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Exploring the trade-off between greenhouse gas emissions and travel time in daily travel decisions: Route and departure time choices

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A B S T R A C T

This study analyzes the problem of conflicting travel time and emissions minimization in context of daily travel decisions. The conflict occurs because the least travel time option does not always lead to least emissions for the trip. Experiments are designed and conducted to collect data on daily trips. Random parameter (mixed) logit models accounting for correlations among repeated observations are estimated to find the trade-off between emissions and travel time. Our results show that the trade-off values vary with contexts such as route and departure time choice scenarios. Further, we find that the trade-off values are different for population groups representing male, female, individuals from high income households, and individuals who prefer bike for daily commute. Based on the findings, several policies are proposed that can help to lower greenhouse gas (GHG) emissions from transportation networks. This is one of the first exploratory studies that analyzes travel decisions and the corresponding trade-off when emissions related information are provided to the road users.

Motivation and background

Transportation sector consumes a large portion of fossil fuel and acts as a significant contributor of greenhouse gas (GHG) emissions. This closely ties transportation sector with the global challenges: climate change and energy security, and underscores the need for effective strategies to minimize emissions and energy consumption from road transportation. In 2011, 27% of total GHG emissions in the U.S. comes from transportation end-user sector and passenger vehicles are responsible for 43% of this total share (EPA, 2013). Emissions from on-road vehicles depend on several attributes that include: fleet composition, age distribution of the vehicles, fuel type, atmospheric attributes, operational characteristics, congestion, and travel choices made by the road users. Travel choices can be short term (e.g., mode of transport, route, departure time, etc.) or long term (e.g., car ownership, residential location, telecommuting, and so on). Previous studies (Ahn and Rakha, 2008; Guo et al., 2012; Ahn and Rakha, 2013; Boriboonsomsin et al., 2012) indicate that route choice decisions can have significant impact on the amount of emissions and energy consumptions in daily trips. Moreover, researchers (Hensher, 2008; Stanley et al., 2011) underscore the effect of mode and departure time choices on travel related GHG emissions. This research studies these two important dimensions of the short-term travel decisions: route and departure time choice for daily travel.

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Recent advances in information and communications technology (ICT) allow the road users to obtain, process, and use information in their travel decision making processes. Providing information on travel time and emissions for a travel alternative (e.g., route and departure time choice) can influence the travel decision (Mahmassani, 1990; Ben-Akiva et al., 1991; Gaker et al., 2011). Studies show that the travel alternative with least emissions does not always coincide with the travel alternative with minimum travel time (Nagurney, 2000; Lin and Ge, 2006; Ahn and Rakha, 2008; Zhang et al., 2010). The non-monotone relationship between speed and emissions leads to conflicting travel time and emissions objectives for the road users (Ahn and Rakha, 2008; Yin and Lawphongpanich, 2006; Aziz and Ukkusuri, 2012). If a user is willing to make a travel decision that leads to lower emissions compared with the least travel time route, she may have to travel additional minutes. A route with lower emissions can have excessively high travel time that may not be acceptable to most travelers. Consider the case, an alternative route exists that offers higher emissions compared with the least emission route (but lower than the least travel time option) and *acceptable* travel time compared with the least travel time route. The notion of *acceptable* travel time is heterogeneous and it varies across population and decision contexts. Our particular interest is to explore the level of acceptability in terms of the trade-off between the travel time and emissions. The next two subsections explain the problem with specific contexts.

Route choice scenario

Table 1 illustrates an example of route choice scenario. The CO_2 emissions are obtained by following EPA guidelines (also see Section 3.2) and considering congestion effects.

The route with least emissions (option B) has 17 min of travel time, which is a significant increase from the least travel time route A (the most attractive option to the users in terms of minimizing travel time). An individual does not necessarily desire higher emissions for the trip, however an increase of 7 min of travel time (option B) may not be acceptable for her. Route $\widehat{B}$, with travel time 3 min higher than route A and emissions 3 lbs higher than route B, could be a choice for a user who is willing to minimize emissions within acceptable additional travel time for the trip. Our hypothesis is that, users will perceive path B as a significantly high travel time route and may not switch to it. However route $\widehat{B}$ could be a choice with acceptable trade-off between travel time and emissions for a certain group of users. The research questions are as follows:

- **Q1** :*What is the likelihood that a user will choose a route with less emissions (not necessarily the least-emission route) over the least travel time route?*
- **Q2** :*How to find the trade-off between emissions and travel time accounting for the variation of taste across the users?*

It is intuitive that the trade-off between emissions and travel time is not homogeneous. The trade-off values will be different for different types of road users. Again for the same person, an additional 5 min may not be acceptable in the morning commute, however may be acceptable in work-to-home return trip. Therefore, it is necessary to account for heterogeneity across individuals in the population and within the same individual for different trip types.

Departure time choice scenario

Table 2 shows an example of departure time choice scenario. Assuming flexibility in the departure time choice an individual can leave earlier or later from her commute from work to home. Departing at a later time can have the benefits of reduced travel time because the congestion may become light. Also, the flow becomes smooth as congestion dissipates and accordingly the speed variations are lower. This results into lower emissions for the trip (Barth and Boriboonsomsin, 2008; Barth et al., 2004). Table 2 shows that, delaying the departure time by five minutes reduces the travel time by one minute, whereas the CO_2 emissions are reduced by 4 lbs. This is because the speed variation becomes smaller (congestion dissipating vs. congestion free) in the latter case. Considering 20 min schedule delay (difference between preferred and actual departure) may not be acceptable to all users. Therefore, we also have a trade-off phenomenon in this case.

The research questions of interest are:

- **Q3** :*What is the likelihood that a user will adjust her departure time to have less emissions (compared to the least schedule delay option) in the trip?*
- **Q4** :*How to find the trade-off between schedule delay (departing early or late) and emissions accounting for the heterogeneity across the users?*

Table 1
Route choice scenario.

Route	Travel time (minutes)	Emission (lbs of CO_2)
A	10	20
B	17	9
$\widehat{B}$	13	12