CICERO Report 2005:07

Impacts of climate change on travel habits

A national assessment based on individual choices

H. Asbjørn Aaheim and Karen E. Hauge

August 2005

CICERO
Center for International Climate
and Environmental Research
P.O. Box 1129 Blindern
N-0318 Oslo, Norway
Phone: +47 22 85 87 50
Fax: +47 22 85 87 51
E-mail: admin@cicero.uio.no
Web: www.cicero.uio.no

CICERO Senter for klimaforskning
P.B. 1129 Blindern, 0318 Oslo
Telefon: 22 85 87 50
Faks: 22 85 87 51
E-post: admin@cicero.uio.no
Nett: www.cicero.uio.no

Tittel: Impacts of climate change on travel habits: A national assessment based on individual choices

Forfatter(e): H. Asbjørn Aaheim og Karen E. Hauge

CICERO Report 2005:07
36 sider

Finansieringskilde: Norges forskningsråd

Prosjekt: Climate change and associated trade patterns – Impacts for the Norwegian economy (CATRINE)

Prosjektleder: H. Asbjørn Aaheim

Kvalitetsansvarlig: Grete Hovelsrud-Broda

Nøkkelord: virkninger av klimaendringer, tilpasning, transport

Sammendrag: Virkninger av endringer i klima på valg mellom transportmidler for lokale reiser beregnes med bakgrunn i data for Bergen. Ved hjelp av et klimascenario for andre store byer i Norge anslås virkningene på landsbasis under forutsetning av at folk i disse byene responderer på samme vis som folk i Bergen. Scenariet gir en økning i offentlig transport og gange eller sykling, mens privat transport reduseres. Virkningene er svært små på landsbasis, men på enkelte steder kan endringene bli av en viss betydning. Studien viser også at nasjonale konsekvenser ikke kan anslås på noen god måte ved å summere virkningene på lokalt nivå.

Språk: Engelsk

Rapporten kan bestilles fra:
CICERO Senter for klimaforskning
P.B. 1129 Blindern
0318 Oslo

Eller lastes ned fra:
http://www.cicero.uio.no

Title: Impacts of climate change on travel habits: A national assessment based on individual choices

Author(s): H. Asbjørn Aaheim and Karen E. Hauge

CICERO Report 2005:07
36 pages

Financed by: The Research Council of Norway

Project: Climate change and associated trade patterns – Impacts for the Norwegian economy (CATRINE)

Project manager: H. Asbjørn Aaheim

Quality manager: Grete Hovelsrud-Broda

Keywords: climate impacts, adaptation, transportation

Abstract: Impacts of climate change on the choice of transport mode for local trips are estimated from data for the city of Bergen in Norway. By means of a climate scenario for other main cities, the impacts for Norway are assessed under the assumption that people in these cities respond similarly to the people of Bergen. The scenario leads to an increase in public transport and in walking and bicycling, while the use of private transport decreases. The total impacts are small, but may be of significance in certain places. The study also shows that national consequences of climate change cannot be properly estimated by aggregating local-level impacts.

Language of report: English

The report may be ordered from:
CICERO (Center for International Climate and Environmental Research – Oslo)
PO Box 1129 Blindern
0318 Oslo, NORWAY

Or be downloaded from:
http://www.cicero.uio.no

Contents

Acknowledgements

The authors thank Bergen Fylkeskommune for provision of data from the travelling habits survey from Bergen. The project was financed by the Norwegian Research Council under the NORKLIMA program.

1 Introduction

Transport contributes to a growing part of global emissions of greenhouse gases. One of the main challenges in climate policy is to adapt the use of transport services to a level that does not represent a serious threat to the stability of the climate system. If emissions are to be reduced in the short term to embark on a sustainable path of development, the demand for transport services will have to change.

At the same time, transport activities may also depend on climatic conditions. Weather conditions are often decisive for which shop to go to, how to travel to work or whether or not to visit someone. Moreover, people tend to change transport habits over the year, which indicates that also the temperature is of importance, particularly for local trips in urban areas. Climate change may therefore affect transport habits. Increasing temperature may extend summer seasons, and summer travel patterns thereby become more dominant. One may also expect a change in precipitation to affect how attractive people consider walking or biking to be. Such changes are likely to constitute a modest act of adaptation to climate change to each individual. But because of the extent of transport activities, and the expected increase in the future, the total impact may be important.

There are only few studies about the impacts of climate change on transportation. US studies estimate effects of precipitation and drought on road accidents, infrastructure and regularity of public transport (Changon, 1996, Adams, 1997 and Qualley 1997 - see IPCC, 2001 II p. 401), without considering adaptation. Some European studies have looked at how floods and windstorms (Perry and Symons, 1994 - see IPCC, 2001 II p. 671) may destroy the infrastructure, and Askildsen (2004) discusses the consequences for temporal stops in goods transport due to extreme weather. But to our knowledge, transport habits and climate is an unexplored area, in the sense that we know neither *how* people's travel patterns respond to changes in the weather, nor *to what extent* they change. Thus, we cannot tell whether such changes represent an important element of adaptation in a national context.

The aim of this paper is therefore twofold: first, to find whether relations between climate variables and transport habits can be established, and in what directions they go; and second, to find how the slight changes in individuals' habits may influence the travel pattern of a country. This is not only a question of aggregating the changes in individual behaviour, but requires also an assessment of possible macroeconomic consequences of changes in travel habits. In other words, one needs to assess the individual response simultaneously with the macroeconomic consequences.

Most studies of impacts of climate change are confined to only one of these perspectives: either a bottom-up approach that studies individuals and aggregates findings to get a national sum, or a top-down approach that studies macroeconomic interrelationships based on rather general assumptions about individual behaviour. This study makes an attempt to narrow the gap between these two approaches by estimating the macroeconomic effects on the basis of recalibrated demand functions of the macroeconomic model to reflect the changing travel habits, thereby providing an example of how micro-studies of impacts of climate change may be utilized in macroeconomic assessments. This is important in itself, because the knowledge about impacts of climate change on the micro-level is rapidly increasing, but it is not clear how to implement this knowledge in national assessments. The estimates of changing habits may therefore be regarded as a study of micro behaviour in the city of Bergen in Norway, and is based on a survey on travel habits in the Bergen area carried out in 2000 (Bergen Fylkeskommune, 2000). To aggregate the results it is assumed that citizens in medium and large cities of Norway respond similarly to climatic changes as the citizens of Bergen, but that they are subject to different weather conditions from the outset and different changes.

The structure of this paper is as follows: Chapter 2 examines possible patterns between choice of transport mode and climatic variables. The econometric model used to estimate the relationships are presented in chapter 3. Chapter 4 presents the results of the econometric analysis. In Chapter 5 we suggest how the results may be represented and implemented in analyses of regional or national aggregates. In Chapter 6, an estimate of the altered transportation costs due to changes in climatic variables are implemented in a macroeconomic model in order to estimate the socioeconomic impacts. Chapter 7 concludes.

2 Weather and travelling patterns in Bergen

The observations in this paper are based on 16 383 local trips from the survey on travel habits in the Bergen area from 2000. People were interviewed by phone in the period 15 March to 31 May 2000 about all the trips they made the day before the interview took place. Travel on weekends and holidays are not included. The main results were presented in Bergen Fylkeskommune (2000). The aim of this section is to trace possible correlations between observations of the weather and reported characteristics of modes of travel and the people who made the trips during the period of the survey. We start with a summary of what the weather was like in Bergen in this period.

Situated at the coast of the Atlantic, beneath high mountains, Bergen is well known for rapid and vigorous changes in the weather. This is advantageous for estimating relationships between weather and behaviour, but represents a difficulty when it comes to the use of data. The reason is, first, that the weather observations are made either on a daily basis, or at a certain hour of the day. Observed weather in the context of the study, then, may be quite different from the actual weather when the interviewees made their decision about how they would travel that day. Second, the variety of weather conditions suggests that applying several weather indicators would increase accuracy, but when it comes to the interpretation of results, it is preferable with few indicators.

The choice of indicators is, of course, limited by the existence of data. The possibilities include temperatures at a certain time of the day and daily minimum, maximum and average, wind speed in casts, the maximum speed over short periods and daily average plus daily precipitation. The observations used in this study are average daily wind speed and temperature, and daily precipitation. This choice was made partly because they did not correlate too much in the observation period,[1] whereas one or more of them turned out to correlate highly with another excluded observation. An advantage of using these indicators is also that they are given in predictions of climate change. Finally, note that the weather data stems from one station in Bergen (Florida). Wind and precipitation may differ also across regions in the Bergen area. The weather at the place at which the decision to travel were made may be different from the weather at the point of observation.

Figure 1 shows the chosen weather indicators in the period. The variations are substantial, especially with regard to precipitation. The first two weeks were relatively wet. Then there was a variable period that lasted until the end of April. The first half of May was warm and dry, while the second half was wet and relatively cold. Seasonal change is clearly reflected in the temperature increase, although the end of May is a relatively cold period. Neither wind nor precipitation exhibit seasonal variations.

An individual's choice of transport mode for a particular trip depends on a long list of observable and unobservable factors. Even if we restrict these to observable data, it is impossible to include all factors that might be of importance. Moreover, bearing in mind that

[1] The correlations are: Temperature/Wind: 0.192; Temperature/Precipitation: -0.096; Precipitation/Wind: 0.196.

the aim is to estimate relationships for general use, it is a goal in itself to restrict the number of explanatory factors. To do so, we examine not only variables that influence access to various modes of transport, but also influence *who* makes the actual trip.

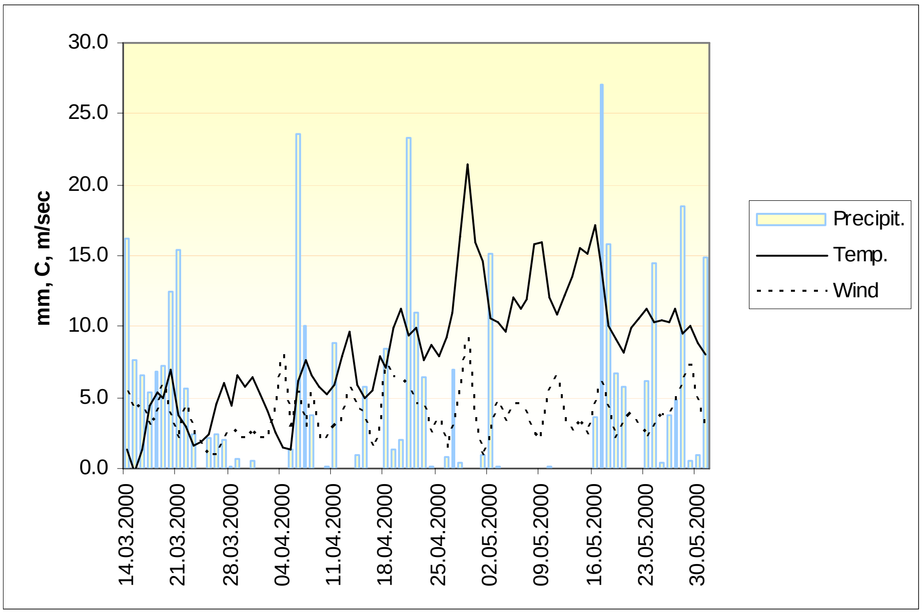


Figure 1. Weather indicators in the observation period 15.03.00 – 31.05.00

An example of different access is that some people have a car available to them, while others do not. This is reported in the survey. However, to use these data in climate scenarios, one may want to substitute access to car with a more easily predictable variable. Thus, since access to car correlates with age, we can choose age as one explanatory factor.

Access to public transport also differs among individuals. This is, however, much more difficult to measure, being subject to distance to the nearest station, frequency, speed, comfort etc. The survey does not provide direct information about access to public transport. This also makes it difficult to point out possible substitute variables. As a proxy for access to public transport, among other possible factors, we apply the division into regions in the survey. The central region consists mainly of the city of Bergen. The four others are simply denoted northern, eastern, southern and western regions. Bergen Fylkeskommune (2000) estimates the total number of trips in this area on an ordinary working day to be 950 000. Most of the excursions across the regions are either to or from the city centre.

Figure 2 displays the number of departures from each region as observed in the survey and the primary mode of travel used. Note that each trip may end up in the same region as it started. Nearly 40 percent of the excursions started in the city centre, while the western and southern regions accounted for approximately 20 percent each. Thirteen percent of the departures were from the north, while the eastern region accounted for less than 5 percent. The modes are divided into walking and bicycling, private (car driver or passenger, incl. taxi and motorcycle) and public transport (mainly bus). Private transport modes account for between 60 and 75 percent of the trips with departures in other regions than the city centre. Public transport was used in between 12 and 15 percent of the trips with departures in these regions. In the city centre, pedestrian and bicycle transport, and private transport account for approximately the same share, whereas 20 percent used public transport.

