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Evaluating policies to reduce greenhouse gas emissions from private transportation

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ABSTRACT

This paper proposes a model system to forecast household greenhouse gas emissions (GHGEs) from private transportation. The proposed model combines an integrated discrete-continuous car ownership model with MOVES 2014. Four modeling components are calibrated and applied to the calculation of GHGEs: vehicle quantity, vehicle type and vintage, miles traveled, and rates of GHGEs. The model is applied to the Washington D.C. Metropolitan Area. Three tax schemes are evaluated: vehicle ownership tax, purchase tax and fuel tax. We calculate that the average GHGEs per vehicle is 5.15 tons of carbon dioxide-equivalent (CO_2E) gases. Our results show that: (a) a fuel tax is the most effective way to reduce vehicle GHGEs, especially for households with fewer vehicles; (b) a purchase tax reduces vehicle GHGEs mainly by decreasing vehicle quantity for households with more vehicles; and (c) an ownership tax reduces vehicle GHGEs by decreasing both vehicle quantity and miles traveled.

Introduction

Rising levels of carbon dioxide and other heat-trapping gases in the atmosphere are believed to warm the Earth and to cause wide-ranging impacts. In the long term, scientists project that these trends will continue and in some cases accelerate, posing significant risks to human health and to other natural resources that are vital to the environment. Societies around the globe need to reduce human-caused greenhouse gas emissions (GHGEs) to avoid worsening climate impacts and to reduce the risk of creating changes beyond our ability to respond and adapt. Policies are needed in order to reduce energy use, limit GHGEs, and build a clean energy economy (Department of Ecology, 2012).

According to the annual report of the United Nations Framework Convention on Climate Change (UNFCCC), in the United States (US) more than 27% of total GHGEs are from the transportation sector. Within this sector, light-duty vehicles are the largest pollutant sources, accounting for 61% of the total GHGEs (EPA, 2013). The estimation from the Organization for Economic Co-operation and Development (OECD) also shows that on-road passenger cars are responsible for around 15% of fossil fuel-related carbon dioxide (CO_2) emissions which are the main component of greenhouse gases (GHGs) (Dargay and Gately, 1997). Although mobile sources contribute large percentages of GHGEs, technology is not yet available to measure and tax emissions from each vehicle (Feng et al., 2005). Therefore, it is necessary to develop and apply effective and quantitative methodologies to support public authority decision making (Liu et al., 2014) and to analyze the impact of taxation policies on reductions of GHGEs.

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GHGEs from light-duty vehicles are closely linked to households' car purchasing and driving behaviors. Preferences on vehicle type and quantity (i.e. the number of vehicles within households) determine car purchases, while driving behavior is best described by households' travel demand or vehicle usage (i.e. vehicle miles traveled, VMT). Therefore, the combination of the number of vehicles owned by a household, vehicle type, and the usage (i.e. VMT) of vehicles is an important determinant of households' vehicle GHGEs and fuel consumption (Vyas et al., 2012). The state-of-the-art in calculating GHGEs from vehicle usage employs either the standard values of conversion that consider lifecycle emissions from the Environmental Protection Agency (EPA) or the emission rates per miles from the California Air Resources Board (CARB) (Feng et al., 2005; Fullerton, 2005; Fullerton and Gan, 2005; Musti and Kockelman, 2011). Other methods which estimate vehicle GHGEs combine demand models and emission simulators such as the EPA's MOBILE6, MOVES, or the EMFAC model developed for California.

To estimate GHGEs from private transportation, this paper proposes an integrated model framework that efficiently forecasts the number of vehicle within a household, vehicle type/vintage, annual miles traveled, and the emission rate of each vehicle. Different from previous research, this model framework is able to estimate the usage pattern of households' primary, secondary, and tertiary vehicles. More specifically, it predicts the VMT of each vehicle and forecasts individual vehicle's annual greenhouse gas (GHG) emissions. To the best of our knowledge, this research is the first to forecast households' vehicle emissions by combining an integrated discrete–continuous car ownership model and MOVES2014. Furthermore, the integrated model accounts for different types of attributes such as socio-demographics, built environment, travel costs, and road traffic conditions. The proposed study also evaluates several tax schemes by applying the model system to real data extracted from the 2009 U.S. NHTS for the Washington D.C. Metropolitan Area.

The remainder of this paper is organized as follows. Section 'Literature review' provides a review of the literature on integrated discrete–continuous car ownership models and on previous methods used to estimate vehicle GHGEs. This is followed by Section 'The model framework' where we present the proposed framework based on four modules: vehicle type and vintage choice, quantity choice, usage decision, and GHGEs rates estimator. Section 'Data sources' introduces data sources necessary for model estimations, while Section 'Model estimation and validation results' presents model estimation and validation results. In Section 'Policy analysis', three different taxation policies are evaluated and their effects to reduce GHGEs are compared. The final Section offers the concluding remarks and avenues for future research.

Literature review

In this section we briefly cover previous studies on vehicle ownership and usage modeling, and we provide main features of existing emission simulators. Additionally, we outline the results obtained from policy analyses on energy and environmental related issues arising from private transportation.

Existing studies in the transportation literature about car ownership modeling attest that vehicle quantity, type/vintage, and usage are the main determinants needed for the calculation of fuel consumption, GHGEs, and other pollutants from private vehicles (Train, 1986). Moreover, researchers have recognized that those decisions are taken simultaneously and that integrated model should be used to model these decisions jointly (Dubin and McFadden, 1984; Hanemann, 1984). The early discrete–continuous models are derived from the conditional indirect utility function and are consistent with the microeconomic theory (Mannering and Winston, 1985; Jong, 1989). More recently, Bhat (2005) has developed multiple discrete–continuous extreme value (MDCEV) models that jointly estimate the holdings and usage of multiple vehicle types by households. Several variables were found to be significant for this problem: socio-demographic variables, built environment attributes, vehicle characteristics, and gasoline prices (Bhat and Sen, 2006; Bhat et al., 2009). However, Bhat's model is restricted by the assumption of fixed total miles traveled by each household. Fang (2008) proposed a Bayesian Multivariate Ordered Probit and Tobit (BMOPT) model to estimate households' vehicle type, quantity, and usage. An ordered probit model was employed to determine households' decisions on the number of passenger cars and trucks. A multivariate Tobit model was applied to estimate household decisions on VMT. The author concluded that the model was appropriate for predicting changes of vehicle quantity, types, and miles traveled. Liu et al. (2014) also developed an integrated discrete–continuous car ownership model that jointly estimated households' vehicle quantity, type, and usage. A multinomial probit model was employed to estimate vehicle quantity while a linear regression model was used to estimate total VMT of each household. The correlation among the discrete and the continuous parts was captured by an unrestricted full variance–covariance matrix of the unobserved factors.

Several emission estimation simulators have been developed and utilized to calculate GHGEs from private vehicles. For instances, the California's Emission Factors model (EMFAC7F), the EPA's Vehicle Emission Modeling software (MOBILE5a), and the EPA's MOVES model (EPA, 1998). According to Bai et al. (2009), MOVES should be preferred to other software for the following reasons: (a) it combines vehicle specific power (VSP) and speed bins, rather than speed correction factors, to quantify running exhaust emissions; (b) it uses vehicle operating time rather than VMT as the unit of measure for various vehicle activities and emissions; and (c) it uses a relational database to manipulate data and enables multi-scale emission analyses and applications from link-level to nation-level.