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an evaluation based on time series

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HOW DO MOTORWAYS SHAPE COMMUTING PATTERNS? AN EVALUATION BASED ON TIME SERIES.

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1. INTRODUCTION

This paper is an offspring from the research project Town, Road and Landscape held by Aalborg University in corporation with the Danish Road Directorate and The Royal Veterinary and Agricultural University – 50% sponsored by the foundation Real Dania (**www.bvl.aau.dk/english**). The projects first phase focuses on the effect of the Danish motorway network on urbanization and spatial interaction patterns in the last 20 years. This paper presents results on how the building of the motorway network has shaped spatial interactions patterns in Denmark over a ten year period.

Almost half of Denmark's 1000 km of motorway has been completed within the last 20 years. The limited access motorway, allowing speeds until 110 km/h (from May 2004, 130 km/h), is the top of the road hierarchy in most parts of the country and forms a continuous network connecting cities all over the country through high-speed corridors.

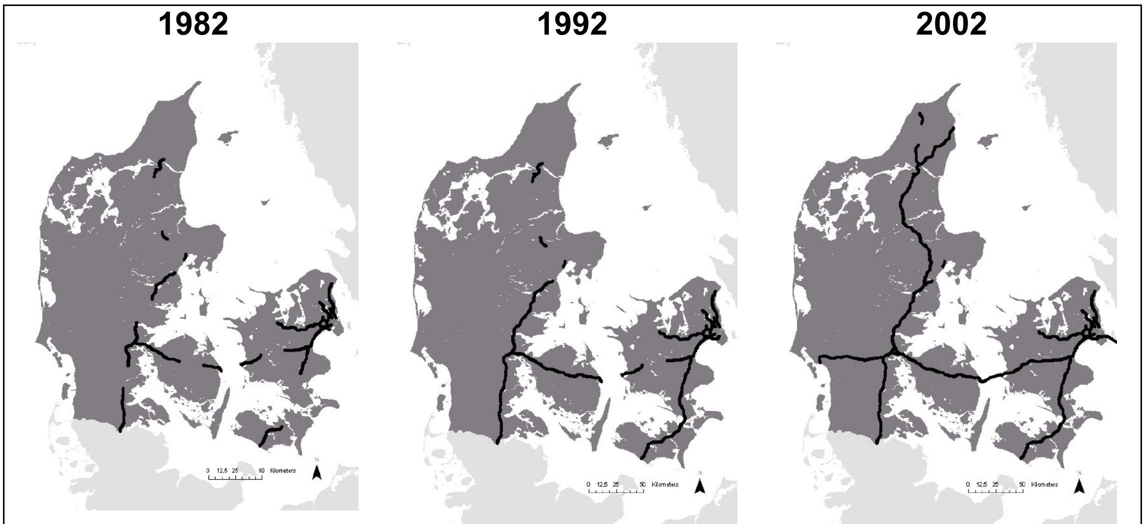

Figure 1: The development of the Danish motorway network from 1982 over 1992 to 2002. The maps show the extension of the network at the beginning of the year.

Theoretically this development has a strong potential to affect the pattern of transportation as well as urban development in general. However as the debate on induced demand shows it is a difficult task to reveal an effect of road building in itself. Ordinary cross-sectional analysis will always run into difficulties when it comes to sorting out the direction of causality: was it the motorway - or - was the road just build in response to adequate forecasts (see fore instance Noland and Lem, 2000 or Cervero, 2001). Time series lending itself to analysis of variations in the “response” to the motorway (before and after) as well as development trends before the road was build could produce some interesting results. Especially the inclusion of the development in the years before a road was build, as an explanatory factor in competition with additions to the transport infrastructure - will allow for at fairly direct testing of the claim that the motorway was merely a response to an ongoing development now producing the apparent relation between road and transportation.

The question asked in this paper is how travel time reductions and changing motorway access is related to changes in the commute pattern. And whether the relations between theses factors and commuting are a new course of development or a continuation of past trends.

1.1 Commuter-statistics

The Danish commuter statistics provides a rare opportunity to analyse spatial interaction patterns over time. Statistics Denmark has kept records of place of work and place of residence at the address level, for the entire workforce since 1981. The database has been constructed and errors continuously corrected so that the register should reflect the actual commuter relations (actual place of work as opposed to company address). However no statistics is provided as to how often the commute is made - thus only commuter “relations” can be analysed. Given the high level of regularity of travel to work the commuter “relations” is anticipated to reflect actual home-work travel flows adequately. The basic data used in this paper is a matrix of the exchange of commuters between 1390 parish-derived geographical zones (clusters of parishes) - by level of education (6. groupings) - and three points in time within the last 20 years: 1982, 1992 and 2002. The dataset is virtually a full count of home- and workplace relations among Denmark’s 2,6 million commuters. These can be distributed into approx. 280.000 different geographical combinations of home and work on the basis of the zones used in this analysis.

