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Geographic heterogeneity in cycling under various weather conditions: evidence from Greater Rotterdam

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ABSTRACT

With its sustainability, health and accessibility benefits, cycling has nowadays been established on research and policy agendas. Notwithstanding the decision to cycle is closely related to local weather conditions and interwoven with the geographical context, research dealing with both aspects is scarce. On the basis of travel diary data, we assess the association of three weather conditions, namely air temperature, wind speed, and precipitation, on cycling trips for leisure and commute purposes for the Greater Rotterdam area, the Netherlands. Besides region-wide logit models and autologistic regressions, place-specific associations of weather conditions are explored through geographically weighted logit models. Considering the entire Rotterdam area, results confirm significant weather effects on cycling while highlighting the necessity to model the residents' locational component. When the confounding effects of individual and household characteristics are controlled, a key finding is that weather effects appear to vary across space, specifically between the more densely settled central environments and the surrounding lower-density areas. Additionally, the results show differences between leisure and commute trips, in which leisure trips appear to be more weather sensitive and show more pronounced spatial patterns.

1. Introduction

Over the last decade, scientific as well as societal interest in climate change adaptation and mitigation has risen extensively. Although uncertainties exist, renewed climatological research reveals evidence for global temperature rise, changes in precipitation patterns, and increased frequencies of extreme weather phenomena (e.g., IPCC, 2007). 'Affecting' as well as 'being affected by', the transport sector is evidently related to climate change in a complex manner (Koetse and Rietveld, 2009; Böcker et al., 2013). In this regard, sustainable, healthy and accessible active transport modes like cycling, recently received a great deal of interest in transport geography and transport studies (e.g., Buehler and Pucher, 2010; Aldred, 2013; Heinen et al., 2013). The effects of weather on these desirable, but also weather-exposed, active transport modes compared to motorised transport are of particular interest. Findings generally indicate warm, calm, dry or sunny weather to stimulate cycling, while cold, wet, windy or cloudy weather have reverse effects (e.g., Müller et al., 2008; Koetse and Rietveld, 2009; Böcker et al., 2013). Recreational trips are typically more affected than utilitarian trips (e.g., Hanson and Hanson, 1977; Nankervis, 1999; Bergström and Magnussen, 2003; Sabir, 2011; Tin Tin et al., 2012).

While many of these contributions control for various confounders (e.g., socio-demographic or household characteristics), the locational component and the spatial variations in weather effects on behavioural outcomes have been largely underexplored. Some empirical results demonstrate different effects of weather on cycling between different spatial settings (e.g., Brandenburg et al., 2004; Phung and Rose, 2008; Thomas et al., 2013). However, so far only limited use has been made of detailed local spatial variation beyond the level of predefined or administrative units and as a consequence significant place-specific associations remain unclear. Such place-specific insights could help policy makers to set up appropriate planning provisions and formulate context-specific policies.

To address these shortcomings, this paper aims to analyse the spatial variation in weather effects on cycling. The analysis draws on unique travel diary data amongst 950 Greater Rotterdam respondents, geo-referenced by residential location, which is coupled to weather data from a local weather station. The first objective is to analyse the effects of air temperature, wind speed, and precipitation on commute as well as leisure cycling per person per day utilising region-wide logit models accounting for

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geographically correlated decision patterns. The second objective is to explore whether and how these effects differ across space. Hereto, we complement the region-wide models with place-based spatial varying coefficient models (i.e., geographically weighted logit models; GWLM), frequently used in housing (e.g., Helbich et al., 2014) and health studies (e.g., Chi et al., 2013), but a fairly new approach in the transport domain (e.g., Wang and Khattak, 2013). The paper is organised as follows. While Section 2 briefly reviews the literature, Section 3 outlines the research design. Section 4 discusses key results. Finally, Section 5 highlights major conclusions and outlines future research avenues.

2. Literature review

To better understand the potential spatial differences in weather effects on cycling, this section elaborates on theoretical insights regarding urban microclimates and empirical findings regarding spatially differentiated weather effects on cycling. Essential microclimate processes are highlighted in Fig. 1, however, for more elaborative discussions see Stewart and Oke (2012) and Theeuwes et al. (2014). During daytime, urban canyons – i.e., areas between buildings facades – may heat more quickly than surrounding lower density or natural areas due to multiple reflections of solar radiation (a) and the absorption of heat in building surfaces (b), although these processes may be counteracted when urban canyons receive considerably less direct solar radiation due to building shadows (c). In contrast, natural areas reflect more of the radiation back into sky and additionally cool due to evapotranspiration – i.e., vegetation's transpiration and water evaporation (d). During nighttime, urban canyons cool much less than natural areas, due to limited sky view (f versus e), and solar energy storage in building surfaces (b). In addition to altering temperatures, urban geometries may also affect wind as well as precipitation patterns. As buildings form obstacles to wind and precipitation, densely built-up areas generally offer more shelter than more open and exposed rural areas. However, tall freestanding buildings direct relatively strong wind caught at higher altitudes downwards and potentially creates uncomfortable drafts and gusts at street level (Blocken and Carmeliet, 2004).

