged to one-car families. Due to the high car taxes, few families in Denmark have two cars, and the experiment would be complicated for these, since both cars should have had an onboard unit and their joint travel pattern should have been analysed. All participants resided and/or had their workplace within the road pricing area (the geography of Copenhagen eliminates through traffic for Commuting). All participants had a daily need of transport.

The participants completed a questionnaire before the experiment, and another plus a telephone interview after; among other things to test whether they changed attitudes. Furthermore, 200 participants also answered a SP-survey before the second round, and 100 before a third round (refer to section 3.4). Besides supplementing the field experiment, this makes it possible to validate SP as a method towards the field experiment. Furthermore, selected participants participated in qualitative focus group interviews.

For comparison, a telephone interview with 1,000 respondents living in the road pricing area was carried out to investigate the general populations awareness and attitudes towards road pricing, as well as to control for possible sample bias (i.e. that the participants in the experiments were not representative of the population).

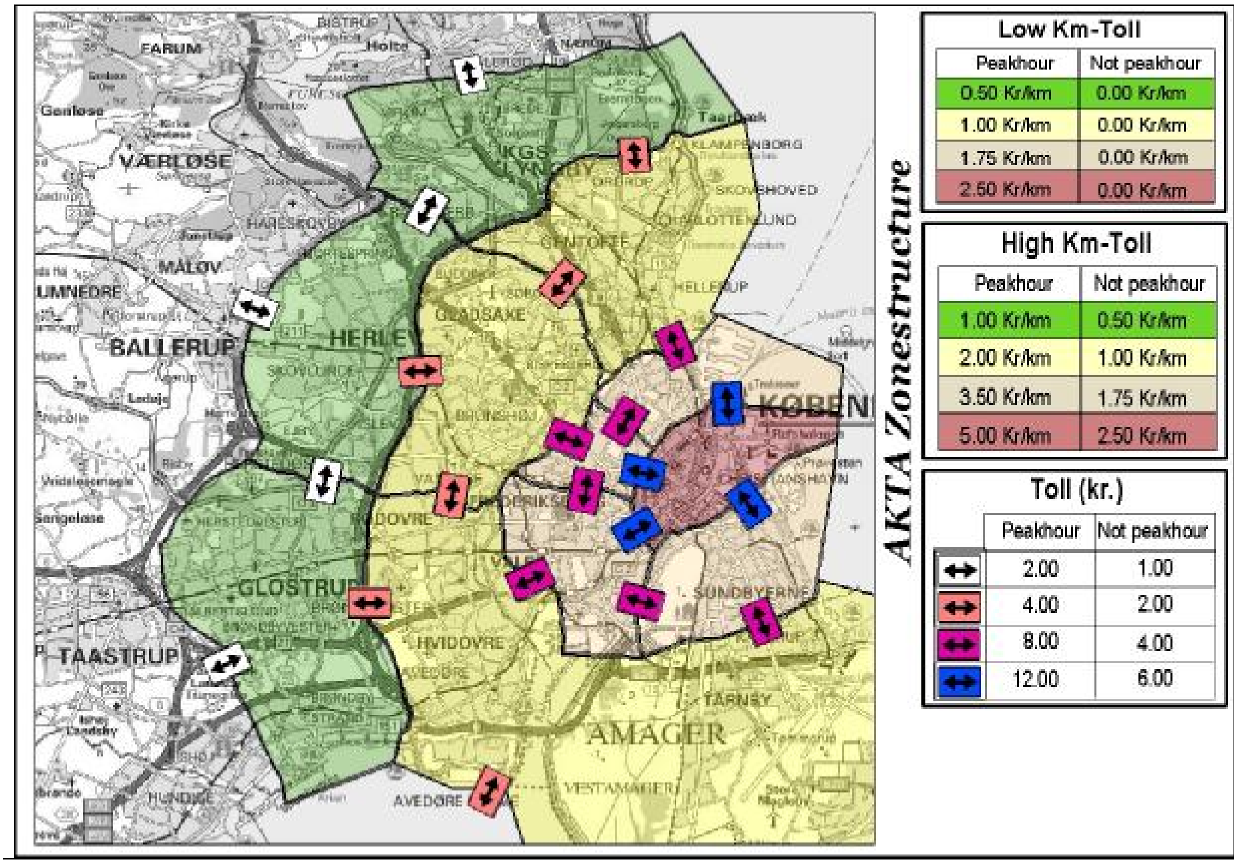
2.2 Pricing schemes

Two pricing schemes were zone-based with four different pricing levels per km. with the most expensive in the inner city, and the cheapest in the suburbs (figure 1). The third scheme was a toll-based system with payment for zone boarder crossings (cordon lines). The pricing varied between the peak and non-peak hours in all scenarios.

The GPS-device calculated dynamically the pricing level, and the participant could for a given trip see the pricing level (zone), be noticed on zonal-crossing (at the cordon scheme), and read the accumulated cost of the trip.

The coordinates were logged each second. They were then imported into a digital map (by GIS-technology) after the field experiment was completed, and related (map-matched) to roads, junctions and origin/destinations of trips. Data can hereby also be compared with automatic traffic counting stations, and speed surveys. This provides a unique dataset concerning route choices, trip patterns, speed, congestion, and speed-flow relationships.

Figure 1 The different road pricing and toll schemes.



Goal oriented pricing schemes was rejected due to experiences from the pre-study (Herslund, 2001), e.g. road-type dependent or marginal costs charging (internalisation of externalities). This was decided due to problems in the participants understanding of too complex schemes, due to technical problems (online map matching by the GPS-devise with an acceptable speed and security/precision), and due to the time-schedule of the project (software validation issues).

2.3 SP-design

The Technical University of Denmark and the Danish Transport Research Institute (DTF) carried out a research project concerning Stated Preference (SP) methods in parallel with the main AKTA experiment. The purpose was to evaluate SP as a method, since AKTA provides an excellent RP-data survey to compare with. The 200 car drivers from the second and 100 from the third round were sampled in a computer based interview that took place while the respondents waited for the GPS-unit to be installed in their car. This reduced the cost of the survey, and was supposed to secure that all from the main AKTA participated in the SP-experiment.

The pricing levels in the SP experiment were the same as the scheme the specific respondent would face in the main AKTA experiment. The SP-experiment was carried out before this to avoid that it could influence the answers.

279 interviews were successfully completed and processed. If the respondent usually travelled to work by car, the most recent car-commuting trip was described in the first part of the interview. If car had not been used for commuting, then the respondent was asked to describe a trip for another travel purpose. The chosen trip was described included origin and destination addresses, departure and arrival times, and travel purpose. If the respondent completed an extra activity on the way (e.g. shopping, visiting bank) these activities were also notified. The departure time defined if the trip should be understood as the ‘peak’ or ‘out-of-peak’ trip. Each respondent then followed 3 SP-experiments before answering questions on socio-economy:

- The first SP-experiment focused on the Value of Time (VoT). Traditional experiments trade of time towards cost. However, some prior experience in Denmark (Nielsen *et al*, 2002), suggest that some car-users are not aware of the cost, and that most travellers considered marginal costs only (fuel). To investigate this issue further, some of the respondents in the AKTA SP were asked to trade of time versus cost (referred to as SP1a in the following), and some time versus length (SP1b).
- The second SP-experiment focused on time-of-the day (ToD) decisions and congestion[2]. The trade off context in this respect was travel cost; travel time, extra time due to congestion and time-of-day (peak hours or not). Travellers in the peak hours may choose to travel outside the peak due to lower cost or congestion. While travellers presently travelling outside the peak may choose to travel in the peak hours, if additional costs make this faster than today (peak spreading as a consequence of pricing). Also this experiment had a trade-off of time versus cost (SP2a) or length (SP2b).
- The third SP-experiment evaluated the choice between an existing trip, which was added road pricing, and a possible alternative route, which was found together with the respondent. The trade-off was then investigated between cost, pricing, free time, and congestion time.

[2] It is noted, that the definition of congestion time followed the definition in Nielsen *et al* (2002), i.e. that *congestion time is the extra expected travel time caused by congestion*. The respondents were asked how long time their usual trip took, and how long time they expected it would have taken without congestion. The difference was then interpreted as the extra time caused by congestion.

3. Carrying out the main experiment

3.1 Recruitment

It turned out to be far more complicated to recruit the participants than anticipated: A total of 25,000 people had to be contacted in order to get a proper sample of 2x200 households (1/3 of the 1,200 who initial agreed to participate).

The telephone interviews (1,000 subjects) did not cause unexpected problems. And the SP-experiments were performed on the participants who have already agreed to participate. In most cases while the equipment was being installed in their car. The car repair shop had in a few cases forgot to mention changed schedules to the interviewers. An interview were then tried to be arranged at the home of the participant. But difficulties with this eventually lead to a slightly smaller sample than the main AKTA. The focus groups were selected among drivers from the main experiment, after this were finalised. It turned out to be a little difficult to recruit participants, wince they had already used a lot of time on the experiment.

