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Quantifying the value of a clean ride: How far would you bicycle to avoid exposure to traffic-related air pollution?

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ABSTRACT

While there is widespread acceptance of the health benefits of bicycling, recent research has highlighted that the benefits may be partially offset by the potential adverse health impacts as a result of bicyclists' exposure to traffic-related air pollution. Using a stated preference experiment, data from 695 commuter cyclists was compiled through a web-based survey and analyzed using a random utility approach to evaluate whether and to what extent cyclists are willing to trade-off air pollution exposure with other attributes such as roadway characteristics, bike facilities, and travel time. Mean and maximum concentrations of nitrogen dioxide (in parts per billion or ppb), a common marker of traffic-related air pollution, were used as the attributes to represent the externality (ranging from 5 to 60 ppb). Empirical results indicate that travel time and traffic volume remain the most important attributes for commuter cyclists in their route decision. We also computed a unique marginal rate of substitution called "Value of Clean Ride" (VCR). For mean exposure, the VCR is: 0.72 min/ppb and for maximum exposure, the VCR is: 0.25 min/ppb (95% distribution: −0.16, 0.67). This essentially suggests that if an alternative route was available with an average nitrogen dioxide concentration that is lower by 5 ppb (a realistic goal in light of the high spatial variability in air pollution within urban areas), then cyclists would be willing to take it if it added no more than about 4 min to their travel time. We also observed that cyclists who received information on short-term impacts of traffic-related air pollution tended to be more concerned with avoiding maximum exposure.

1. Introduction

The reliance on private automobile for travel has resulted in a vast array of negative externalities – traffic congestion, air, and noise pollution. Transportation professionals and metropolitan planning organizations are challenged to find potential solutions to reduce vehicle use while promoting environmentally friendly and physically active transportation alternatives. Towards this end, transportation demand management strategies that encourage active transportation, particularly bicycling, for both commuting and short distance utilitarian trips are encouraged (Eluru et al., 2008; Mailbach et al., 2009; Rojas-Rueda et al., 2011). For instance, in addition to investing in infrastructure and bike share programs, local governments often sponsor and endorse events such as "bike to work day" or "bike month" to promote bicycle use among the general public (Ahmed et al., 2013). The adoption of bicycling has the potential to reduce congestion and air pollution (and greenhouse gas emissions) in well-connected dense urban regions while offering individuals a low-cost travel option that provides personal health and fitness benefits (Wen and Rissel, 2008). In fact, there is evidence to suggest that the health benefit is one of the primary stimuli for people wanting to participate in active commuting

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(Anable and Gatersleben, 2005).

While there is widespread acceptance of the potential health benefits of bicycling, recent research has highlighted that the benefits may be partially offset by the potential adverse health impacts as a result of exposure to traffic-related air pollution. In fact, it has been reported that in some cases, cyclists may be exposed to higher concentrations of traffic-related air pollutants than other road users owing to their close proximity to traffic, high respiration rates, and longer journeys (Panis et al., 2010; Bigazzi et al., 2016; Broach and Bigazzi, 2017). In addition, data suggest that exposure to traffic-related air pollution during cycling may contribute to altered autonomic regulation of the heart (Weichenthal et al., 2011), increased oxidative DNA damage (Vinzents et al., 2005), and acute myocardial infarction (Peters et al., 2004). The exposure is particularly of concern for the vulnerable segments of the community including children, pregnant women, seniors, and individuals with pre-existing respiratory conditions such as asthma (Sharker and Karimi, 2014; McLaren and Williams, 2015).

