INVESTIGATING THE EFFECTS OF TRANSPORTATION AND URBAN FORM VARIABLES ON PASSENGER TRAVEL CO_2 EMISSIONS: INTEGRATED DATASET AND ESTIMATION RESULTS

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ABSTRACT

To support the development of policies that reduce greenhouse gas (GHG) emissions by encouraging the use of efficient transportation modes, it is necessary to better understand the impacts that various urban form, transportation, and policy and regulation variables have on passenger travel related CO_2 emissions. This study presents the integration of a dataset from multiple sources to capture a suite of pertinent variables followed by the development of a statistical model of CO_2 emissions per capita as a function of various explanatory variables for 146 urbanized areas in the United States. The model takes into account the selectivity bias resulting from the fact that adopting policies and regulations aimed at reducing emissions in an urbanized area may be partly driven by the presence of environmental concerns in that area. The results indicate that selectivity bias is present and that population density, transit market share, lane-miles per capita, private vehicle occupancy, and average travel time, have a statistically significant influence on CO_2 emissions.

Keywords: Urban passenger travel CO_2 emissions, mode split, transit ridership, private vehicle occupancy, population density.

1. INTRODUCTION, MOTIVATION, AND ISSUES

Policies that encourage increased use of more efficient transportation modes, such as public transportation and high-occupancy private automobiles, are often considered one of several possible tools aimed at improving the sustainability of transportation. This study develops a statistical model that provides an important step towards quantifying the potential benefits that could be derived from such policies in terms of potential reductions in greenhouse gas (GHG) emissions. In order to do so, a comprehensive dataset is integrated by including data from multiple sources on the largest urbanized areas in the US in a manner that achieves consistency across the variables.

Passenger transportation related energy consumption and GHG emissions per capita in urbanized areas are expected to be dependent on the supply and demand characteristics of the multiple modes of passenger travel in these areas. Due to the efficient nature of public transportation and the greater flexibility in relying on multiple sources of energy, it is expected that, in general, an increased use of public transportation has potential advantages in reducing GHG emissions. Similarly, high private vehicle occupancy is expected to mitigate the negative impacts of the single-occupancy vehicle mode. In addition to understanding the effect of individual transportation mode choices, it is equally important to take into account the direct or indirect effect of government policies and regulations aimed at reducing GHG emissions.

Several studies have investigated the effects of urban form on automobile and energy use (Newman and Kenworthy, 1989; Lomax *et al*., 1994; Holtzclaw *et al*., 2002; Bento *et al*., 2005; Ewing *et al*., 2007; Glaesar and Kahn, 2008; Hankey and Marshall, 2010; Parshall *et al*., 2010; Karathodorou *et al*. 2010). In addition, some studies have investigated the relationship between GHG emissions and transportation (Cambridge Systematics, Inc , 2009; Kockelman *et al*., 2009; Maghelal, 2011; Southworth and Sonnenberg, 2011). Also, certain studies and workshops have recognized the potential importance of such variables and quantified their impacts in specific cases (Urban Land Institute, 2008; Brown *et al*., 2008; Massachusetts Institute of Technology, 2009; Schipper *et al*., 2010; University Transportation Research Center – Region II, 2010; Barla *et al*., 2011; Lindsey at al., 2011; Tiwari *et al*., 2011). A more detailed summary of these studies is presented in Mishalani *et al*. (2012a). To expand beyond these efforts, an explicit modeling and general quantification of the impact of the extent of transit and high-occupancy private automobile use on GHG emissions in the context of transportation supply, demand, policy, and regulation characteristics is needed to develop further insights in support of effective policy making.

In this study, only CO_2 emissions are examined since these emissions constitute 93.4% of the GHG produced in the transportation sector (Energy Information Administration, 2008) In addition, the CO_2 emissions focused on are those resulting from passenger travel and the impacts of travelers' choices within the confines of available infrastructure and existing urban form. Therefore, unlike other studies, freight transportation is not considered. Moreover, CO_2 emissions resulting from the construction of transportation infrastructure and the manufacturing of passenger vehicles (private and public) are outside the scope of this study.

The rationale motivating the marginal nature of the scope of this study is the objective to quantify the relative changes in CO_2 emissions that could result from policies and regulations that might alter existing conditions, a common scenario that policy-makers face.