3.2 Problems with the GPS-technology

The GPS technology caused much more problems that anticipated. Each GPS-based observations depends on the number of satellites within "sight", the quality of each signal (depending on atmospheric conditions) and the course of the receiving unit. This caused the following problems:

- *Signals were lost* (no co-ordinate observation) due to too few satellite signals. This happened often in "street valleys" where buildings shaded the signal, and of course also in tunnels and parking garages, after which a delay was experienced before the unit could find a signal again. About 90% of the trips lost signals to some extent. Most of the trips could be reconstructed unambiguous by analysing the log-files, but about 3% of the trips had fall-outs to an extent, where the trip – or even trip chain – could not be recreated unambiguous, but must be estimated.
- The *co-ordinate accuracy* was reduced due to too few satellites or atmospheric conditions. This happened far less frequent than total fall out of signals. When there are a sufficient number of satellite signals, it can estimate the co-ordinate pretty precise. The co-ordinates accuracy and location were however altered systematically in a few situations when the cars drove fast in a curve – e.g. on ramps to motorways. But the routes could in most cases be recreated unambiguous.
- *Segmentations in trips* were sometimes recorded wrongly by the equipment: Some trips were segmented in sub-trips due to signal fallouts or significant bottlenecks. While some trips with short intermediate errands were wrongly jointed into one trip. This could be due to short time-intervals of the errand (e.g. bringing kids to kinder garden, where the engine is kept running), or due to unfortunate combinations of a short errand and fall out of satellite signals. The segmentation of trips is both prob-

lematic for the post analyses of trip patterns and behaviour, and for the map-matching program which algorithm work different when a trip start/end compared to an ongoing trip.

- *Specific cars* had significantly more fallouts than others. This could be due to the place of instalment of the equipment in the car, the construction of the car, and other electronically equipment within the car. To reduce this problem, analyses of the log files could have been carried out after e.g. a 2-week period. However, it was estimated that the costs doing this were higher than the obtained additional accuracy by affording a larger sample.

Due to the significant amount of problems with the GPS-observations, an algorithm had to rebuild the routes. The post survey and practical experiences with the equipment revealed however in addition some more severe technical problems, than those found in the log-files, e.g. that:

- 46% of the participants had *experienced* technical problems, of which:
- 14% experienced that the unit stopped working.
- 5% experienced that the battery was discharged (total fall out).
- 5% experienced that the unit did not show the pricing level – but worked none-the-less.
- 5% had a non-functional unit at average at a given time during the experiment, where all participants where contacted.

These problems seldom took long time to solve, and the participants were *aware* of these problems. Furthermore, neither the post survey nor the focus group interviews indicated that the participants had discovered the amount of problems with fallouts registered in the log-files. Hereby, it can be concluded, that this did not influence their driving pattern and decision making in the main experiment. The analyses in AKTA were accordingly not influenced hereby; given that post experiment corrections and interpretations of the observations are made. If a unit e.g., did not register in a period, this should be defined as a technical fall-out, not as reduced trip making.

It can however also be concluded, that more work needs to address technology issues, if a GPS-based pricing system is to be implemented full scale. In this respect it is noted, that the present algorithms for map-matching (linking GPS-observations to the specific roads), and for recreation of routes (linking GPS-points around a fall out) use a sequence of points before and after the present fall-out. To obtain the same real-time accuracy will demand significant algorithmic development.

3.3 Results from the after survey

The participants were contacted by phone after the experiment to answer a few general questions about their behaviour and the experiment.

The first round included 201 cars/households of which 183 answered the after interview (112 were answered by men, and by 71 women). 71 households had only one user/driver of the car, 102 had 2 users, and 8 had 3 or more users. The interweaved person were in 138 cases the most frequent user of the car, while the couple in 26 cases used the car equal, and the partner used it more frequent in 16 cases. 75 thought the payment/savings equalled the expectation, 47 had expected more, 30 expected less, and 25 did not know. 112 had tried to save/earn money. 88 were willing to participate in focus groups. And 11 would maybe consider it later.

Table 1 shows the changes in behaviour distributed on the different pricing schemes in the experiment. Although the procedures in the experiment had been explained very thoroughly both orally and written, many participants had misunderstood the design. Several had e.g. changed behaviour in the control period, and a few even in the control period only. In the designs with no control, one had only changed behaviour in the low km. charge period, but not in the high km. period. A total of 24 participants had more or less misunderstood the experiment (13%).

Table 1 Saving strategies for the first 201 cars (183 answers). Numbers and (percent). Note that the two periods could be in both order (e.g. high km. before control or visa/versa). But these have been joined in the table for simplicity. Shaded fields indicate illogical behaviour. Bold desired behavioural effect.

Pricing levels	No saving	Saving 2nd period only	Saving 1st period only	Saving both periods	Total
Control + High km.	25 (60%)	**8 (19%)**	2 (5%)	*7 (17%)*	42
Control + Low km.	34 (63%)	**12 (22%)**	1 (2%)	*7 (13%)*	54
Control + Toll	6 (38%)	**4 (25%)**	0	*6 (38%)*	16
Low km. + High km.	9 (35%)	5 (19%)	1 (4%)	**11 (42%)**	26
Low km. + Toll	6 (35%)	0	0	**11 (65%)**	17
High km. + Toll	13 (46%)	1 (4%)	0	**14 (50%)**	28

Source Jens Peder Kristensen, PLS RAMBØLL.

Out of the participants that understood the experiment, some had chosen to change behaviour – other not: Some participants did not *believe* they had an alternative, the alternative was too inconvenient, or they did not consider the pricing high enough to make them change behaviour (their willingness to pay and value of time were too high). In the experiments with two pay periods, some did only change behaviour in the period with the highest pay level.

172 cars/households from the second round where interviewed, of which 95 tried to save money. Table 2 shows the changes in behaviour distributed on the different pricing strategies. A total of 17 participants had more or less misunderstood the experiment (10%). This was somewhat improved compared to the first round, but also disappointing, since extra care had been made to explain the experiment due to the experiences with the first round.

Table 2 Saving strategies for the second 200 cars (172 answers). Symbology as in table 1.

Pricing levels	No saving	Saving 2nd period only	Saving 1st period only	Saving both periods	Total
Control + High km.	23 (69%)	**7 (21%)**	0	*3 (9%)*	33
Control + Low km.	13 (45%)	**6 (21%)**	1 (3%)	*9(31%)*	29
Control + Toll	13 (48%)	**12 (44%)**	0	*2 (8%)*	27
Low km. + High km.	11 (39%)	2 (7%)	2 (7%)	**13 (46%)**	28
Low km. + Toll	12 (40%)	4 (13%)	2 (7%)	12 (40%)	30
High km. + Toll	7 (30%)	1 (4%)	2 (9%)	13 (57%)	23

Source Jens Peder Kristensen, PLS RAMBØLL.

3.4 Deciding a the third round

After analysing the results from the first and second round – especially the responses at the focus group interviews – it was suspected, that the design may not resembled real life under road pricing, i.e. earning money is not the same as paying money. In the first two rounds, the expected payments from the participants were estimated, and they were paid the difference between this and their behaviour under pricing. To validate this design, a third round was decided upon where all participants were paid money according to their actual travel behaviour in a control period. They were then explained that a similar amount would be invoiced after the pricing round if they did not change behaviour.

The pricing period was longer as well (12 weeks instead of 8 or 10), since it was debated whether the period was too short in the first two experimental rounds, i.e. whether the participants could postpone trips to after the period or accept alternatives to car travel in a short period. The experimental design was simplified as well since all had a control period followed by a high km. based scheme (the most efficient of the schemes in the first two rounds).

All results have not yet been analysed as detailed from the third round as from the first two. 85% of the participants earned money opposite to about 50% in the first two rounds. The amount of money paid was also higher. However, all followed the high km. based pricing level and in a longer period, why a complete analyses remain to be carried out similar to the results reported in section 4 for the first two rounds.

4. Results

4.1 Focus groups

Before the AKTA experiment, a number of focus group interviews were carried out in the FORTRIN pre-study (Herslund, 2001). This was then used in the design of AKTA. The main findings were:

- Road pricing is regarded more fair than the present tax system in Denmark, where the fixed charges are up to 180% registration tax and 25% VAT, when you buy a car. On top of that you pay an annual tax of an average of 2,900 DKK (~ 400 Euro) – varying after car-type (energy use).
- The GPS system provokes no great fear of surveillance. The greatest fear of the participants is that politicians will turn variable road pricing into a tax spiral.
- There seems to be differences in attitudes towards road pricing dependent on where r the respondents side.
- There is greatest effect on the driving pattern when the price differentiation is based on zones and time. But road pricing is believed to influence *other* drivers more than the one being asked.
- Participants found that the tariffs of the road-pricing scenario will increase expenses, but still will have only little impact on private driving, because the price level is too low to significantly change behaviour.

A thorough focus group interview was carried out after the second experimental round in AKTA. The findings are reported in more detail in Nielsen & Herslund (2002), while the main results are presented in table 3. Here all significant statements from the participants where recorded. The "No" indicates the order of which they appeared in the interview, which followed a predefined structure taken care of by the moderator and her assistant. The participants were then asked how important these issues were (which could be both due to a positive or negative attitude).

Table 3 Each participant's weighting of the 5 major issues discussed in the focus group (on a scale where 5 is the highest weight).

No	Statement	Weight per participant											Mean
6	High pricing level makes an impression	3	4		5			2	4	5	2	5	2.7
9	Road pricing can change route, mode and leisure trips, but not lead to drastically decisions (to move, sell the car, etc)			5	2	4	4	3	3		3		2.2
11	Commuting can only difficult be changed	4	3		4	3		4	2	2			2.0
5	Low pricing - low impact	2		3				5	5		5		1.8
3	Would like to receive the result from own experiment (trip statistics, etc.)					5	5			4		2	1.5
15	Real money are more realistic – or just that one know what one can earn					1	2				4	3	0.9
2	Control disappointing in the beginning (display inactive)			4							1	4	0.8
13	Scheme must be national-wide – not a tax on Copenhagen	1		2	1			1	1	3			0.8
1	Surveillance is a problem		5							1			0.5
14	The experiment is as realistic as it can be			1		2	3						0.5
4	Unfair to pay in the night, weekends, holydays, etc.	5											0.5
13	Road pricing class divide the society further				3								0.3
10	The experiment period is too short		2										0.2
16	More information was needed on the way the payment and refunds are calculated						1					1	0.2
1	Nice to learn the complete result of the study (for all participants)		1										0.1
8	Speed control is a problem												0.0

It is interesting to note, that the participants mostly focussed on the changes of traffic behaviour, rather than political issues. Even with the high charging level, the participants stated that they would not consider "drastically" decisions such as selling the car, using public transport to work, moving to another address, or changing job. They were aware that they could be forced to take such decisions with a sufficient high level of pricing, but it should be significantly higher. It should be noted, that the fixed car taxes are extremely high in Denmark, why the marginal costs are relatively less important – even at the high pricing level.