Given growing evidence of the adverse health effects of traffic-related air pollution on bicyclists, there is a need to provide solutions to reduce exposure. While it may be impossible to entirely rid urban environments of anthropogenic air pollutants, one potential solution could be supplying bicyclists with a route planning tool that would inform them of a "lower exposure alternative" (Hertel et al., 2008; Sharker and Karimi, 2014). This tool could be especially beneficial to those who regularly spend more than 45–60 min on daily commutes. For some users, altering their route may result in increasing their daily commute by only a few minutes, but could reduce their long-term commute-time pollution exposure significantly. This was demonstrated by Hatzopoulou et al. (2013) using origin-destination (O-D) survey data for more than 2000 cycling trips in Montréal, Canada. On average, exposures to ambient Nitrogen dioxide (NO_2) were estimated to be lower by 0.76 ppb (ppb) (95% CI: 0.72, 0.80) relative to the shortest route, with decreases of up to 6.1 ppb for a single trip. In general, the benefits of decreased exposure were achieved with little increase (less than 1 km) in the overall route length.

The tool provides clear evidence of benefits from assessing route choice options in the context of exposure. However, bicycling route choices are seldom made in isolation with only emphasis on exposure. In this context, a critical question to ask is, what impact, if any, will such exposure information have on bicyclists' route choice decisions? Will they be willing to make trade-offs in terms of travel time or distance or other roadway attributes to reduce their exposure to traffic-generated emissions? There has been scant research investigating the issue. The emphasis of our research effort therefore is to bridge the research on bicycling route preferences with emerging research on examining the influence of air pollution on travel behavior. More specifically, we attempt to investigate the influence of exposure information on route choice while controlling for the other major dimensions (such as travel time, roadway characteristics, traffic characteristics, and bike facility characteristics) that influence the decision process. The study employs a stated preference (SP) elicitation approach for individual level route choice preference data compilation. The data compiled is analyzed using a random utility approach to evaluate whether and to what extent individuals are willing to trade-off exposure with other route attributes. In addition, a policy analysis exercise is also conducted to illustrate the applicability of the proposed approach.

The remainder of the paper is organized as follows. A discussion of the relevant literature is presented in Section 2. In Section 3, the materials and methods are described in detail including survey design, experimental setup, survey administration, and econometric approach used in the analysis. Section 4 provides the model estimation and trade-off analysis results. Section 5 concludes the paper and presents directions for future research.

2. Highlights of previous research

To the best of authors' knowledge, there has been no earlier work examining the influence of exposure to traffic related air pollution on bicycling route choices. Hence, we focus our review along two dimensions: (1) studies exploring bicycle route choice preferences and (2) earlier work examining the impact of air pollution in the context of travel decisions.

2.1. Route choice preferences

There is a vast body of literature examining the impacts of different exogenous factors on cyclist's route choice preferences (Sener et al., 2009 provides a detailed review). Of particular interest to our research are studies conducted to evaluate underlying behavioral mechanisms that actually guide the bicyclist's decision process. The majority of these studies have examined preferences for commuter cyclists and/or recreational cyclists. However, some have investigated preferences of would-be or potential cyclists (Su et al., 2010; Winters et al., 2011). The data elicitation approaches considered include stated preference and revealed preference (RP) techniques with a clear preference for the SP approach (for SP studies see Stinson and Bhat, 2003; Hunt and Abraham, 2007; Tilahun et al., 2007; Sener et al., 2009; Caulfield et al., 2012; Chen and Chen, 2013; for RP studies see Menghini et al., 2010; Hood et al., 2011; Broach et al., 2012; Yeboah and Alvanides, 2015). This approach allows the analyst to explore various attributes that affect route choice behavior, most often unavailable under real world conditions. In an SP survey, routes that have varying attribute levels across multiple attributes can be easily generated with rigorous experimental design. On the other hand, employing RP data would significantly limit the potential routes, route attributes, and attribute levels that can be explored in the analysis. The approaches employed for data analysis include ordinary least squares (OLS), binary logit (BL) or multinomial logit (MNL), mixed multinomial logit (MMNL), multinomial probit (MNP) models, and heuristic approaches.

These earlier studies provide valuable insights into the multitude of factors impacting route evaluation and subsequent route choice. For instance, for commuter cyclists (individuals who use the bicycle for commuting to and from work or school), travel time has the paramount importance with regards to their route choice decision (Stinson and Bhat, 2003; Sener et al., 2009). That is, they are more likely to choose the quickest route to reach their destination. However, commuter cyclists are willing to incur additional