2. DATASET, VARIABLES OF INTEREST, AND EXPLORATORY ANALYSIS

The integrated dataset was compiled from several different data sources, including the 2000 US Census (US Census Bureau, 2010), 2003 National Transit Database (NTD) (National Transit Data, 2010), and the 2003 Federal-Aid Urbanized Area (FAUA) database (Federal Highway Administration, 2010). Since each data source is collected on a difference schedule, data closest to 2000 was used. In addition, different data sources are collected at different levels of spatial aggregation. Data included in the integrated dataset were collected at the urbanized area (UZA), FAUA, and county level. The population and area variables are available across most data sources and, therefore, allow the development of meaningful adjustments to achieve consistency across the data sources where urban boundary definitions differ for the same urbanized areas. The result of the adjustments and integration effort was a consistent dataset of the variables of interest for the 146 most populous US cities. The full details of creating this cross-sectional dataset are described in Mishalani *et al.* (2012a).

The response variable of interest is the CO_2 emitted in an urbanized area as a direct result of passenger transportation using all modes of travel. The units used are metric tons CO_2/year and the determined CO_2 emissions are normalized by the total population of the urbanized area. The portion of this variable caused by private vehicles was derived by converting vehicle miles traveled by private automobiles to fuel use and, subsequently, to CO_2 emissions based on the distribution of vehicle fuel efficiency. CO_2 emissions resulting from public transportation was converted from the transit fuel consumption data reported in the NTD (Nation Transit Data, 2010).

The key explanatory variables considered in this study are transit share, transit service utilization, average vehicle occupancy, roadway lane-miles/capita, average travel time, population density, and the presence or absence of a vehicle emissions inspection program. The transit market share is represented by the ratio of transit passenger-miles traveled to the total passenger-miles. Given that CO_2 emissions are dependent on energy consumption, which in turn is dependent on distance traveled, it is important to include distance traveled in this transit market share variable. Because of the efficiencies that transit travel could achieve, an increase in this variable is expected to result in a reduction in CO_2 emissions. Transit service utilization, as measured by the ratio of passenger miles traveled to the total space miles provided, is an important variable because if transit utilization is low, the advantages offered by the “mass” use of public transportation would be lost. Therefore, an increase in transit efficiency is expected to reduce CO_2 emissions.

The supply of infrastructure enabling travel by private automobiles could also have an important effect on CO_2 emissions. This variable is measured by roadway lane-miles per capita. A greater supply of roadways for private automobile use is likely to increase the reliance on this mode, producing higher CO_2 emissions as a result. Also, a higher median household income could suggest the presence of more travel and an increased likelihood of using the private auto mode, resulting in an increase in CO_2 emissions. Private automobile occupancy, on the other hand, would have the opposite effect because the marginal increase in energy consumption and resulting CO_2 emissions due to additional passengers in a private automobile is very low. Average commute travel time across all modes is expected to be pertinent because an increase in this variable is likely to lead to an increase in CO_2 emissions due to the implied longer trips travelers take in an urbanized area. Population density is of interest because an increase in density could relate to more travelers traveling shorter distances leading to lower CO_2 emissions per capita.

These variables are summarized in Table I. Also included is the correlation coefficient with the response variable, CO_2/capita. While the signs of the coefficients are consistent with a priori expectations, not all of the variables in the table exhibit high correlations with CO_2/capita in absolute terms, transit service utilization being a notable example. Notice that the values of transit service utilization are fairly low, with a mean value of 0.112, and equally important, the spread in this variable is very narrow, with a standard deviation of 0.038 and coefficient of variation (ratio of the standard deviation to the mean) of 0.339. While median household income reflects a degree of positive correlation with the response variable CO_2/capita, albeit limited, its coefficient of variation is also very low at 0.166.

Table I – Summary Statistics of Pertinent Variables

Variable	Min	Max	Mean	Median	Std. Dev.	Coef. Of Variation	Corr. with CO_2/cap.
CO_2/Capita (metric tons CO_2/yr)	0.725	3.191	1.535	1.525	0.365	0.238	1
Transit share	0.000065	0.166	0.0155	0.00833	0.0206	1.329	– 0.171
Density (persons/sq. mi.)	852	7068	2490	2321	980	0.394	– 0.319
Avg. Travel Time (minutes)	16.23	37.43	22.86	22.12	3.92	0.171	0.157
Private Vehicle Occupancy (persons)	1.093	1.382	1.182	1.175	0.050	0.042	– 0.278
Transit Service Utilization	0.023	0.273	0.112	0.112	0.038	0.339	– 0.091
Lane-miles/Capita	0.000046	0.00151	0.000642	0.000630	0.000253	0.394	0.537
Median Household Income ($)	28,975	74,133	42,380	41,373	7,028.7	0.166	0.217

Since urbanized areas or states may institute certain policies and regulations that have direct or indirect impacts on reduced GHG emissions, the use of indicators of such policies and regulations or their proxies are important to considered. One such proxy variable that is readily available is whether urbanized areas have regulations in place that require that vehicles be inspected for emissions on a regular basis (usually annually) and maintained if the test indicated that emissions exceed specified thresholds. While these federally-mandated inspection programs are instituted to address emissions of pollutants – such as hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), and volatile organic compounds (VOC's) – and not GHG emissions (Rilett, 2002), the presence of such inspections in an urbanized area could be viewed as a proxy indicator of the presence of other policies and regulations aimed at mitigating environmental concerns, some of which could be related to GHG emissions.