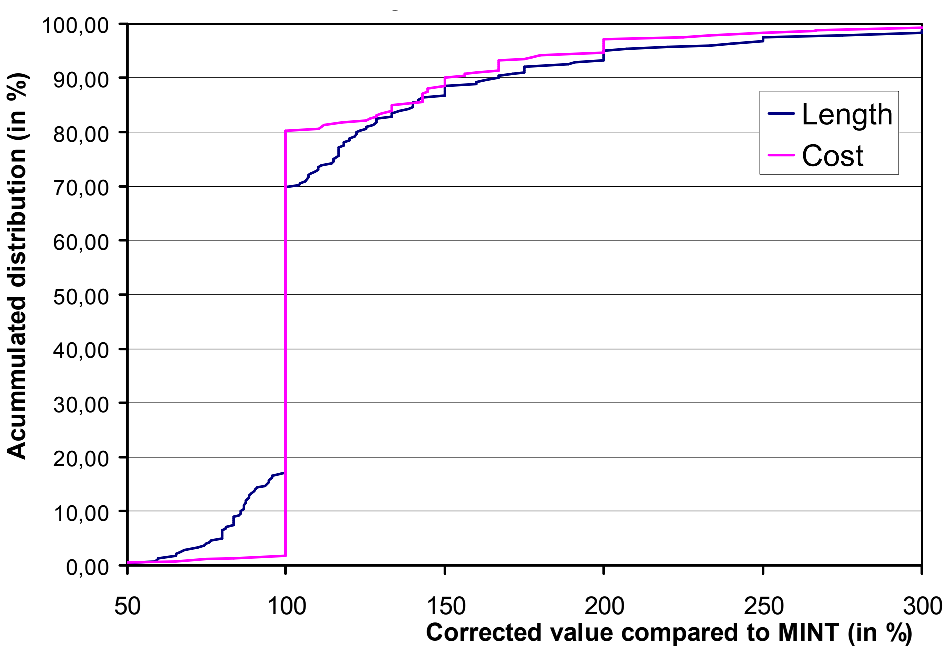
Surveillance was not really a big issue – some of the participants stated even that one can be followed by mobile telephone, bank account, video cameras on the streets, etc., and that a GPS-based system is not worse. This is quite opposite to the role surveillance having in the press and by politicians. Which however doesn't seem in line with the view by the population, and the FORTRIN results.

4.2 Knowledge on travel length and time

A core issue concerning the efficiency of a road pricing system is the value of money of the population, i.e. their willingness to pay and awareness of the cost of pricing and driving costs. Accordingly, it was decided to investigate this issue as part of the SP-experiment.

Figure 2 shows how the respondent corrected the SP-softwares' (MINT) estimate of cost and length (which were calculated fully correlated by a cost per km. ratio). Lengths were more often corrected than cost (57% agreed with length, 82% with cost). This may be interpreted as the respondents having a better feeling of length than of cost for their typical trip. The length equals more their real choice situation. The correction of length had the same average size independent of trip length. This was expected, since the error from the model estimates are due to uncertainties (aggregation) within the zone of departure and zone of arrival (which is independent of the trip between the two zones).

Figure 2 Respondents' correction of SP-estimates of cost and time based on zonal data.



After the respondents had accepted length and cost for the trip, they were asked what they normally considered as the cost of driving per km. As seen in figure 3, they typically answered rounded values (0.5, 1, and 2 DKK are the most frequent answers). The interval between 0.5 and 1 DKK equals reasonable well marginal driving cost (about 45% of the answers), and values around 2 DKK (about 45% of the answers) equals average cost (incl. capital cost, etc.).

Only very few respondents claimed however that their estimates included fixed costs (figure 4), why there seem to be an inconsistency between their cost-estimates and assumptions behind them. 6% of the participants even stated 0 DKK per km., since other were paying for their trip (employer, partner, friend, parents, etc.). They had – however – prior in the interview accepted a cost for the trip. The answers depend accordingly on the interview context. Finally about 4% of the answers in figure 3 were out of reasonable cost range (either too low or high cost per km.).

The answers from the respondents that estimated their cost per km. can easily be compared to their priory accepted length and cost for the specific trip (i.e. the ratio between the two). Figure 5 shows large disagreements between the answers provided by each person. As can be seen as many as 40% of the respondents (plus the 6% free of cost payment) answered with an inconsistency of more than 100%.

Figure 3 Answered cost per km. as accumulated and frequency distribution.

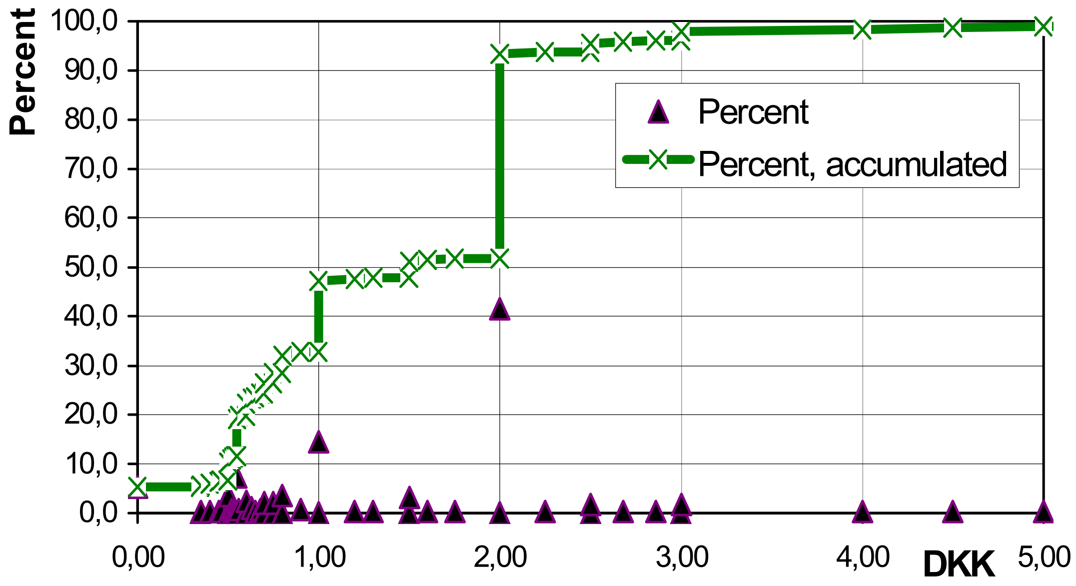


Figure 4 Participants stated components in their cost calculations.

