Impact of weather on daily travel demand

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Abstract

This paper investigates the effects of weather conditions on individual travel demand distinguishing modes of transportation and different trip purposes. We use Dutch travelers' data for a period of 10 years (1996-2005), and locally and hourly measured meteorological data. Daily travel demand measured by number of trips is modeled as a negative binomial process. Our results suggest strong effects of weather on transportation and strong substitution of travel modes at extreme temperatures. Precipitation enhances the modal shift from bicycle to public transport and car. Commuting and business trips are least influenced by weather, whereas recreational trips are more sensitive to weather changes.

1. Introduction

In this particular study, we are interested in effect of weather on travel demand. Travel demand is an important issue in transportation. Travel demand is a derived demand and it can, therefore be altered directly, or indirectly, by large number of factors including price of transportation, fuel prices, taxes and weather. The role of weather is particularly important in a country like the Netherlands, where about 25 percent of the population makes use of the bicycle on a daily basis. Biking is more sensitive to weather variation compared to other modes of transportation. Therefore, any abrupt change in weather may have substantial influence on travel demand in general and for bicycle use in particular.

The Royal Netherlands Meteorological Institute (KNMI) predicts that temperature in the Netherlands will continue to rise in the future. Mild winters and hot summer are anticipated to become more common. There may be more extreme precipitation and on average winters may be wetter. Furthermore, the summer will likely have more intense rain with a reduction in number of rainy days (KNMI, 2006). Given the expected future climate change, the impact of weather on travel demand is therefore, an important consideration for policy makers and future planers. This study aims to investigate the impacts of weather on individual travel demand for different trip purposes and for different modes of transportation.

Generally, we would expect a negative effect of rain and extreme temperatures on transportation demand. This is particularly true for trips made for recreational purposes, as they can be easily rescheduled or canceled.[1] For example, Richardson (2000) finds negative effects of both rain and temperature, with rainfall and both high and low temperature decreasing the number of cycling trips in metropolitan area of Melbourne, Australia. Goetzke and Rave (2006) confirm these findings. Chung et. al. (2005) shows that the number of trips made on the Tokyo Expressway in Japan is lower during rainy days and are in particular during weekends. Hofmann and Margaret (2005) study urban bus performance on some selected routes in Ireland and report that ridership is reduced during rainy days. In addition, rain increases congestion, which reduces the reliability of bus services.[2] Winters et al. (2007) show for Canadian cities that utilitarian biking is negatively influenced precipitation and low temperatures. There are few studies which do discuss the impact of weather on other mode of transportation than bicycle use. Bertness (1980) also studied the impact of summer precipitation in the Chicago area. He reported 3-5 percent reduction in ridership of mass transit systems during rainfall due to fall in discretionary riders such as shoppers. However,

[1] A general overview of empirical findings about the influence of weather on transportation is given by Koetse and Rietveld (2009).

[2] Some studies also reported slightly different results, such as, Nankervis (1999) finds trivial effects of precipitation on bicycle use in Melbourne. However, his study is based on students, who can be expected to have fewer substitution possibilities.

this study focuses on the impact of rainy days during summer only. Hence, this study is missing the impact of rain on public transit ridership during winter.

Changes in weather may also cause a modal shift. Khattak and De Palma (1996), who studied traveler behavior in Brussels find that adverse weather causes changes in mode and route choice as well as departure time of automobile commuters. Furthermore, changes in departure time due to adverse weather conditions appear to be of more importance for automobile commuters than changes in route and mode choice.[3] Bergström and Magnusson (2003), using a survey of employees of four major companies in two Swedish cities, show that the number of car trips is 27 percent higher while the number of bicycle trips is 47 percent less, during summer as compared to winter. Aaheim and Hauge (2005) find for Bergen (Norway) that increases in precipitation and wind increase the likelihood of use of public transportation use as compared to walking and biking.[4]

Despite their useful insights, these studies have some major limitations. First, the weather indicators used in these studies were recorded once a day, or only a few values of a limited number of weather indicators were available. In countries in which weather is subject to hourly changes, such as the Netherlands, such an approach is not feasible. Second, most studies are based on surveys that only cover a few months period. Since climate changes likely has a differential effect on weather conditions in different seasons periods covering only a few months are insufficient if the focus of research is on the general impact of climate change on travel demand. Third, the numbers of observations used in these studies are small, which makes it difficult to obtain precise estimates. Fourth, travel demand for other modes of transportation such as of bus, tram, metro, train etc., is not studied thoroughly. Fifth, the focus of previous studies is mostly on commuting and recreational trips (e.g. Richardson, 2000; De Palma and Rochat, 1999, etc.) while ignoring other trip purposes. Finally, previous studies compare the influence of weather on individual travel demand across the different days. It does not explain what happens if weather across different region of the country is different during same day.

We aim to examine the influence of weather conditions on individual travel demand, while using data that have a large coverage in terms of geographical location, time duration and weather indicators. It distinguishes between several modes of transportation and trips undertaken for different purposes. An important contribution of this paper is that local, hourly measured weather data are used. The data cover the entire Netherlands for a 10 years period.

[3] De Palma and Rochat (1999) conduct a similar survey among Geneva commuters and found are similar results.

[4] At the regional level, their analysis shows that weather conditions do not induce a switch between public and private transport. Furthermore, at the macro level the impact of climate change on travel patterns appears small for Norway.

Additionally, we use day specific panel data methodology which measures the influence of weather on travel demand across the country on the same day. That is an improvement over methodologies used in previous studies which study same phenomena but across different days. Our analysis should give more exact and precisely estimated impacts of weather on comprehensive measures of travel demand.

The remainder of the paper is organized as follows. Section 2 is devoted to the data, its sources, and the variables used in analysis. Section 3 contains model specifications for travel demand. Section 4 presents the empirical results of the econometric models and elaborates the findings. Section 5 concludes paper.

2. Data and variables

This study uses data from two sources. First, we make use of the Transportation Surveys of Dutch Central Bureau of Statistics (OVG/MON Surveys) from year 1996 until 2005. Over the course of an entire a year, large numbers of individuals in the Netherlands were asked to fill out a questionnaire on their travel behavior during a certain day.[5] In total we have one million individuals and 3.5 millions trips. The number of people and the reported trips for every year are presented in Appendix A.

The weather data, provided by KNMI for same period contains weather conditions measured on an hourly basis by 32 weather stations spread over the Netherlands. Weather conditions in this paper refer to the hourly measured temperature, wind strength (BFT), precipitation duration (minutes of precipitation), precipitation intensity (mm), snow and visibility, for the whole of the Netherlands.

Transportation and weather data sets were matched such that each trip observation was assigned the hourly weather conditions during which the trip took place from the weather station which is nearest to individual place of departure. On average distance to a weather station is about 12 to 13 km, which means that our measurement of weather conditions is local.

We are interested in the influence of weather on transportation demand. The transportation surveys used in this study provides the exact time of the trip made by a person

[5] We combined the OVG and MON data sets to get data for 10 years since 1996. Some variables which were part of the OVG data set, are not included in the MON data set; also, some variable categories have been changed over the years. For these reasons, some of the variable categories (such as age) are defined such that they become consistent with the next year survey in order to merge them.

during a specific day. We measure daily travel demand by number of trips made by a person during a specific day, so we use an aggregated approach.[6]

Individual may vary travel distance as the numbers of trips remains the same. So we also use the daily distance traveled as a measure of individual travel demand. This measure addresses possible distance effects of weather. To get more comprehensive picture of impacts of weather and climate changes on transportation demand, we will employ both measures.

We focus on the daily travel demand, so we need measure of daily weather conditions in the Netherlands. We use a weighted average of weather variables per day, where weights are based on the distribution of trips made during different hours of the day.[7] Hence, the weather of those hours in which more trips are made (such as peak hours), are assigned with a larger weight than other hours of days.

