The Environmental Impacts of Carpooling in the United States

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Extended Abstract

Policies to reduce GHG emissions from road transportation encompass a wide range of strategies *(1–3)*. Common examples of the policies include high efficiency vehicles *(4)*, travel demand management (flexible hours, teleworking) *(3)*, shifting from personal car to public transport *(3, 5)*, alternative fuels (hydrogen, electricity, biofuel) *(4, 6)*, various types of taxation (toll road, parking charges) *(7)*, reducing engine weight *(8)*, zero-carbon alternatives (cycling and walking) *(5, 7)*, and High Occupancy Vehicle (HOV) lanes *(5, 7)*. All of the strategies for reducing emissions can be classified into three groups: *Reduce* (Reducing GHG emissions per passenger kilometer), *Avoid* (Avoiding unnecessary energy consumption and promote other modes of transportation), and *Replace* (replacing fossil fuels with low-emission alternative fuels) as described in *(9)*.

This study focuses on the contribution of High Occupancy Vehicle (HOV) lanes and carpooling to *Avoid* strategies, specifically exploring the role of HOV lanes in carpooling decisions and quantitatively evaluating the effects of carpooling on air pollutants and carbon dioxide equivalent (CO_2e) emissions. 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.

In this study, we first develop a set of statistical models to investigate the impact of the HOV lanes and other potential factors on carpooling behavior in all 50 states and the District of Columbia. Next, we estimate the average emission reduction that will occur as a result of carpooling in each state. The results of this analysis can help policymakers to optimize infrastructural investments by identifying locations that maximize the response of drivers to added HOV lane-kilometers.

Current literature provided rather limited evidence on how potential factors such as HOV lanes can affect carpooling behavior and how carpooling can influence the rate of emissions from passenger cars. Moreover, macro-level datasets have not been used very often to model the carpooling propensity within the states and compare vehicular emissions across the states. Therefore it is the objective of this research to bridge the current gap by utilizing the existing macro-level data.

Our analysis of carpooling propensity as a function of HOV lane availability aims to quantify the influence of multiple variables on carpooling rate in the states by developing a multiple regression model. We selected this approach as it provides a simple framework for investigating the relationship among a given set of variables. Potential factors influencing carpooling propensity can be classified into three main categories: infrastructural, cost-related, and socio-demographic factors. This paper explores 7 variables in these three categories that are assumed to affect carpooling behavior and employs several datasets to encompass these variables.

Carpool

We define independent variable as the rate of carpooling in each state. In this study, carpooling refers to share of carpoolers to work in total workers. The source datasets for this variable is the State Transportation Statistics (STS), released by the US Department of Transportation.

Infrastructure-related factors

One of the main independent variables in this study is the HOV lane infrastructure as it can contribute to the carpooling rate within a given state. We define the percentage of existing HOV lane-miles to the total road miles as one of the infrastructural variables. The data source for the HOV data is the 2008 HOV lane performance by the Federal Highway Administration. To the authors' best knowledge, this data is the most recent comprehensive data on HOV lanes. To be consistent with this dataset, all the other variables in this study are for 2008. The data source for the total mileage is the 2008 STS. Another infrastructure related variable is the public transit service. As an indicator of public transportation, we consider the percentage of the total public transit route-miles (rail and non-rail) to the total road miles as a variable in the model. The data for this variable is provided by the 2008 National Transit Database (NTD) report.

Cost-related factors

Reducing costs can be a contributing factor to carpooling propensity. We choose the average travel time to work as one of the cost-related variables in the model. Mean travel time to work for each state is provided by the 2008 STS. Moreover, changes in gas price may trigger the initiative to carpool *(10)*. This study uses the average gas price in the state based on the Energy Information Administration report.

Socio-demographics factors

This study has incorporated "average household size" and "average number of vehicles in the household" as the variables that are assumed to affect carpooling behavior. These variables are derived from the American Community Survey (ACS). Contribution of education level, income, and race to carpooling rate is investigated through Human Development Index (HDI). The HDI is a composite measure, which combines health, education, and income indices into a single measure on a scale of 0 to 10. The HDI variable in the model is compiled from Measure of America. For more information about this measure refer to (33).