1.2 Methodology

The analysis presented in this paper will primarily focus on changes in commuting from 1992 to 2002 and the effects of travel time changes or changes in the location vis-à-vis the motorway network in the same period. Additionally the development in the preceding decade (1982-1992) will be included in the analysis to address whether the relations found are actually new or a continuation of trends. In other words – whether transport infrastructure is moulded by or moulding commuting patterns.

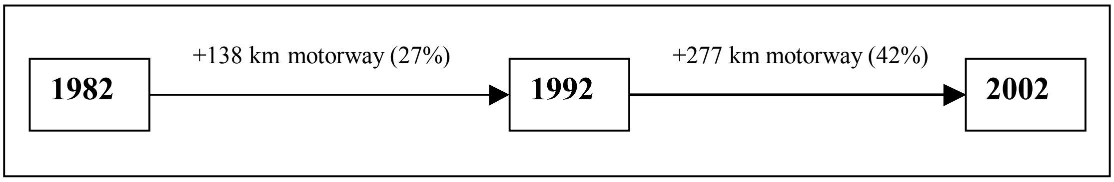

Figure 2: Time perspective used in the analysis. The changes in commuting in the latest period was analysed – with statistical control for the development in the preceding period and a number of other factors.

To explore the effect of the completion of the motorway network on commuting patterns three types of data set are build, to allow for regression analysis of 3 types of dependent variables: commuter flows between pairs of origin and destination zones (pairs of origins and destinations as cases), commuting distances (zone of residence and zone of work as cases) and commuting to the CBD of the largest cities (Copenhagen and Aarhus – residence zones as cases). All dependent variables are drawn from the commute matrix. Commuting distances are calculated on the basis of shortest road distance between the zones (home and work within the same zone is assigned a fixed distance based on the size of the zone).

GIS-based transport network data for 2002 and 1992 is an important prerequisite for the analysis as travel times and travel time reductions, accessibility, travel distances etc. is based on this. As GIS-based 1992 data was not available it was necessary to take the 2002 data back in time through the exclusion of the larger road projects that had been build between 1992-2002, and through the adjustment of speed limits on the network and ferry routes in correspondence with new legislation and new ferries. All measurements of travel times and distances (including accessibility etc.) are based on a representation of the zone by the centroid of the largest urban area within the zone. Travel times was measured based on speed limits as knowledge of actual travel speeds is only available for selected sites on the network in recent years. Thus a basic assumption for the analysis is that travelling according to the speed limits will represent the travel times and the travel time changes adequately, at least when the focus is on a large geographical scale. As time-saving is thought to be the relevant measure inducing changes in commuting patterns – the time savings brought about by the motorways can not be singled out individually in the analysis. The significance of the motorways will have to be inferred from the general effect of travel time savings.

The changes in commuting from 1992 to 2002 were analysed using multivariate regression analysis. The general formula for the selection of variables for the analysis is that the base year (1992) as well as the change (1992-2002) is included. The main focus is of course on travel times (1992 and 1992-2002 reductions) and access-egress to/from motorway. There are some differences between the regression models. Travel time savings can not be included directly in the analysis of commuting distances. In the analysis of commute distances the question is rather whether a differential development in time-based and distance based accessibility induces longer commutes. Thus the analysis of commute distances represents travel time changes through a number of indexes for such a development. Other explanatory variables included in the analysis (control variables) is characteristics of origin/destination zone (population, workplaces, balance, proportion of residents or workers with long education) and variables describing the area in which the zone is located (accessibility – cumulative measures, population-workplaces balance, relative attraction). The variables included have been limited by the contents of the present commute matrices and what could be obtained from GIS-based network analysis. Apart from the education level all variables included is therefore spatial and described the general “opportunity surface”. Given the zonal data and the large geographical scale analysed this is not likely to pose a significant problem. It is however an area where the analysis could be improved in the future.

The regression results are presented on the next pages under 3 headlines: exchange of commuters between zones, commuting distances and commuting to the city. The analysis of exchange of commuters and commute distances analyses variations within Denmark while “commuting to the city” focuses on a delimited area around the city. As the analysis displays what could be termed a “non-normative” or “ad hoc” (Cervero, 2001 or Handy, 1997) approach every section begins with a listing of the variables included in the analysis. The regression models presented are without the historical (1982-1992) development in commuting as explanatory variable. The effect of the historical development is commented in the text.

2. EXCHANGE OF COMMUTERS BETWEEN HOME AND WORK ZONES

The analysis of the growth in commuting between pairs of home and work zones is an attractive option that allows for simultaneous inclusion of access to the motorway in the home as well as in the work zone. An attempt was made to statistically explain the growth in commuting from 1992 to 2002 between pairs of home and work zones in Denmark. To relief the burden of data processing only 20% of the existing home-work zone combinations in the original dataset were included. The explanatory variables included in the analysis can be divided into travel time – including travel time reductions, access/egress to/from the motorway, origin and destination characteristics, and eventually the development in commuting between home and work zones in the preceding decade (1982-1992) (see table 1).