We specified different measures of weather. We measure temperature by five dummy variables (below or equal to 0^o C, 0^o C to 10^o C, 10 ^{o}C to 20 ^{o}C, 20 ^{o}C to 25 ^{o}C and temperature greater than 25 ^{o}C).[8]

In order to measure the effect of precipitation we include a dummy variable for precipitation up to 0.1mm per hour, a dummy variable for precipitation greater than 0.1mm per hour and precipitation duration per hour (in minutes). Wind strength is measured in Beaufort scale.[9] A dummy variable is used if hourly weighted average of wind strength is equal to or exceeds 6 Bft.

Visibility is measured by a dummy variable which is one if (hourly weighted average) horizontal visibility on road is less than 300 meter during a day.

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[6] A disaggregated approach with a level of trip may also be used, see e.g. Sabir et. al. (2009). However, the main advantage of an aggregate approach is that one may address travel demand and mode choice decisions simultaneously. Furthermore, the aggregate approach provides total travel demand for the whole day whereas the disaggregate approach provide only travel demand per trip. Therefore, aggregation at a day level is useful.

[7] A simple average will not be an adequate measure for weather conditions as most of the trips are made during daytime and there are substantial differences in weather conditions of day and night.

[8] Because of climate change we would expect more of extreme weather event especially on summer days as on average the temperature will increase. Therefore, the dummy variable for temperature greater than 25^o C will reflect the expected effects of climate changes on travel demand. This specification of temperature categories will portray a clearer picture of variation in travel demand that can be cause by weather and climate change.

[9] The Beaufort scale (BFT) measures wind strength on a scale of 1 to 12. On this scale, 6 BFT represents powerful winds with a speed between 39 and 49 kilometers per hours (or 10.8 to 13.8 meters per second) over a period of at least 10 minutes. Similarly, 12 BFT represents a hurricane with wind speeds larger than 117 kilometers per hour (or larger than 32.6 meters per second).

The effect of snow on travel demand is measured by a dummy variable. Unfortunately, we do not have an explicit measure of falling snow or snow on the ground. However, we use a proxy for snow an interaction effect of precipitation and temperature less than or equal to 0 ^{o}C. However, it may be noted that measuring snow by this way may only capture the effects of falling snow and therefore, it *does not* control for the effects of snow on ground.

Furthermore, we control for regional differences in Netherlands by controlling for provinces. Furthermore, we include seasonal dummy variables to control for seasonal variation. Similarly, to see if demand is different on different days of the week we include a dummy for weekdays. The descriptive of all variables are given in Appendix A. A complete list of explanatory variables along with the descriptive is given in appendix B.

3. Theoretical model and estimation methods

3.1 Number of trips

The advantage of using daily number of trips as a measure of travel demand is that it is easy to apply, and it can be used to measure total travel demand or travel demand for specific transport modes or travel demand for different trip purposes. The number of trips is a count variable. The benchmark model for count data is the Poisson regression model (Gurmu and Trivedi 1996, Greene 2007, Cameron and Trivedi 2005). Poisson model is based on the assumption of equality of mean and variance both being equal to the Poisson parameter λ. To identify and estimate the effects of systematic factors on the number of trips made per person, we can specify as $\lambda_i = (\beta x_i)$, where, β is a vector of regression coefficients and x_i a vector of independent variables. Then the Poisson regression model can be specify as, $P(Y_i = y_i) = exp(-\beta x_i)(\beta x_i)^{y_i} / y_i!$, where, $P(Y_i=y_i)$ is the probability of daily trips made by individual . However, an obvious limitation of Poisson model is that it cannot cope with the case that the variance exceeds the mean, a feature called overdisperssion (Cameron and Trivedi 2005).[10] The alternative model suggested in the literature is the negative binomial model. One way of deriving the negative binomial model is by introducing an unobserved effect into the conditional mean of the Poisson model (Cameron and Trivedi 1986). This redefines the last equation $log\, \lambda_i = x_i \beta + \varepsilon_i$, where ε_i is the disturbance term, which represents specification. This implies that:

[10] This approach also fails to account for conditional interdependence of counts because counts may be dependent on the previous occurrence of such event.

$$P(Y_i = y) = \frac{exp(-\beta x_i + \varepsilon_i)\ (\beta x_i + \varepsilon_i)^{y_i}}{y_i\,!} \qquad (1)$$

Equation (1) is named the compound Poisson model by Cameron and Trivdi (1986). The negative binomial model can be deriving from the compound Poisson by specifying a gamma distribution for ε_i, and allowing λ_i to vary randomly. In other words, the compound Poisson model with ε_i having a gamma distribution gives the negative binomial distribution.[11] We will estimate negative binomial model with day specific fixed effects as it will provide the influence of weather on travel demand of different individual across the country during the same day instead. In absences of fixed effects, the model provides the effects of weather on travel demand across different days. We prefer the earlier approach because it is an improved technique and is more relevant for the type of weather data available for this study.

3.2 Total distance travelled

Another possibility of estimating the travel demand is to consider the distance traveled by individual during a day.

Let Y_i be the distance (km) traveled by a person per day (or by a specific mode or for a specific trip purpose), then we have, $Y_i = x_i\beta_i + \varepsilon_i$, where, β represents a vector of coefficients on explanatory variables x_i. This model can be estimated by OLS. However, OLS will result into inefficient inconsistent estimates because of the excess zeros in the dependent variable as not every person make trip by each mode of transportation or for every trip purpose on same day (Cameron and Trivedi 2005). This problem can be address through using the Tobit model. Historically developed for addressing the issues of the censoring data, the Tobit model can be used while censoring at zero value of travel distance. Therefore, we specify our model in Equation earlier equation as a Tobit model for total distance travelled by per person per day, distance travelled by different modes of transportation and distance travelled for different trip purposes. Hence: $Y_i^* = x_i\beta_i + \varepsilon_i$, where Y_i* is called a latent variable (because we do not observe it directly). This model is estimated with the condition: $Y_i = Y^*$ if $Y^* > 0$, 0 otherwise.

[11] In the present case, Y_i is the number of trips made by an individual during a day; x_i is the vector of variables such as weather variables, seasonal variables and location of the trip departure place.

4 Empirical results and discussion

4.1 Number of trips

Three different estimation of same model are made: estimation of total travel demand, travel demand for different modes of transportation and travel demand for different trip purposes. The entire analysis in this section is based on estimating equation (4) with day specific fixed effects. The results of the weather variables are summarized in Table 1. The complete results of the model are given in Appendix C. The results are plausible and had correct sign for almost all variables. A general observation for figure 1-9 is that model spilt varies strongly (as also presented in Appendix 1). Therefore, one should consider both, the absolute changes and the relative changes while interpreting the results. For example, a relative change in BTM of say 20 percent is smaller in absolute terms than a relative change in bicycle of say 5 percent because the model share of bicycle is much larger than that of BTM in the Netherlands. Same hold true for transportation modes like train as compared with car and bicycle.

Strong wind has negative impacts on the individuals travel demand as shown in Table 1 and in Fig 1. Total travel demand is about 2 percent lower in strong wind conditions as compared with normal wind. The demand for walking and car trips are 2 and 3 percent lower, respectively during strong wind as compared with normal wind. The largest reduction happens for demand of bus, tram and metro trips (BTM), which show a reduction of about 22 percent in windy conditions. These findings imply that total travel demand is sensitive to strong wind and this hold true in particular for BTM. There may be two reasons for it. At the supply side, during strong wind, there may be limited operation of the tram, metro services during because of failure or because of safety reasons. At the demand side, people may not take many trips under strong windy conditions, especially, if a weather warning/alerts is given as well.