The meaning of these theoretical microclimate differences for cycling or other outdoor activities is shown in several studies. Their findings are either directly or indirectly related to differences in exposure to weather between different areas. A few studies link spatially differentiated weather effects directly to physical attributes of the built environment. For instance, Miranda-Moreno and Nosal (2011) find that the negative effect of rain on cycling is more than twice as strong for a bicycle path connecting a low-density residential area, than for a path connecting a less weather-exposed dense residential area in Montreal (Canada). For Melbourne, Australia, Phung and Rose (2008) report that weather-exposed cycling trails along the bay have a relatively high optimal riding temperature of 32.5 °C (compared to 28 °C for other investigated trails) and are, due to its weather exposure, exceptionally sensitive to precipitation and wind speed. Similarly, Nikolopoulou and Lykoudis (2007) analyse the effects of thermal conditions and wind speed on pedestrian activity at a seashore boulevard and a sheltered inner-city plaza in Athens, Greece. Although looking at pedestrians, their findings may also be indicative for other weather-exposed travel, such as cycling. They find that thermal conditions have a positive effect on attendances in winter, particularly in the sunlit parts, and a negative effect in summer. Due to its cooling effect, higher wind speeds increase the percentage of people in the sun, but nevertheless negatively affect overall attendance. The associations appear to be much stronger in the exposed seashore plaza than the inner-city plaza.

Other studies attribute observed spatial differences to the way places and routes are used and by whom. Studies from Vienna, Austria (Brandenburg et al., 2004), Melbourne (Phung and Rose, 2008), and the Netherlands (Thomas et al., 2013) find large weather effects on paths primarily used for recreational purposes and paths used at off-peak times, compared to paths used primarily for commuting and paths used at peak times. Brandenburg et al. (2004), additionally, find differences in recreation cyclist counts between two recreational areas. One area has most of its visitors living nearby, which results in less sensitivity to cloudy or slightly rainy weather. For the other area, visitors have to cycle further, in which case cyclists are not only exposed for a longer period of time, but also cloudy or slightly rainy weather brings in more uncertainty, which reflects in a stronger negative association with

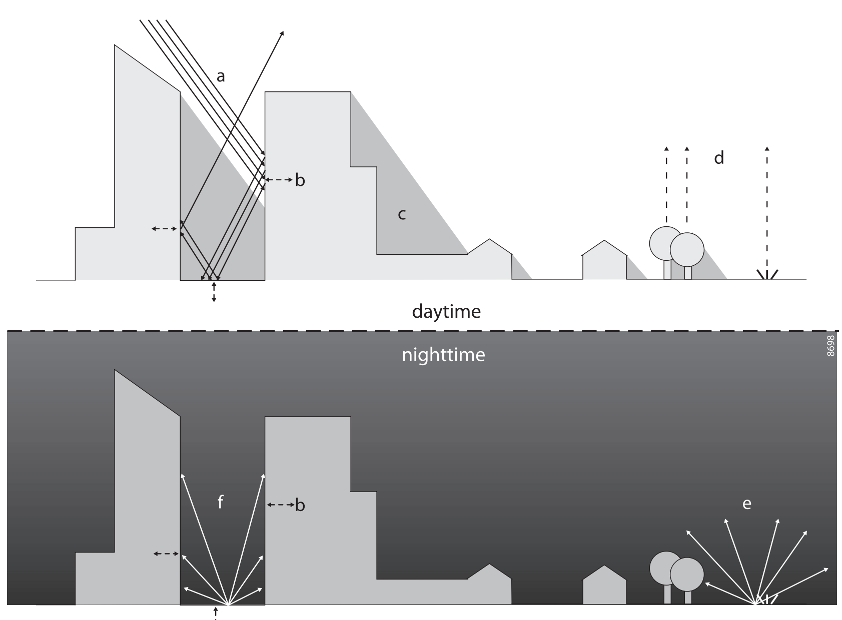

Fig. 1. Urban microclimate processes (individual letters are explained in the text).