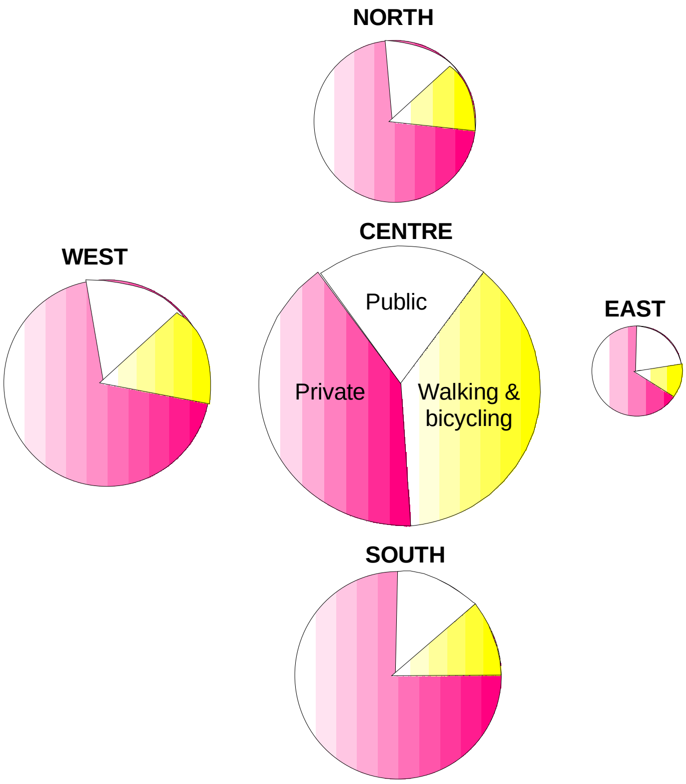


Figure 2. Division of observed trips into region of departure and mode

Used as an indicator for the real options for how to make a certain trip, the departures depicted in figure 2 are imperfect in many respects. The options do not depend only on where to start the trip, but also where to end up; the quality of public transport differs depending on destination; the attractiveness of walking or bicycling depends on the path, and so forth. Moreover, the options are different in practice for short and long distances. Walking is considered by most people if the distance to travel is less than a kilometre, but by few if more than 10 kilometres.

The survey provides information about destinations, but it turned out to be impossible to estimate distance with reference to reported starting and end points. Instead, distance was estimated from the reported duration of each trip, total waiting time, and assumptions about speed of the chosen mode. The estimate is uncertain, however, and for the purpose of this study it suffices to categorise distances in order to roughly distinguish between distances where the choice of mode can be considered very different. Therefore, distances were classified into five groups:

1) less than 1.0 km
2) 1.0 – 2.5 km
3) 2.5 – 7.5 km
4) 7.5 – 25.0 km
5) more than 25.0 km.

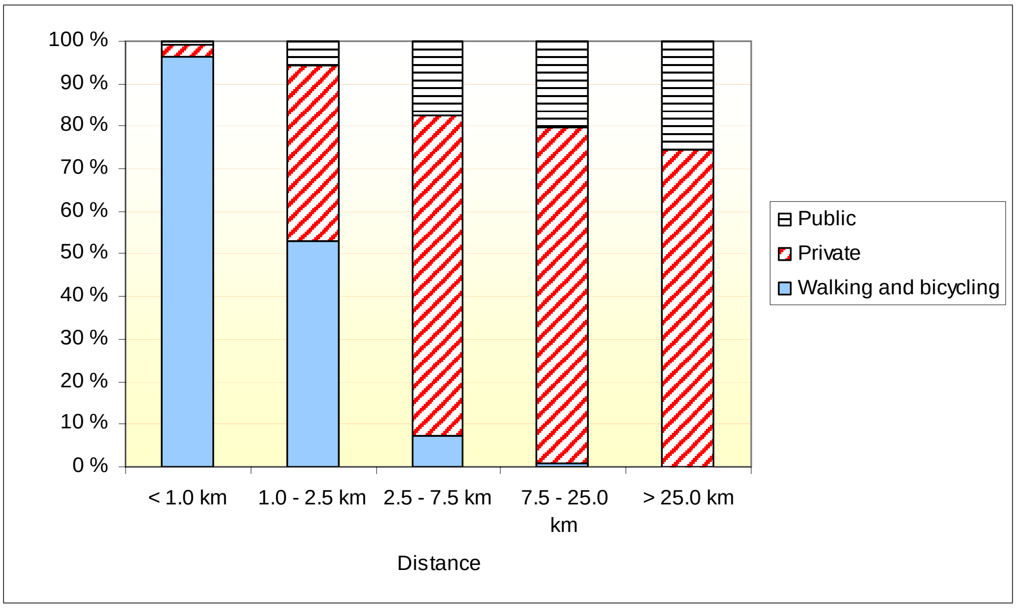


Figure 3. Distribution of travel mode by distance

Figure 3 shows the mode choice in each estimated class of distance. The choice of walking and bicycling totally dominates short distances, perhaps more than one might expect. This may be because a large share of trips less than 1 km are in fact much shorter, but it may also be due to our method of estimating distance, for which the weakest point probably is the short distances. As the distance grows, the two other modes increase their importance. Public transport takes over an increasing share as the distance increases, but private transport has the largest share for all distances longer than 2.5 kilometres.

In addition to the availability of alternatives, the choice of mode is also likely to depend on the purpose of the trip. This can be addressed directly from the survey. The various purposes reported were grouped into travel related to work (including school), to daily errands (shopping, caring for others etc.) and to leisure. Figure 4 shows the choice of mode for travel for various purposes in each region. Some patterns can be traced. Public transport is chosen most frequently for travel related to work in all the regions, and is in general more common for trips from the city centre than from other regions. Private transport dominates trips to carry out daily errands. The highest share of pedestrian and bicycle transport is found in travel related to leisure, which includes physical exercising. Pedestrian and bicycle travel is more frequent in trips from the centre than from any other region regardless of purpose. This can be explained by the fact that trips from the city centre are generally shorter. Private transport dominates in the south compared with other regions. Note also that the highest share of public transport is for work-related travel from the east, and the lowest share is for travel related to errands from that same region.

So far we have looked at factors related to a specified trip that may make a person think differently about which mode choice to make. In a social context, such differences may also depend on *who* is travelling. The possibility of distinguishing between individuals is constrained again by the observations in the survey, primarily to gender, age and income. The income measured applies for the household, and is usually difficult to get correct in interview surveys. Because of the general advice to limit explanatory factors as far as possible, the income variable was not used.

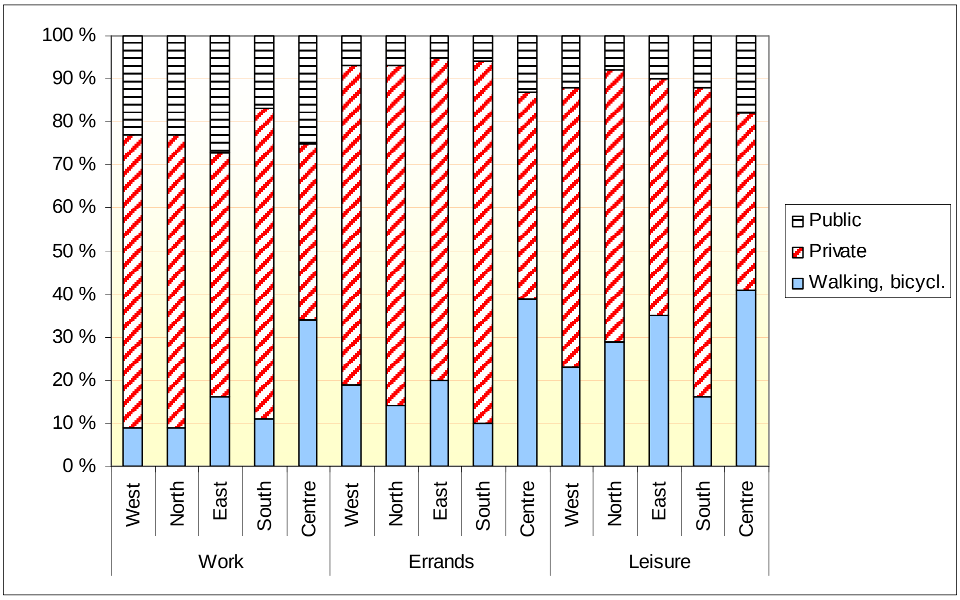


Figure 4. Distribution of travel mode choices by purpose and region of departure

Although we aim at examining a possible relationship between choice of mode and weather, the weather is admittedly far from being the most important factor behind the choice. It is therefore difficult to illustrate possible relationships between choice of mode and the persons who travel directly from the data, but in order to indicate possible differences, Figure 5 shows daily precipitation on the average for the three alternative modes, sorted by the individual characteristics, age and gender.

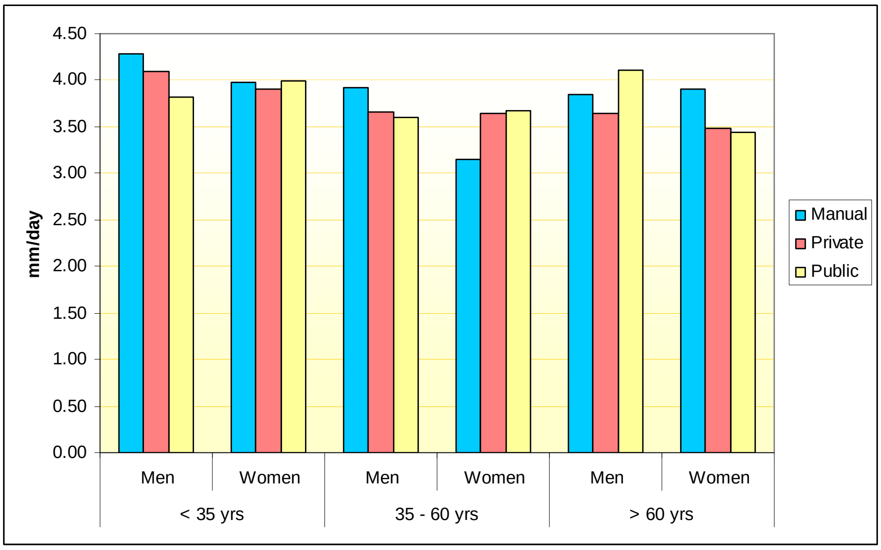
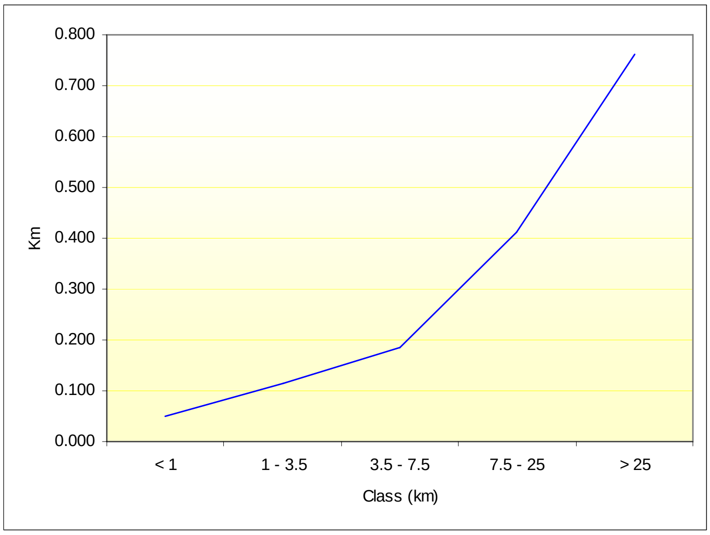


Figure 5. Daily precipitation on the average for the day of travel for gender and age groups, by the choice of mode

The differences are relatively small, but tendencies can be traced. What seems most surprising is that, with the exception of women between 35 and 60 years of age, average precipitation is higher for pedestrian and bicycle travel than for private and public transport.

Intuition suggests the opposite; that is, one would expect that people prefer private or public transport to walking or bicycling when it rains. One explanation for why the opposite is observed may be the abovementioned weaknesses in the observations – for example, that even though it was raining more the day people chose to walk, it did not rain when they made the decision. On the other hand, the differences are partly so large, and seemingly systematic that this is unlikely to be the only explanation.



dist = ln(A)*exp(a*pr); ln(A) = -1.537 (0.217), a = 1.06 (0.0066), R^2 = 0.989

Figure 6. Estimated reduction in travelling distance at a 10 mm increase in precipitation

Another possibility is that when people make their choice, precipitation correlates systematically with some other explanatory factor. Checking this out, it was found that increased precipitation leads to a significant shortening of the distance. Figure 6 shows the estimated shortening of travel distance at a 10 mm increase in daily precipitation for each class of distance. Thus, the increase in average precipitation for pedestrian and bicycle in figure 5 may be caused by shortened distances, which makes pedestrian and bicycle more likely.

3 A quantal response model for the choice of transport mode

Although it is necessary to map travelling patterns when analysing possible impacts of climate change, it must be realized that the characteristics discussed in the previous section are important to the subject of this study only if they reflect possible differences in the propensity to change mode under a changing climate. This is a question of subjective choice. Thus, possible dependencies must be estimated with a reference to a theory of choice. We straightforwardly apply a simple quantal response model, which is thoroughly described in the literature (see e.g. Domenchich and McFadden, 1975, and Maddala, 1982). The model was developed with the aim of estimating so-called discrete choices by individuals, such as choice of transport modes. What follows is a brief description of its main properties.