The Clean Air Act amendments of 1990 require all cities that do not meet federal health standards to implement emission inspection programs. However, the majority of the cities (70 of 110) that were required to implement the inspections in 1990 already had such programs in place, indicating that many of these cities were conscious of and acting proactively to curb the effects of pollution (Almanac of Policy Issues, 2002). The proxy nature of the inspection variable in terms of its ability to indicate the presence of other policies or regulations that have an impact on mitigating GHG emissions, or more directly to possibly increase policy-makers' awareness of broader environmental issues that could subsequently influence the adoption of GHG emissions mitigating measures is quantitatively illustrated in Mishalani *et al*. (2012b). In that study, it is shown that there is a significant dependence between cities that are adopting the California Air Resources Board's (CARB) standards to reduce GHG emissions and the cities that have emissions inspection programs in place.

In addition to inspection providing a possible indication of other policies and regulations, it could also have a favorable impact on the attitudes of travelers by raising awareness, causing them to make better choices regarding the miles per gallon (MPG) levels of vehicles they purchase, drive in a manner that produces less CO_2 emissions, or select more efficient travel modes such as public transportation and high occupancy private automobiles. In fact, Gaker *et al*. (2011) found that people are willing to change their travel behavior to reduce CO_2 emissions, even if doing so comes with a higher personal cost in terms of time or money.

Inspection and Maintenance (I/M) programs are categorized as "basic", "low enhanced", or "enhanced" (Wilson, 2000). Due to the small number of cities in the "low enhanced" category and to simplify the modeling, a binary variable indicating the presence or absence of an I/M program is included in the integrated dataset for each urbanized area. In 2000, 70 of the 76 cities in the dataset had an inspection program in place.

Finally, for reasons discussed in the subsequent section, the levels of CO and NO_x transportation related pollution (US Environmental Protection Agency, 2012) are also included in the integrated dataset.

3. MODEL SPECIFICATION AND ESTIMATION

In specifying the relationship of interest, the role the automobile inspection indicator variable plays as a proxy for the presence of other policies and regulations aimed at mitigating GHG emissions is important to consider. More specifically, the presence of an inspection program in an urbanized area could be indicative of other policies and regulations that have an impact on its CO_2 emissions, while simultaneously such policies and regulations are to some extent influenced by the presence of environmental concerns that are typically associated with higher levels of CO_2 emissions. Therefore, a possible self-selection into an emissions inspection category may be at play among the urbanized areas in the dataset due to this simultaneity leading to a selectivity bias.

An approach presented in Mannering (1987) and Washington *et al*. (2003) is used in this study to investigate the presence of and correct for this possible selectivity bias. Doing so corrects for the effect of self selection on the estimated coefficients of the other explanatory variables. Calculating the selectivity bias correction variables requires the estimation of a decision model relating an urbanized area's probability of adopting an emissions inspection program as a function of explanatory variables that drive such a decision. To estimate the probability of an urbanized area adopting an automobile emissions inspection program, a binary logit model is developed with appropriate explanatory variables. Since inspections mainly focus on controlling the levels of CO and NO_x transportation related pollution, these are reasonable explanatory variables to consider. The details regarding the logit model estimation results are presented in Mishalani *et al*. (2012b).

The selectivity bias correction (SBC) variable is introduced as a variable in the specification when estimating two separate linear in the parameters models, one using data of urbanized areas where inspection programs are present and the other where they are not, using ordinary least squares. The use of the SBC variable in the specification is shown to result in coefficient estimates for all the explanatory variables that are corrected in a manner that eliminates the biases resulting from self selection (Mannering, 1987; Washington *et al*., 2003).

The urbanized areas are split into two separate groups by inspection category (70 urbanized areas with emissions inspection programs and another 76 without such programs), and separate regression models are estimated for each group using the corresponding SBC variables in addition to the explanatory variables discussed above. This segmentation allows the coefficients of all explanatory variables to be different based on whether emissions inspection programs are present or not. More details on the determination of SBC for the purpose of model estimation are presented in Mishalani *et al*. (2012b).