Model

The variables described above were used to form the basis for a multiple regression model to assess their relevance to predicting carpool propensity by state, according to HOV lane-miles. All independent variables were first scaled and normalized. Based on the correlation coefficient matrix, average number of vehicles in household and public transit infrastructure in the state were negatively correlated (-0.76). Therefore, we exclude public transit variable, which has lower correlation coefficients with the dependent variable compared to number of vehicles in household. Since the focus of the study was the impact of the HOV lanes on the carpooling rate, we began with using all infrastructural explanatory variables as the core variables in model (1), then extended this framework to accommodate the cost-related variables in model (2), and socio-demographic characteristics in model (3), as described in TABLE 1.

Results for model (1) indicate that infrastructural variable HOV have a statistically significant impact on the carpooling rate, a positive impact of 0.447 (see TABLE 1, column 1). Results for model (2) highlight the fact that incorporating cost-related variables does not lower the significance of infrastructural variable, and HOV lane infrastructure remains highly significant in increasing the carpooling rate (0.393). In this model, travel time to work plays an important negative role in carpooling propensity (-0.314) that means the shorter the average trip to work, the higher will be the carpooling rate. However, gasoline price plays an important positive role in carpooling rate (0.331) and higher gasoline prices yield more interest in carpooling. Finally, when socio-demographic variables are added to model (3), the HOV lanes infrastructure variable at state level still plays an important roll in carpooling rate (0.322). Gasoline price remains highly significant (0.307). Interestingly, presence of socio-demographic variables in the model (3) eliminates the importance of travel time duration, while gas price is still highly significant in the model. Average number of vehicle in household does not have a statistically significant impact on carpooling rate; while average household size and HD index show significant impacts on carpooling rate (0.256 and -0.495 respectively). In order to determine multicollinearity problem in the model we employ variance inflation factor (VIF). Reported VIFs are all less than 10, indicating no multicollinearity among the explanatory variables (TABLE 1, last column).

TABLE 1 Carpool Propensity Models and Variables' VIFs

Variables	**Model (1)**	**Model (2)**	**Model (3)**	**VIF**
HOVLane	0.447*** (0.128)	0.393*** (0.131)	0.322*** (0.106)	1.871
TravelTime		-0.314** (0.119)	-0.076 (0.131)	2.864
GasPrice		0.331** (0.126)	0.307*** (0.093)	1.435
HHsize			0.256** (0.112)	2.107
HHvehicles			0.120 (0.119)	2.342
HDIndex			-0.495*** (0.091)	1.382
Constant	0.000 (0.127)	0.000 (0.110)	0.000 (0.077)	
Observations	51	51	51	
R^2	0.199	0.422	0.736	
Adjusted R^2	0.183	0.385	0.700	
Residual Std. Error	0.904 (df = 49)	0.784 (df = 47)	0.548 (df = 44)	
F Statistic	12.203*** (df = 1; 49)	11.434*** (df = 3; 47)	20.451*** (df = 6; 44)	

Numbers in parentheses are standard errors.
***Significant at the 1 percent level
**Significant at the 5 percent level
*Significant at the 10 percent level

According to model (3), if other variables are held constant, the carpooling rate would increase by 1.257% per additional 1% of HOV lane-kilometers in a given state. The most significant factor is gas price, which results in 2.332% increase in carpooling rate for any added dollar in gas price per gallon. Carpooling increases by 1.654% an additional person in the household. As HD index level in the state increases by one, the carpooling rate would decrease by 0.829%. One of main factors that positively correlated with the HDI index is education. It is found that educated peoples have more intention to drive alone and less carpool, which is the same result as what was concluded in *(11)*. Moreover, this index is positively correlated with income. Therefore, the results show that solo drivers are associated with higher income. This result was concluded in previous research on the demographics of carpooling *(12)*. In the next section the authors explore how changes in HOV lane-miles, as the only significant infrastructural factor in the carpooling propensity model, can affect emissions considering GWP in different states.

Emission Reductions

There are two main types of emissions associated with motor vehicles. First, GHG emissions, which contribute to climate change; Second, several types of emissions contribute to urban air pollution. Motor vehicles emit GHGs including carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) that contribute to climate change. Other pollutants include carbon monoxide (CO), nitrogen oxides (NOx), particulate matter with fewer than 10 and 2.5 microns diameter (PM_{10} and $PM_{2.5}$), volatile organic compounds (VOC). Two different models are used to calculate the two types of emissions.