Let x denote a particular mode of transport. Attached to each of these there is a vector b which describes the qualitative characteristics of each mode. Let z be an aggregate of all other commodities and services. Moreover, let ε represent a stochastic term that captures each individual's evaluation of the quality characteristics of each transport mode. This term is not observable, but may be subject to a known distribution among individuals. Now, the utility of individual *i* of choosing transport mode *j* can be written as a general function of all the observed variables, adapted to each individual by means of the stochastic term, ε_{ji}

$$u_i = u(x_j, b_j, z, \varepsilon_{ji})\,. \tag{1}$$

Observations of the elements of the quality vector b_j must be quantified, such as the price of mode x_j or the time spent on travelling a certain distance using mode x_j. They may also include qualitative elements, such as the comfort of travelling by mode x_j, if the quality can be represented by quantitative variables. This study aims at testing whether climatic variables such as precipitation, wind or temperature can explain the choice of transport mode by testing whether people shift mode when the weather changes. Hence, we assume that variation in weather indicators affect the utility of individual, *i*, but to a different extent for the different transport modes.

Denote by $\Phi_i = \Phi(b_j, \varepsilon_{ji})$ the contribution to individual *i*'s utility of choosing mode *j*, and specify this relationship to

$$\Phi_j(b_j, \varepsilon_{ji}) = \exp(\alpha_j + \sum_k \gamma_{jk} b_{jk} + \varepsilon_{ji})\,, \tag{2}$$

where *k* represents the different attributes. Then, the utility function can be written as $u(\Phi_j(b_j,\varepsilon_{ji})x_j, z)$. A main feature of the choice problem is that the alternatives are mutually exclusive. To take this into account, we assume that the alternatives enter the utility function linearly. Then, we face the problem of

$$\max u(\sum_j \Phi_j x_j, z)\,, \tag{3}$$

under the familiar budget constraint,

$$r = \sum_j p_j x_j + qz \tag{4}$$

where *r* is income, p_j is the price of transport alternative *j* and *q* is a price index for the aggregate of all other goods and services.

The solution to this problem gives rise to the indirect utility function $V(p_j/\Phi_j, q)$, where p_j/Φ_j can be interpreted as the shadow price of transport mode *j*, adjusted for its subjective quality (Muellbauer, 1975). The demand function for x_j and *z* are found by Roy's identity

$$x_j = -\frac{\frac{\partial V}{\partial p_j}}{\frac{\partial V}{\partial r}} = \frac{f(\frac{p_j}{\Phi_j}, q)}{\Phi_j}\,, \tag{5}$$

$$z = -\frac{\frac{\partial V}{\partial q}}{\frac{\partial V}{\partial r}} = g(\frac{p_j}{\Phi_j}, q)\,, \qquad (6)$$

(see e.g. Hanemann, 1984). The stochastic term in Φ_j captures individual differences in taste that cannot be attached to any observably explanatory factor. It can therefore be considered as a random variable explaining the probability of picking a person from a sample who will choose alternative *j* under a given set of explanatory variables. Under such a given set, the stochastic term is the only factor that differs between two alternative transport modes. Alternative *a* will therefore be preferred to alternative *b* if $V(p_a/\Phi_a,q) > V(p_b/\Phi_b,q)$. This can be expressed by the probability

$$\Pr\{V(\frac{p_a}{\Phi_a}, q) > V(\frac{p_b}{\Phi_b}, q)\} = \Pr\{\lambda_a + \varepsilon_{ai} < \lambda_b + \varepsilon_{bi}\}, \qquad (7)$$

where $\lambda_j = \alpha_j + \Sigma_k \gamma_{jk} b_{jk}$ - ln $p_{j,}$ (j = a,b) because of (2).

By (7), the preference for each alternative is transformed into probabilities attached to individual choices, which we denote by π_j. The term π_j is the probability that a randomly chosen individual prefers alternative *j* to any other alternative under the given set of observations. This is equal to the simultaneous probability for a stochastic variable, *z*, to exceed the *difference in expected utility* between alternative *j* and all other alternatives:

$$\pi_j = \int_{-\infty}^{+\infty} \mathrm{F}(\lambda_\mathrm{j} - \lambda_1 + z, \lambda_\mathrm{j} - \lambda_2 + z, ..., \lambda_\mathrm{j} - \lambda_\mathrm{n} + z)dz \qquad (8)$$

If *z* has a Weibull distribution, it can be shown that

$$\pi_j = \frac{\exp(\lambda_j)}{\sum_i \exp(\lambda_i)} \qquad (9)$$

(see Domenchic and McFadden, 1975).The term λ_j consists only of observable elements, but is not itself observed. Only the individual choices, which include the stochastic element, are observed. However, since the observations are assigned a stochastic term with a known distribution, the overall probability can be estimated.

Some comments about shortcomings are needed. First, the survey covers a period of 2 ½ months. One may question whether the changes in this period adequately represent long-term changes. Therefore, the estimates will be based on the assumption that people respond to short-term variations in the same way as they would to climate change in the long-term. This is a strong assumption indeed, but not unusual in analyses of impacts of climate change. That is, one asks what the impacts would have been had they occurred today (see e.g. Fankhauser, 1995). Among possible long-term impacts not being accounted for, we can mention changes in the total amount of transport, or that people move within the Bergen area as a consequence of climate change.

4 Estimation

The model is based on economic behaviour, and thus includes price and income variables. However, price data were not available, nor was any change in the price of public transport reported in the observation period. We therefore had to assume that all prices remained constant throughout the period. The remaining explanatory factors for mode choice were divided into six measurable variables (temperature, precipitation, wind, gender (dummy), age, distance) and two non-measurable variables (region from which the trip started, and purpose of the trip).

Section 4.1 presents results with the aim of tracing patterns of choice across travel purposes and regions, and concludes with suggestions as to how regions and purposes could be divided in order to apply as benchmarks for modelling climate impacts in Bergen. Section 4.2 presents such benchmark estimates.

4.1 Patterns in choice of mode

To begin with, the full model with the six measurable variables was estimated for each of the three purposes in each of the five regions – a total of fifteen relationships. It is difficult to draw clear conclusions about correlations between weather conditions and mode choice on the basis of these estimates. Table 1 summarizes the results by counting the number of "yes" and "no" to claims addressed by each of the estimated parameters for the fifteen categories of purpose × region. The answers are read from the parameter estimates on γ, which show the *partial* effect on the comparison between public transport and one of the other two modes from a change of an explanatory variable. For example, the claim "more rain increases the likelihood that people choose public mode to walking and bicycling" was confirmed in 9 of the categories and rejected in 6. However, in only two of the nine categories where the claim was confirmed was the parameter estimate significant on a 95 percent level ($t > 2$). Note that one cannot conclude about increasing and decreasing shares from a comparison between pairs of mode choices. To see how the distribution among all three modes changes the simultaneous probability distributions will have to be calculated. These will be shown later.

Except in the case of increasing age, there is a tendency to answer "yes" to all the claims. This also applies for the weather indicators; that is, the more rain, the higher temperature or the more wind, the more likely is it that people prefer public transport to pedestrian and bicycle if the share of private transport is unaltered, or to private transport if the share of pedestrian and bicycle is unaltered. In most cases the tendency is, however, weak with few significant parameters. The only explanatory variable with a clear effect on mode choice is distance, which leads to a shift towards more public transport as it stretches out. We also checked for systematic patterns in "yes" and "no" across categories of regions and purpose. However, no clear pattern could be identified. That is, neither the significant parameters, nor the "yes" and "no"-answers clustered in particular regions or for certain purposes.

The question then arises whether some of the parameters in fact could be the same for all fifteen categories. To check this out, a 95 percent confidence interval was estimated for each parameter to find whether, for some parameter, the intervals overlapped for all the categories. No such fully overlapping intervals were found. In other words, on a detailed level, when the individual trips are divided into all the fifteen categories of region × purpose, it is difficult to trace patterns for how mode choice depends, in particular, on weather conditions.

This indicates that some characteristics not included in the model dominate the explanatory power of the included explanatory variables. This might be factors of less significance on a more aggregated level. Thus, when estimating for all purposes in each region, and for each purpose in all regions, significant differences across the categories more or less vanish. In particular, none of the parameters assigned to the weather indicators are significantly different, although most of these estimates are still relatively imprecise. Some preliminary conclusions may, however, be suggested with reference to the results of the estimations from these aggregates. Table 2 displays the ranges for those estimates with t-values higher than 1.

Table 1. Summary of partial effects on mode choice from changes in measurable variables in fifteen categories of region and travelling purpose

Claim	**"Yes"**			**"No"**		
	Tot.	**$1<t<2$**	**$t>2$**	**Tot.**	**$1<t<2$**	**$t>2$**
More rain increases public mode to walking and biking	9	3	2	6	1	-
More rain increases public to private mode	8	4	-	7	1	-
High temperature increases public mode to walking and biking	9	4	1	6	-	-
High temperature increases public to private mode	11	5	1	4	-	1
More wind increases public mode to walking and biking	9	3	-	6	2	2
More wind increases public to private mode	8	2	3	7	2	1
Women prefer public mode to walking and biking	11	3	-	4	2	1
Women prefer public to private mode	13	3	9	2	-	-
The older, the more likely public mode to walking and biking	5	1	1	10	3	4
The older, the more likely public to private mode	6	1	2	9	1	7
The longer distance, the more likely is public mode to walking and biking	15	-	15		-	-
The longer distance, the more likely is public to private	12	1	4	3	1	-

First, among the climate indicators, wind exhibits the most significant impact on the choice of transport mode, but the direction depends on where and what purpose the trip has. Second, the responses differ depending on the purpose of the trip. Thus, pedestrian and bicycle transport increases with higher temperature for work travels, at the expense of both private and public transport. As expected, higher precipitation decreases pedestrian and bicycle transport to work. Private transport increases as a result, while public transport remains relatively unaffected. Travel for leisure has a similar pattern, but the responses to precipitation are much stronger than for work-related travel. Higher temperature increases pedestrian and bicycle use as well as public transport for leisure purposes, resulting in a decline in private transport.

Table 2. Ranges for parameter estimates with t-value > 1 for travel purpose aggregated over regions and regions aggregated over travel purpose

Variable	Mode (vs. public transport)	No. of obs. with t > 1	Average of slightly significant estimates (t>1)				Estimate
			Purpose across all regions		Region across all purposes		All
			Min	Max	Min	Max	
Constant	Walk/ bike	8	7.693	9.904	5.739	9.391	7.985
	Private	8	0.570	5.093	1.939	4.175	2.561
Precipitation	Walk/ bike	2	-0.037	-0.037	-0.054	-0.054	-0.010
	Private	1	0.000	0.000	-0.021	-0.021	-0.004
Temperature	Walk/ bike	3	-0.037	-0.037	-0.151	-0.035	-0.009
	Private	6	-0.022	-0.020	-0.027	0.033	-0.009
Wind	Walk/ bike	3	0.048	0.048	-0.098	0.122	-0.011
	Private	5	-0.033	-0.033	-0.113	0.107	-0.017
Gender	Walk/ bike	5	-0.190	-0.190	-0.328	0.370	-0.196
	Private	8	-0.849	-0.438	-0.625	-0.159	-0.495
Age	Walk/ bike	6	0.010	0.022	0.016	0.055	0.016
	Private	8	-0.018	0.034	0.006	0.043	0.016
Distance	Walk/ bike	8	-3.833	-2.532	-3.353	-2.875	-3.002
	Private	6	-0.193	-0.193	-0.525	-0.081	-0.245

The pattern for errands is different. According to the estimates, the choice of mode hardly depends on precipitation at all. An increase in the temperature reduces pedestrian and bicycle transport, while private and public transport increases. This partly confirms the extra difficulties in predicting the mode choice for errands. Indeed, the rather counterintuitive negative effect on pedestrian and bicycle transport of higher temperature applies in many of the region × purpose subgroups, and turns out sometimes to be significant as well. One possible explanation of this result is that the survey covers trips made on working days only, whereas a large share of the errands, which include shopping, are made on Saturdays.

When comparing across the regions, three characteristics should be commented. First, in the western and southern regions mode choice exhibits a similar pattern with respect to temperature and precipitation: pedestrian and bicycle transport takes over for private as either temperature or precipitation increases, leaving public transport more or less unaltered. This tendency is intuitive in the case of temperature increase, but less intuitive in the case of precipitation. Note, however, the effect of more precipitation is counteracted by the finding that the travel distance shortens. The estimates for the northern region are generally sharper than for the other regions. Except for the effect on pedestrian and bicycle choice from temperature, which is negative, the directions are also intuitive.

The eastern region differs from the other regions because of its low share of public transport. The estimates for the eastern regions are problematic because the constant terms are very uncertain. This implies that also the estimated level of each probability is very uncertain. As a result, the calculated probabilities based on these estimates show relatively large changes in choice of mode as a result of small changes in the climatic variables.

The sensitivities of the choice probabilities in the central region are intuitive for each category, but the estimates are relatively uncertain, and few are significantly different from zero. The uncertainty may be explained by the different properties when it comes to running errands, which exhibit different patterns from the two other purposes. For example, the effect on pedestrian and bicycle transport of higher temperature is, again, positive for these excursions. This may be because trips made on Saturdays are excluded. Another hypothesis could be that people make longer errand-related trips when the temperature increases, or when the summer approaches.

To sum up, patterns and correlations are not easily traced when dividing the material into predefined regions and purposes. This is not necessarily because there are no such dependencies, but may be due to the limitations in the explanatory variables, both with respect to numbers and to the difficulties in measuring them adequately. People respond differently to changing weather conditions depending on the purpose of the travel, but there are similarities between trips for the purposes of work and leisure. Errand-related travel shows a greater likelihood to change in response to climate than do the other types of travel, and the trends frequently run counter to how one would expect changing weather to affect mode choice in general. There are also important differences between the regions. This comes as no surprise, since there are differences also with respect to the observed travel patterns. Thus the relationships between choice of mode and weather indicators depend on whether the travel starts in the city centre or in one of the outer regions. In particular, the correlation between weather and choice of travel mode from the east seems to differ from that in the other three outer regions.

