

Spatial and temporal heterogeneity in cycling speed: weather's effects on cycling speed

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Cycling is sensitive to weather since it is an active transport mode, and cyclists are exposed to the air. Weather's influence on cycling tends to increase with climate change as daily weather conditions become extreme, and this can be a big challenge in promoting bicycle usage. Therefore, some studies examined how weather affects people's daily mode choice and cycling trip generation. Generally, they adopted the average or maximum daily weather conditions and found that cold, rainy and windy weather conditions decrease cycling usage (Böcker et al., 2013; de Kruijf et al., 2021; Helbich et al., 2014; Nahal and Mitra, 2018; Tin Tin et al., 2012; Zhao et al., 2018). However, they cannot reveal the extent of difficulty and its variation because of weather conditions during cycling. The reason is twofold. First, weather conditions vary during a day and even during a trip. For example, precipitation can start suddenly, and its rate constantly varies. It means that the average daily weather value cannot reflect conditions during cycling. Second, mode choice and trip generation do not include behaviour changes during a ride. Understanding this difficulty extent is important, since on the one hand it tells the detailed influence of weather on cycling, and on the other it can help efficiently formulate policies to mitigate this influence and provide better cycling environments.

By linking the cycling speed and weather conditions at different places and times, it is possible to detect the burdens caused by different weather on cycling. Cycling speed partially reflects the magnitude of resistance that cyclists encounter during a trip, and normally cycling speed decreases with the increase in resistance. Meanwhile, weather conditions are a source of resistance, which influences cycling speed. It says that we can understand the difficulty created by weather by testing weather conditions' influence on cycling speed variation during a trip after controlling for other influential factors. However, this topic receives less attention.

Weather's influence on cycling speed is not immutable but changes across seasons and places. Regarding seasons, temperatures have large season contrasts, and cyclists' feelings towards temperatures vary during different seasons. In summer, cyclists may feel uncomfortable and be negatively affected by a higher temperature, but it is likely to positively influence cyclists in winter. Regarding places, weather's influence on cycling behaviour changes across places for two reasons. First, land-use at a place affects its climate, and second, some types of land-use can serve as shelters to mitigate the influence of weather on cycling. Although seasonal and spatial differences provide more insights into the relationship between weather and cycling behaviour, only a few studies tested them (Helbich et al., 2014; Zhao et al., 2018).

Therefore, this study aims to test the influence of weather conditions on cycling speed variation, considering weather's different influences across seasons and places. To this end, we use a whole year-round cycling dataset collected by GPS devices in Utrecht province, the Netherlands. GPS devices record a tracking point with positions and timestamps every 10 seconds, so cycling speed can be calculated at every tracking point to show speed variation. Weather conditions, such as temperature, humidity, precipitation and wind, are recorded every 10 minutes. We first estimate a geographically weighted

model to check the existence of the spatial heterogeneity of weather's influences on cycling speed. Then multilevel models are estimated to examine the weather's influence, and interaction terms between weathers and seasons as well as between weathers and land-use types are included to examine how weather's influences vary at different seasons and places.