To calculate the reduction in air pollutants the authors used the Environmental Protection Agency (EPA) emission factors. With regard to GHGs, motor vehicles mainly emit CO_2, however, N_2X and CH_4 are also partially included. CO_2 emissions are directly related to the VMT, while the rest are related to factors including vehicle speed, acceleration, type, weight, and load. In this paper the authors employ CO_2e to estimate the emissions of all the GHGs using the EPA Greenhouse Gas Equivalencies Calculator model. CO_2e is a measure used to describe GHGs as one measure based on their GWP[1].

This analysis calculates emission mitigation for two scenarios: a business as usual (BAU) scenario and an alternative scenario. The BAU scenario describes the variables as they were observed in 2008, while the expansion scenario describes variables in a developed HOV lane infrastructure, in which each state has increased its percentage of HOV lanes by 0.5 meters for every hour of total daily travel time to work[2]. Then we would expand the amount of HOV lanes in proportion to how much people drive, and we can see what difference in emission mitigation that makes across states. Model (3) is used to estimate the increase in the carpooling rate due to the alternative scenario in each state. The percentage of emission reduction for the expansion scenario compared to the BAU scenario is then calculated for both GHGs and the air pollutants.

The percentage reductions in annual CO_2e due to the alternative scenario are illustrated in FIGURE 1. The results show that District of Columbia stands out as showing the greatest potential to reduce annual CO_2e under the expansion scenario, by 4.53%. Increased HOV lane-kilometers in the next three states - Hawaii, New York, and New Jersey - have a moderate impact on reducing CO_2e by 1.64%, 1.37%, 1.35%, respectively. The rest of the states including Maryland, California, Massachusetts, Connecticut, and Rhode Island have lower influence on GHG emission mitigation by 1.13% to 0.68% of CO_2e reduction; however, they still contribute to climate change, as the cumulative impact is still significant. The smallest reduction belongs to North Dakota, South Dakota, and Montana by 0.02%, 0.03%, and 0.05% respectively, implying the incompatibility of this strategy with those states. The national annual reduction in CO_2e achieved by increasing HOV lane-kilometers base on the alternative scenario is estimated at 1.83 million metric tons, or approximately 0.16% of U.S. light-duty vehicles' emissions.

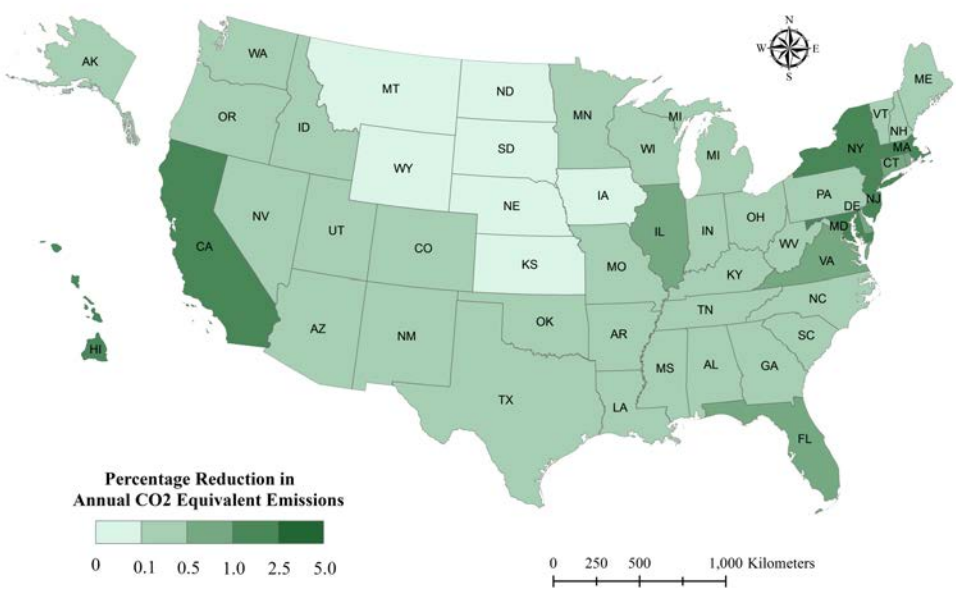

FIGURE 1 Percentage reduction in annual CO_2e for alternative scenario compared to BAU scenario.

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[1] The 100-year GWP for CH_4 and N_2X is 25 and 298 respectively (EPA).
[2] Total daily travel time to work is calculated by total number of workers by the average travel time to work.

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