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Integrated modeling of car/motorcycle ownership, type and usage for estimating energy consumption and emissions

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ABSTRACT

Devising effective management strategies to relieve dependency on private vehicles, *i.e.* cars and motorcycles, depends on the ability to accurately and carefully examine the effects of corresponding strategies. Disaggregate choice models regarding the ownership, type and usage of cars and motorcycles are required to achieve this. Consequently, this study proposes integrated car and motorcycle models based on a large-scale questionnaire survey of Taiwanese owners of cars and motorcycles, respectively. Incorporating gas mileage and emission coefficients for different types of cars and motorcycles into the proposed models can enable the estimation and comparison of reductions in energy consumption and emissions under various management strategies. To demonstrate the applicability of the proposed integrated models, scenarios involving 10% and 30% increases in gas prices are analyzed and compared. The results indicate that gas price elasticities of cars and motorcycles are low, ranging from 0.47 to 0.50 for cars and 0.11 for motorcycles. Additionally, a high ratio of discouraged car users shifting to use of motorcycles neutralizes the effects of increased gas price in reducing energy consumption and emissions. Pollution of *CO* and *HC* even slightly increased because motorcycles are much more polluting in terms of *CO* and *HC*. At last, the reductions of energy consumption and emissions under 10% and 30% increase (or decrease) in other manipulating variables are also estimated and compared. The countermeasures for reducing ownership and usage of cars and motorcycles are then recommended accordingly.

1. Introduction

The buoyant economic growth associated with the continuous construction of highway infrastructure for convenient movement of individuals and freight internationally has inevitably led to rapid growth of numbers of private motor vehicles during recent decades. Taking Taiwan for instance, in 1990, Taiwan had only 2.3 million registered cars and 7.1 million registered motorcycles, while in 2008 these figures had increased to 6.7 million and 14.0 million, respectively, representing an almost tripling or doubling over less than two decades. The trend toward greater ownership of private vehicles has not only created ubiquitous congestion on urban roadways and intercity highways, but also excessive emissions and energy consumption. Towards sustainable transportation, it is crucial to propose countermeasures capable of effectively curtailing ownership and usage of high-emissions and low fuel efficiency cars and motorcycles. In doing so, it is essential to model choice behaviors related not only to ownership and usage, but also to car and motorcycle type, since gas mileage and emission coefficient of cars and motorcycles differ considerably with engine size and age.

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Numerous studies have modeled the behaviors of ownership, type, and usage of cars (see de Jong et al. (2004) for detailed discussions of different car ownership models). However, most such studies focused solely on specific aspects of car ownership and usage behaviors. In the context of motor vehicle energy consumption and emissions, although higher ownership and greater usage of motor vehicles will undoubtedly lead to greater energy consumption and tail pipe emissions, choices regarding motor vehicle type also affect energy consumption and pollution emissions, since coefficients of energy consumption and emissions vary markedly across different engine sizes and ages (Chiou and Chen, in press).

Furthermore, most related studies primarily focus on choice behaviors related to cars, and few dealt with motorcycles. In the face of the recent rapid and sharp rise in fuel price, numerous car drivers have shifted to use motorcycles, a comparatively fuel efficient but high polluting mode. Thus, it is necessary to study motorcycle related choice behaviors. Particularly, motorcycles are the most prevalent transport mode in urban street in Taiwan and their numbers are over twice that of cars, explaining the importance of motorcycles in any model for estimating energy consumption and emissions. Based on this, this study proposes integrated models for cars and motorcycles with consideration of choice behaviors related to ownership, type, and usage. Based on the proposed integrated models, the energy consumption and emissions of cars and motorcycles under various scenarios are estimated.

The remainder of this paper is organized as follows: A brief review of literature is given in Section 2. The framework of the integrated models is presented in Section 3. The dataset, obtained via a nationwide questionnaire survey of owners of cars and motorcycles in Taiwan and used to model estimation, is briefly introduced in Section 4. The disaggregate choice models of ownership, type, and usage of cars and motorcycles are proposed and calibrated in Sections 5 and 6, respectively. To investigate the applicability of the proposed models, a scenario analysis of increased gas prices is presented in Section 7. Finally, concluding remarks and suggestions for future research are presented.

2. Literature review

Vehicle ownership can be analyzed by using either aggregate or disaggregate model. Because our study collected disaggregate data, literature review focuses in particular on the disaggregate models. The earlier studies addressed the car ownership problem by identifying the causal relationship between number of cars in a household and key explanatory variables (e.g., socio-economic and demographic characteristics). The ordered or unordered-response choice models can be applied to explore the household's decision to own vehicles (Bhat and Pulugurta, 1998; Chu, 2002; Whelan, 2007; Matas and Raymond, 2008; Potoglou and Kanaroglou, 2008). A number of studies have examined households' or individuals' vehicle type choices to identify the factors affecting vehicle purchasing or holding behavior (e.g., Zhao and Kockelman, 2000; Mohammadian and Miller, 2003a; Choo and Mokhtarian, 2004; Cao et al., 2006; Potoglou, 2008). Given the number of vehicles in a household, individual's choices of vehicle type and usage can be modeled jointly to account for their endogenous relationship (Mannering and Winston, 1986; de Jong, 1996). The type choice involves selecting one among a set of alternatives in terms of make, model, and vintage of the vehicle. Due to unordered nature of discrete data, vehicle type choice can be analyzed by the multinomial logit or nested logit model. On the contrary, the vehicle usage measured as kilometers per year is a continuous variable, and the regression model is therefore appropriate.

The recent development of vehicle ownership model has moved from static to dynamic modeling by incorporating household vehicle transactions (e.g., Hensher, 1998; Mohammadian and Miller, 2003b). Such dynamic model requires a longitudinal panel data that contains information on household vehicle transactions, i.e., households may acquire one or more new vehicles, trade one of their existing vehicles for another vehicle, dispose of a vehicle from their current fleets, or do nothing. A comprehensive integrated model consists of vehicle transactions as well as activity scheduling and mode choice (Roorda et al., 2009).

Although extensive research has been undertaken in developing a variety of car ownership models, few articles have been devoted to study motorcycle ownership. For example, Tuna and Shimizu (2005) explored motorcycle transactions and vehicle type choice, given that the household has decided adding a new motorcycle. On the other hand, Burge et al. (2007) developed a motorcycle ownership model containing choices of the number of motorcycles owned by a household and the engine sizes of these motorcycles. Both studies modified the existing car ownership models to address motorcycle ownership decisions. Sanko et al. (2006) proposed bivariate ordered probit model, an extension of univariate ordered-response model, to analyze joint decisions of the number of cars and motorcycles owned in a household. Nevertheless, the current literature still lacks an integrated model of ownership, type and usage for cars and motorcycles.

3. Model framework

An integrated model system could include households' or individuals' choices of the number of vehicles, transactions, type, and usage for cars and motorcycles, respectively. However, joint estimations of such model system are computationally difficult due to a large number of alternatives to be considered simultaneously. The proposed model system is decomposed into several sub-models which extend the work of Mohammadian and Miller (2003b) by accommodating the choice of the number of vehicles as well as usage for allowing evaluation of reduction in energy consumption and emissions. The proposed integrated models for cars and motorcycles, respectively, comprise three disaggregate choice sub-models, including ownership, type, and usage, as shown in Figs. 1 and 2, respectively, as detailed below.