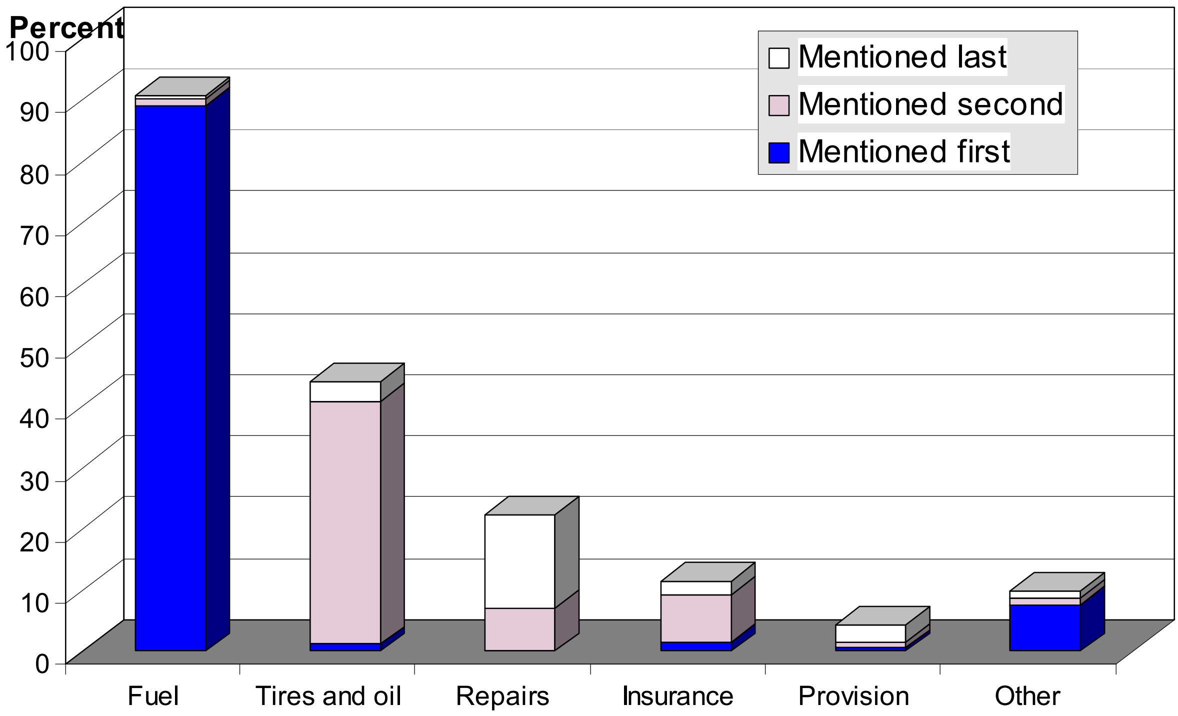
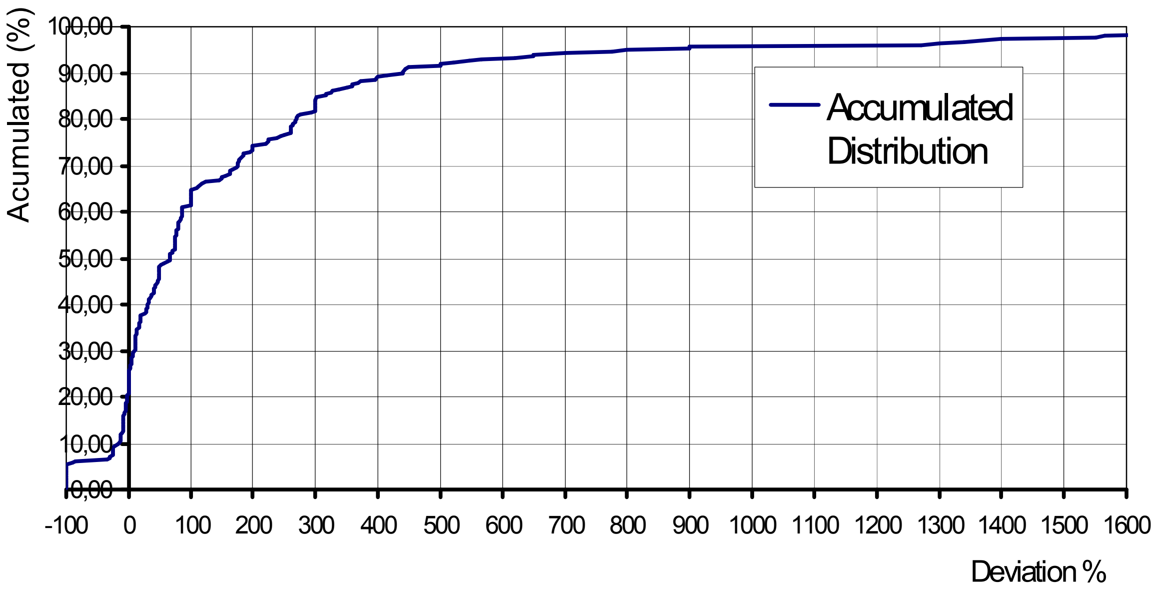


Figure 5 Comparison between accepted costs divided by accepted length with stated cost per km. (%). Accumulated distribution.



4.3 Main results from the experiment

Table 4 shows the main results from the experiment. Only results with a control period combined with a pricing scheme is shown. The km. /day in the control period is lowest in the cordon based system, and highest in the low km. based system. This can maybe be explained by the misinterpretation of the experiment by some of the participants (refer to table 1 & 2), or due to personal variations (few persons within each segment).

The payment estimate per day based on the control period is higher in the cordon based system than in the high km. based system. The behavioural responses (DKK/day, km./day) are highest in the two expensive pricing schemes, which could be expected, and the impacts of the low km. based tolls are so small (some of the responses even have illogical signs), that it must be concluded that no significant behavioural responses could be found. Except maybe a slightly reduction of traffic in the afternoon peak (e.g. postponing shopping trips to after the peak, where the pricing is zero).

The km./day decrease more with the high km. based system than the cordon based system, even though the absolute payment per day is about 30% lower. This can be explained by it is easier to save by changing route and destination in the km.-based system than in the cordon based system. If for example an alternative destination is closer than the preferred, but still on the other side of a cordon, then it is only possible to save in the km.-based system. This result may depend on the design of the cordon system, Bonsall *et al* (1998a) found e.g. higher response to tolls than km.-based system.

The average DKK/km. increases in the km.-based systems, even though the payment decrease. The interpretation must be, that the behavioural changes are higher on the inexpensive trips (e.g. leisure trips outside the city centre and peak hours), while commuting trips are changed to a less extent (more likely in the expensive city centre zones and peak hours). This result is in line with the discussions in the focus group interviews, but not clearly in line with the number of trips in the different periods..

The main reduction in number of trips in the high km. based and cordon based schemes are accordingly in the morning peak, which is somewhat surprising, since this must be changed commuting trips. The afternoon peak have relatively smaller changes, which is also a surprise, since it could be assumed easier to post-pone or change shopping and leisure trips (time and destination is less constraint than commuting).The reason can be, that the afternoon trips are part of more complicated trip chains with less flexibility. The changes in weekdays and weekends are surprisingly high in the km.-based system compared to the peak (since the pricing is only 50% of the peak hours and the public transport service at a lower level), while the response on the cordon based system is more in line with what could be expected.

Table 4 Responses on different pricing schemes, main experiment (based on approximately 100,000 trips).

Trips	High km. based toll			Low km. based tolls			Cordon based pricing		
	Control	High	Change	Control	Low	Change	Control	Cordon	Change
All period	4,3	4,0	-7,8%	4,2	4,2	0,1%	4,0	4,0	-0,5%
Morning peak	0,53	0,47	-12,0%	0,45	0,45	0,3%	0,51	0,48	-6,6%
Afternoon peak	0,76	0,72	-5,5%	0,76	0,73	-4,0%	0,70	0,71	0,7%
Weekday	2,0	1,8	-9,2%	1,9	2,0	1,5%	1,8	1,9	2,9%
Weekends	1,1	1,0	-5,2%	1,1	1,0	0,2%	1,0	0,9	-4,9%
Kr/km	0,75	0,78	4,0%	0,22	0,23	4,2%	1,2	1,1	-6,4%
Kr/day	26,2	24,4	-7,5%	9,4	9,6	2,4%	38,8	33,4	-16,2%
Km/day	38,2	34,0	-12,4%	46,5	45,2	-2,8%	34,8	31,5	-10,5%

Source: Paolo Menegazzo and Christian Würtz have helped producing the numbers in the figure.

4.4 AKTA SP

Several different utility functions have been estimated, which contains variables related to cost c (cost, length assumed correlated with marginal cost, and road pricing), time t (free flow time and extra time due to congestion), socio-economic attributes s, and an error term ε assumed to be Identical Independent Gumbel Distributed *iid* over alternatives (1).

$$U_i = V_i + \varepsilon_R = \beta_c c + \beta_l t + \beta_{st} S + \varepsilon \qquad (1)$$

Some of the coefficients are allowed to vary around their mean by applying an Error Component (2). Due to software limitations in the present work, all distributions are assumed Normal (the standard deviation of the coefficient is presented in the following, from which the distribution parameters can be calculated. To reduce the degree of freedom in the estimates the same SD can be assumed for several coefficients. Or different SD can be applied on each coefficient.

$$\beta' = \beta + \xi \qquad (2)$$

4.4.1 Model estimation

The best MNL and EC models are presented in table 5. Models 1 and 2 are MNL models according to (1) while models 3, 4 and 5 add error components according to (1 and 2). Model 1 includes one cost coefficient. Model 2 deals with three cost coefficients; one related to driving costs, one related to driving distances reformulated into driving costs, and one related to road pricing. The length related driving cost assumed that the cost/km. were 0.55 DKK.

Models 3 to 5 include one or more error components in its structure. The only difference between model 2 and 3 is that a random error was defined in model 3 connected to all time and cost coefficients (i.e. a very hypothetical situation, but a useful test of whether heterogeneity exist in data). A dramatic improvement is observed in model 3, showing a lot of taste variation. Further disaggregation of the error components in models 4 and 5 gave even better results as all proved to be significantly different from zero. The best model estimated is model 5 where error components were placed behind different cost coefficients, free flow travel time and congested travel time, i.e. six error components in total.

Table 5 Estimation results from the best MNL and EC models based on the SP-data

File	model 1		model 2		model 3		model 4		model 5	
Observations	3388		3388		3388		3388		3388	
Final log (L)	-1662,6		-1645,7		-1571,1		-1561,3		-1538,1	
D.O.F.	8		10		11		14		16	
Rho²(0)	0,292		0,299		0,331		0,335		0,345	
Rho²(c)	0,290		0,297		0,329		0,333		0,343	
drvcost	-0.300	(-14.1)	-0.405	(-11.0)	-2.010	(-4.4)	-2.350	(-3.3)	-4.45	(-2.9)
fftime	-0.187	(-16.0)	-0.184	(-15.1)	-0.976	(-4.3)	-0.997	(-3.4)	-1.50	(-2.9)
cngtime	-0.299	(-19.9)	-0.296	(-19.1)	-1.530	(-4.5)	-1.48	(-3.4)	-2.25	(-3.0)
rdprice	-0.350	(-16.0)	-0.358	(-15.7)	-2.08	(-4.3)	-2.38	(-3.0)	-3.09	(-2.9)
inpeak	0.612	(2 .6)	0.614	(2.6)	1.52	(2.4)	1.67	(2.2)	2.64	(2.0)
offpeak	1.10	(3.4)	1.17	(3.6)	2.63	(2.4)	2.49	(2.2)	3.37	(2.0)
t_malep	-0.674	(-2.5)	-0.705	(-2.6)	-1.86	(-2.5)	-1.93	(-2.2)	-3.28	(-2.1)
asc51	0.188	(2.4)	0.189	(2.4)	0.355	(1.5)	0.329	(1.3)	0.436	(1.5)
costdst			-0.157	(-4.7)	-1.09	(-3.9)	-1.18	(-2.9)	-1.65	(-2.1)
costSP3			-0.346	(-9.4)	-1.96	(-4.0)	-2.38	(-2.9)	-2.59	(-2.8)
ercmp					-1.16	(-4.0)				
cost1_e							-2.00	(-2.7)	-6.21	(-2.7)
fftime_e							-1.12	(-3.1)	-1.74	(-2.7)
cngtime_e							0.904	(2.9)	1.16	(2.7)
cost4_e							-1.48	(-2.3)	-1.96	(-2.7)
cost2_e									7.33	(2.3)
cost3_e									0.924	(1.8)

The variables in the models are defined as:

- *drvcost*; driving cost coefficient in the SP1a (VoT experiment) and SP2a (time of day experiment, TOD).
- *fftime*; free flow time coefficient.
- *cngtime*; congested time coefficient (extra time due to congestion compared to *fftime*).
- *rdprice*; coefficient for road pricing in the road pricing experiment (SP3).
- *inpeak*; dummy variable from TOD experiments (SP2) saying that if the respondent originally travelled in peak hour, then when presented with an out-of-peak alternative he or she might (or might not) prefer to switch. A positive value means that the original time of travel (which is peak) is preferred.