Dependent variable

- Change in number of commuters exchanged from origin zone (home) to destination zone (work) 1992-2002. The pairs of home and work zones are used as cases.

Travel time

- Minutes by car from origin to destination, 1992
- Change in minutes travel time by car, 1992-2002

Geography

- East-West commute (Dependent on The Great Belt Toll Bridge or ferries)

Access / Egress to/from motorway

- Motorway ramp within 1½, 3 and 5 km of origin, 1992
- Motorway ramp constructed within 1½, 3 and 5 km of origin, 1992-2002
- Motorway ramp within 1½, 3 and 5 km of destination, 1992
- Motorway ramp constructed within 1½, 3 and 5 km of destination, 1992-2002

Origin characteristics:

- Employed population (night pop.), 1992
- Change in employed population, 1992-2002
- Day-night population ratio within the zone and within 15 minutes by car, 1992
- Change in day-night population ratio within the zone and within 15 minutes by car, 1992-2002
- Proportion of population with academic (or similar level) education, 1992
- Change in proportion of population with academic (or similar level) education, 1992-2002
- Jobs within 15 and 30 minutes by car from origin centroid, 1992
- Change in number of jobs within 15 and 30 minutes by car, 1992-2002

Destination characteristics:

- Workplaces (day pop.), 1992
- Change in the number of workplaces, 1992-2002
- Day-night population ratio within the zone, 1992
- Change in day-night population ratio, 1992-2002
- Proportion of employed with academic (or similar level) education, 1992
- Change in proportion of employed with academic (or similar level) education, 1992-2002
- Jobs within 15 and 30 minutes by car from destination centroid, 1992
- Change in number of jobs within 15 and 30 minutes by car, 1992-2002
- Relative attraction of the destination zone compared to the supply of jobs within 15 and 30 minutes by car, 1992.
- Change in the relative attraction of the destination parish compared to the supply of jobs within 15 and 30 minutes by car, 1992-2002.

Development history:

- Change in number of commuters exchanged from origin zone (home) to destination zone (work), 1982-1992.

Table 1: Variables included in the analysis of changes in the exchange of commuters between zones.

Attempts were made to explain the development in commuting in absolute numbers, in percentage points as well as relative to production and attraction factors (a simple gravity expression). Generally the levels of explanation yielded by the regression models (R-square) where very low. Probably because there is a lot of random variation to the changes in commuting between small zones over the relatively short 10 year period subject to analysis. The model formulation most successful in explaining the changes in between zone commuting was the one explaining the added number of commuters in absolute numbers (see table 2). The degree of explanation is only a little more than 7% for the model before development history is introduced as explanatory variable.

	Unstandardized Coefficient: B	Standardized Coefficient: Beta	Sig.
(Constant)	8,3380		0,000
Minutes by car, 1992	-0,0120	-0,052	0,000
Minutes by car 1992, (LN)	-0,6230	-0,059	0,000
Change in minutes by car, 1992-2002	-0,0334	-0,046	0,000
Origin: Motorway ramp constructed within 3 km, 1992-2002	0,6297	0,008	0,059
Origin: Resident working population 1992	0,0001	0,014	0,006
Origin: Change in resident working population, 1992-2002	0,0027	0,093	0,000
Origin: Number of jobs within 15 minutes of travel time (LN)	-0,3488	-0,058	0,000
Destination: Number of workplaces, 1992	0,0001	0,028	0,000
Destination: Change in number of workplaces 1992-2002	0,0019	0,246	0,000
Destination: Number of jobs within 15 minutes of travel time, 1992 (LN)	-0,2252	-0,039	0,000
Destination: Relative attraction compared to the supply of jobs within 30 minutes travel time 1992	2,2480	0,016	0,005
Destination: Change in relative attraction 1992-2002	15,4409	0,026	0,000

Table 2. Linear regression model explaining the change in number of commuters commuting from one zone (home) to another (work) from 1992 to 2002. The cases are the pairs of zones. Data for whole country (Denmark) is included. Model estimation was based on a sub sample of 20% of the pairs of zones (parish derived geographical clusters=zones) exchanging commuters. N=48252, R-square = 0,071, Sig. (F-test) = 0,000.

Travel times at the offset (1992) have been allowed to occur in logarithmic and linear shape to account for nonlinearity in this relation. A distance decay is an important part of the explanation for commuter growth in absolute numbers. When it comes to the changes of the transportation network in the period, the development of between zone travel times from 1992-2002 seems to affect the commuting negatively (=travel time reductions affects commuting positively) and there is a tendency for zones that has gained motorway access within 3 km to commute more. Thus there is some evidence for a travel time affected development in commuting patterns as well as a motorway bias at the origin/home zone.

The effect of travel time reductions is supported by the other attempts to explain the development of between zone commuting. The evidence on motorway bias besides travel time savings is more mixed and probably reflects the weak nature of this relation.