The coefficients of the selectivity bias correction variables are found to be significant in the model for the urbanized areas without emissions inspection and insignificant for urbanized areas with inspection. An investigation of the empirical cumulative distribution functions of the SBC variable shows that both the range and variance of the SBC for cities with inspection are smaller than it for cities without inspection, providing an explanation of why this variable is not significant in the segmented model for urbanized areas with emissions inspection. The significance of one of the two SBC coefficients, nevertheless, is indication that self-selection is present in the dataset and the applied corrections are meaningful. In addition, the p-values of the estimated coefficients of the explanatory variables – the details of which are presented in Mishalani *et al*. (2012b) – indicate that transit market share, lane-miles per capita, average private vehicle occupancy, inspection regulation, average travel time, and population density have a statistically significant influence on CO_2 emissions.

Moreover, the presence of emissions inspection programs in urbanized areas appears to have an appreciable influence on the levels of impact other variables have on reducing CO_2 emissions. For example, the coefficients of transit share and average private vehicle occupancy in the models for each of the two inspection categories are different by a factor of 10. Furthermore, the differences in the coefficients of each explanatory variable, except 1/density, are found to be significant (with p-values < 0.075). The large and significant differences provide evidence for the important role the inspection variable plays. Recall that, as discussed and illustrated in section 2, the inspection variable is adopted as a proxy indictor of policies and regulations urbanized areas might have in place that are aimed at reducing GHG emissions. In addition, as also discussed in section 2, the inspection variable could be indicative of possible favorable travel choices travelers make as a result of the awareness brought about by emissions inspection programs. Therefore, the estimation results indicate that such policies, regulations, and behavior significantly affect the impacts various urban form and travel variables have on CO_2 emissions. Nevertheless, in the absence of a definitive link between the inspection variable and the hypothesized indications discussed above, along with the inability of the inspection variable to distinguish between the two indications on its own, the discussed effects are worthy of further investigation as part of future research.

Among the variables considered, transit utilization and household income are found not to exhibit statistical significance. While theoretically expected to impact CO_2 emissions, the low degree of variability in these two variables as reflected in the coefficient of variation reported in Table I of section 2 limits the potential of capturing the role these variables are expected to have in the estimation results.

4. SUMMARY AND FUTURE RESEARCH

This study focuses on modeling the impact that population density, transportation demand and supply variables, and policy and regulation variables have on CO_2 passenger travel emissions in a manner that takes into account selectivity bias resulting from the simultaneity that exists between CO_2 emissions and automobile emissions inspection programs. Such programs are viewed as indications of other policies and regulations aimed at reducing GHG emissions. These regulations on the one hand are expected to reduce CO_2 emissions and on the other hand are more likely to be adopted in urbanized areas with relatively higher CO_2 emissions. As a result, the model developed in this study takes important steps in quantifying the impacts and roles various variables have on CO_2 emissions.

Based on the estimated model, the possible impacts changes in certain explanatory variables might have on CO_2 emissions are worth investigating. Doing so would be conducted for specific urbanized areas to quantifying the orders of magnitude of changes in certain variables that might be necessary to produce desired reductions in CO_2 emissions thus. Naturally, such an investigation would be more meaningful if joint variable effects are considered in light of the correlations present among several of the explanatory variables. By considering several urbanized areas of varying characteristics, the results could provide policy makers with insights on the scale of CO_2 reductions that might be achievable through the application of certain measures.

As discussed at length in this paper, the presence of automobile emissions inspection programs in urbanized areas, while not targeted at the reduction of GHG emissions, is used as a proxy for other policies and regulations aimed at addressing GHG emissions. Moreover, as is also discussed, such programs could have a favorable effect on travel choices by increasing the awareness of environmental concerns in general. While some indication of an association between inspection programs and policies meant to reduce GHG emissions is available as pointed out in section 2, investigating this association further is worthwhile. In addition, exploring the potential effects inspection programs might have on increased awareness and changes in travel behavior is important.

One of the main limitations of the model developed in this study is its inability to capture the effect of transit service utilization in terms of the degree to which available capacity is used. This variable, however, is expected to be critical in realizing the full impact of transit share on passenger travel related CO_2 emissions. In addition, other potentially important variables, such as those relating to gas tax policy, transit fare policy, and congestion pricing, are not captured in the integrated dataset considered in this study. Furthermore, as in the case of transit utilization, their variability across urbanized areas in the US is expected to be limited. Extending the developed model to include such variables would naturally be worthwhile. Doing so, however, requires the amassing of a dataset that includes these variables and ensures that their variability across urbanized areas is sufficiently large. Expanding the dataset to include urbanized areas in Europe, East Asia, and Latin America is expected to be valuable in this regard.

In summary, integrating a rich dataset from multiple sources in a consistent manner has proved to be valuable in light of the modeling results arrived at. Furthermore, in addition to advancing the state of knowledge based on empirical evidence from US urbanized areas, the findings of this study lay a foundation for important further modeling that could capture a richer set of variables and dimensions.

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