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## Investigating the impacts of weather variability on individual's daily activity–travel patterns: A comparison between commuters and non-commuters in Sweden

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### ABSTRACT

Understanding travel behaviour change under various weather conditions can help analysts and policy makers incorporate the uniqueness of local weather and climate within their policy design, especially given the fact that future climate and weather will become more unpredictable and adverse. Using datasets from the Swedish National Travel Survey and the Swedish Meteorological and Hydrological Institute that spans a period of thirteen years, this study explores the impacts of weather variability on individual activity–travel patterns. In doing so, this study uses an alternative representation of weather from that of directly applying observed weather parameters. Furthermore, this study employs a holistic model structure. The model structure is able to analyse the simultaneous effects of weather on a wide range of interrelated travel behavioural aspects, which has not been investigated in previous weather studies. Structural equation models (SEM) are applied for this purpose. The models for commuters and non-commuters are constructed separately. The analysis results show that the effects of weather can be even more extreme when considering indirect effects from other travel behaviour indicators involved in the decision-making processes. Commuters are shown to be much less sensitive to weather changes than non-commuters. Variation of monthly average temperature is shown to play a more important role in influencing individual travel behaviour than variation of daily temperature relative to its monthly mean, whilst in the short term, individual activity–travel choices are shown to be more sensitive to the daily variation of the relative humidity and wind speed relative to the month mean. Poor visibility and heavy rain are shown to strongly discourage the intention to travel, leading to a reduction in non-work activity duration, travel time and the number of trips on the given day. These findings depict a more comprehensive picture of weather impact compared to previous studies and highlight the importance of considering interdependencies of activity travel indicators when evaluating weather impacts.

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## 1. Introduction

Human activities produce massive greenhouse gas emissions, which trigger the climate change and more unpredictable weather conditions. It is well known that most societal activities are subject to seasons and are highly influenced by weather

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conditions, especially extreme weather. Climate change, global warming and more frequent extreme weather have brought huge loss to the society in general. Within the last decade, extreme weather conditions, such as heavy snow and flood, lead to chaos and disasters in cities which cost billions of euros. An estimate given by Stern (2007) showed a permanent decrease in annual global GDP of between 5% and 20% if no mitigation efforts are carried out. The recent IPCC reports (2015) summarized and quantified the negative impacts of climate change on physical systems (glacier melting, coastal erosion, etc.), biological systems (terrestrial ecosystem, wild fire, etc.) and human systems (food production, health, etc.), and showed that those negative impacts were not trivial. For instance, the quantified annual impact of climate change on crop yields can reach up to –2%. Thus, it is becoming important to be able to understand and forecast the possible individual behavioural changes given the fact that future climate and weather will become more unpredictable and adverse. There has been a significant body of studies investigating the uncertain effects of weather and climate change upon society in comprehensive manner, particularly within the domains of agriculture, natural disasters and water resources, but not in transport. One of good exceptions is a comprehensive review by Koetse and Rietveld (2009) which summarized the effects of climate change and weather conditions on transport. In their study, they found that only a few studies had focused on travel behaviour analysis prior to 2009. Since then, however, there have been more recent literature reviews (e.g., Böcker et al., 2013a; Dijst et al., 2013) showed a rapid expansion of studies investigating the role of weather in travel behaviour during the past five years. From a behavioural analysis point of view, it is important to understand to what extent the change in weather conditions determines the likelihood of a change in travel behaviour. This knowledge is crucial for analysts and policy makers to incorporate the uniqueness of local weather and climate within our policy design and infrastructure management, especially, in countries like Sweden, where the weather and climate patterns in southern and northern parts differ significantly.

There have been many studies that have explored the impacts of weather elements on individuals' travel choices. For example, Madre et al. (2007) show that adverse weather was one of the main reasons for trip cancellation, especially in reference to snow, rain and strong wind, whilst Saneinejad et al. (2012) argue that the variation of temperature played only a small role in the variation of daily commuter trip rates when all modes were considered. In line with this, Cools et al. (2010) found that the changes in travel behaviour in response to weather conditions were highly dependent on trip purpose.

At the same time, the previous results so far also demonstrate substantial inconsistencies in terms of findings. For example, Cools and Creemers (2013) showed that different ways of acquiring weather information did not influence the individual's behavioural adaptation, whilst Kilpeläinen and Summala (2007) study, for example, highlighted the significant influence of acquiring weather forecasts on car drivers' travel plans. Sabir (2011) found that seasonal dummies were found as significant factors that influenced the use of all travel modes, whilst Khattak and Palma (1997) demonstrated otherwise.

The way in which these studies represented/measured weather conditions, different geographical characteristics of the study areas and the different observed periods of the dataset(s) may contribute to these inconsistencies. Furthermore, most of the previous studies also ignored the interactions among the individual's activity–travel indicators; hence, their reported weather influences on each specific activity–travel indicator in these previous studies may be less straightforward, since the role of weather on one activity–travel indicator would have an indirect influence on another activity–travel indicator and vice versa. Ignoring these interactions would lead to a biased conclusion in interpreting the impact of weather on individuals' activity–travel patterns.

Thus, this paper aims to analyse the impacts of weather variability on the individual's daily activity–travel engagement, taking into account the relativity of the impacts of weather variability and also how these changes influence the interactions of the individual's daily activity–travel patterns. For example, this will enable us to directly measure the effect of a given weather variable, e.g. precipitation, on each activity travel indicator whilst taking into account the indirect effect through other activity travel indicators (mediation variables). In this paper, weather variability was separated into a monthly variation (long term impact) and a daily variation (short term impact). Structural equation models were further developed in order to examine the direct and indirect impacts of weather parameters to the interactions of the individual's activity–travel indicators, including daily activity duration, trip generation (number of trip chains and trips per day per individual), daily travel time and walk/cycling mode share. The model results will reveal to what extent the weather effects are due to direct/indirect effects. It is expected the indirect effects are not trivial and may play an important role. Besides, the model results will also disentangle the effects of climate (long term impact) and weather (short term impact) as well as their interaction effects.

The next section provides a literature review on the impacts of weather characteristics on the travel behaviour indicators. Then the datasets used in this paper will be described. This is followed by presenting the proposed model structure for both commuters and non-commuters, respectively. Following on, estimation results from both models are interpreted and compared. Finally, this paper concludes by summarizing the direct and total effects from both the weather and socio-demographic variables.

## 2. The weather variability and individual travel choices

In the last decade, there has been a significant increase of body of knowledge that investigates the impacts of weather on individual travel behaviours. Mainly this was triggered by the increased weather uncertainty and more frequent occurrences of severe weather conditions which have caused major disruptions on transport infrastructures and cost hundreds of millions to both travellers and businesses. A study from France showed that adverse weather was one of the main reasons

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