Note that the regression model in table 2 – apart from production and attraction related variables – contains negative correlations with accessibility variables at the origin as well as at the destination zone. These where included in the analysis to describe the areas in which the zones are located. The correlations points to a tendency that is generally present in the data: the largest growth in commuting originates and ends outside the strongest centres and thereby adds to the erosion of the existing build up of commuter relations towards the dense core areas.

The introduction of the development history 1982-1992 in the equation increases the explanatory power of the regression model remarkably as R-square rises from 0,071 to 0,112. As the R-square using the development history as the only explanatory variable would be 0,065 it seems that the development history mostly adds to the level of explanation – without competition with the other variables already in the model.

The introduction of the development history does however affect the variables in the model slightly. The importance of the changes in travel times and attractions in explaining the variation in numbers of commuters from 1992-2002 is reduced. Travel times were apparently reduced the most where the growth in number of commutes was the largest in the decade before. Additionally attractions increased the most where it had already been increasing in the decade before. The correlation between historical growth and the other explanatory variables in the model is not of an extend where the statistical significance of the other variables is questioned by the introduction of development history in the regression model.

The large contribution to the explanatory power of the model points to a high degree of trend-continuation or maybe path dependence (Arthur, 1988) in the evolvement of commuter flows. But the relative lack of interference between development history and the other variables suggests that travel times reductions and new infrastructure among other factors contributes independently to the shaping of commuting patterns.

3. COMMUTING DISTANCES

The commuting distances was calculated for the home- as well as for the work zone. The result was 2 datasets that allowed for analysis of the increase in commute distances from 1992 to 2002 for zones of origin as well as zones of destination. The inclusion of location vis-à-vis the motorway in the analysis in this context is straight forward. The effect of transport infrastructure development on travel times could however not be incorporated as directly as in the previous model. Logically the opportunities offered within given travel distances would be the main spatial factor determining commute distances. The contribution of infrastructure development may however increase the opportunities offered within fixed travel times as the increasing speed allows the agents to cover longer distances within the same travel time. To reflect this, indexes for the differential development between time-based and distance-based accessibility was calculated (short, medium and long range).

These where included in the analysis together with location vis-à-vis the motorway, distance based accessibility and a number of other variables (se table 3).

The analysis result for the changes in commute distances for resident population (night populations) is shown in table 4. The difference between the development in time and distance based accessibility in the long range (45 minutes and 30 km) has a significant and positive correlation with the change in the commute distance. This means that the zones that had the largest increase in time-based accessibility compared to distance based accessibility had larger increases in commute distances.

Location close to the motorway in 1992 also seems to affect the development in commute distances positively. The changes in location vis-à-vis the motorway in the period from 1992 to 2002 is on the other hand not represented in the model.

The inclusion of the historical 1982-1992 development in commute distances into the model as an explanatory variable increases the R-square from 0,245 to 0,251 – but does very little besides this. The historical development in commute distances in itself has a negative correlation with the development in the preceding decade suggesting that the location of working population with growing commute distances shifts over time. It is likely that this reflects processes of urban growth and saturating tendencies as time-budget constraints impose themselves on a larger proportion of the commuters within a given zone. The significance of the other variables in the model is not changed by the inclusion of the historical development - and if anything - the contribution from motorway variables (beta) to the variation in commute distance increases.

Dependent variable:

- Change in average commute distances for resident working populations (night population) 1992-2002. The zones are used as data units.
- (Change in mean commute distances (one way – calculated) for employees by place of work (day population) 1992-2002)

Motorway access

- Motorway ramp within 1½, 3 and 5 km, 1992
- Motorway ramp constructed within 1½, 3 and 5 km, 1992-2002

Accessibility – distance based measures:

- Workplaces (resident working population) within 10, 20 and 30 km, 1992
- Change in number of workplaces (resident working population) within 10, 20 and 30 km, 1992-2002

Accessibility: differential development in time and distance based measures: short, medium and long range.

- Short range differential: relative increase in jobs (population) within 15 minutes minus relative increase in jobs (population) within 10 km, 1992-2002.
- Medium range: relative increase in jobs (population) within 30 minutes minus relative increase in jobs (population) within 20 km., 1992-2002.
- Long range: relative increase in jobs (population) within 45 minutes minus relative increase in jobs (population) within 30 km, 1992-2002.

(Attraction)

- (Relative attraction of zone compared to the number of jobs offered within 10 and 20 km, 1992)
- (Change in relative attraction, 1992-2002)

Workplaces – resident population ratio

- Workplaces – resident population ratio within zone, 1992
- Change in workplaces - resident population ratio within zone, 1992-2002
- Workplaces – resident population ratio within 10 and 20 km, 1992
- Change in workplaces - resident population ratio within 10 and 20 km, 1992-2002

Characteristics of home/work zone:

- Population, 1992
- Population change, 1992-2002
- Workplaces, 1992
- Change in number of workplaces, 1992-2002
- Proportion of resident population with academic (or similar level) education, 1992
- Change in proportion of resident pop. with academic (or similar level) education, 1992-2002
- Proportion of employees with place of work within the zone that has academic (or similar level) education, 1992
- Change in the proportion of employees with place of within the zone that has academic education (or similar level), 1992-2002.