- *offpeak*; dummy variable from TOD experiments (SP2) saying that if the respondent originally travelled in out-of-peak hour, then when presented with a peak alternative he or she might (or might not) prefer to switch. A positive value means that the original time of travel (which is out-of-peak) is preferred.
- *t_malep*; in the TOD experiments (SP2), men who travel originally in the peak are more willing to stay in the peak than women.
- *asc51*; alternative specific constant in the SP3 placed on the left side alternative (i.e. the original route). The positive value means that, when everything else is equal, the respondents prefer the original route.
- *costdst*; cost coefficient calculated via distances in SP1b and SP2b.
- *costSP3*; cost coefficient in the SP3.
- *ercmp*; error component coefficient applied only in model 3. The coefficient was applied on all cost and time coefficients in all SP-experiments. The purpose of model 3 was to discover that the error component improve significantly the model estimations.
- *cost1_e*; cost error component coefficient applied: On all cost coefficients in model 4, and on cost coefficients in the SP1a and SP2a in model 5.
- *fftime_e*; free flow error component coefficient applied on all SP experiments.
- *cngtime_e*; congested time error component coefficient applied on all SP experiments.
- *cost4_e*; road pricing error component cost coefficient in models 4 and 5.
- *cost2_e*; error component cost coefficient in model 5 applied on SP3.
- *cost3_e*; error component cost coefficient (where costs are calculated on distances) in model 5. It is applied on the SP1b and SP2b.

Table 6 shows the VoT's in model 2, which is a MNL model, and table 7 VOT from EC model 5. VoT's in EC models are often calculated as the ratio between the time and cost coefficient (first rows in table 7). However, the distribution of the VoT is more correctly described as the distribution of the time coefficient divided by the distribution of the cost coefficient. The mean of this distribution is not the same as the ratio of each distribution. The ratio of two normal distribution is Cauchy distributed, which has an undefined variance and mean. The interpretation of this is, that when the denominator (tail of the distribution of the cost coefficient) approach zero, then the VoT's limits infinite. If the distribution contains negative values, then the VoT is negative, which is of course illogical. Due to software limitations, the present study assumed Normal distributed VoT none-the-less.

The second VoT's in table 7 are simulated. The denominator (cost distribution) where first truncated at zero. However, this skewed the cost distribution too much, why the distribution was then truncated symmetrically around the mean with the left truncation at zero and the right at twice the mean. However, when the draws at the simulation approach zero, the VoT's still approach infinite. Accordingly a second truncation was done on free flow VoT over 250 DKK and congestion VoT over 400 DKK. The same truncation was decided at the AKTA RP to deal with participants who showed lexicographic behaviour concerning time. The cut-off-values were decided as about twice the maximum VoT of the none-lexicographic participants with the highest VoT. The numerator (time coefficient distribution) is assumed to have a central mean, why truncation or simulation should not be necessary. This was validated by simulation, after which the mean value was used. As seen in table 7, the simulation increased in general the VoT from EC-models compared to the ratio method. It would be expected that the larger EC, the larger difference on the VoT estimates. However, this also increases the likelihood of truncation and the cut-off of maximum VoT values. Why it is not sure that the VoT would increase (the congestion time in the road pricing SP decrease).

Table 6. VOT in DKK/hour in model 2 (MNL model)

Time component	Cost/time SP	Length/time SP 0.55 Kr/km SP	Length/time SP 0,7 Kr/km RP	Road pricing SP
Free flow time	27.3	70.3	89.5	31.9
Congested time	43.9	113	144	51.3

Table 7. VOT in DKK/hour in model 2 (EC model)

Calculation method	Time component	Cost / time SP	Length / time SP 0.55 Kr/km SP	Length / time SP 0,7 Kr/km RP	Road pricing SP
Ratio of coefficients	Free flow time	20.2	54.5	69.4	34.7
	Congested time	30.3	81.8	104	52.1
Simulation	Free flow time	39.4	-	108	44.1
	Congested time	45.5	-	131	49.6

In the SP3, driving costs were presented together with road pricing. This gave a higher VOT (less negative cost-coefficient) than in SP1 and SP2, i.e. the respondents' willingness to pay for time savings increase. However, road pricing has a higher coefficient than marginal cost (both coefficients are still more positive than in experiments without pricing), which indicates that road pricing none-the-less is considered worse than marginal cost.

The congested travel time is weighed more negatively than free flow travel time in all models, as could be expected (which is consistent with prior Danish studies, e.g. Nielsen *et al*, 2002).

The length based experiments showed a much higher VoT than the cost experiment. The results are both showed with the low cost/km. (0.55 DKK/km. - basically a very fuel economic car), and the value used in the RP (0.7 DKK/km. – average car and fuel price as at the time the experiment took place). The interpretation can be, that people in the cost experiment states their thought willingness to pay, while they in real life primarily want to minimise time, and that the length / time experiment better describe this.

The model also contained a number of dummies. The inpeak and offpeak dummies reveal a tendency to not change time of day (inertia). This explain maybe the relatively little change in the time of day of trips in the main AKTA experiment (section 4.3). It is not surprising that peak hour drivers want to stay in the peak; they have already accepted extra time due to congestion. However, it is a bit surprising that non-peak drivers want to stay out of the peak all-other-things equal. This indicates that they have chosen the non-peak as the best time of day for their specific trip, rather than to avoid congestion in the peak.

The Asc51 variable shows inertia to change route compared to the usual route. T_malep (TOD-game) shows that males are less willing to change TOD than females (opposite the result of Bonsall *et al*, 1998a). This is a bit surprising, since woman could be expected to have more constraint in time (shopping, collect children, etc.). However, if the usual trip is a morning commute (most of the cases), men could have more strict constraints for this specific trip.

4.4.2 Income effect models

Since willingness to pay may depend on income, different parameterised models were tested as well. The more traditional way of modelling income effect is by splitting the sample by income classes. Several split in classes within the answer intervals between 100, 200, 300, 400, 500, 750 and 1,000 thousand DKK in brutto income for 2001 were tested (no observation in other classes).

Data allowed however only to estimate two cost coefficients (table 8); one for income groups up to DKK 400.000, and the other for income above DKK 400.000. 70% of the sample (195 respondents) belongs to the first income group while 30% (84 respondents) belong to the higher income group. The income effect could not be estimated reasonably in the SP1b and SP2b experiments where travel distances were presented to the respondents, i.e. it turned out that lower income group respondents have higher VOT than those with high income.

Table 8. VOT in income dependent EC-models (below / over DKK 400.000), calculated as ratio of coefficients.

	SP1a and SP2a (cost/time trade offs)	SP1b and SP2b (length/time trade offs)	SP3 (road pricing experiment)
Free flow travel time	18.9 / 22.8 (20.2)	Not significant (54.5)	32.1 / 44.8 (34.7)
Congested travel time	28.4 / 34.3 (30.3)	Not significant (81.8)	48.2 / 67.2 (52.1)

The VOT from the EC model without income intervals (figures in the parentheses) are closer to the lower income respondents than to those with high income. The reasons for that are that the low-income sample is greater than the high-income sample, and that the distribution of the high-income respondents across income groups is more uniform than in the case of low-income travellers.

The last model type estimated in the study were two models with increasing VoT as function of income, either with an additional βc/I term, or βc/I*c (the latter removing the unit problem in the coefficient). However, both formulations had low t-values as well as illogical signs on the coefficients.

4.5 The RP Route choice model

The first step in the model estimation based on the GPS-data was to estimate a route choice model (the only model based on RP-data that have been finalised and reported in the present paper). This model is described in the following.

4.5.1 Utility function

The route choice model was based on a linear utility function (3), as the SP-model. However, the error term is the sum of error terms at the arcs a along the specific route R. Since routes can be correlated (sharing links), ε can not be assumed independent distributed among alternatives, and can neither be assumed identical distributed (splitting an arc in two into the digital map would imply a doubled error term). In the present study, Gamma distributed error terms were assumed, since these are non-negative and overcome the overlapping route problem (Nielsen *et.al,* 2002). The coefficients β could also follow distributions (i.e. error components as in formula 2). However, no distributions were assumed a priori (the empirical distributions were revealed).

$$U_R = V_R + \varepsilon_R = \beta_c RoadPricing + \beta_l Length + \beta_{tff} Time_{ff} + \beta_{tcon} Time_{con} + \sum_{a \in R} \varepsilon_a \qquad (3)$$

4.5.2 Estimation

The estimation of the route choice model was carried out by running an all-or-nothing route choice model several times for each trip per person. Each run used different combinations of the coefficients in the utility function. The sums of the coefficients were restricted to one, since it is the ratios between them who determine the choice. This lowered the possible number of combinations, which were pre-defined in a factorial design (Nielsen, 2002) to avoid building the calculation graph dynamically for each run. This speeded up the calculation time in the specific software (ArcGIS). However, a C++ programme is being written to speed up the software and to estimate more complex utility functions, i.e. to search the solution space more intelligently.