Total travel demand is not affected in *extreme cold weather* (temperature less than 0^o C). However, demand for different modes of transportation shows an interesting pattern during same weather conditions as shown in Fig 2. During extreme cold weather, the demand for bicycle fall by about 7.7 percent and that of BTM increases by about 16.9 percent as compared with temperature between 0^o C to 10^o C. The demand for walking trips also increases by about 12.5 percent in similar weather conditions. The demand for car and train are not affected in extreme cold weather conditions. Lower demand for bicycle are plausible findings, as one would expect lesser bike trips during extreme cold weather given that biker are more vulnerable to extreme weather conditions. The increase in walking trips may be a surprise. However, this may be increased due to increase in travel demand for the BTM because then we should expect more walking trips towards (or from) the excess points. Since, total travel demand is not affected during extreme cold weather as compared with normal weather normal weather (temperature between 0^o C to 10^o C), and on the same time, the travel demand for other mode of transportation is influence strongly. This indicate modal shift from biking to BTM during extreme cold weather.

Similar to extreme cold weather, total travel demand also show an interesting pattern in *warmer weather* (temperature between 10^o C to 20^o C) as can be seen in Fig 4. The demand for walking reduces slightly in warmer weather. However, travel demand for car reduces by around 4 percent in warmer weather compared with normal weather. Also, the demand for BTM trips falls by around 3.5 percent in same weather conditions. On the contrary, demand for biking increases by 9.2 percent in same weather conditions. Since, the total travel demand is not affected during warmer weather, this also show the modal shift from car and BTM use to bicycle use in warmer weather as compared to normal weather.

During temperature between 20^o C to 25^o C there is a big reduction in travel demand for car, BTM. However, demand for biking increase by around 18 percent in same weather condition. Given that total travel demand is not affected, this implies that people have strong tendency to switch to biking from automobile and public transportation during warmer weather conditions. It may be noted that modal shift is stronger during higher temperature. Total travel demand reduces by about 5 percent during *extreme warm weather* (temperature greater than 25^o C). Travel demand for automobile is also reduced by about 15 percent during extreme warm weather as compared with normal weather. Additionally, the travel demand for BTM also reduce by about 20 percent in extreme warm weather conditions. However, this fall in travel demand of car and BTM are balanced by around 22 percent increase in demand for biking and 17.5 percent increase in travel demand for other modes of transportation. The other mode of transportation increases strongly because this category contains moped, motor, scooter, taxi, truck, delivery van. These findings show even stronger modal shift phenomena from car and BTM usage to the biking. To sum up, total travel demand is effected by different weather conditions and there is strong modal shift from biking to public transport and car usage in cold weather and vice versa in warm and extreme warm weather.

We analyzed the effects of *precipitation* on travel demand by two ways. First, using the duration of precipitation (measured by minutes of precipitation during an hour). Second, the intensity of precipitation (measured in millimeters of precipitation).

Weather and Changes in Travel Demand

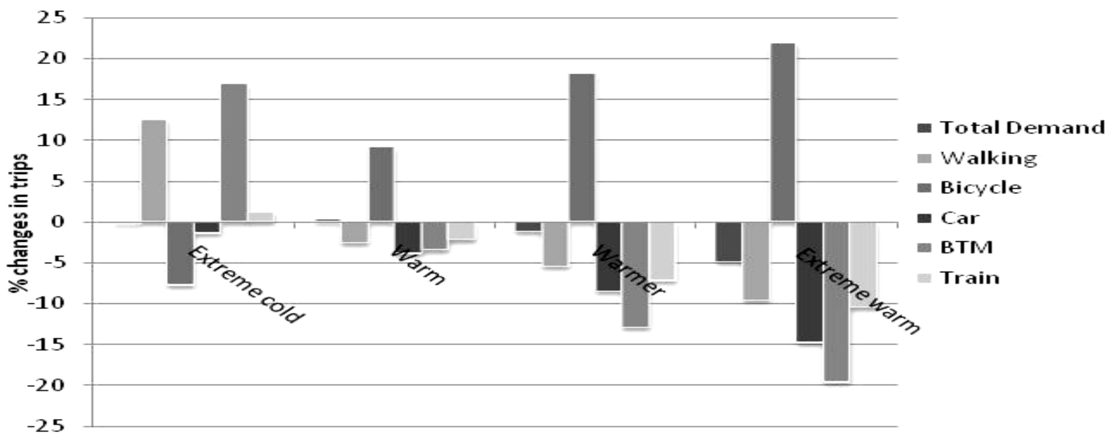

Fig 1: Travel demand in different temperature

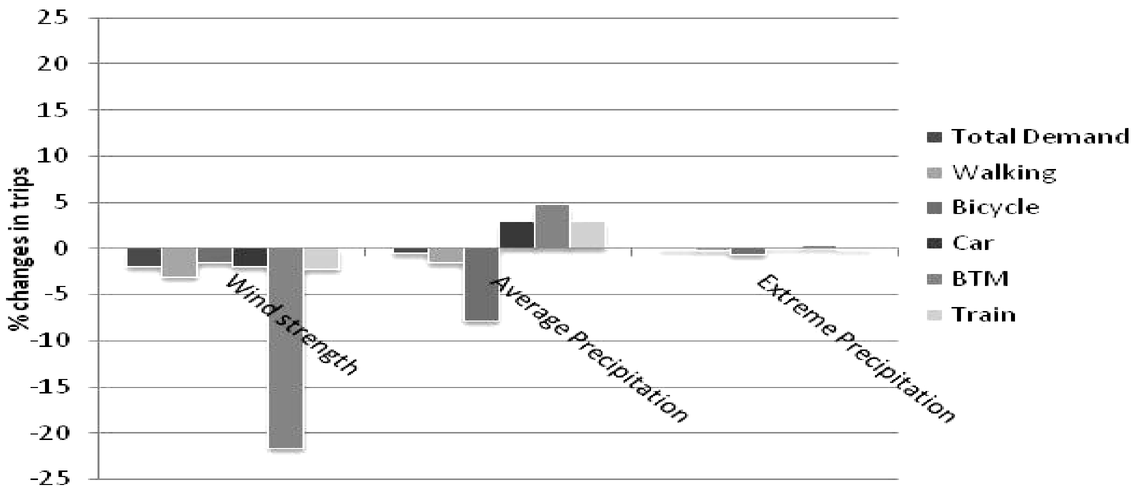

Fig 1: Travel demand in strong wind and precipitation

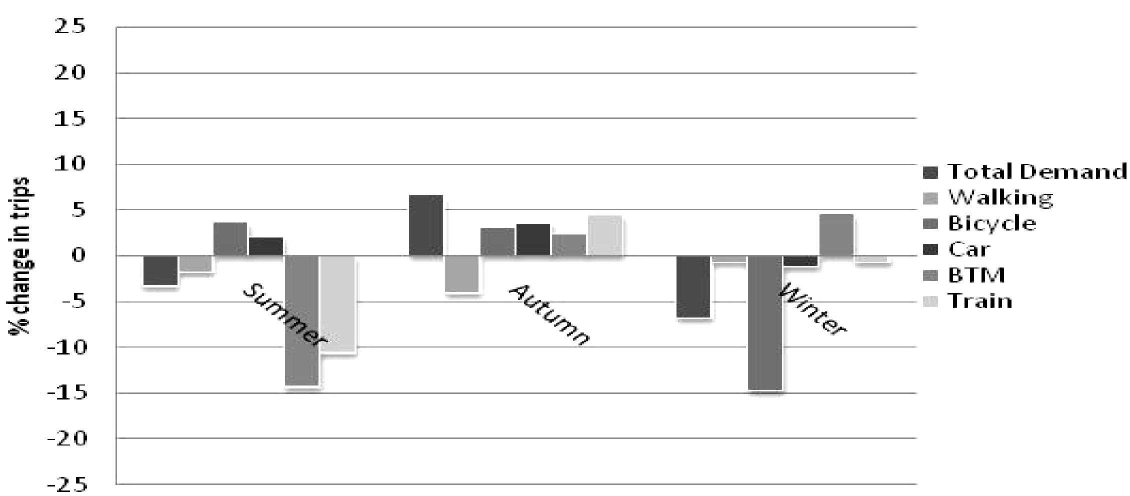

Fig 3: Travel demand in different seasons

Table 1: Impacts of weather conditions on individuals daily trips (Percentage changes in number of trips)