Development history:

- Change in average commute distances for resident populations (night population) (employees by place of work – day population) 1982-1992

Table 3: Variables included in the analysis of changes in commuting distances for resident populations and employees by place of work. The variables included in the two are very much alike – with the major exception that the first analysis focuses on access to workplaces (day population) and the other on access to resident working population (night population).

	Unstandardized Coefficient: B	Standardized Coefficient: Beta	Sig.
(Constant)	9,1223		0,000
Difference between time and distance based accessibility development 1992-2002 in the long range (45 min/30km)	1,0980	0,137	0,000
Motorway ramp within 5 km, 1992	0,6822	0,144	0,000
Accessibility: workplaces within 20 km, 1992 (LN)	-0,6388	-0,407	0,000
Workplaces pr. resident working pop. ratio, 1992	-0,1801	-0,098	0,006
Change in workplaces pr. resident pop. ratio, 1992-2002	-0,9875	-0,214	0,000
Change in workplaces pr. resident pop. ration counted within 20 km, 1992-2002	-11,2371	-0,251	0,000

Table 4: Linear regression model explaining the change in commute distances (km) for resident working populations (night populations) in all Danish zones 1992-2002. N=1340, R-square = 0,245, Sig. (F-test) = 0,000.

	Unstandardized Coefficient: B	Standardized Coefficient: Beta	Sig.
(Constant)	2,4865		0,000
Motorway ramp constructed within 3 km, 1992-2002	2,0492	0,073	0,005
Change in relative attraction compared to the supply of jobs within 10 km travel time 1992-2002	2,8266	0,138	0,000
Change in working population resident within 10 km, 1992-2002	-0,0001	-0,215	0,000
Workplaces pr. resident working pop. ratio, 1992	0,3171	0,099	0,014
Change in workplaces pr. resident working pop. ratio, 1992-2002	1,4921	0,185	0,000
Change in the proportion of the employees that has an academic education, 1992-2002	12,9599	0,069	0,020

Table 5. Linear regression model explaining the change in commute distances (km) for working population by place of work (day population) in all Danish zones 1992-2002. N=1339, R-square = 0,085, Sig. (F-test) = 0,000.

The regression model explaining the increase in commuting distances registered at the work zones can be seen in table 5. The degree of explanation offered by the model is considerably lower than what was the case for home-zone model. The likely explanation is that the development seen from the “work-end” of the commute is a lot more dependent of contextual and historical factors. As the dataset is relatively disaggregate the result would for example be influenced by the relative persistence of historical core areas irrespective of the developments in accessibility that often are stronger outside these areas. Consequently the development at this end of the commute is a lot more difficult to explain.

Variables reflecting travel time reductions are also missing in this regression model. The exception is the change in location vis-à-vis the motorway. If access to the motorway has become possible within a 3 km range – the commute distance seems to increase more than in other zones. There might be some travel time in this – but above all it suggests a motorway bias to the development in commute distances. The workplaces closest to the motorways may attract workers over longer distances because of a biased job-search - which may again originate from the knowledge that many people has of the areas adjacent to the roads ("the city as a trip" – see Golledge and Stimson, 1997) and/or because commuters for other reasons favour commuting on the motorways compared to other roads and modes.

The inclusion of development history in the regression model reflects the differences between the processes governing commuting at the home and the work end of the trip respectively. Inclusion of the development from 1982-1992 in the model almost doubles the degree of explanation from R-square 0,085 to 0,160. The impact of the other explanatory variables does however resemble what was seen at the home end of the commute – as the significance and explanatory importance of these are only marginally affected. Together the effect of "history" and the other explanatory variables suggests that there is an effect of transport infrastructure and other objectively identifiable changes to the commute incentive – but there is also a high degree of path dependence supporting established urban patterns and hierarchies.

4. COMMUTING TO THE CITY

The development in commuting to predefined destinations is another way to analyse the developments in commuting patters that again will allow for a direct inclusion of travel time reductions in the analysis.

It was chosen to analyse the developments in commuting to the centres of Denmark's two largest cities Greater Copenhagen and Aarhus. These centres attract commuters over long distances and developments in transport infrastructure is likely to have en imprint on the commuting patterns through the opening of new settlement options for the workforce dependent on the central city.