4.2 Benchmark estimates

In order to generalise the results, the conclusions above indicate that the material should be re-estimated with a modified grouping of purposes and regions. Thus, travel related to work or leisure was grouped together, while errand-related travel was treated separately. The central region was also kept separate, while the outer regions are represented by an aggregate of the western and southern regions..

Figure 7 shows the choice probabilities for work- and leisure-related travel from the city centre at different temperatures. Pedestrian and bicycle travel takes over for both private and public transport, with the largest reduction in private transport. As temperature may represent the seasonal changes, the results here indicate that those who appear on the city streets on a bike in spring are primarily those who have left their car at home.

Figure 8 shows a similar calculation for variations in precipitation. Pedestrian and bicycle transport decreases with precipitation, increasing both public and private transport. The sensitivity of pedestrian and bicycle transport is relatively large, although the range of daily precipitation in the figure is very wide. 50mm of rain is a lot of rain, even in Bergen. Note, also that public transport takes a larger share of those who abandon the pedestrian and bicycle mode as precipitation increases.

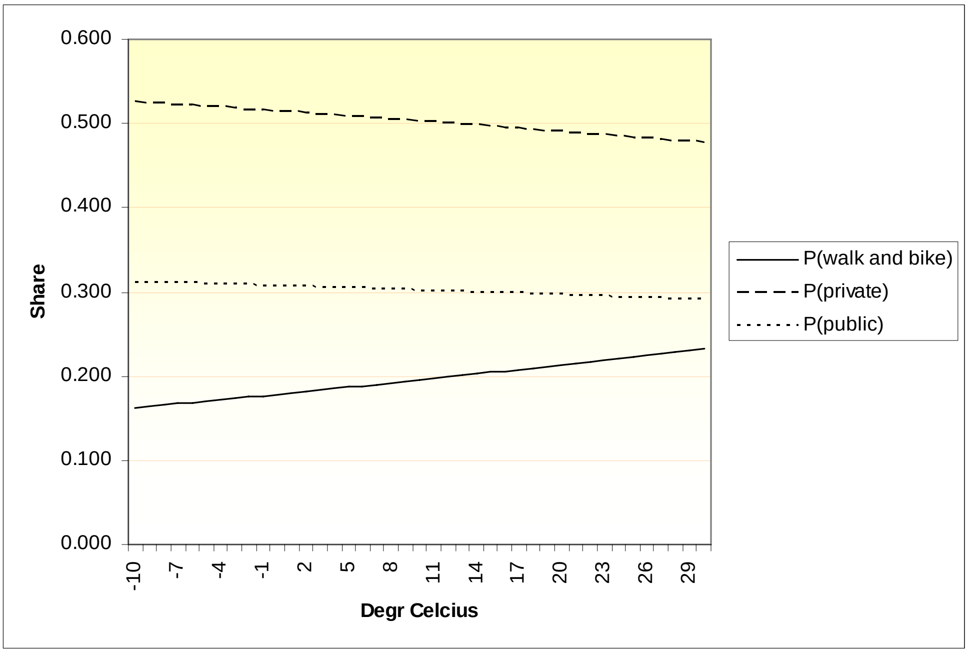


Figure 7. Choice of mode for work- and leisure-related travel from city centre at different temperatures

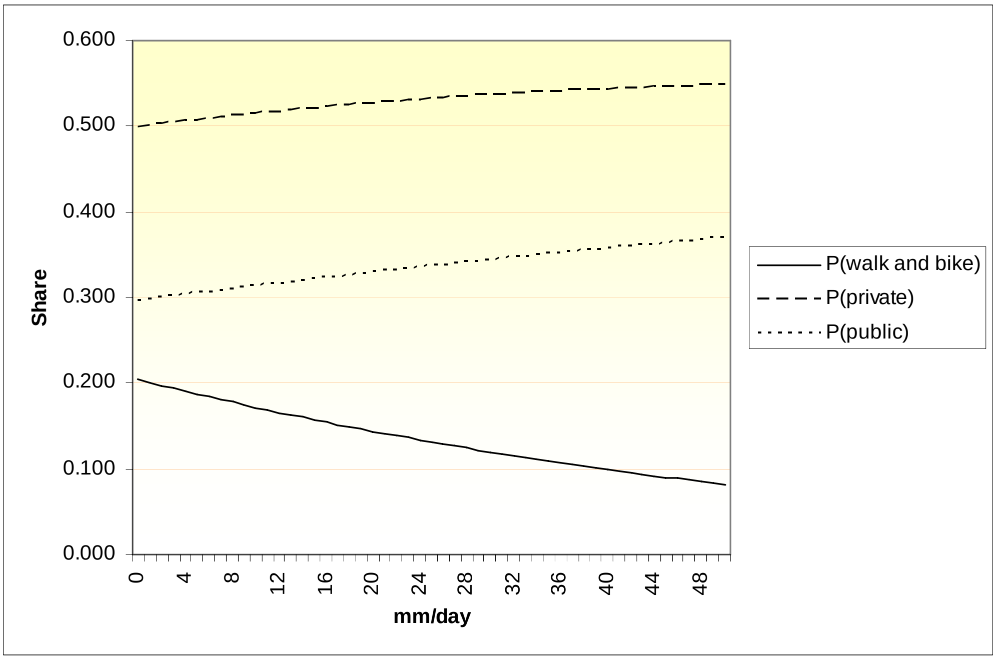


Figure 8. Choice of mode for work- and leisure-related travel from city centre at different daily precipitation

Similar calculations were made for the aggregate of the southern and the western regions, which we henceforth call the outer region. Comparison with the trips starting in the city centre, we note the following. First, the choice of mode for work- and leisure-related travel is not as sensitive to the weather as it is in the city centre. This may be because a much smaller share is pedestrian and bicycle transport, which is the most sensitive in both the city centre and the outer regions. The high share of pedestrian and bicycle use in the city centre can be explained by the fact that a much larger share of the travel from the city centre is short-distance trips. Thus, for work and leisure, pedestrian and bicycle transport constitutes only about 3 percent of the travel in these two outer regions, and this share is more or less insensitive to precipitation, but public transport takes over for private as precipitation increases. Warmer weather increases the share of pedestrian and bicycle transport slightly, leading to an equal reduction in both private and public transport.

The choice of travel mode for running errands in the outer region hardly depends on precipitation at all, while an increasing temperature leads to a substitution from private to public transport. This may reflect that the choice of mode differs depending on which errand the travel is related to, and that the composition of errands (shopping, accompany children, etc.) changes depending on temperature or season.

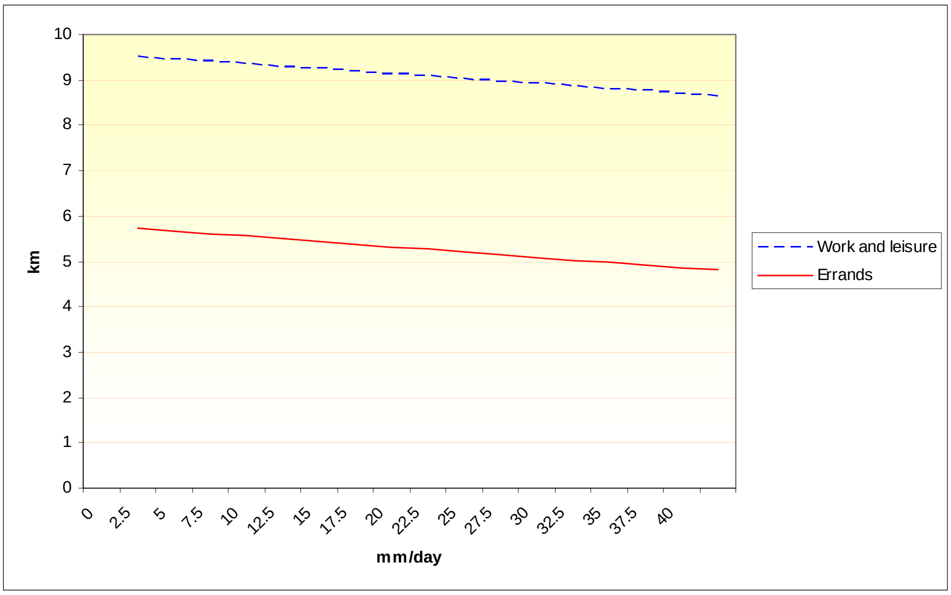


Figure 9. Average travelling distance at varying daily precipitation, by travel purpose

As pointed out earlier, a change in weather may also change the travel distance. How much depends on the purpose of the travel. Thus, travel related to work will probably not be affected a lot, whereas trips related to both errands and leisure may be. Figures 9 and 10 show the estimated change in travelling distance at different temperatures and precipitation, measured in kilometres. Only precipitation turned out to be significant when estimating over the entire sample, while the wind and temperature coefficients were very uncertain. When grouping purposes, there are indications that temperature also may have an influence on the distance for work and leisure travel. The distance travelled for the purpose of leisure lengthens significantly. Work-related travel is not affected, which was expected, but there is a relatively uncertain tendency towards reduced distances of trips related to running errands. This may be explained by changes in the composition of errands under different weather conditions, as mentioned above. Precipitation shortens the distance for all purposes with a level of significance around 75 percent.

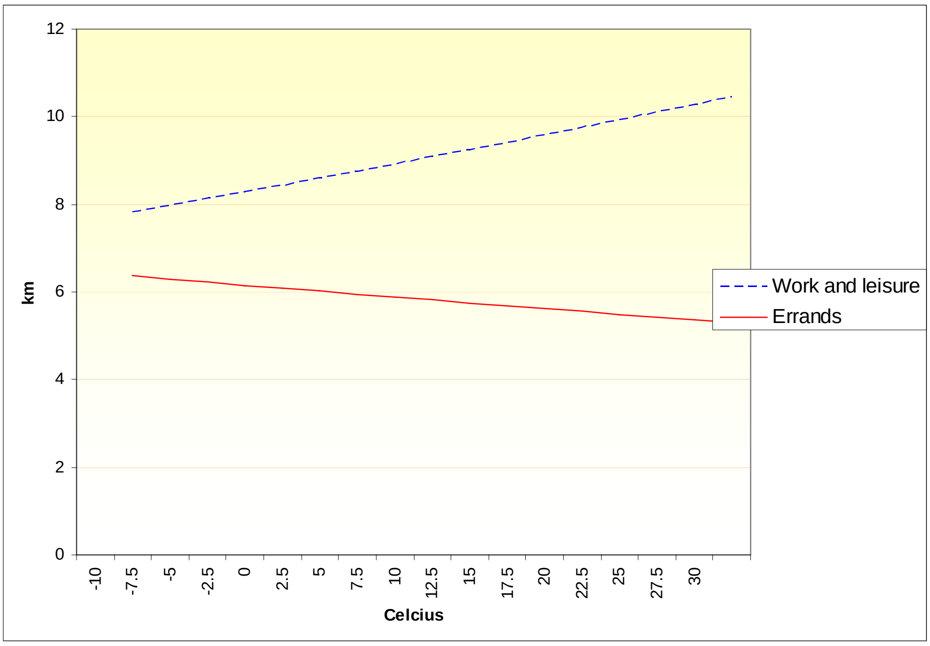


Figure 10. Average travel distance at varying average temperature, by travel purpose

Figure 10 displays the results of looking at travel distance as a function of temperature. As already noted, it is likely that the distance of work-related trips is more or less independent of temperature. The increase in the aggregate of work and leisure trips is, therefore, entirely an effect of longer trips for leisure purposes as temperature increases.

Note that travel for the purpose of leisure includes those who are exercising and those who just go for a walk. Combined with the observation that the share of pedestrian and bicycle travel also increases with temperature both from the city centre and the outer region, the increase in average travel distance for work and leisure seems plausible.

To predict responses to changes in the weather, we are, in other words, faced with two effects, which might be called a substitution effect, shown by the choice probability curves in figures 7 and 8, and a distance effect, shown in figures 9 and 10. Being mutually dependent, the substitution effect may change if the total distance changes. Thus, the choice between modes may become more or less sensitive to changing weather in one state of the weather than in another. Figure 11 shows the choice probabilities for work and leisure travel given a shortening of the average distance for trips from the city centre.

In this case, the choice of mode becomes more sensitive to precipitation if the distance shortens, which it does when precipitation increases. Thus, there is a substitution effect that can be read out of the lines in figure 11. This substitution is strengthened because a shorter distance implies a shift to the steeper curves ("light" lines) in the diagram.

The results exhibit some tendencies that seem reasonable, in the sense that they can be explained, at least after dividing the material into selected groups. However, they are by no means sharp enough to give clear answers to the questions raised initially, namely whether the choice of mode for local travel depends on weather, in which direction this dependency goes, and how strong the change in choice of mode is for given changes in the weather. Clearer answers probably require a more sophisticated transport model than the one described in section 2, where either more of the information provided by the travelling habits survey could be utilized, or additional information, not provided by the survey, could be defined. However, from a methodological point of view, the results suffice to serve as an example of 'micro-information' to be used as a basis for estimating impacts of climate change on travelling habits for Norway, as long the aggregation as such does not depend on the quality of the micro information.