		Wind Strength	**Temperature**				**Precipitation**			**Snow**	**Visibility**	**Seasonal**		
Analysis	Demand of Trips	Wind Bft	$\leq$ 0^{o} C	10^{o} C to 20^{o} C	20^{o} C to 25^{o} C	> 25^{o} C	Minutes	Up to 0.1 mm	> 0.1 mm	Dummy	< 300m	Summer	Autumn	Winter
Analysis I	Individuals	**-2.04**	-0.20	0.27	-1.17	**-4.87**	**-0.16**	**-0.74**	-0.63	**-3.88**	2.31	**-3.36**	**6.65**	**-6.84**
Analysis II	Auto	**-2.07**	-1.40	**-3.90**	**-8.47**	**-14.80**	*0.06*	**0.68**	**2.85**	-2.75	4.11	**2.05**	**3.58**	-1.23
	Bicycle	-1.59	**-7.76**	**9.19**	**18.11**	**21.95**	**-0.73**	**-5.20**	**-7.89**	-4.08	-6.27	**3.66**	**3.00**	**-14.76**
	Walking	**-3.15**	**12.56**	**-2.60**	**-5.47**	**-9.58**	**-0.25**	-0.65	*-1.61*	1.38	3.38	*-1.83*	**-4.10**	-4.10
	Bus and Trams	**-21.73**	**16.88**	*-3.44*	**-12.90**	**-19.62**	**0.26**	**6.19**	*4.73*	**-14.97**	43.15	**-14.39**	2.35	*4.52*
	Train	-2.30	1.21	-2.21	**-7.19**	-10.45	-0.05	0.61	2.90	-10.19	11.88	**-10.65**	**4.41**	-0.79
	Other	-1.64	-1.22	**12.32**	**10.97**	**17.53**	**-0.28**	**-4.11**	**-8.30**	-11.12	-8.75	4.02	***-4.04***	**-12.47**
Analysis III	Commuting	-1.07	-10.94	0.53	-0.48	-3.86	-0.09	-1.038	*-2.11*	6.77	4.19	**-19.42**	**10.13**	**-6.33**
	Business	-2.46	-12.66	-1.73	*-6.88*	**-13.69**	-0.06	0.24	0.54	8.34	-7.80	**-7.37**	1.17	-0.74
	Shopping	**-5.50**	**4.64**	-0.05	-1.43	*-4.75*	**-0.19**	**1.32**	1.00	-9.40	-0.47	**13.71**	0.35	-0.74
	Recreational and Sports	-0.19	**-4.37**	**5.17**	**10.23**	**8.26**	**-0.36**	**-2.64**	*-1.45*	**10.39**	-4.54	**-5.07**	**-3.47**	**-10.01**
	Educational	-1.65	**5.11**	**-2.68**	**-5.72**	-7.25	-0.01	**-1.90**	**-3.22**	**-9.16**	1.17	**-45.17**	**6.47**	-0.83
	Visiting family & Friends	**-3.24**	**6.25**	0.80	1.89	**7.97**	**-0.26**	**-3.99**	**-6.05**	-3.19	*9.44*	**4.75**	**-3.59**	**-10.28**

Note: *The number indicates the percentage changes in daily number of trips made by per person per day. The bold ant italic numbers are significant at 5 and 10 percent level of significance respectively. The reference category for wind, temperature, precipitation (mm), snow, visibility and seasonal variables are Wind strength greater than 6 bft, temperature between 0 ^{o}C to 10^{o}C, no precipitation, no snow, visibility greater than 300 meter and spring, respectively.*

The duration of precipitation variable shows that total travel demand for individuals are negatively affected by precipitation. Total travel demand reduces by 1.6 percent for 10 minutes of precipitation. Nevertheless, for the same amount of precipitation the demand for bicycle reduces by about 7 percent. However, travel demand for BTM trips increase by about 2.5 percent for every 10 minutes of precipitation. The results clearly indicate higher changes in travel demand for BTM as compared with total travel demand. Car trips also increases by about 0.7 percent. This implies that people switches from biking to BTM and car as the duration of precipitation increases. Thus with increases in duration of precipitation, the public transport will be more extensively used and also roads will be more congested with additional car to cope with the extra demand created by increased duration of precipitation.

The effects of second measure of precipitation on travel demand are presented in Fig 7. There is a minor fall in total travel demand during average precipitation as compared with no precipitation. The demand for biking trips falls by about 5 percent during average precipitation as compared with no precipitation. However, demand for BTM increase by about 6.2 percent and car trips increase by about 0.70 percent. Since, there is a slight fall in total travel demand, and demand for biking trips during average precipitation but the demand for BTM and car are increases. Especially there is a higher change in demand for biking and BTM, so this also reflects the modal shift phenomena in favors of car and BTM from biking.

Total travel demand is not affected during extreme precipitation conditions. The main reason for this may be that it is not extreme precipitation is not so frequent event. And our study covers 10 years period so normally such effect average outs in longer period. The demand for biking falls strongly (about 7.8 percent) during extreme precipitation as compared with no precipitation. This is a big fall and that what we would expect during an extreme conditions for biking. However, in contrary to biking, car and BTM trips increases strongly during extreme precipitation.

These finding also suggest modal shift phenomena from biking to car and BTM. This suggests that there will be more burdens on road network during extreme precipitation because of additional demand for car usage. Also the BTM will be more crowded with people because of the additional demand created during extreme weather conditions.

We used number of specification for *visibility* variable to analyze the impacts of visibility on the travel demand. However, we could not find statistically significant impacts of visibility on travel demand, or on the demand of different modes of transportation on the demand of transportation for different trip purposes. This suggests that visibility is not influential for the transportation demand in the Netherlands.

Total travel demand is about 4 percent lower during *snow* as compared with no snow.[12] The travel demand for BTM falls by about 15 percent during snow. Nevertheless, travel demand for other modes of transportation is not affected by snow. These suggest that people prefer to cancel their trips instead of switching to other modes of transportation during snow.

The lower part of the Table 1 shows the effects of weather on the number of trips made for *different trip purposes*. As expected, the demand for commuting and business trips is hardly affected by weather. Because, in most cases commuting and business trips cannot be canceled or delayed.

The demand for recreational and sports trips reduces in extreme cold and increase in warmer weather as compared with normal weather. Whereas, strong wind, precipitation duration and precipitation intensity reduce demand for recreational trips. However, the reduction in demand for recreational and sport trips for these weather effects is around 2 percent. This shows that the demand for recreational and sport, trips is more vulnerable to weather conditions as compared with any other kind of trips. The reason is that these trips are more flexible and can be easily rescheduled or canceled as compared with other kind of trips such as commuting or business trip. Visiting family and friends is another type of trips, which

[12] It may be noted that snow in this analysis only measure the effects of *falling* snow. It *does not* control for snow on roads or snow on bike routes, which may have different effects.

demand is influenced by weather. The demand for visiting family and friends trips are 6.2 percent and 8 percent higher during extreme weather conditions. This confirms the vulnerability of these trips to extreme weather conditions. These are also plausible findings, as visiting family and friends trips are generally more flexible to be postponed or delayed as compared to commuting trips but are less flexible as compared with recreational and sports trips. Precipitation duration has minor effects on travel demand for visiting family and friends. Additionally, average precipitation also reduces these trips by about 4 percent as compared to no precipitation. Demand for educational trips fall by about 5.8 percent in warm weather conditions. This may be because of the summer vacations period during which all schools are closed. Shopping trips also fall in warm weather conditions. This fall may be for the reason that people may prefer to take recreational trips instead of shopping trips in warm weather.

Sensitivity Analysis

We also estimated the same three models of section 4.3, while excluding the seasonal variables and not using day specific fixed effects. In such case, the modal will measure the influence of weather on travel demand across different days rather than the affects of weather on travel demand on same day across different parts of the country. We remove seasonal variables to check if it captures the effect of weather variables. Additionally, only negative binomial model was estimated to see if the effects among different days are comparable to the affects of weather across same day. The results of these two analyses are comparable in most cases (e.g. for model of total travel demand or demand for car or bike). This implies that both methodologies do provide similar results even though they are slightly different. However, the results of two methodologies were not comparable for all models we estimated. In few cases (e.g., commuting trips) there are slight differences in the size of the coefficients of variables.