Of the two cities it is especially commuting to Aarhus that should be expected to be affected by additions to the motorway network from 1992-2002. In this period Aarhus was connected to North Jutland by motorway. As a result Aarhus effectively gained an extra motorway arterial and could be accessed by motorway over long distances from north and south. Since 2002 what is effectively a third motorway arterial (east-west) focussing on Aarhus has opened and is likely to greatly enhance the centrality of the city. Around Copenhagen only a minor addition to the network was seen and most of what was already there had been completed prior to 1982 (se figure 1: Island of Zealand and the motorway network focussing on central Copenhagen to the East).

Dependent variables

- Change in commuting from home zones to destinations in CBD of Greater Copenhagen (Municipalities of Copenhagen or Frederiksberg), the CBD of Aarhus or the municipality of Aarhus (covering the entire urban area of Aarhus, respectively, from 1992 to 2002. The change in commuting is measures as the differences in the share of commuters to the destination from 1992-2002 (percentage points).

Travel time

- Minutes by car from the zone to the CBD of the city, 1992
- Change in minutes travel time by car, 1992-2002

Geography

- Commuting involves crossing The Great Belt (only relevant in the analysis of Copenhagen)

Access to the motorway

- Motorway ramp within 1½, 3 and 5 km of zone, 1992
- Motorway ramp constructed within 1½, 3 and 5 km of zone, 1992-2002

Accessibility – travel time based measures

- Jobs within 15 and 30 minutes by car from origin centroid, 1992
- Change in number of jobs within 15 and 30 minutes by car, 1992-2002

Workplaces – resident population ratio

- Workplaces – resident population ratio within zone, 1992
- Change in workplaces - resident population ratio within zone, 1992-2002
- Workplaces – resident population ratio within 15 and 30 minutes by car, 1992
- Change in workplaces - resident population ratio within 15 and 30 minutes, 1992-2002

Attraction

- Relative attraction of the destination area compared to the supply of jobs within 30 minutes by car, 1992
- Change in the relative attraction of the destination area, 1992-2002

Characteristics of the home zone

- Employed population (night pop.), 1992
- Change in employed population, 1992-2002
- Proportion of population with academic (or similar level) education, 1992
- Change in proportion of population with academic (or similar level) education, 1992-2002

Development history

- Change in commuting from home zones to destinations in the CBD of Greater Copenhagen, the CBD of Aarhus or the municipality of Aarhus, respectively – defined corresponding the dependent variables, from 1982 to 1992.

Table 6. Variables included in the analysis of changes in commuting from “home zones” to destinations in Denmark’s two largest cities.

The results from the three different regression analyses can be seen in table 7. The travel time in 1992 has in all three models been transformed with a 4th degree polynomial function representing an increase with distance – a peak and after the peak a decreasing tendency until a distance of indifference has been reached. The analysis area was delimited to include zones at a distance to the respective city where the increasing distance to the city seem indifferent to the development in commuting into the city. Around Copenhagen this means that zones on the Island of Fyn – separated from Copenhagen by “The Great Belt” and a Toll-bridge was included.

	Destination area:					
	Copenhagen CBD		Municipality of Aarhus		Aarhus CBD	
	Beta	**Sig.**	**Beta**	**Sig.**	**Beta**	**Sig.**
(Constant)	-	0,004	-	0,002	-	0,005
Minutes by car to the CBD (3 different 4th degree polynomial functions)	0,413	0,000	0,612	0,000	0,798	0,000
Motorway ramp within 5 km, 1992	-	-	0,108	0,006	0,057	0,011
Motorway ramp constructed within 5 km, 1992-2002	0,100	0,016	0,075	0,039	-	-
Motorway ramp constructed within 3 km, 1992-2002	-	-	-	-	0,047	0,020
Change in workplaces pr. resident working pop. ratio, 1992-2002	-0,087	0,034	-	-	-	-
Proportion of the population that has an academic education, 1992	0,203	0,004	0,066	0,090	-	-
Change in the proportion of the population that has academic education, 1992-2002	0,152	0,040	0,143	0,000	-	-
Workplaces within 15 minutes, 1992	-	-	-0,181	0,000	-0,132	0,008
Change in number of workplaces within 15 minutes, 1992-2002	-0,269	0,000	-	-	-	-
Workplaces pr. resident pop. ratio counted within 15 minutes, 1992	-	-	-	-	-0,058	0,038
Change in workplaces pr. resident pop. ratio counted within 15 minutes, 1992-2002	-0,114	0,007	-0,176	0,000	-0,056	0,010
Relative attraction of the destination area, 1992	-	-	0,124	0,002	-	-
N	498		416		440	
R-square (the model above)	0,342		0,494		0,823	
R-square (model above + development history)	0,341		0,512		0,831	

Table 7. Three regression models explaining the development in commuting to the CBD of Greater Copenhagen (Municipalities of Copenhagen and Frederiksberg), the municipality of Aarhus and into the CBD/core of Aarhus. The increasing share of commuters to these destinations from 1992 to 2002 measured as percentage points for zones of residence are the dependent variables. Analysis includes zones within 150 minutes of Copenhagen and within 90 minutes of Aarhus (1992-travel times).