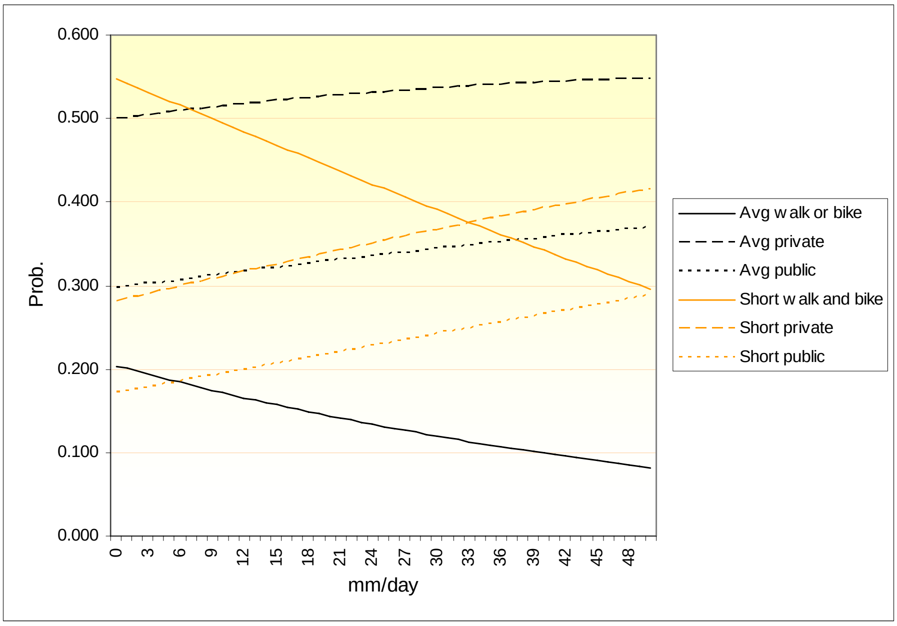


Figure 11. Probabilities that choice of mode depends on precipitation and travel distance for work- and leisure-related travel from the city centre

5 Generalizations

The aim of this section is to generalize estimates of the probabilities for mode choice in Bergen in order to apply to analyses on regional and national level. To predict impacts of climate change on personal transport, we use climate scenarios from the RegClim project (Norwegian Meteorological Institute, 2001) Section 5.1 describes how weather data from the RegClim scenarios have been simulated. The estimates of the choice probabilities for the city centre and the outer region, as well as those expressing the sensitivity to travelling length, are first used to 'blow up' the survey data to apply for the whole area of Bergen. In the next step, we generalize to the largest cities in Norway in order to predict the impacts on person transport on the national level.

5.1 Simulation of weather and calibration

On the basis of simulations of how an increase in the concentrations of greenhouse gases affects the global atmosphere, the Norwegian Institute for Meteorology has made weather forecasts for regions of Norway over the next fifty years (RegClim, 2001). The increase in concentrations refers to emissions in the IPCC IS92 scenarios. There are, of course, numerous sources of uncertainty in such forecasts, both in the downscaling of global climate scenarios and in the creation of the global "frame". They do not, therefore, express what meteorologists believe will happen, but are merely predictions based on what we know so far. They also provide a useful reference for further studies of impacts of climate change and facilitate the comparison of different impacts studies.

The predicted effects of climate change are shown in table 3. The average temperature and precipitation will increase in all parts of Norway, in nearly all seasons. Precipitation will increase much more in the western region, where it is the highest from the outset, compared to the other two regions. The northern and western regions will receive most of the increase in the autumn. The annual average temperature will increase between 1.0 and 1.6 ºC, but with seasonal increases up to 2 ºC in the winter in the northern region. The increases in autumn and winter temperatures in the eastern and western regions are also substantial.

Table 3. Expected changes in average annual and seasonal temperatures and precipitation between the periods 1980–2000 and 2030–2050 by region in Norway

Region		Tempereature (ºC)		Precipitation (mm/day)	
		Level*	Change	Level*	Change
Northern	Year	2.8	1.6	2.8	0.3
	Spring	1.7	1.4	2.0	0.2
	Summer	10.6	1.2	2.4	0.1
	Autumn	2.8	1.7	3.7	0.8
	Winter	-3.9	2.0	3.2	0.2
Western	Year	7.6	1.0	6.2	0.8
	Spring	6.5	0.9	4.3	0.1
	Summer	13.9	0.7	5.1	1.0
	Autumn	8.2	1.1	8.9	1.5
	Winter	1.6	1.2	6.4	0.6
Eastern	Year	6.2	1.1	3.1	0.2
	Spring	5.0	1.0	2.3	-0.1
	Summer	15.6	0.6	3.5	0.1
	Autumn	8.0	1.3	4.3	0.3
	Winter	-3.8	1.3	2.5	0.4

*) Average levels for Tromsø (Northern), Bergen (Western) and Oslo (Eastern).
Source: RegClim

In order to use the estimates of the probabilities for mode choice in Bergen to simulate impacts of the climate forecasts in table 3, we also need information about daily variations in temperature and precipitation as well as combinations of precipitation and temperatures every day. The daily patterns on which the averages in table 3 were based on may be provided. In most cases, however, scenarios for climate change as well as models predicting temperature and precipitation changes give only averages.

To be able to utilize average information and thereby become more flexible with respect to data requirements for predictions of mode choice behaviour, the averages were spread out on days by means of specified distribution functions for each season in each of the three regions.

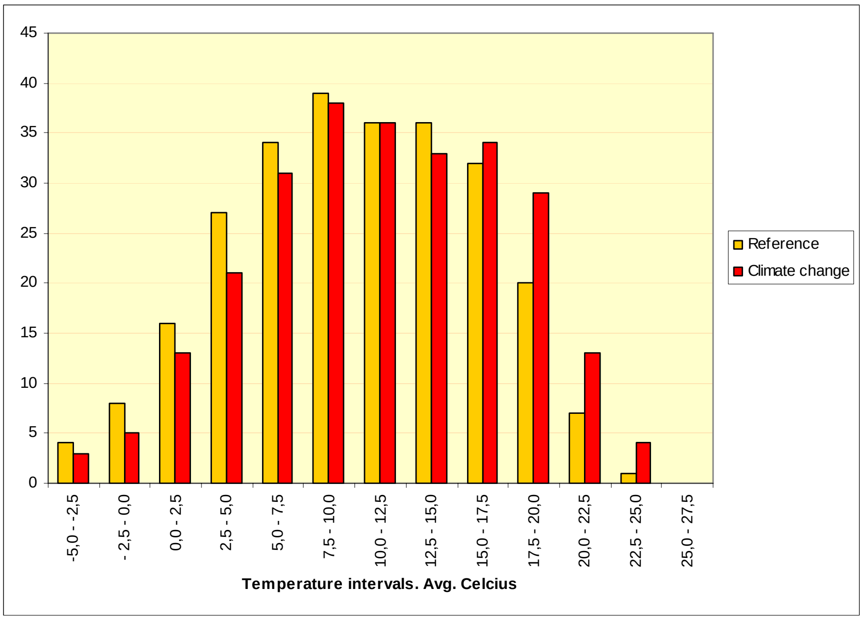


Figure 12. Distributions of daily average temperature in Bergen over the reference year and climate change alternative

The temperature is assumed to be normally distributed, with the observed present variation both before and after a change in climate. Precipitation was distributed according to a logarithmic function and prior assumptions about the number of “dry” days. Figure 12 and Figure 13 show distributions of temperature and precipitation in Bergen over the year. The distributions for the other regions were adapted to the observations of each region and the climate change scenario was based on the changes shown in Table 3.

It is assumed that people tend to change their choice of travel mode in response to changes in both temperature and precipitation. The annual average fraction that chooses one particular mode is therefore sensitive to the daily combinations of temperature and precipitation that year. In order to attach a given set of observations to each choice, precipitation days were drawn randomly from each seasonal distribution and coupled with temperature days.[2] This introduces a random element in the predictions, which reflects the fact that the mode choice will change according to annual variations in the weather also under a stable climate.

[2] Only the sample averages were used as observations for the non-climate independent variables.

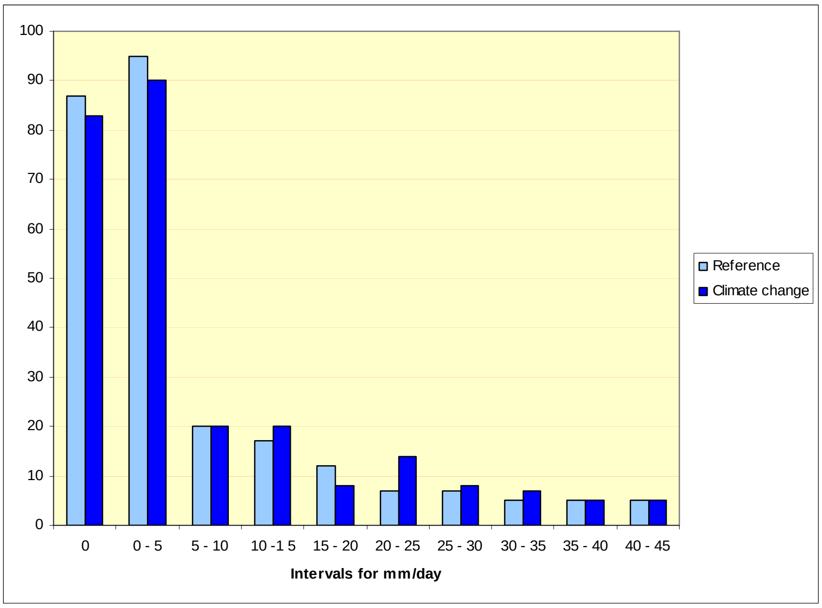


Figure 13. Distributions of precipitation per day in Bergen over the reference year and climate change alternatives

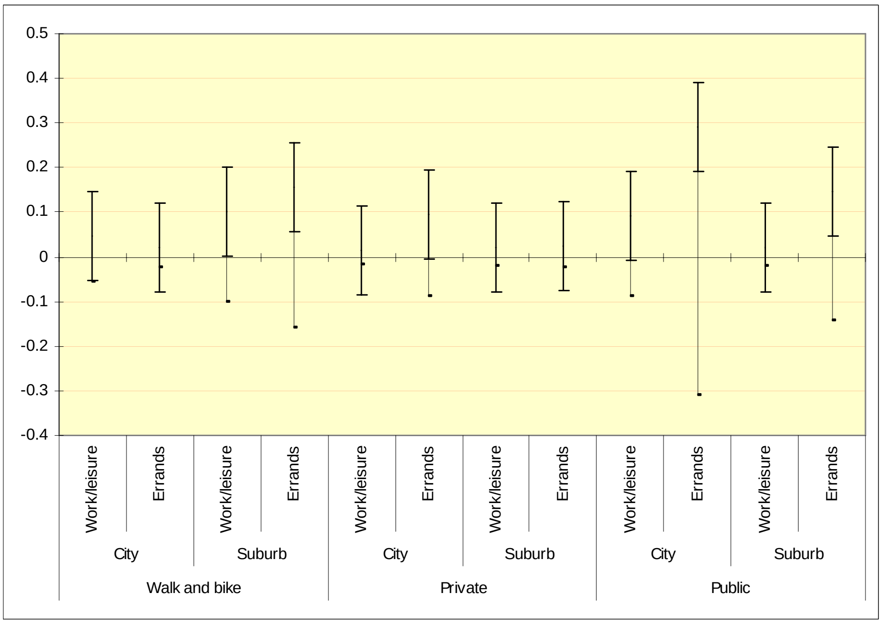


Figure 14. Maximum and minimum estimates of choice of travel mode for combinations of daily temperature and precipitation in Bergen.

To avoid the risk of basing the estimations on an “extreme” combination of temperature and precipitation, the random coupling was run 2 500 times. The resulting predicted mode choices thereby exhibit intervals that reflect the range within which mode choices change for possible combinations of daily temperature and precipitation, if distributed as in figure 12 and 13. The ranges are shown in Figure 14. We note that the intervals are relatively narrow, especially when considering the fact that the max and min values are the absolute minimum and maximum choice probabilities for the 2 500 draws. The intervals for Bergen in figure 14 show that travel to work and for leisure starting in the city centre seems to be the most sensitive to the combinations. Still, even in that case, the maximum variation for the mode choice is +/- 0.3 percent, which applies to public transport for errands from the city centre. In most of the classes, the variation is less than +/-0.1 percent.

In order to generalize results from Bergen it was assumed that people in other sizable cities in Norway respond in a similar way to changes in the weather as people in Bergen do. The cities differ, however, from the outset, also with respect to the transport mode shares for the different purposes. For each city, the Bergen estimates were calibrated with the aim of reproducing the observed probabilities for each mode. From equation (9) in Section 3, denote the choice probability for mode $j=1 \ldots J$ for a given purpose in the city centre or in the outer regions in city c as π_j^c. Then,

$$\pi_j^c = \frac{\exp(\alpha_j^c + \sum \beta_{jk}^c b_{jk}^c)}{1 + \sum_{j=1}^{J-1} \exp(\alpha_j^c + \sum \beta_{jk}^c b_{jk}^c)} \tag{10}$$

Assume that β_{jk} is invariant across cities for all j and k, and that differences in π_j^c across cities are due to only differences in the constant term α_j^c. From (10), it follows that

$$\alpha_j^c = \frac{\pi_J^c}{\pi_j^c} \sum \beta_{jk} b_{jk}^c \ , \tag{11}$$

where the superscript c denotes observed, city-specific variables.