4.2 Distance travelled

Distance travel by individual during a day is another aspect of this analysis. The three different analysis of individual transportation demand from number of trips is repeated, but now travel demand is measure by distance per person per day (dependent variable) instead of number of trips per person per day. In second analysis, dependent variable is distance travelled by specific mode of transportation as a measure of travel demand for that specific mode of transportation. Finally, in third analysis, dependent variable is the distance travelled for specific trip purpose as a measure of travel demand for that specific trip purpose. It may be noted that unlike the first approach, this approach measure mainly the impact of weather on travel demand across days.[13] As stated earlier, instead of OLS, Tobit model is used.

[13] We did not used day specific fixed effects for Tobit models for two reasons. First, the results of day specific fixed effects negative binomial and that of without day specific fixed effects were comparable.

However, it may be noted that the coefficients of the Tobit model provides marginal effects of the explanatory variables on the latent variable (i.e. Y* in current case). But we need to know the expected value of the distance travel by a specific mode of transportation (or for a specific trip purpose) given that that trip has been made by that specific mode (or for that specific purpose). For this reason, we estimated the marginal effects of all X variables (which includes weather variables and non-weather variables) on Y. The changes in travel distance due to weather conditions are presented in Table 2.[14]

The results show that strong wind reduces the average total distance by 2.3 km as compared with normal wind. This is about 7.4 percent reduction in average total distance. This is consistent with findings of the previous section though here our effects are higher. However, the first model finding is preferable given that it is done with fixed effects panel model. Similarly, during strong wind, average distance of bicycle falls by 0.30 km as compared with normal wind conditions. This reflects 13 percent reduction in average distances of bicycle. Average travel distance by BTM reduces by about 0.3 km (or 20 percent) during strong wind. This finding is also consistent with the previous section, which suggests about 20 percent reduction in demand of BTM.

In extreme cold weather, the total average distance fall by about 0.85 km (or about 2.7 percent) as compared with normal weather conditions. Average bicycle distance also falls by about 0.30 km during extreme cold weather as compared with normal weather. In contrary, walking distance increase by about 0.19 km per person per day during extreme cold weather. This implies that people continue to take the short distance trips in extreme cold weather.

As the temperature, increases from 0 ^{o}C to 25 ^{o}C or higher, the average car distance and also the average BTM distance, decreases whereas average bike distance increases but the average total distance either remain unchanged or slightly change. This also implies modal shift phenomena from car and BTM to biking in warmer weather.

Average total distance is not affected by duration of rain. If there is on average 10 minutes of rain, the bicycle distance per person per day reduces by about 0.21km (9 percent). These are also plausible results, as one would expect less average distance per biker if there is longer duration of precipitation.

The average car distance per person reduce by 0.84 km (demand for car trip reduces by 3.5 percent). The effect of rain duration on other modes of transportation is statistically not significant.

Second, to estimate Tobit model with day specific fixed effects was computationally cumbersome through software package STATA.

[14] Marginal effects are presented in Appendix C.

Table 2: Impacts of weather conditions on daily average distance

		Wind Strength	Temperature				Precipitation			Snow	Visibility	Seasonal		
Analysis I	Demand	> 6 bft	< 0 ^oC	10 ^oC to 20 ^oC	20 ^oC to 25 ^oC	>= 25 ^oC	Mints	Up to 0.1 mm	> 0.1 mm	Dummy	< 300 meter	Summer	Autumn	Winter
Analysis II	Total trips	**-2,33**	**-0,85**	**1,12**	*0,49*	**-2,28**	-0.24	**-0.06**	-0.03	**-2.70**	0.65	0.18	**1.44**	**-1.32**
	Walking	-0,04	**0,19**	**-0,07**	**-0,15**	**-0,30**	0.02	**-0.01**	0.01	**0.45**	0.15	**-0.08**	**-0.07**	**0.09**
	Bicycle	**-0,30**	**-0,30**	**0,51**	**1,14**	**1,33**	**-0.45**	**-0.04**	**-0.27**	-0.23	0.04	**0.19**	**0.16**	**-0.60**
	Car	**-0,88**	*0,41*	**-0,27**	**-1,53**	**-3,17**	**0.84**	**0.02**	**0.52**	**-2.62**	-0.41	**0.31**	*0.19*	**-0.62**
	Bus/Trams/ metros	**-0,28**	*0,11*	*-0,05*	**-0,22**	**-0,27**	0.01	**0.005**	*0.05*	**-0.27**	0.29	**-0.22**	**0.14**	**0.14**
	Train	-0,23	-0,07	0,02	-0,19	-0,43	0.09	-0.001	-0.04	-0.53	0.86	**-0.37**	**0.48**	0.17
	Other	0,003	**-0,12**	**0,13**	**0,18**	**0,20**	**-0.09**	**-0.003**	**-0.06**	-0.07	*-0.19*	0.02	-0.01	**-0.08**
Analysis III	Commuting	**-0,30**	**0,40**	-0,03	**-0,61**	**-0,86**	**0.24**	*-0.01*	**0.34**	**-0.66**	**2.04**	**0.19**	**0.91**	0.01
	Business	-0,13	-0,09	0,02	0,01	0,09	0.05	*0.005*	0.05	-0.32	-0.15	**-0.21**	**0.12**	0.03
	Shopping	**-0,10**	**0,07**	0,004	**-0,04**	**-0,25**	**0.08**	**-0.002**	**0.07**	**-0.15**	*-0.12*	**0.15**	*-0.02*	-0.02
	Recreational and Sports	-0,04	**-0,13**	**0,20**	**0,33**	**0,56**	**-0.08**	**-0.01**	**-0.13**	**0.63**	-0.18	-0.01	**-0.05**	**-0.21**
	Educational	-0,004	-0,01	**-0,01**	**-0,03**	**-0,04**	-0.01	0.00002	-0.001	-0.02	0.02	**-0.08**	**0.04**	**0.01**
	Visiting family &Friends	-0,06	-0,07	**0,19**	**0,31**	**0,47**	**-0.19**	-0.001	**-0.12**	0.04	**0.12**	**0.23**	**-0.19**	**-0.17**

Note: The number indicates changes in average distance (Km) of per person per day. The bold ant italic numbers are significant at 5 and 10 percent level of significance respectively. The reference category for wind, temperature, precipitation (mm), snow, visibility and seasonal variables are Wind strength greater than 6 bft, temperature between 0 ^oC to 10^oC, no precipitation, no snow, visibility greater than 300 meter and spring, respectively.

The effect of precipitation intensity is also statistically significant for most of the transportation modes. The result clearly reflects the substitution effect by showing 1.7 percent (or 0.04 km reduction in average distance) and 11 percent (or 0.27 km reduction in average distance) reduction in average bicycle distance during average precipitation and extreme participation, respectively, as compared with no precipitation. In contrast, average car distance increases by 0.87 percent and 2.3 percent during average precipitation and extreme precipitation, respectively, as compared with no precipitation. However, on same time, average total distance is not affected during extreme precipitation conditions. Hence, the modal shift phenomenon during precipitation is observable.

Total average distance per person is 2.7 km lower during snow as compared with no snow conditions. In addition, the average car distance also fall by 2.2 km and that of the BTM fall fall by 0.27 km during snow as compared with no snow. The effects of snow for other mode of transportation are statistically not significant. These findings are consistent with finding in previous section.

Average total distance for commuting and business trips is not affected strongly from weather conditions with few exceptions. Interestingly, here we can see that weather do had influence on the commuting trips distance although business trips are not affected by weather conditions. The reason for this could be that during summer there are less commuting trips due to vacations and hence lower average commuting distances.