The travel time reductions in the period are not represented in any of the models. Instead all of the models display a “motorway bias” in the development in commuting. For the two Aarhus models this bias include location vis-à-vis the network that was there in 1992 as well as location vis-à-vis the additions made to the network in the period from 1992 to 2002. In the case of Copenhagen only the change of status from poor to excellent access to the motorway – caused by additions to the network in the period seems to have an effect. The likely explanation for this difference is that the motorway access generally is far better around Copenhagen than around Aarhus – and that the best motorway access is in the zones in the central parts of the urban area that also have large increases in cross and reverse commuting.

It is of course not possible to conclude from this that travel time reductions are insignificant in the case of commuting to the city. The location vis-à-vis the motorway will also to some extend be equivalent to travel time reductions. Most of all however the result must be taken as an indication of a strong motorway/arterial bias conditioning the significance of the "raw" travel time reductions. A likely explanation for the motorway bias may be that the increase is due to central city workers finding homes in the vicinity of transport facilities (transportation sorting – see Voith, 1991; Aitken and Fik, 1988) Their search for housing may very well be severely biased by the infrastructure corridors.

The inclusion of the historical development (1982-1992) in the analysis does not alter the significant effects of location vis-à-vis the motorway on the development in commuting (1992-2002). I the Copenhagen case the historical development do not even have a statistical correlation with the developments in the study period. This suggests a growth process where zones have changed status in the region over the last 20 years. New zones have been included in the periphery and "old" zones have increasingly engaged in cross commuting.

In the Aarhus case the inclusion of the development history reduces the effect of the motorway variables slightly. The straight forward explanation being that the motorways were build as a north-south connection between the large towns in east Jutland. This has been an important corridor for more than 1000 years and the growth in interaction along this axis continues (see fore instance Whebell, 1969 on the history of communication corridors). The significance of the location vis-à-vis the motorway in the model even when the historical development is included does however suggest that the motorway in itself shapes commuting (in the area the 5 km range would in many cases correspond to a difference between the side of town closest to the motorway – and the other).

5. CONCLUSIONS

The effect of changes in the location vis-à-vis the motorway network and travel time reductions on the change in different commute variables from 1992-2002 has been analysed statistically. The results from the regression analysis with respect to the "motorway" and travel time reduction variables is summarised in table 8. Results are commented further under the headlines: Travel time reductions, Motorway bias and Continuation of historical trends?

	Improved access/egress to/from the motorway network	Reduced travel times
Commuting between pairs of zones	yes (from the origin – but the relation is weak)	yes
Commute distances: home zones	(no)	yes
Commute distances: work zones	yes	no
Commuting to the city: Copenhagen	yes	no
Commuting to the city: Aarhus	yes	no

Table 8. Summary of analysis results related to changes in access to the motorway network and travel times. Yes and no respectively states whether the analysis results was confirmative of the significance of location vis-à-vis the motorway or travel times in explaining the dependent variables.

5.1 Travel time reductions

The significance of travel time reductions for the changes in commuting is confirmed in the analysis of the number of commutes between pairs of home and work zones and in the analysis of the increase in commute distances for resident populations. Thus travel time reductions seem to induce an increase in the exchange of commuters and to stretch the commute lengths when the opportunities offered by the development in time-based accessibility outrun the development in distance-based accessibility. The differential development in time vs. distance based accessibility can easily be visualised on the basis of the analysis-zones. Visualisation is much more difficult with the interaction between pairs of home and work zones. A flow map (see: Nielsen and Hovgesen, 2004) can "translate" the regression result into surfaces of spatial interaction above a given level. However the summarised flows need to be presented relative to existing flows to avoid that map merely reflects the spatial distribution and size variation of the analysis zones (see figure 3).

The travel time reductions are not alone due to the extension of the motorway network. The maps in figure 3 do however suggest that the developments in the interaction pattern largely follow the infrastructure corridor supported by the motorway. The many of the grey "holes" in the yellow surface on the map to the left are in existing larger agglomerations – which also suggest that the development in travel times support the growth of commuting outside and in the periphery of the existing urban centres. The map to the right bases its measure on accessibility and shows that the transport infrastructure (travel speeds) as well as a location in the vicinity of a larger urban area (allowing the time based accessibility to increase) are the factors that jointly affects the development in commute distances.