5.2 Generalizations on regional level

For individual travel choices we use the survey of travel habits in Bergen from 2000 (Bergen Fylkeskommune 2000), which recorded the number of daily trips made per person over 13 years old, in addition to travel mode and travel purpose for each trip. In order to get a picture of the social travel pattern in the Bergen region, these numbers were multiplied by the population over 13 years old in the city centre and outer region of Bergen. Table 4 shows the total number of annual trips in the city centre and outer region of Bergen divided by the purpose of the travel. The table also shows the percentage distribution of the trips between different transport modes. As table 4 shows, private transport is far more important in the outer region of Bergen, while especially pedestrian and bicycle transport is more important in the centre.

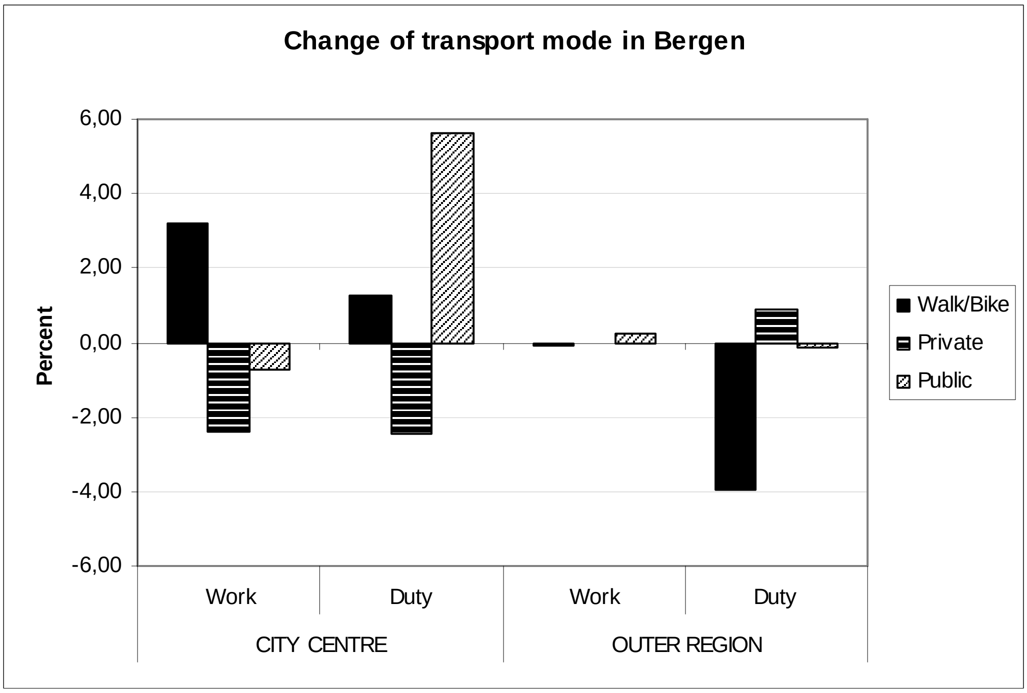
Table 4. Distribution of modes in reference scenario for transport options in Bergen

Bergen		Trips per year	Walk and bicycle	Private	Public	Total
City centre	Work/leisure	119 169 600	36.5	41.4	22.0	100
	Errands	70 412 925	38.7	49.0	12.3	100
Outer regions	Work/leisure	48 150 575	17.6	64.3	18.1	100
	Errands	32 083 150	17.1	76.7	6.2	100

Sources: Bergen Fylkeskommune (2000), Statistics of Norway (2001).

Our estimates of the consequences of climate change on the travel pattern in Bergen are presented in figure 15. As the figure shows, there are no drastic changes in choice of transport mode due to changes in temperature and precipitation. According to our estimates, the largest change in choice of transport mode will be for errands in the city centre of Bergen, while there will be only slight changes in choice of mode for work travel in the outer regions of Bergen.

Figure 15. Estimated percentage changes in transport mode in Bergen due to climate change



In the city centre of Bergen, the use of private transportation is reduced for both work- and errand-related travel. For work travel, private transportation is replaced by pedestrian and bicycle transportation, while people running errands are more likely to choose both public and pedestrian and bicycle transportation. In the outer regions of Bergen, the choice of transport mode for work travel remains quite similar, while there is approximately a 4% reduction in the use of pedestrian and bicycle transportation for errands.

The predicted weather changes presented in section 5.1 indicate increased precipitation and temperature throughout the year in Bergen. Presumably increased temperature and precipitation can have opposite effects on the choice of travel mode. In warmer weather, it can be more tempting to walk or bike, while in wetter weather it can be less tempting.

Bearing in mind that an increase in precipitation reduces the distance travelled for a given trip, pedestrian and bicycle transport may therefore increase with increasing precipitation in the city centre. In the city centre of Bergen, for example, where everything is closer at hand, it is possible to run over to the corner shop if it is raining instead of driving to the supermarket. This is less convenient in the outer regions. This can explain why increased precipitation can increase the use of pedestrian and bicycle transportation in the city centre, while it gives a reduction in the outer regions.

5.3 Generalizations at a national level

The model we have developed so far has been used to predict the response to climate change on the regional level. In this section we will utilize these results to estimate responses to climatic changes on the national level. In order to generalize the results for Bergen, we have to assume that citizens in the rest of the country respond identically to climatic changes as they do in Bergen when faced with the same change in the climate. However, the regions differ significantly with respect to normal climate, and there are large differences in the supply of public transportation across cities and between cities and the rest of the country.

In particular, it would be unreasonable to assume that people in rural areas, which have a totally different supply of public transportation, would change their travel habits in the same way as in Bergen. When generalizing to the national level, therefore, we have chosen to focus only on the largest cities and their surrounding areas.

The cities taken into consideration when generalizing to the national level are Oslo, Bergen, Trondheim, Stavanger, Tromsø, Kristiansand, Tønsberg, Drammen, Porsgrunn, Skien, Fredrikstad and Sarpsborg. These cities are grouped according to available data from surveys of travel habits in four categories: Oslo, Bergen, Stavanger/Trondheim and the remaining cities. Oslo, Bergen, Stavanger/Trondheim are further divided into a city centre and outer regions. Analogous to the survey of travel habits in the Bergen area (Bergen Fylkeskommune 2000), we have defined each city centre as the municipality of that town, and the outer regions as the municipalities surrounding this municipality[3]. The exception is Oslo, where we define the outskirts as Akershus county.

There are large differences in population size between the largest cities of Norway. The population over 13 years old is presented in table 5 below. Oslo is by far the most populated city in Norway. The second highest populated city is Bergen, which has about half the population size of Oslo and approximately the same as the next two cities, Stavanger and Trondheim, put together. The gender distribution is quite similar in all cities. In urban areas there is a small majority of females (51%), while there is a small male majority (51%) in suburban Bergen, Trondheim and Stavanger. Oslo distinguishes itself from the other cities concerning age distribution, with a larger share of inhabitants between 20 and 39, and a smaller share of inhabitants under 20. These regional differences in population size, age and gender distribution have been corrected for in the model, although they do not affect the results significantly.

There are some interesting differences in travel patterns between Norwegian cities. As table 6 shows, people in the city centre of Oslo, Bergen, Trondheim and Stavanger travel less frequently compared to people in the outer regions of these towns. In addition, each trip is shorter – which is logical because services are closer at hand in urban areas. Such differences do not seem to apply between the centre and outer regions of smaller towns. As the average number of daily trips and average daily travel length in the remaining cities are quite similar as the rest of the country, we have not separated out the outer regions of these cities as a separate category.

---

[3] The suburbs of Trondheim: the municipalities of Klæbu, Malvik, Melhus, Orkdal, Skaun, Selbu, Rissa, Leksvik, Frosta and Stjørdal. The suburbs of Stavanger: the municipalities of Kvitsøy, Rennesøy, Sandnes, Sola and Strand. The suburbs of Tromsø: the municipalities of Karlsøy, Lyngen, Storfjord, Balsfjord and Lenvik. The suburbs of Tønsberg: the municipalities of: Nøtterøy, Stokke, Ramnes, Våle and Borre. The suburbs of Kristiansand: the municipalities of: Søgne, Songdalen and Vennesla. The suburbs of Nedre Glomma: Våler, Hvaler, Råde, Skiptvet and Rakkestad. The suburbs of Grenland: Bamble, Siljan, Sauherad, Nome and Drangedal. The suburbs of Drammen: Lier, Røyken, Hurum and Nedre Eiker.

Table 5. Population over 13 years old in large cities of Norway

	Population	
	City centre	**Outer regions**
Oslo	432 415	378 271
Bergen	188 358	102 705
Stavanger/Trondheim	212 390	133 900
Other 6 cities	350 399	188 827

Source: Statistics of population structure, Statistics of Norway (2002)

Table 6. Average trips per day, kilometres travelled per day and kilometres per trip, by region.

		Trips/day	**Km/day**	**Km/travel**
Oslo	City centre	3.14	31.7	10.1
	Outer region	3.36	49.1	14.6
Stavanger/ Trondheim	City centre	3.31	37.9	12.0
	Outer region	3.38	40.6	12.0
Other 6 cities	City centre	3.50	39.9	11.4
	Outer region	3.36	39.1	11.6

In all cities, public transportation is applied more in the city centre than the outer regions. Looking at the purpose of the travel, public transportation is applied more for work-related travel than errands in all areas. Table 7 illustrates how travel was distributed between purpose and mode in the different cities in 2001 according to surveys of travel habits (Bergen Fylkeskommune 2000, Institute of Transport Economics 2002 and 2003).

We have used the model described in section 5.1 to estimate how the distribution of trips between purposes and modes will change due to climate change in all the cities. Table 8 presents the estimated distribution in a scenario with changed climate. Comparing table 7 and 8 shows the changes are quite small. These small changes can nevertheless give notable effects on the demand for fuel and public transportation at the national level. In the following we will look more closely at the estimated changes in the different cities.

Table 7. Percentage of trips in main cities in Norway, by purpose and mode in reference scenario

			Walk/bike	Private	Public	Total
Oslo	City centre	Work/leisure	29.08	48.34	22.58	100
		Errands	37.24	50.76	12.01	100
	Outer region	Work/leisure	26.28	61.42	12.30	100
		Errands	18.94	76.66	4.74	100
Bergen	City centre	Work/leisure	36.54	41.44	22.02	100
		Errands	38.75	48.97	12.28	100
	Outer region	Work/leisure	17.55	64.34	18.11	100
		Errands	17.09	76.66	6.25	100
Tr.heim/	City centre	Work/leisure	30.42	56.06	13.51	100
Stavanger		Errands	27.48	65.52	7.01	100
	Outer region	Work/leisure	30.32	58.86	10.83	100
		Errands	16.06	79.76	4.18	100
Other 6 citites	City centre	Work/leisure	28.56	60.76	10.68	100
		Errands	19.44	75.22	5.34	100
	Outer region	Work/leisure	31.16	60.16	8.68	100
		Errands	19.08	76.45	4.47	100

Source: Report 588/2002, Institute of Transport Economics (2002), Report 637/2003, Institute of Transport Economics (2003) and Bergen Fylkeskommune (2000).

The estimated changes in transport mode in Oslo due to climate change are presented in figure 16. In the city centre of Oslo, our estimates suggest a reduction in private transportation for both work-related travel and errands. Private transportation used for work-related travel is being replaced by pedestrian and bicycle transportation, while private transportation for errands is mostly being replaced by public transportation. In the suburbs of Oslo, the use of pedestrian and bicycle transportation for errands is reduced by approximately 2%, and replaced by a small increase in private and public transportation. The choice of transport mode for work travel stays quite similar.

The changes in transport mode in Oslo show the same trends as in Bergen, but on a smaller scale. In comparison with the climate scenarios from RegClim, the predicted changes in temperature and precipitation, generally speaking, are greater in Bergen than Oslo. The exception is a greater increase in winter precipitation, and a somewhat greater increase in spring and fall temperatures in Oslo.

Table 8. Percentage of travels in main cities in Norway in climate scenario, by purpose and mode.

			Walk/bike	Private	Public	Total
Oslo	City centre	Work/leisure	29.60	47.86	22.54	100
		Errands	37.38	50.21	12.41	100
	Outer region	Work/leisure	26.38	61.33	12.29	100
		Errands	18.56	76.69	4.76	100
Bergen	City centre	Work/leisure	37.71	40.43	21.86	100
		Errands	39.25	47.78	12.97	100
	Outer region	Work/leisure	17.53	64.31	18.15	100
		Errands	16.42	77.34	6.24	100
Tr.heim/ Stavanger	City centre	Work/leisure	30.60	55.90	13.50	100
		Errands	27.91	65.17	6.92	100
	Outer region	Work/leisure	29.99	59.11	10.90	100
		Errands	16.04	79.83	4.13	100
Other 6 citites	City centre	Work/leisure	29.47	59.86	10.67	100
		Errands	19.82	74.52	5.66	100
	Outer region	Work/leisure	31.25	60.07	8.68	100
		Errands	18.43	77.08	4.49	100

Figure 17 illustrates the estimated changes in transport mode in Trondheim and Stavanger due to climate change. The estimated percentage changes in transport mode are much smaller in Trondheim and Stavanger than Bergen and Oslo. Even though the estimated changes are smaller, some of the same trends can be seen. The use of pedestrian and bicycle transportation will increase at the cost of private and public transportation also in the centres of these cities. While the choice of transport mode for work travel in the outer regions in Bergen did not show changes worth mentioning, pedestrian and bicycle transportation for work travel in suburban Trondheim and Stavanger is estimated to decrease by 1%, while private and public transportation both increase by less than 1% each. Pedestrian and bicycle transportation and private transportation stay almost unchanged for errands in the outer regions in Trondheim and Stavanger, while public transportation experiences a 1% reduction.