In the present initial analyses, 48 different combinations of coefficients were run for each trip. And the best fit(s) to the observed route was recorded. The fit was measured as the ratio of the length of the trip which had been fitted to the observed route. Since the network contains 350,000 links, this task was quite calculation demanding. In some (most) cases several combinations gave the same fit (in the extreme case even that a path is both the shortest and fastest). Each fit was then weighted proportional to the number of best fit for the route it tried to match.

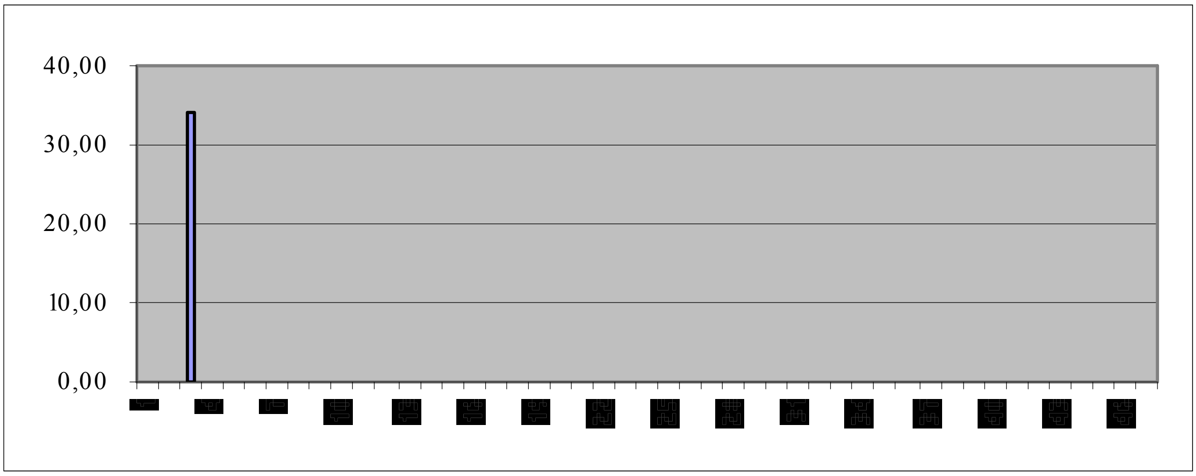
It was examined in a pilot study whether an added error term could improve the results (as in formula 3). However, this was seldom the case. The analyses were accordingly conducted by deterministic utility functions for each trip, as this improved calculation time dramatically. The interpretation must be, that most of the heterogeneity can be explained by differences in the coefficients in the utility function, and that the remaining unexplained variation can not be explained by a distribution around the deterministic utility function.

The RP-model was based on a marginal cost calculation of fuel (8.5 DKK/l, 12 km./l) which resulted in a cost per km. of 0.7 DKK, which were higher than the SP (why the results in table 6 and 7 were scaled to the RP-values as well). Using a lower or higher cost/km. scale the VoT linearly, why the same assumptions must be made to compare the results.

4.5.3 Within person variation

The utility functions for all trips for each car could be compared. Figure 6 shows as an example the most utility maximising (rational) participant (car) in the experiment. About 2/3 of the participants had fairly consistent preferences – although following wider distributions than in the example. And it was in general possible to fit their routes quite well (in the 80-100% match interval).

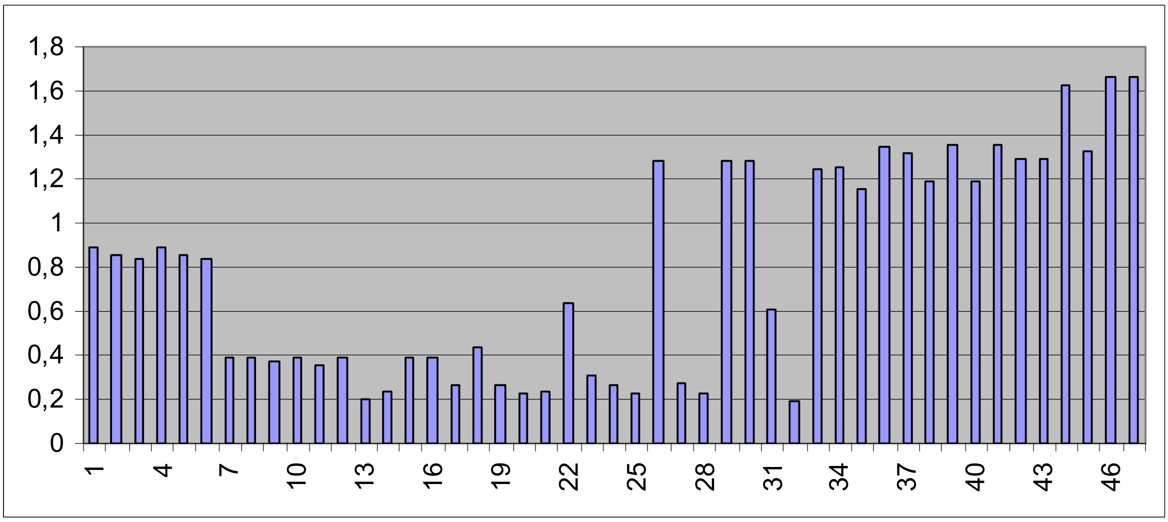
Figure 6 Utility maximising participant. The numbers along the x-axis are the number of the each combination of values in factorial design for the estimation, which in this case contains length, free flow time and congestion time. 1 is lexicographic behaviour concerning length and 48 lexicographic behaviour concerning time.



Source Forthcomming M.Sc.-thesis by Paolo Menegazzo.

However, some participants had a very wide range of preferences. And at the same it was difficult to match the routes (40-60% best match interval). It seems like these participants did not know the network very well – or didn't care. By manual analyses of samples of routes it could be seen that they often followed illogical routes (i.e. non explainable after any criterion the author could figure out). It appears that more work need to be done to explain this group route choices – if it at all is possible.

Figure 7 Person with varying preferences



Source Forthcomming M.Sc.-thesis by Paolo Menegazzo.

The best matches for a "random" participant in the experiment are e.g. shown in figure 7, where the preferences vary very much. Using the most likely combination of coefficients may not be a good idea in this case, since it is the weighting of time components only (lexicographic behaviour on the edge of the distribution). Accordingly it is better to use the mean of the values, or the median of the distribution. The mean is used in the following.

4.5.4 Between person variation

The distribution of preferences between persons can be revealed by comparing the mean of each person's preferences. In the following, results are only presented for the 85 participants in the control period (no road pricing), since further analyses are ongoing. Figure 8 and 9 shows the distribution of value of times for the 85 users. The often used assumption in logit models (that the coefficients are fixed) does clearly not hold. This confirms the SP-based models, where the error component models had much better log.likehood values than MNL. The empirical distributions in the RP are per definition non-negative, as the coefficients have to be positive to make the route choice model work. The distributions are skewed to the right (the mean is larger than the median), and they look a bit log.normal – although the number of observations is too little to determine this for sure. Some of the users have very high value of time, which is due to lexicographic or near lexicographic behaviour (time minimisation only). The observations appear bundled at some few outlier levels, which is because the factorial design where the search algorithm had fewer grid-points in this area of the function.

Figure 8 Frequency and accumulated distribution of free flow value of time in DKK. (7.3 DKK equals approximately 1 Euro). Mean VoT = 73 DKK, median = 58.