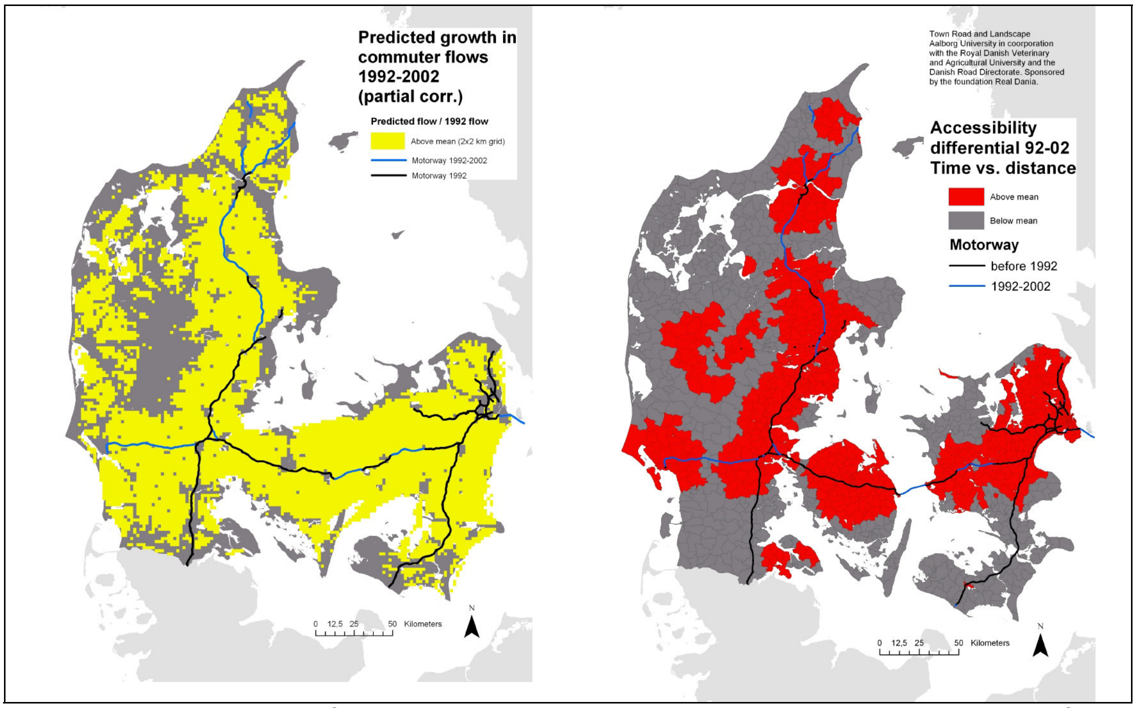

Figure 3. The map to the left (grey/yellow) shows the predicted relative increase in commuter flows (summarized on a 2x2 km grid - on the basis of commuter passages registered from desire lines). Prediction was based on the analysis in table 2 with all non-travel time factors held constant. The map to the right (grey/red) shows the variation in the differential accessibility development variable that has positive correlation with the development in commuting distances for the residential population.

5.2 Motorway bias

The significance of location vis-à-vis the motorway is confirmed in all analysis. In most cases it is also the changing status with respect to motorway access in the study period that is related to an increase in out commuting, commute distance or commuting to the city. The only exception is the analysis of the increasing commute distance for resident population where it is only motorway access at the beginning of the period (1992) that has an impact on the commute.

It seems that motorway access in itself (besides travel time reductions) is an important spatial factor shaping the commutes. Improved motorway access is related to more out commuting, more out commuting to the central city, and in-commuting over longer distances (increased catchment area). In the analysis of commute distances for work-zones and commuting to the city the motorway access variables appear without the travel time reductions being represented in the models. This means that the motorway access variables are likely to partly represent travel time reductions, but also that motorway access in itself is a far better descriptor of the factors shaping this particular aspect of the commute. A likely explanation is an infrastructure biased search for residences among workers dependent on the central urban areas and possibly infrastructure bias in job search as well as firm location. In another part of the research project “Town, Road and Landscape” such tendencies has been confirmed in qualitative interviews with companies locating along the Danish motorways. Thus the evidence points to a “motorway bias” to the development in the commuting pattern. This bias has some resemblance with the "arterial bias" to the knowledge of urban space earlier found by Horton and Reynolds (1971).

5.3 Continuation of historical trends?

The development in commuter flows and distances in the decade before the one explained by the regression models was introduced in the models to explore the significance of historical trends in the relationship between transport infrastructure and commuting. Ideally the inclusion of the historical development should allow concluding whether the relations between infrastructure and the development in commuting represent a new course of development compared to the development in the preceding decade.

The inclusion of the historical development in the statistical models increased the explanation considerably in the model explaining exchange of commuters between zones and in the model explaining commute distances for the working population by place of work. The effect of the other explanatory variables in the models was however largely unaffected by this exercise. This point towards the conclusion that the construction and management of transport infrastructure creates new commute patterns. The contribution from the historical development to the degree of explanation indicates that the development in commute patterns to a large degree is path dependent, especially when it comes to which areas that are central areas and destinations for the most and longest commutes. The changes in "objectively" identifiable commute incentives such as travel times also affects the commute pattern but judged from the analysis results covering developments in the nineties this effect is largely additive to trend continuation in explaining changes in the commute pattern. This point towards two types of "central areas" attracting commuters over long distances: the historical centres and centres that has the advantage of accessibility by car. Both seem to get their share of the increase in commuting.

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