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Quantifying the environmental impacts of increasing high occupancy vehicle lanes in the United States

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ABSTRACT

To what extent will increasing High Occupancy Vehicle (HOV) lane-kilometer incentivize carpooling and reduce emissions of air pollutants and greenhouse gases? To answer these questions, we develop a multiple regression model relating HOV lanes and other socioeconomic factors to carpooling propensity in all 50 U.S. states and the District of Columbia, then calculate the extent to which increasing HOV lane-kilometers would lead to reductions in carbon dioxide equivalent (CO_2e) and major air pollutants across the U.S., by state. Increasing HOV lane extent has the greatest potential to reduce annual CO_2e in the District of Columbia, followed by Hawaii and New York. The smallest potential is found in states with the lowest population density, led by North Dakota. We then explore the extent to which recommendations made at one level of data aggregation (that of individual states) may be valid for another level, such as individual counties. The only state with sufficient data available to disaggregate the model to the county level is California, where we found a lower potential for state-wide CO_2e emission reductions under the county-level model as compared to the state-level model (0.69% as compared to 1.08%, under the same hypothetical scenario), albeit with significant differences in emission reduction potential between counties with higher vs. lower population densities. This analysis demonstrates the potential to generate generalizable insight into the magnitude of vehicle emission reductions that might be achieved through expanding HOV lanes, and highlights the importance of data disaggregation in identifying the optimal locations for potential reductions.

1. Introduction

In the United States (U.S.), greenhouse gas (GHG) emissions from the transportation sector have grown faster than any other sector over the last two decades (EPA, 2013). Transportation is responsible for nearly one-third of total emissions in the U.S., among which over one-third can be attributed to passenger cars and another one-third to light-duty trucks (Salari and Javid, 2017). Reducing vehicular emissions has multiple benefits; in addition to reducing the contribution of transportation to global climate change (Arce et al., 2014; Ghommem et al., 2012; Khatiwala et al., 2013), it can also potentially reduce air pollution, and conserve finite resources of oil and other fossil fuels (Javid et al., 2014).

Long-term efforts to reduce transportation-related emissions focus on alternative energy technologies (Javid and Salari, 2016; Salari and Javid, 2016a). Short-term, however, on-road transportation policies could play a key role in reducing carbon and other

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GHG emissions via a wide range of strategies that can be classified into three groups. As described in Javid et al. (2014), the first is to *reduce* GHG emissions per passenger kilometer using strategies such as reducing engine weight (Skippon et al., 2012) or high efficiency vehicles (Yang et al., 2009). The second is to *avoid* unnecessary energy consumption by promoting other modes of transportation such as teleworking (McCollum and Yang, 2009), public transport (McCollum and Yang, 2009; Stanley et al., 2011), toll road, parking charges (Chapman, 2007), cycling and walking, and carpooling (Javid et al., 2016; Stanley et al., 2011). The third is to *replace* fossil fuels with low-emission alternative fuels such as alternative fuel vehicles (Javid and Nejat, 2017; Leighty et al., 2012). In the *avoid* category, High Occupancy Vehicle (HOV) lane refers to any special lane designated for exclusive use by high-occupancy vehicles including carpools, vanpools and buses. These lanes can help mitigate GHG emissions by promoting carpooling (vehicles with two or more passengers), reducing the number of vehicles on roads, and relieving traffic congestion (Javid, 2016).

This study focuses on the contribution of HOV lanes to *avoid* strategies, specifically exploring the role of HOV lanes in influencing carpooling rates, and quantitatively evaluating the effects of carpooling on carbon dioxide equivalent (CO_2e) and criteria air pollutants emissions. We first develop a series of multiple regression models to investigate and identify the impact of the HOV lanes and other potential infrastructure and socio-economic factors on carpooling propensity in the U.S. Next, we estimate the emission reductions that could result from an HOV expansion scenario that would incentivize carpooling. We integrate multiple datasets to demonstrate how this model is able to quantify the impacts of HOV lanes on carpooling propensity and emission mitigation from the county level, where decisions are typically made, up to the state and national level where policies are assessed. The resulting modeling framework has a wide range of applications, including evaluating the effectiveness of carpooling, and assisting city authorities, policymakers, and transportation planners in optimizing marketing and infrastructural investments. To that end, we first summarize the existing literature, then describe our carpool estimation model and the research dataset. We next describe the emission model, and end with our conclusions, recommendations, and further avenues of research.