Average total distance travelled for sports and recreational trips and for visiting family and friends trips increases during warmer weather as compared with normal weather. The average distance recreational and sports trips increase by 0.56 km and that of the visiting family and friend increase by 0.6 km. This suggests that people prefer to go more for recreational trips and visiting their family and friends in warmer weather as compared with normal weather. Similarly, during average and extreme precipitation conditions, recreational, sports trips are affected negatively, and the average distance for these trips reduces. Interestingly, average distance during snow for recreational and sports trips increases by 0.63 km as compared with no snow conditions. This may appear as a surprise. As we are using crude measure for snow, which only capture the falling snow effects instead of the snow on ground, therefore this increase in average distance during snow may be capturing the effects that people are going to indoor sports and recreational activities rather than going for sports in open air. In most of the cases, indoor sports facility is not very close to house, so one would expect longer average distances for these trips during falling snow.

We use some *non-weather variables* as well in order to control for the effect of no-weather factors. These variables include seasonal variations, gender, age, days of week and provinces. Total travel demand varies during different seasons. The total travel demand is lower during summer and winter. During summer, there is vacations period so one would expect lower travel demand during summer months which we can also observe by fall in the travel demand for almost all kind of trips. BTM trips fall strongly during summer where as car and biking trips increases. During autumn there are increases in total travel demand followed by increases in demand for car, bicycle and train trips, as compared with spring. This is also plausible findings because we would expect people coming back from vacations and back to the routine life. Total travel demand fall during winter, with highest fall in biking trips, where as there is increases in the BTM trips. These are also plausible as one would expect less demand during winter because of vacations period and reduction in the recreational and sports activities because of cold weather as can be also noted by fall in the demand for recreational and sports trips. These all finding are plausible.[15]

[15] People under 18 years of age use walking and biking more as compared with people of any other age group. Travel demand for car is higher for 18 to 30 age group people or people having age greater than 65 years as compared with age group between 30 to 40 years. Gender variable shows that males walk less and use less car as compared to females. The weekday variable shows no variation in total travel

5. Conclusions

This paper investigates the impacts of weather conditions on the individual travel demand. We use individuals travel data of Dutch travelers for 10 years period covering 1996 to 2005. This travel data is matched with locally measured hourly meteorological weather data. The weather variables were categories in such a way that it not only gives a clear picture of the effects of different weather conditions on travel demand but also the effects of expected climate changes on travel demand. We also investigate the impacts of weather on demand for different modes of transportation and demand of transportation for different trip purposes.

We use two approaches to measure travel demand. First, using the number of number of trips made during a day as a measure of travel demand. Secondly, using distance travelled during a day as a measure of travel demand. Results from both approaches are comparable and consistent. The results of the study can be summarized as follows;

First, weather, in general has influence on individual travel demand. Second, unlike the total travel demand, there is strong variation in the demand for trips made by different modes of transportation in different weather conditions. This suggests that weather causes model shift. Third, extreme weather conditions (cold/warm) show a strong modal shift among bicycle, car and public transportation. During extreme cold weather, biking is substituted by increase in public transport and walking. During extreme warm weather, car and public transport is substituted by bicycle. Fourth, substitution between different modes also occurs during precipitation. There is strong substitution from bicycle to bus, tram and metros during average precipitation. Whereas, during extreme precipitation, people prefer to use car also, however, substation from bicycle to bus, tram and metro is stronger than substitution from bicycle to car. Fifth, snow reduces the individual total trips strongly but demand for different modes of transportation is not affected by snow, except demand for BTM that reduces during snow. Sixth, there are no statistically significant effects of visibility on individual travel demand. Seventh, the demand for commuting and business trips is not affected by weather conditions. However, we find negative effect of weather variables on recreational and sports trips. Finally, we also use distance travelled by individuals as a proxy for demand for transportation. This also support the result obtained from the negative binomial panel model.

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demand as compared with weekend. However, there is variation in travel demand for different modes of transportation. The demand for walking and car trips is lower during working day as compared with weekends. However, the travel demand for biking, bus, tram and metro are higher during working days as compared with weekends.

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Appendix A

Table A-1 : Yearly number of recorded trips and individuals

Year	Trips	Individuals
1996	471463	137322
1997	465285	128451
1998	450519	122486
1999	407922	124610
2000	405311	126994
2001	367477	114174
2002	287428	88469
2003	223432	68839
2004	217908	63258
2005	206139	60775
Total	3502884	1035378

Table A-2: Mode share (Percentages) Year 1996-2005

	Trip Purposes						Overall averages
Modes	Commuting	Business related	Educational	Shopping	Visiting family & Friends	Recreational & Sports	
Walk	3.8	3.0	21.6	16.1	19.0	24.4	14.7
Bike	23.4	9.6	42.6	29.9	23.0	24.6	25.5
Car	56.3	79.4	13.7	48.9	51.1	45.6	49.2
Bus/Tram/Metro	4.8	1.2	9.3	2.4	1.9	1.4	3.5
Train	8.4	4.2	10.1	1.1	2.7	1.9	4.7
Other	3.2	2.6	2.6	1.6	2.2	2.1	2.4

These tables are based on the linked data of weather and transportation, which does not include the missing data.

Table A-3: Descriptive of weather variables

Variables	Mean
Wind strength (Bft)	0.034
Temperature < 0 °C	0.049
Temperature 0 °C to 10 °C	0.409
Temperature 10 °C to 20 °C	0.462
Temperature 20 °C 25 °C	0.067
Temperature > 25 °C	0.013
No Precipitation	0.361
Precipitation ≤ 0.1 mm	0.384
Precipitation > 0.1 mm	0.254
Precipitation Duration	4.280
Snow	0.018
Visibility < 300 meter	0.002
Visibility > 300 meter	0.998
Spring	0.255
Summer	0.230
Autumn	0.262
Winter	0.253
Age < 18 years	0.226
Age 18 to 30 years	0.134
Age 30 to 60 years	0.459
Age > 60 years	0.181
Male	0.493
Weekday	0.722

Variables	Mean	
	Trips	Distance
Total	3.34	31.4
Walking	0.54	0.5
Biking	0.87	2.3
Car	1.61	22.8
Bus\tram\metro (BTM)	0.10	1.5
Train	0.13	3.6
Other	0.07	0.7
Commuting	0.40	6.1
Business	0.10	2.2
Education trips	0.33	2.4
Recreational & sports	0.64	4.9
Family & friend visiting	0.53	5.7
Shopping	0.79	3.7
No purpose	0.14	-
Other trip purpose	0.30	3.2
Unknown purpose	0.31	3.3

Table A-4 Descriptive for per person per day

Appendix B

Table B-1: Mode of transportation (Negative binomial fixed effects panel model)