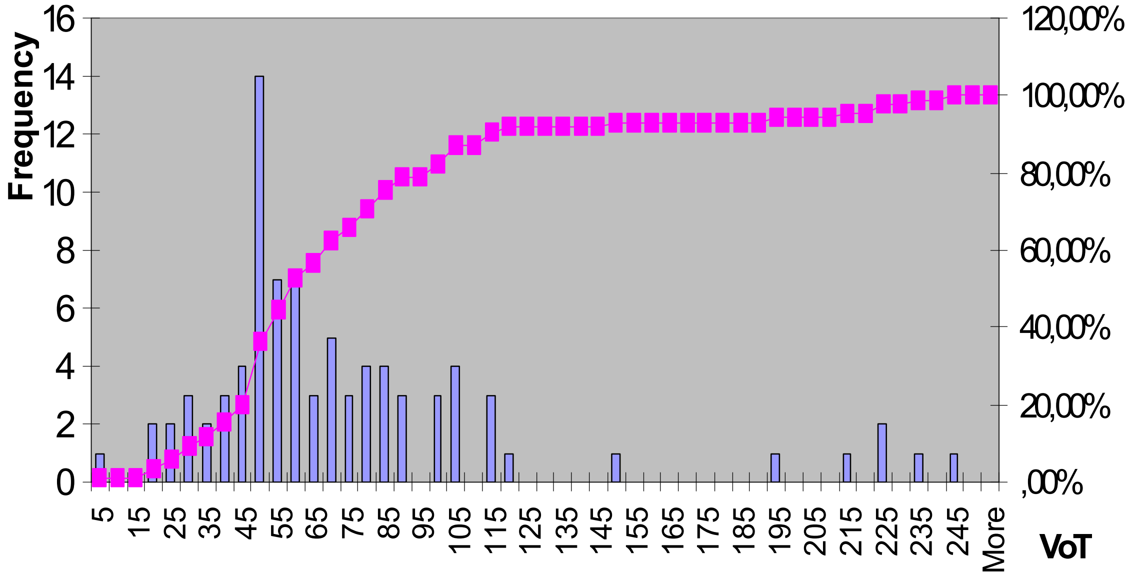
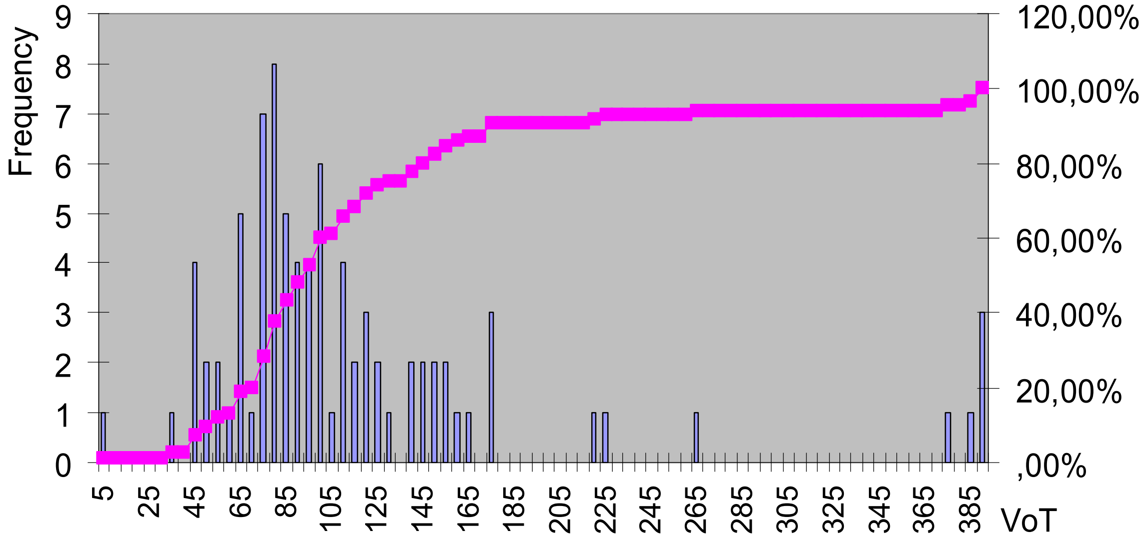


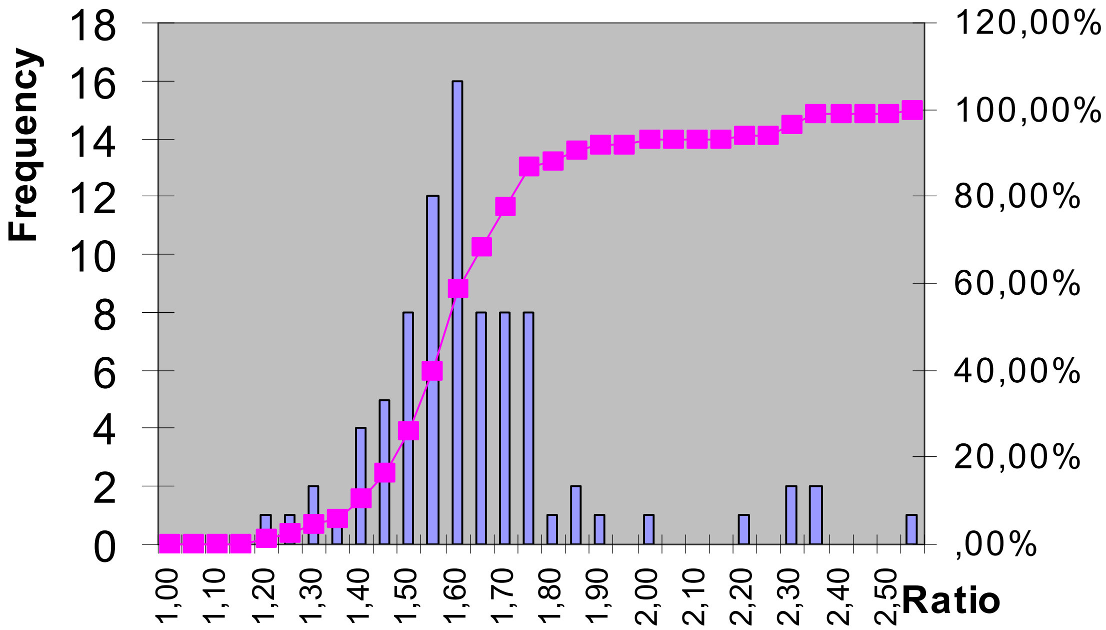
Figure 9 Frequency and accumulated distribution of value of congested time. Mean VoT = 119 DKK, median = 92.



The VoT from the RP-based model is about 1/3 lower than the SP length experiment based on the same cost per km. The RP VoT are on the other hand much higher (a factor 2-3) than the SP cost experiment. If the empirical distribution in figure 8 is fitted with a Normal distribution, the best fit will most likely be around the "mass" of the distribution and with a right tail fitted to the high values. This again will imply a tail on the left side as well, since the Normal distribution is symmetrical. The VoT calculation by simulation in table 7 truncates the denominator, which to some extent take care of this, and should make the VoT estimates comparable.

Another issue is whether the two distributions are independent. The ratio between the two would then contain values below one. As can be seen from figure 10, this is clearly not the case. The smallest ratio is 1.2 (VoT for congestions time is always higher than free flow time). The mean and median is 1.6, which indicates a near symmetrical relationship between the two time-components (which was confirmed in a scatter diagram, not shown in the paper). Basically, this illustrate that if one has a high free flow value of time, then the value of time for congestion is even higher. If one has a small free flow value of time, then the congestion value of time is bigger than this. The ratio is in both cases symmetrically distributed among 1.6.

Figure 10 Frequency and accumulated distribution of the ratio between free flow value of time and congested value of time. Mean = 1.6, median = 1.6.



The quality of the digital maps attribute data is better for free flow times than congestion time, since the latter has been modelled (by a speed flow relationship). This may explain the rather large variation in figure 10, and the symmetricy of this. Both attribute fields in the map will be reassessed based on the AKTA-data (which also contains driving speed).

4.5.5 Estimation of impact of road pricing

The estimation of route choice under road pricing was done in the same way as the model estimation in the control period. Only the high km.-based scheme has been analysed. It turned out to be difficult to estimate a utility function with one further variable due to present software limitations[3]. Another approach was applied instead, where the model was re-estimated assuming the same coefficient on road pricing than marginal cost (length multiplied 0.7 DKK/km). This resulted in a slightly lower VoT than in the control period, i.e. a higher response on road pricing than if assumed equal to marginal cost. This is different from the SP, where the respondents tends to state less change in behaviour than if cost was equal (both the *rdprice* and *costSP3* in the SP were lower, which equals a higher VoT than from the coefficient without road pricing, *drvcost*). The SP model contained in addition a number of dummies for inertia, why it would suppress changes further, while this in the RP is built into the coefficients. It should be noted though that the road pricing experiment in the SP was based on time-of-day decisions (but in a joint model estimation over all 3 experiments), while the RP data analysed all time periods. However, it is surprising that the road pricing in fact lead to such high changes in behaviour in the main RP-experiment.

The opposite was the case in the only comparable experiment known by the authors (Bonsall *et al*, 1998a & b). However, the pricing schemes were defined differently, the urban settings were different, and the pricing level lower. The high km.-based scheme in AKTA varied from 1 DKK per km. to 5 DKK per km. in the peak hours. The marginal driving cost was assumed to be 0.7 DKK (0.55 DKK in the SP). The increase in cost is accordingly quite large. The cost level for public transport is about 1 DRK per km. (rough average in the zonal-based price system).

4.5.6 Income effect

Figure 11 shows the VoT as function of house hold income, where the values for each income group have been averaged. The figure shows a clear increasing relationship. However, somewhat surprisingly with the highest VoT level at the third highest income level. This can be due to other socio economic attributes (e.g. higher time budget constraints in children families, while the average age of the highest income categories must be assumed higher), or higher fixed budget constraints (e.g. housing). Or the explanation is simply due to the small sample.

The figure explain the SP-model, i.e. one VoT level under 400,000 DKK and another over, which seems to be the best piecewise specification. However, it doesn't explain why a SP-based model with a linear increasing VoT could not be estimated. Except that the SP-data may not include enough observations to estimate this interrelationship.