Comparing the predicted changes in weather in Trondheim/Stavanger with Bergen, Trondheim/Stavanger will have greater increases in precipitation than Bergen, but smaller increases in temperature. In the fall and winter, these areas can actually expect somewhat colder temperatures. There is no straightforward explanation to why the predicted changes in transport mode are smaller here than in the other cities when the climate changes are not less. One possible explanation is that the two cities, situated in two different weather regions, will experience different changes is climate variables, and the impacts of climate change in the two cities compensate each other, so put together the changes look small.

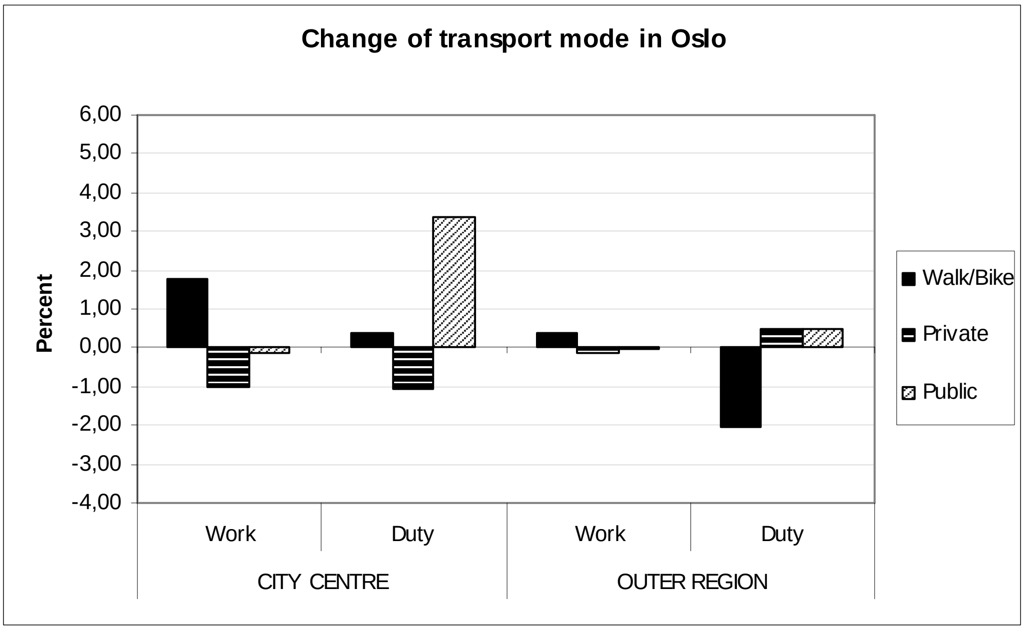


Figure 16. Estimated percentage changes in transport mode in Oslo due to climate change

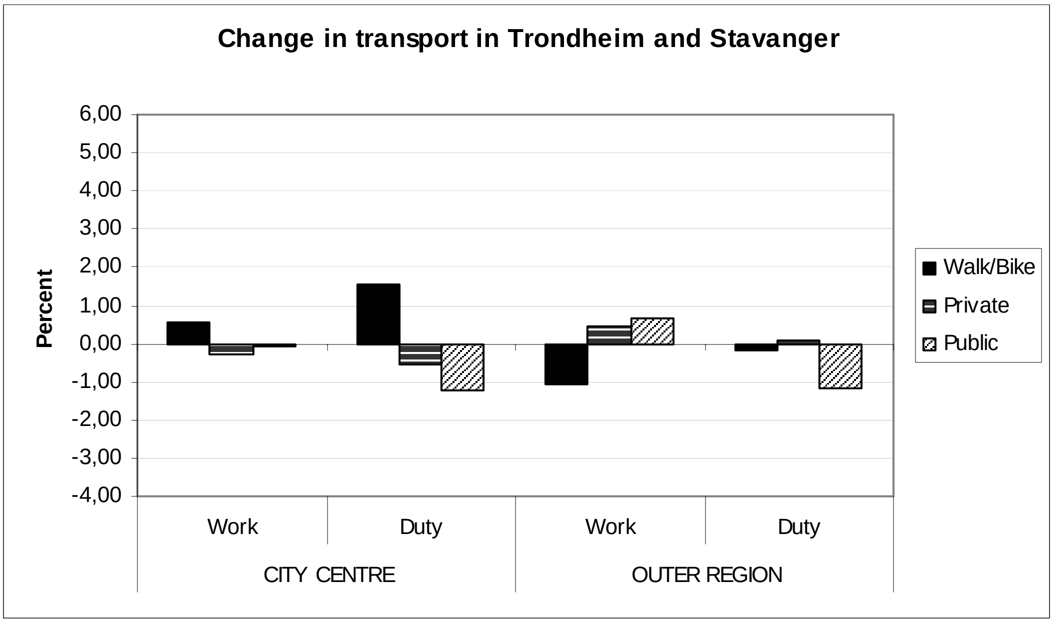


Figure 17. Estimated percentage changes in transport mode in Trondheim and Stavanger due to climate change

The estimated changes in transport mode in the other large cities[4] in Norway are presented in figure 18. Comparing these changes with the estimated changes in Bergen in figure 15, we see the exact same pattern. Relating this to the predicted changes in weather conditions, there are quite similar patterns there as well. The deviation in the climate scenarios is a larger increase in temperature in spring, fall and winter, and a larger increase in precipitation in the spring and fall.

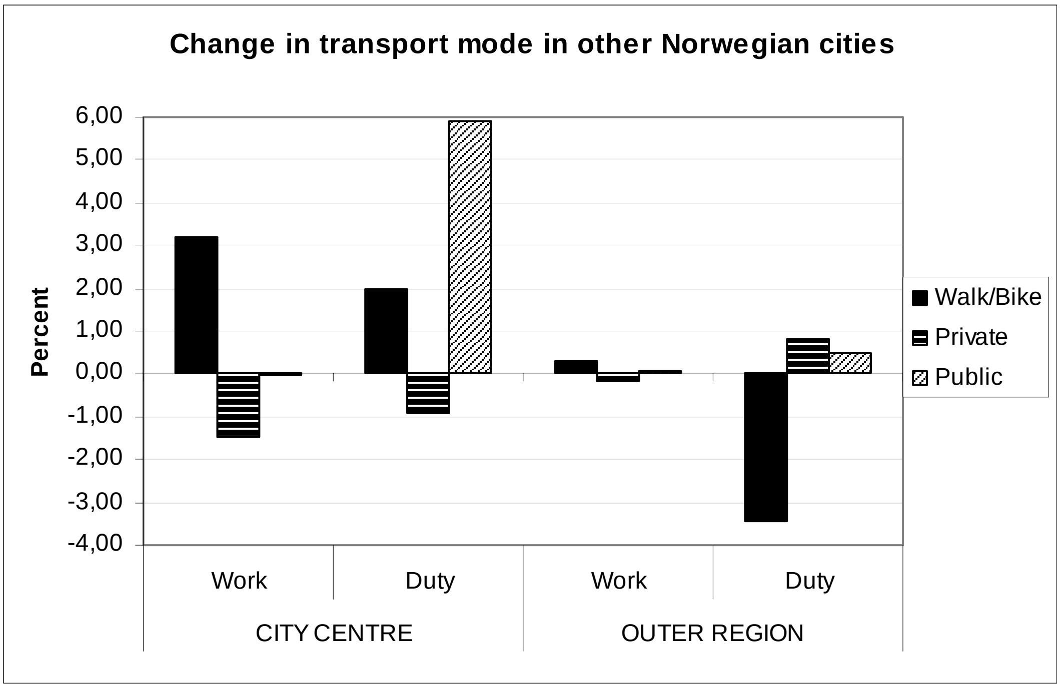


Figure 18. Estimated percentage changes in transport mode in the other large cities due to climate change

6 Economic impacts

6.1 Changes in demand for fuel and public transportation

Changes in travel patterns alter the demand for the different modes of travel, and thus the cost each household spends on transportation. These changed travel patterns also affect the total demand for fuel and public services. In the following section we will calculate the changes in costs of transportation in order to use the national aggregates in analyses of the socioeconomic impacts of altered travel patterns.

The cost of transportation is a summation of all households' transportation expenses. The transportation expenses of one household are the sum of the cost of public transportation and private transportation, as pedestrian and bicycle transportation do not result in any direct expenses.

The cost of public transportation is the total expenditure for tickets. As for the cost of private transportation, we have assumed that it only consists of the cost of gasoline, diesel and

[4] Tromsø, Kristiansand, Tønsberg, Drammen, Porsgrunn, Skien, Fredrikstad and Sarpsborg

road tolls. In other words, we assume capital expenses are independent of choice. The costs of fuel consist of the amount of gasoline or diesel which is consumed, multiplied with the price of gasoline and diesel respectively. In addition, there is a higher cost per trip for the share of trips passing through a road toll. We have assumed that 2/3 of all traffic passing through a road toll is private transportation.

Our estimation of public transportation costs is based on total national sales revenues of public transportation divided between regions according to their share of national local public transportation.

Table 9. Cost of public transportation

		Cost per travel	Travel volume	Total cost
Oslo	City centre	7.81	66 515 900	519 636 082
	Outer region	26.52	29 726 125	788 424 629
Bergen	City centre	17.76	34 817 750	618 335 843
	Outer region	17.76	10 718 400	190 350 350
Stavanger/ Trondheim	City centre	23.08	20 099 475	643 888 753
	Outer region	23.08	9 657 725	222 896 867
Other 6 cities	City centre	31.32	25 850 825	809 585 591
	Outer region	31.32	18 072 450	565 985 616

Our estimate for cost per trip using public transportation spans from 8 to 31 NOK. Oslo is the city with the lowest per-trip cost for public transportation. In Oslo, one adult ticket costs NOK 20, while child/student and concessionary tickets are NOK 10. In addition, there are discount rates such as day, week, month and season passes. Even though the youngest and oldest inhabitants use public transport more extensively than other age groups, an estimate of NOK 8 seems somewhat low. The estimate for the outskirts of Oslo is higher at NOK 27, which seems quite reasonable as there are longer travel distances in the outskirts of the city in to the city centre. The cost per trip increases as the size of the city falls, which seems reasonable.

Our estimation of private transportation costs is based on the average consumption of gasoline and diesel per household divided by the average household size, multiplied by the population and the price of gasoline and diesel respectively. Five of the largest cities in Norway have city road tolls.[5] Due to road tolls, the cost of private transportation is more expensive in urban than suburban areas.

[5] Bergen, Oslo, Kristiansand, Trondheim and Tønsberg.

Table 10. Private transportation costs

		Total fuel costs (1000 NOK)	Road tolls (1000 NOK)	Total cost (1000 NOK)	Travel volume (1000 km)	Cost per trip (NOK)
Oslo	City centre	1 825 376	593 448	2 418 824	178 436	13.56
	Outer reg.	2 286 961	-	2 286 961	213 047	10.73
Bergen	City centre	821 339	146 073	967 412	84 023	11.51
	Outer reg.	367 569	-	367 569	55 743	6.59
Stavanger/ Trondheim	City centre	1 119 527	105 286	1 224 813	110 759	11.06
	Outer reg.	709 850	-	709 850	78 135	9.08
Other 6 cities	City centre	1 822 494	168 593	1 991 087	208 210	9.56
	Outer reg.	814 213	-	814 213	177 715	4.58

Sources: Fjellinjen AS (2004), Kristiansand Bompengeselskap AS (2004), Statens Vegvesen (2004), Statistics of Norway (2003, 2002, 2001, and 1999) and Trøndelag Vegfinans AS[6] (2004).

Total transportation costs consist of the sum of public and private transportation costs. Our estimate of the total transportation costs are presented in the table 11.

Table 11. Total transportation cost

		Total cost of private transport (1000 NOK)	Total cost of public transport (1000 NOK)	Total cost of transport (1000 NOK)	Cost/trip private transport (NOK)	Cost/trip public transport (NOK)
Oslo	City centre	2 418 824	519 636	2 938 460	13.56	7.81
	Outer reg.	2 286 961	788 425	3 075 386	10.73	26.52
Bergen	City centre	967 412	618 336	1 585 748	11.51	17.76
	Outer reg.	367 569	190 350	557 919	6.59	17.76
Stavanger/ Trondheim	City centre	1 224 813	643 889	1 688 701	11.06	23.08
	Outer reg.	709 850	222 897	932 747	9.08	23.08
Other 6 cities	City centre	1 991 087	809 586	2 800672	9.56	31.32
	Outer reg.	814 213	565 986	1 380 199	4.58	31.32

[6] Personal communication

The change in transportation costs due to climate change is the estimated percentage change in travel habits multiplied with the average cost per trip for the two purposes and three modes. Table 12 presents our estimation of changed transportation costs due to climate change. There are some clear tendencies in the travel patterns, although costs and benefits balance each other out to some extent. The cost of private transport is reduced in all city centres. Less is spent on private transportation to work and leisure travel in suburban areas, except for Trondheim and Stavanger, while the cost of running errands increases in all outer regions. There is also a substantial increase in the expenditures for public transport for errands in the city centre of Oslo and Bergen.