Variables	Total		Walking		Bicycle		Car		Bus/Tram/ Metro		Train		Other	
	Coeff.	**S.E**	**Coeff.**	**S.E**	**Coeff.**	**S.E**	**Coeff.**	**S.E**	**Coeff.**	**S.E**	**Coeff.**	**S.E**	**Coeff.**	**S.E**
Weather Variables														
Wind strength (Bft)	**-0.02**	0.005	**-0.03**	0.01	-0.02	0.01	**-0.02**	0.01	**-0.24**	0.04	-0.02	0.03	-0.017	0.035
Temperature < 0 °C	-0.002	0.01	**0.12**	0.02	**-0.08**	0.01	-0.01	0.01	**0.16**	0.04	0.01	0.04	-0.012	0.045
Temperature 0 °C to 10 °C	0.003	0.005	**-0.03**	0.01	**0.09**	0.01	**-0.04**	0.01	*-0.04*	0.02	-0.02	0.02	**0.116**	0.021
Temperature 20 °C 25 °C	-0.01	0.01	**-0.06**	0.01	**0.17**	0.01	**-0.09**	0.01	**-0.14**	0.04	**-0.07**	0.04	**0.104**	0.034
Temperature > 25 °C	**-0.05**	0.01	**-0.10**	0.03	**0.20**	0.02	**-0.16**	0.02	**-0.22**	0.08	-0.11	0.07	**0.162**	0.064
Precipitation ≤ 0.1 mm	**-0.01**	0.003	-0.01	0.01	**-0.05**	0.01	*0.01*	0.004	**0.06**	0.02	0.01	0.02	**-0.042**	0.016
Precipitation >0.1 mm	-0.01	0.004	*-0.02*	0.01	**-0.08**	0.01	**0.03**	0.01	*0.05*	0.03	0.03	0.03	**-0.087**	0.025
Precipitation Duration (Minutes)	**-0.002**	0.0002	**0.00**	0.001	**-0.01**	0.0005	**0.0006**	0.0003	**0.003**	0.001	-0.0005	0.001	**-0.003**	0.001
Snow	**-0.04**	0.01	0.01	0.03	-0.04	0.03	-0.03	0.02	**-0.16**	0.08	-0.11	0.08	-0.118	0.089
Visibility less than 300 meters	0.02	0.02	0.03	0.05	-0.06	0.04	0.04	0.03	**0.36**	0.11	0.11	0.12	-0.092	0.146
Summer	**-0.03**	0.01	*-0.02*	0.01	**0.04**	0.01	**0.02**	0.01	**-0.16**	0.03	**-0.11**	0.03	0.039	0.026
Autumn	**0.06**	0.01	**-0.04**	0.01	**0.03**	0.01	**0.04**	0.01	0.02	0.02	**0.04**	0.02	*-0.041*	0.023
Winter	**-0.07**	0.01	-0.02	0.01	**-0.16**	0.01	-0.01	0.01	*0.04*	0.02	-0.01	0.02	**-0.133**	0.027
Other Variables														
Age less than 18 years	**-0.05**	0.002	**0.55**	0.01	**0.66**	0.01	**-0.54**	0.004	**-0.90**	0.02	**-1.97**	0.02	**0.225**	0.016
Age between 30 to 60 years	**-0.02**	0.002	**0.16**	0.01	**0.05**	0.01	**0.17**	0.003	**-1.30**	0.01	**-1.29**	0.01	**-0.539**	0.016
Age greater than 60 years	**-0.42**	0.003	**0.26**	0.01	**-0.25**	0.01	**-0.46**	0.005	**-1.06**	0.02	**-1.95**	0.02	**-0.489**	0.020
Male	**-0.04**	0.001	**-0.25**	0.004	**-0.21**	0.003	**0.16**	0.002	**-0.36**	0.01	**0.08**	0.01	**0.456**	0.011
Weekday	**0.32**	0.01	**-0.07**	0.01	**0.46**	0.01	**-0.27**	0.01	**0.54**	0.02	**0.74**	0.02	**0.141**	0.021
Number of Groups	3653		3653		3653		3653		3538		3554		3594	
Log likelihood	-2265508.4		-910137.33		-1191510.9		-1735822.8		-183260.39		-189723.73		-187584.42	
Wald Chi 2 (31)	37082.66		13937.93		51749.54		70125.69		13097.81		22468.82		6166.36	

Note: This model has been estimated with controlling for 12 provinces. The bold ant italic numbers are significant at 5 and 10 percent level of significance respectively. The reference category for wind, temperature, precipitation (mm), snow, visibility and seasonal variables are Wind strength greater than 6 bft, temperature between 0 °C to 10°C, no precipitation,. no snow, visibility greater than 300 meter and spring, respectively.

Table B-2: Trip purposes (Negative binomial fixed effects panel models)

	Commuting		Business		Shopping		Educational		Sports & Recreational		Visiting family & friends	
Variables	**Coff.**	**S.E**	**Coff.**	**S.E**	**Coff.**	**S.E**	**Coff.**	**S.E**	**Coff.**	**S.E**	**Coff.**	**S.E**
Weather Variables												
Wind strength (Bft)	-0.01	0.01	-0.02	0.03	**-0.06**	0.01	-0.02	0.01	-0.002	0.012	**-0.03**	0.01
Temperature < 0 ºC	-0.12	0.07	-0.14	0.18	**0.05**	0.02	**0.05**	0.02	**-0.045**	0.016	**0.06**	0.02
Temperature 0 ºC to 10 ºC	0.01	0.01	-0.02	0.02	-0.001	0.01	**-0.03**	0.01	**0.050**	0.008	0.01	0.01
Temperature 20 ºC 25 ºC	-0.005	0.02	*-0.07*	0.04	-0.01	0.01	**-0.06**	0.02	**0.097**	0.013	0.02	0.01
Temperature > 25 ºC	-0.04	0.04	**-0.15**	0.07	*-0.05*	0.03	-0.08	0.05	**0.079**	0.025	**0.08**	0.03
Precipitation ≤ 0.1 mm	-0.01	0.01	0.002	0.02	**0.01**	0.01	**-0.02**	0.01	**-0.027**	0.006	**-0.04**	0.01
Precipitation >0.1 mm	*-0.02*	0.01	0.01	0.02	0.01	0.01	**-0.03**	0.01	-0.015	0.009	**-0.06**	0.01
Precipitation Duration (Minutes)	-0.001	0.001	-0.001	0.001	**-0.002**	0.0004	-0.0001	0.001	**-0.004**	0.0005	**-0.003**	0.0005
Snow	0.07	0.07	0.08	0.18	**-0.10**	0.03	**-0.10**	0.04	**0.099**	0.027	-0.03	0.03
Visibility less than 300 meters	0.04	0.05	-0.08	0.13	-0.005	0.04	0.01	0.06	-0.046	0.048	**0.09**	0.05
Summer	**-0.22**	0.03	**-0.08**	0.03	**0.13**	0.01	**-0.60**	0.02	**-0.052**	0.010	**0.05**	0.01
Autumn	**0.10**	0.03	0.01	0.02	0.003	0.01	**0.06**	0.02	**-0.035**	0.009	**-0.04**	0.01
Winter	**-0.07**	0.03	-0.01	0.03	-0.01	0.01	-0.01	0.02	**-0.105**	0.010	**-0.11**	0.01
Other Variables												
Age less than 18 years	**-0.13**	0.02	**-0.94**	0.13	**-0.45**	0.01	**1.56**	0.01	**0.031**	0.007	**0.13**	0.01
Age between 30 to 60 years	**-0.11**	0.005	**0.46**	0.02	**0.38**	0.01	**-2.35**	0.01	**0.120**	0.006	**-0.12**	0.01
Age greater than 60 years	**-0.33**	0.02	**0.81**	0.03	**0.42**	0.01	**-3.27**	0.03	**0.057**	0.007	**-0.18**	0.01
Male	**0.16**	0.004	**0.76**	0.01	**-0.53**	0.004	**-0.02**	0.005	**-0.038**	0.004	**-0.07**	0.004
Weekday	**3.63**	0.02	**1.56**	0.04	**-0.43**	0.01	**3.97**	0.04	**-0.557**	0.007	**-0.67**	0.01
Number of Groups	2552		3403		3650		3183		3653		3653	
Log likelihood	-371129.13		-154067.01		-1062107.4		-407438.15		-1025604.3		-947279.53	
Wald Chi 2 (31)	29978.34		6434.3		55477.16		160883.44		7241		12346.38	

Note: This model has been estimated with controlling for 12 provinces. The bold ant italic numbers are significant at 5 and 10 percent level of significance respectively. The reference category for wind, temperature, precipitation (mm), snow, visibility and seasonal variables are Wind strength greater than 6 bft, temperature between 0 ^{o}C to 10^{o}C, no precipitation,. no snow, visibility greater than 300 meter and spring, respectively.