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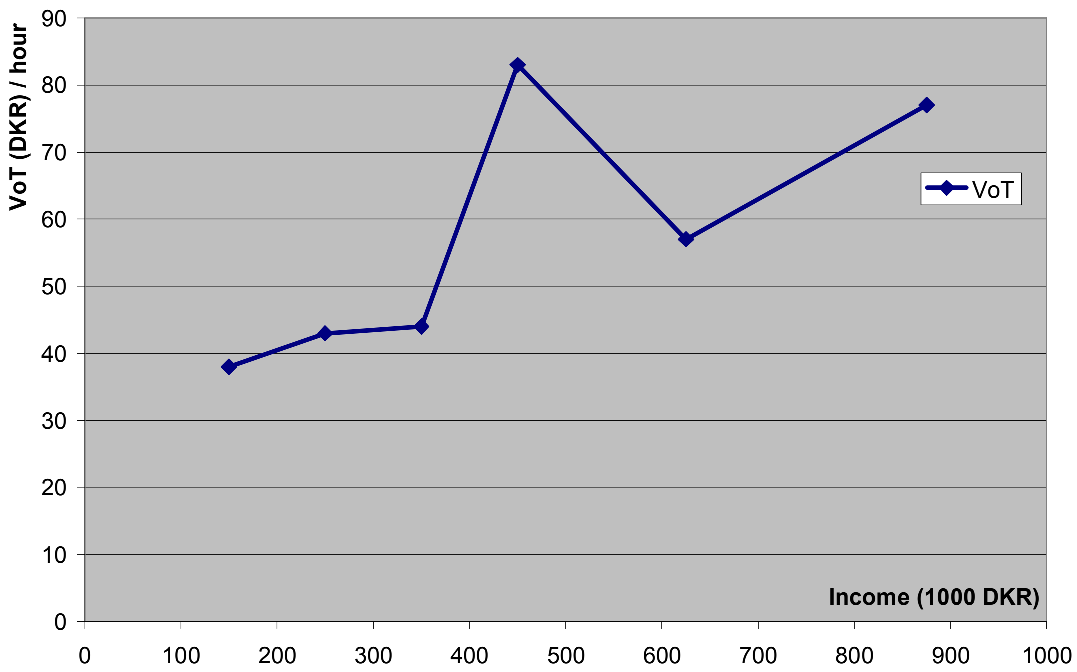
[3] The route fit algorithm must use predefined parameter combinati ons in ArcGIS when implemented in ArcObjects, as the calculation time otherwise was unreasonable high (year estimate). The estimator is currently being reprogrammed in C++ with a better path solver and estimation routine to overcome this.

Figure 11 Value of Time as function of house hold income (1,000 DKK)



5. Discussion and conclusions

The many different results and findings of the experiment is discussed and summarised in the following.

5.1 GPS as Experimental method

The GPS-experiment was perceived as realistic, and it seems like the behavioural responds are realistic as well as it was also possible to estimate a behavioural (route choice) model on the GPS-data. This is maybe surprising, since the variables are highly correlated. However, due to the experimental design many observations exist per car which compensates for the correlation. A few participants acted illogical none-the-less. This - however – could also be the case in a real life implementation of road pricing. One could claim that the error term in usually discrete choice models also reflect this, since the choice set is reduced to a binary one.

5.1.1 The GPS technology

The GPS-technology performed more problematic than anticipated. A significant amount of extra work had (and are) to be carried out in order to develop methods and software to process and repair the data. Since the participants had not experienced all problems, their behaviour was not affected hereby. However, if a GPS-based system is to be used for a full-scale pricing scheme, much further work needs to be carried out concerning methodological, software and technical issues.

5.1.2 The main experimental design

Theoretically, a factorial design is optimal since a small sample can be utilised better by this approach. However, it appeared that some of the participants could not understand the experimental design: Not only those who tried different prising schemes without any control period (which must be strongly dissuaded in other experiments), but also those who ran a control period followed by one pricing scheme. Some even misunderstood the design in the second round, where the project responsible were aware of this problem, and where further care had been taken to explain the experiment to the participants. By conducting a post-experiment survey by phone, it was however possible to pinpoint those participants who had misunderstood the design.

It is recommended that the participants are presented for their expected costs after the control period. Or better to pay them the amount, as this makes the following period more realistic, since they have to pay “real” money back. To do this, data from the GPS-units have to be downloaded and processed in order to calculate the payment prior to the second round, which is a technically and organisationally obstacle though.

The pricing periods in the experiment were too short; at least 12 weeks must be used for the control period and for each subsequent pricing level. This was compensated in a third experimental round, where the very initial results indicate a somewhat higher degree of change in behaviour.

5.2 Changes in behaviour and evaluation of different pricing schemes

It can be concluded that Road Pricing does affect behaviour; it is not considered as another fixed cost, but as a marginal cost that drivers responds to. The responses are even higher than if they are only considered as a marginal cost with the same willingness to pay.

The *high km.-based pricing level* clearly made an impression on the participants (between 1 and 5 DKK/km. in the peak hours, and half price in the out of peak hours; 1 Euro equals 7.3 DKK). Even if they could not change behaviour, they had examined alternative travel options before rejecting these. The participants considered changing route, mode and “occasional” trips. And some changed behaviour. The main changes were new routes, and for “occasional” trips new destinations, time of day (to non peak) and to some extent fewer trips. Commuting trips were supposed to be difficult to change, e.g. shifting away from the peak hour, working home (telecommuting) or using another mode (bicycle or public transport). However, it turned out that the participants none-the-less changed these as much – or even more – than other trips.

The l*ow km.-based pricing level* was in general not sufficient high to change behaviour, although a few participants did some minor changes when it was easy. Most participants believed that it was "random" if they travelled more or less in the low pricing period than the control period, e.g. that they had more visits in the Central Copenhagen or a vacation in one of the two periods than the other. This was also confirmed by the main AKTA experiment.

The *km.-based schemes* were in general considered more fair than the cordon-based. The participants had none-the-less more difficulties to understand these than the cordon-based system. It is interesting to note, that the fairer and economically justified schemes the more difficulties are experienced to understand the schemes. The km.-based scheme turned none-the-less out to be the most efficient in term of behavioural changes.

5.3 Attitudes towards road pricing

The participants' and interviewed persons' attitudes to road pricing were less emotional than expected (especially considering the debate in the Danish press). Most participants did not consider surveillance as a problem (that the cars can be tracked by the logged co-ordinates). The possibility to control speed-violations was neither considered important. The participants disagreed on whether road pricing is fair or not, including whether the society becomes more class-divided between people that can pay or not, and for people who cannot change behaviour (e.g. with fixed meeting hours or with children in school and day care). Only few participants had very strong attitudes against road pricing, and very few were positive.

5.4 Comparison between SP and RP models

It was obvious, that the participants had little feeling with the real cost – marginal or average – of driving. Dependent on the formulation of the question, different answers were given which were highly inconsistent with each other. The VoT from the SP-experiments that traded off cost with time differed with about a factor 3 from the RP-data. While the SP with trade off of length and times were in the same magnitude, although not equal.

Using error components improved the SP-based models significantly. A quite large heterogeneity of the coefficients was found (high variance compared to the mean, with high t-values). A similar large heterogeneity was found in the RP-data. The RP-data indicates that the VoT follows log.normal distributions, and that the VoT of different time-components are correlated. About 1/3 of the participants in the RP-experiment showed non-explained behaviour, while the other clearly acted utility maximising. The SP-based logit models assume utility maximisation with an error term. Since the choices here are binary, the unexplained variation will be taken care of by the alternative specific constants and error term. This is more difficult in the RP-based model estimation.

The RP-data showed an increasing VoT with income. This could – with some good will - be assumed linear increasing, or clustered around a level below 400,000 DKK and another level over.

The SP-model could only be estimated as a two level VoT due to far less observation than the RP-data set. A split of 400,000 DKK gave the best fit, which was confirmed by the RP-based model.

It is not easy to compare absolute numbers of VoT from the RP and SP-models due to different assumptions on cost/km. as well as problems with calculation of VoT from EC-model with Normal distributions. This will demand a significant software development of the SP-estimation software – which was out of the present projects scope. However, it appears that the SP in the same formulation as the RP (Length-time tradeoffs) overestimates VoT slightly. The ratio between different time-components (free flow time and congestion) remains pretty equal, and the magnitude of heterogeneity is similar as well.

The SP states that the value of road pricing is higher than the value of marginal driving cost (fuel manly). However, both cost coefficients became less negative compared to the situation without road pricing (VoT increased). The RP on the other hand showed that the participants changed behaviour slightly more (i.e. a lower VoT) than expected assuming that the value of money were equal. It must be concluded, that respondents tend to underestimate their behavioural changes due to road pricing in the SP-experiment compared to the field experiment, where it is real money (or they may answer strategically in the SP). This is surprising since they could be expected to change less behaviour in real life due to time-constraints (constraints in their time-budget), habit or lack of reasonable alternatives (as in Bonsall *et al*, 1998a & b).

It was possible to investigate the issues of heterogeneity and income dependent VoT's a bit more in depth using the RP-data than the SP. In this respect it must also be stated that although RP-data is more difficult to use for estimation (due to the correlation of variables, that cannot be controlled as in the SP); it contained far more observations per participant. The SP consist of 3 sub-experiments with 6 trade-offs per participant. While the RP contained between 200 and 1,000 trips per car, each trip with an individually estimated utility function, resulting in about 100,000 observations in the present model. It would accordingly be expected that more coefficients, error components and non-linerities could be estimated from the RP. However, the sample has not yet been separated on trip purposes. And the issues of different socio-economic variables have not yet been analysed. Accordingly, the SP models are more advanced in this context.

It must be noticed that the budget for the full RP AKTA experiment was over 10 Mio DKK, while the AKTA SP budget were about 0,5 Mio DKK (including internal funding). The RP contains much more information. But the SP provides – if formulated as length/time experiments and EC-models - good indicators on the behavioural responses.

5.5 Perspectives for further work

The RP-data need to be split further into trip purposes to estimate other impacts than route choice. This includes possible small errands where the driver are waiting or collecting a passenger. However, only household and work place is known in the data, while the other purposes must be estimated from land use data.

A problem so far not dealt with is the possibility of several drivers. The driving pattern (speed acceleration, etc.) could maybe be estimated from the commuting trip and combined with information on multiple drivers from the pre and post interviews used to indicate other drivers. However, it can also be the case that the driving behaviour of the same person depends on the context, e.g. driving in peak hour, driving home fast to collect children, compared to a leisure trip in the evening.

The route choice estimator is being re-implemented to be able to estimate more complex utility functions. While the SP-model need to be able to apply correlated log.normal distributions. This would facilitate a comparison of the two approaches, where all-other-things are truly equal.

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