Table 12. Altered transportation cost due to climate change. NOK

			Private	Public
Oslo	City centre	Work/leisure	-14 717 050	-607 207
		Errands	-10 195 409	4 070 028
	Outer region	Work/leisure	- 1 934 978	- 270 654
		Errands	4 682 743	693 544
Bergen	City centre	Work/leisure	13 768 320	-3 468 055
		Errands	-9 673 820	8 376 689
	Outer region	Work/leisure	- 90 756	397 589
		Errands	1 440 010	-38 321
Stavanger/ Trondheim	City centre	Work/leisure	-2 012 377	-321 422
		Errands	-2 775 301	-1 348 495
	Outer region	Work/leisure	1 626 472	1 154 154
		Errands	318 387	-508 538
Other 6 cities	City centre	Work/leisure	-1 281 420	483 288
		Errands	183 177	1 252 118
Total			-48 198 345	9 864 719

Looking at the aggregate of large Norwegian cities, the total private transportation costs will be reduced as a result of climate change, and the total public transportation costs will increase. In addition, people will start walking and biking more, and the overall effect is therefore a reduction in total transportation costs. The results vary, however, from region to region. The major part of the changes takes place in Oslo and Bergen. Thus, whereas the cost of public transport increases for the country at large, it will actually decrease in Trondheim and Stavanger. Moreover, nearly 95 percent of the reduced cost of private transportation stems from Oslo and Bergen.

6.2 Macroeconomic consequences

Although there are large differences between the different cities, the aggregate costs reported in Section 6.1 are moderate. Neither the estimated national increase in public transport of nearly 10 million NOK nor the decrease in the costs of private transport of nearly 50 million NOK is of any substance if compared with the total value of economic activities in Norway. Even though the directions of the substitution from private transport towards public transport and walking and bicycling are positive in the context of establishing national strategies for mitigating climate change, the overall effect is also far too small to be considered a factor that should be taken into account in designing climate policy.

Also in the context of local policy making, the implications turn out to be moderate in most cases. However, there are substantial differences between cities and between urban and suburban areas. On a disaggregated scale, changes in travel patterns may be large enough to attract interest. In Bergen, for example, the costs for public transport increase by more than 8 million NOK for errands, while they are reduced by nearly 3.5 million NOK for work and leisure travel. This may be of interest to local policy makers, but there are indirect effects not included in such a bottom-up estimate. For example, a reduction in total travel costs implies that households save money, which may be spent on other things.

In order to trace such effects and estimate their magnitudes, the “first-order effects” shown in table 12 were implemented in a general equilibrium model for Norway. Changes in travel patterns due to climatic changes can be interpreted as a “shift in taste” in the economic model. Such a shift can be represented by a change in the parameters in the utility function for the households. The magnitude of the shifts are found by recalibrating the demand functions so as to fit transport demand to the transport pattern after climate change has taken place.

The model consists of six sectors and six commodities: a forestry sector, a wood industry sector, and “other industries” sector and a service sector, plus the two energy sectors electricity and oil. The impacts found from the climate change scenarios affect the economic activities described in the model in three ways. First, a reduction in the use of private transport leads to a reduction in the demand for fuel oils. The deliveries from the fossil fuel sector to households thereby go down by nearly 44 million NOK. Second, less passing through city turnpikes contributes a reduction in the demand for services of approximately 4.5 million NOK. On the other hand, the increase in the use of public transport leads to an increase of nearly 10 million NOK in the deliveries to the households from the service sector, where transport is included.

Third, there are secondary effects of these changes. An increase in public transport requires increased deliveries of fuel to the service sector. Similarly, households save more than 38 million NOK from the increase in walking and bicycling, which they can spend on other goods and services. These implicit impacts of the change in the consumer pattern are found endogenously by the model.

The main results from the run of the macroeconomic model are shown in Table 13, and compared with the initial, direct economic results of the climate change scenario. Inclusion of the macroeconomic effects of the changes in travel habits increases the positive result of the initial change because a secondary process of adaptation is taken into account: the responses to climatic change forces other sectors of the economy to change slightly. Thus, reduction in the demand for fossil fuels is nearly fifteen percent lower when the macroeconomic effects are taken into account, and the increase in the use of public transport is four percent higher. This is because of the general increase in demand following the initial savings. The household expenditures on toll roads do not increase significantly (less than 0.001 percent). This is because of its small budget share, which implies that it does not take advantage of the general increase in the demand for services. According to the model, the savings then spur an increase in the demand for fossil fuels by an increase in private transport that avoids the turnpikes, and by increasing the demand for fossil fuels for non-transport purposes.

Table 13. Direct and indirect economic impacts of changes in travel pattern responses to climate change

	Direct response (million NOK)	Macroeconomic impact (million NOK)	Difference (%)
Demand for fossil fuels	-43.7	-37.4	-14.4
Household expenditures on toll roads	-4.5	-4.5	0.0
Household expenditures on public transport	9.9	10.3	4.1

On the supply side of the economy, the release of primary resources following the reduction in the demand for fossil fuels leads to an increase in the production of industry goods and services of approximately the same size, whereas the output of electricity increases by 1.4 mill. NOK. All in all, GDP is enhanced by 17.2 million NOK. As noted, all of these figures are insignificant in a national context. But Figure 13 nevertheless shows that it may be important to do the macroeconomic analyses in order to adjust micro-based estimates for macroeconomic impacts. It may be added, also, that transport is a relatively inflexible activity, in the sense that it is relatively inelastic to changes in prices brought about by changes in the macro economy. Hence, for impacts on activities of a more flexible character, the macroeconomic consequences may be more substantial.

7 Conclusions

The point of departure for this paper was some calculations “on the backside of an envelope” showing that moderate climatic changes that affect many people may have more significant macroeconomic impacts than dramatic changes that hit a few. The literature on the impacts of climate change has, however, focused mainly on dramatic, or at least significant, changes. In order to get a general and total overview of possible economic impacts of climate change on countries, the moderate changes and their consequences may, however, constitute a vital part and should therefore be detected and analysed. The focus on significant changes also seems to imply a local focus. Hence, there is a lot of knowledge about impacts of climate change in exposed areas, but there are few attempts to utilise this knowledge on more aggregated scales.

In order to analyse the macroeconomic impacts of possible changes in travel habits one has to deal both with the question of individual responses to moderate changes and with the question of linking local and national scales. We know very little about how travel habits depend on the climate, and if such dependencies can be traced, they are likely to be subject to local variations. Moreover, it is difficult to implement travel habits based on studies of individuals into top-down macroeconomic analytical tools. To the extent that studies of individuals are used to make national assessments, bottom-up approaches are usually applied, that is, to multiply local impacts to the national scale. Then, the market effects of the changes are left out of the analysis. In this paper, we combine information about individual behaviour on the micro-level in a top-down analysis. The paper may therefore be regarded also as an example of what information is needed, and which assumptions are required to utilize studies of micro behaviour in macroeconomic assessments.

Based on the survey of travel habits in the city of Bergen, we can conclude that travel habits do depend on weather conditions, but it is difficult to trace the explanatory factors from the observations recorded in the survey. Each individual's decision of how and where to travel depends on more factors than those captured by the survey, such as the start point and end point of the travel, and personal characteristics of those who travel. The observations of the weather were also limited to daily averages and totals, which may differ significantly from the weather at the time when the decision about transport mode was taken. As for the responses, it is also worth mentioning that wind turns out to be the most important explanatory factor for choice of travel mode, but had to be assumed unchanged in the scenarios because forecasts of wind speed were not available.

It is nevertheless interesting to find that it is sometimes easier to trace patterns for a large group of people than for small groups. When regions and travel purposes within the Bergen area were coupled, some correlations were actually found. First, that travel distance shortens with an increase in precipitation, except for travel to work. Thus, more rain makes walking and bicycling less attractive, but the distance also shortens, and this contributes to an increase in walking or biking. In some cases, the latter effect is stronger than the former. For some cases, increasing temperature also increases pedestrian transport, but this depends on the purpose of the excursion. For errands, the opposite seems to be the case. In general, switches between public and private transport are relatively unaffected by the weather.

The next question was how the results for Bergen could be utilised to estimate the impact of climate change on travel habits in Norway in general. We assumed, first, that climate change would not affect travel patterns in small cities and rural areas in Norway. Second, it was assumed that individuals in the larger cities choose transport mode with the same parameters as the individuals in Bergen do. The response to a given change of climate thereby depends on the level of temperature and precipitation in the city where they live, and the response to the climate scenario depends on how much the climate changes. In general, the response in Bergen is higher than in the other cities because the climate changes to a greater extent. It also turned out that the changes in Stavanger and Trondheim are smaller than in the other cities because travelling habits do not change a lot at the initial levels of temperature and precipitation in these cities, according to the estimates.

The macroeconomic impacts of changing travel patterns resulting from climate change in Norway were found to be small. One reason is, of course, that expenditures on local travel constitute a relatively small share of the budget in Norwegian households. When focusing only on one item in the budget, very few impacts would count significantly in a national context. A more important reason is, however, that the impacts of the climate scenario in this study draw the total result in different directions. For some purposes and regions, public transport increases at the expense of private of walking and biking, while for other purposes the tendency is the opposite. This indicates that it is still important, and perhaps most important, to know what the local impacts of climate change are. On the other hand, the extent of the local effects depends on what happens on the macro level, and the adjustment needed to take these into account may be substantial. For example, the bottom-up estimate of the reduction in total fossil fuel use was nearly 15 percent higher than the corresponding macro estimate.

8 References

Adams, C.R (1997): "Impacts of Temperature Extremes", *Workshop on the Social and Economic Impacts of Weather, Boulder Co.* National Center for Atmospheric Research, Boulder, Co, USA

Askildsen, Thorkel C. (2004): “Ekstremværsituasjoner og transporteffekter: Næringslivets transporrtilpasninger til klimaendringer” (Extreme weather and transport effects: The transport industry's adaptation to climate change) in Norwegian. *CICERO Report 2004:10.* Oslo

Bergen Fylkeskommune, 2000. *Reisevaner i Bergensområdet i 2000 med utviklingstrekk fra 1992*. Commissioned by Bergen Kommune, Statens Vegvesen Hordaland and Hordaland fylkeskommune.

Changon, S.A. (1996): “Effects of summer precipitation on urb an transportation”, *Climatic Change* **32 (4)**, *481-494*

Domenchic, T.A. and D. McFadden (1975): *Urban Travel Demand*, North-Holland. Amsterdam.

Fankhauser, S.: 1995, *Valuing Climate Change. The Economics of the Greenhouse*, Earthscan Publications Ltd, London.

Fjellinjen AS, (2004): *Annual passes through road toll in Oslo*. Personal communication

Hanemann, W.M. (1984): “Discrete/continuous Models for Consumer Demand”, *Econometrica* **52**, 541-561.

Kristiansand Bompengeselskap AS, 2004. *Annual passes through road toll in Kristiansand* Personal communication

Maddala, G.S. (1982): *Limited Dependent and Qualitative Variables in Econometrics,* Cambridge University Press. New York.

Muellbauer, J. (1975): “The Cost of Living and Taste and Quality Change”, *Journal of Economic Theory* **10**, 269-283.

Norwegian Meteorological Institute, 2001. *Climate data.* http://shimmer.oslo.dnmi.no/portal/page?_pageid=35,96278,35_96303&_dad=portal&_schema=PORTAL

Perry, A.H. and L. Symons (1994): “The wind hazards in the British Isles and its effects on transportation”, *Journal of Transport Geography* **2**, 122-130.

Qualley, W. (1997): “Impact of Weather on the Use of Weather Information by Commercial Airline Operations”, *Workshop on the Social and Economic Impacts of Weather, Boulder Co.* National Center for Atmospheric Research, Boulder, Co, USA

Statens Vegvesen (Norwegian Public Roads Administration), 2004. Annual passes through road toll in Bergen and Tønsberg. Personal communication

Statistics Norway, 2001. *Population statistics*. http://www.ssb.no/emner/02/01/10/folkemengde/ 03.09.04

Statistics Norway, 2002. *Statistics of population structure*. http://www.ssb.no/emner/02/01/fobhushold/tab002-09-02-02.html

Statistics Norway, 2003. *Energy accounting and energy balance* http://www.ssb.no/emner/01/03/10/energiregn/arkiv/tab-2003-12-05-17.html

Statistics Norway, 2004a. *Structure statistics, land transportation*. http://www.ssb.no/emner/10/12/stvei/tab-2004-06-09-01.html http://www.ssb.no/emner/10/23/stvei/tab-2004-06-09-03.html

Statistics Norway, 2004b. *Transport statistics.* http://www.ssb.no/emner/10/12/samferdsel_kostra/tab-2004-06-29-01.html

Statistisk Sentralbyrå, 1999. ”Energiforbruk per husholdning” *Report 99/22*. Statistics Norway. Oslo

Transportøkonomisk Institutt (Institute of Transport Economics), 2002. ”Den nasjonale reisevaneundersøkelsen 2001-Nøkkelrapport”, *TØI rapport 588/2002*. Oslo

Transportøkonomisk Institutt (Institute of Transport Economics), 2003. ”Den norske befolkningen reiser”, *TØI-rapport 637/2003*. Oslo