2. Previous research on carpooling strategies and benefits

Previous studies related to this study generally fall into two main categories: those that emphasize potential factors influencing carpooling propensity, and those focusing on the impacts of carpooling on fuel savings and emissions. In Table 1, we summarize the existing literature in these two categories, and describe them briefly below. A third group of studies explores the influence of rideshare collaboration challenges on carpooling propensity. For example, Correia and Viegas (2010) simulated commuter trips to analyze the impact of time-space constraints on carpooling potentials; other similar studies that explore the influence of location and time schedule on carpooling propensity and optimization include Teodorović and Dell'Orco (2008), He et al. (2014), and Hussain et al. (2016).

Previous research on carpooling propensity focused on the demographics of carpooling. The geographic scope of such studies ranges from an entire country (Jacobson and King, 2009), to a region (Cho et al., 2013; Devarasetty et al., 2014) or a city (Caulfield, 2009; Correia and Viegas, 2011; Dubernet et al., 2013), while survey datasets range from small (Correia and Viegas, 2011; Devarasetty et al., 2014) to large (Caulfield, 2009; Jacobson and King, 2009) together with simulation data (Cho et al., 2013; Dubernet et al., 2013; Galland et al., 2014). Methodologies consist of a wide range of statistical models and simulations. The majority of these adopt a logit Discrete Choice Model (DCM) to examine intentions to carpool. Some studies argue that income (Correia and Viegas, 2011; Devarasetty et al., 2014) and age (Correia and Viegas, 2011) significantly influence individual's decision to carpool. More specifically, Correia and Viegas (2011) found that younger individuals in lower income level households are more willing to carpool in Lisbon, Portugal. In contrast, Devarasetty et al. (2014) indicated that higher income travelers are more likely to carpool based on data from Denver, Miami, and San Diego. Investigating household characteristics, Caulfield (2009) found couples and households with only one vehicle to be more likely to rideshare. Correia and Viegas (2011) found carpooling is not associated with gender, in contrast to Caulfield (2009), who found females to be more likely to rideshare. Devarasetty et al. (2014) indicated that socio demographic factors are better predictors of carpooling propensity, compared to psychological factors. Among cost-related factors, per vehicle-trip costs such as parking spots (Jacobson and King, 2009), travel time, and tolls (Devarasetty et al., 2014) have also been found to positively affect carpooling rate. Correia et al. (2013) investigated the influence of attitudes on carpooling propensity using a stated preference survey in Lisbon, Portugal. They found that the success of carpooling strategy depends on personal attributes including gender, age, income, and education, as well as the interaction between different persons. The effects of psychological factors, however, are not easy to determine in a large-scale analysis such as we describe here.

The extent to which carpooling reduces vehicular emissions has been tested by a few studies. Jacobson and King (2009) used a mathematical model to determine fuel savings due to increases in ridesharing in the U.S. They found that for one additional passenger per 100 vehicles, annual CO_2 emissions would be reduced by almost 7.2 million tons. This annual saving could be increased to 68.0 million tons for one additional passenger in every 10 vehicles, if no additional travel is required to pick up passengers. Focusing on an individual town, Caulfield (2009) found that carpooling can save 12,500 tons of CO_2 annually in Dublin, Ireland. Another study by Concas and Winters (2015) found that carpooling trip-chaining behavior and its effects on peak-period congestion could reduce vehicular emissions.

Lessons learned from the literature indicate that factors affecting carpooling propensity can vary substantially from one study to the next. This inconsistency could be due to several facts including differences in methods (e.g., simulation, regression analysis, structural equations), included variables (socio-demographics, economics, and infrastructure), participant attitudes, regional specifications or extent of the study, and level of spatial aggregation. The choice of level of spatial aggregation (i.e. city, county, state, and country) depends on the availability of data and the objective of the study. Conclusions derived at one spatial scale may not be valid at another – an important point that is explored further in this analysis. Previous studies have not examined the effect of spatial scale