Appendix C

Table C 1: Modes of transportation (Marginal effects of the Tobit model)

Variables	Total		Walking		Bicycle		Car		Bus/Tram/Metro		Train		Other	
	Coeff.	**S.E**	**Coeff.**	**S.E**	**Coeff.**	**S.E**	**Coeff.**	**S.E**	**Coeff.**	**S.E**	**Coeff.**	**S.E**	**Coeff.**	**S.E**
Weather Variables														
Wind strength (Bft)	**-2.33**	0.31	-0.04	0.06	**-0.30**	0.07	**-0.88**	0.22	**-0.28**	0.05	-0.23	0.19	0.003	0.03
Temperature < 0 °C	**-0.85**	0.31	**0.19**	0.06	**-0.30**	0.07	*0.41*	0.22	*0.11*	0.06	-0.07	0.19	**-0.12**	0.03
Temperature 0 °C to 10 °C	**1.12**	0.15	**-0.07**	0.03	**0.51**	0.03	**-0.27**	0.11	*-0.05*	0.03	0.02	0.09	**0.13**	0.02
Temperature 20 °C 25 °C	*0.49*	0.28	**-0.15**	0.05	**1.14**	0.07	**-1.53**	0.19	**-0.22**	0.05	-0.19	0.17	**0.18**	0.03
Temperature > 25 °C	**-2.28**	0.53	**-0.30**	0.09	**1.33**	0.13	**-3.17**	0.35	**-0.27**	0.10	-0.43	0.33	**0.20**	0.06
Precipitation ≤ 0.1 mm	**-0.06**	0.01	**-0.01**	0.00	**-0.04**	0.00	**0.02**	0.01	**0.00**	0.00	0.00	0.01	**-0.003**	0.001
Precipitation >0.1 mm	-0.03	0.14	0.01	0.02	**-0.27**	0.03	**0.52**	0.10	*0.05*	0.03	-0.04	0.09	**-0.06**	0.01
Precipitation Duration (Minutes)	-0.24	0.22	0.02	0.04	**-0.45**	0.05	**0.84**	0.15	0.01	0.04	0.09	0.14	**-0.09**	0.02
Snow	**-2.70**	0.66	**0.45**	0.13	-0.23	0.15	**-2.62**	0.44	**-0.27**	0.11	-0.53	0.40	-0.07	0.07
Visibility less than 300 meters	0.65	1.24	0.15	0.23	0.04	0.27	-0.41	0.86	0.29	0.26	0.86	0.84	*-0.19*	0.11
Summer	0.18	0.19	**-0.08**	0.03	**0.19**	0.04	**0.31**	0.13	**-0.22**	0.03	**-0.37**	0.11	0.02	0.02
Autumn	**1.44**	0.16	**-0.07**	0.03	**0.16**	0.03	*0.19*	0.11	**0.14**	0.03	**0.48**	0.10	-0.01	0.02
Winter	**-1.32**	0.18	**0.09**	0.03	**-0.60**	0.04	**-0.62**	0.13	**0.14**	0.04	0.17	0.11	**-0.08**	0.02
Other Variables														
Age less than 18 years	**-23.70**	0.17	**2.08**	0.05	**3.04**	0.05	**-16.14**	0.11	**-1.17**	0.02	**-6.88**	0.07	**0.13**	0.02
Age between 30 to 60 years	**-10.72**	0.17	**0.40**	0.03	**-0.38**	0.04	**3.15**	0.12	**-2.15**	0.03	**-7.00**	0.10	**-0.45**	0.02
Age greater than 60 years	**-26.18**	0.16	**1.48**	0.05	**-1.32**	0.04	**-11.37**	0.12	**-1.25**	0.02	**-5.84**	0.06	**-0.29**	0.02
Male	**8.58**	0.11	**-0.74**	0.02	**-0.64**	0.02	**8.76**	0.08	**-0.50**	0.02	**0.59**	0.07	**0.45**	0.01
Weekday	**4.76**	0.13	**-0.15**	0.02	**2.28**	0.02	**-3.98**	0.09	**1.04**	0.02	**3.46**	0.07	**0.32**	0.01

Note: This model has been estimated with controlling for 12 provinces. The bold ant italic numbers are significant at 5 and 10 percent level of significance respectively. The reference category for wind, temperature, precipitation (mm), snow, visibility and seasonal variables are Wind strength greater than 6 bft, temperature between 0 °C to 10°C, no precipitation,. no snow, visibility greater than 300 meter and spring, respectively.

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Table C 2: Different trip purposes (Marginal effects of the Tobit model)

Variables	**Commuting**		**Business**		**Shopping**		**Recreational and Sports**		**Educational**		**Visiting family and friends**	
	Coeff.	**S.E**	**Coeff.**	**S.E**	**Coeff.**	**S.E**	**Coeff.**	**S.E**	**Coeff.**	**S.E**	**Coeff.**	**S.E**
Weather Variables												
Wind strength (Bft)	**-0.30**	0.11	-0.13	0.08	**-0.10**	0.02	-0.04	0.04	-0.004	0.004	-0.06	0.05
Temperature < 0 ^oC	**0.40**	0.11	-0.09	0.08	**0.07**	0.02	**-0.13**	0.04	-0.01	0.004	-0.07	0.05
Temperature 0 ^oC to 10 ^oC	-0.03	0.05	0.02	0.04	0.004	0.01	**0.20**	0.02	**-0.01**	0.002	**0.19**	0.02
Temperature 20 ^oC 25 ^oC	**-0.61**	0.09	0.01	0.08	**-0.04**	0.02	**0.33**	0.04	**-0.03**	0.003	**0.31**	0.05
Temperature > 25 ^oC	**-0.86**	0.17	0.09	0.16	**-0.25**	0.03	**0.56**	0.08	**-0.04**	0.01	**0.47**	0.09
Precipitation ≤ 0.1 mm	*-0.01*	0.004	*0.005*	0.003	**-0.002**	0.001	**-0.01**	0.00	0.00002	0.0002	-0.001	0.002
Precipitation >0.1 mm	**0.34**	0.05	0.05	0.04	**0.07**	0.01	**-0.13**	0.02	-0.001	0.002	**-0.12**	0.02
Precipitation Duration (Minutes)	**0.24**	0.08	0.05	0.06	**0.08**	0.01	**-0.08**	0.03	-0.01	0.003	**-0.19**	0.03
Snow	**-0.66**	0.22	-0.32	0.17	**-0.15**	0.04	**0.63**	0.10	-0.02	0.01	0.04	0.11
Visibility less than 300 meters	**2.04**	0.49	-0.15	0.31	*-0.12*	0.07	-0.18	0.16	0.02	0.02	**0.12**	0.20
Summer	**0.19**	0.06	**-0.21**	0.05	**0.15**	0.01	-0.01	0.02	**-0.08**	0.002	**0.23**	0.03
Autumn	**0.91**	0.06	**0.12**	0.04	*-0.02*	0.01	**-0.05**	0.02	**0.04**	0.002	**-0.19**	0.02
Winter	0.01	0.06	0.03	0.05	-0.02	0.01	**-0.21**	0.02	**0.01**	0.002	**-0.17**	0.03
Other Variables												
Age less than 18 years	**-1.06**	0.20	**-1.00**	0.14	**-0.42**	0.01	**0.11**	0.03	**0.27**	0.005	**0.34**	0.03
Age between 30 to 60 years	**-1.02**	0.05	**0.91**	0.03	**0.47**	0.01	**0.30**	0.02	**-0.48**	0.01	**-0.19**	0.03
Age greater than 60 years	**-2.33**	0.11	**3.45**	0.25	**1.04**	0.02	**0.73**	0.03	**-0.26**	0.003	**0.39**	0.03
Male	**1.91**	0.04	**1.59**	0.03	**-0.61**	0.01	*0.03*	0.02	**0.01**	0.002	**-0.15**	0.02
Weekday	**7.89**	0.04	**2.38**	0.03	**-0.09**	0.01	**-1.92**	0.02	**0.38**	0.004	**-3.47**	0.03

Note: This model has been estimated with controlling for 12 provinces. The bold ant italic numbers are significant at 5 and 10 percent level of significance respectively. The reference category for wind, temperature, precipitation (mm), snow, visibility and seasonal variables are Wind strength greater than 6 bft, temperature between 0 ^oC to 10^oC, no precipitation,. no snow, visibility greater than 300 meter and spring, respectively.