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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.

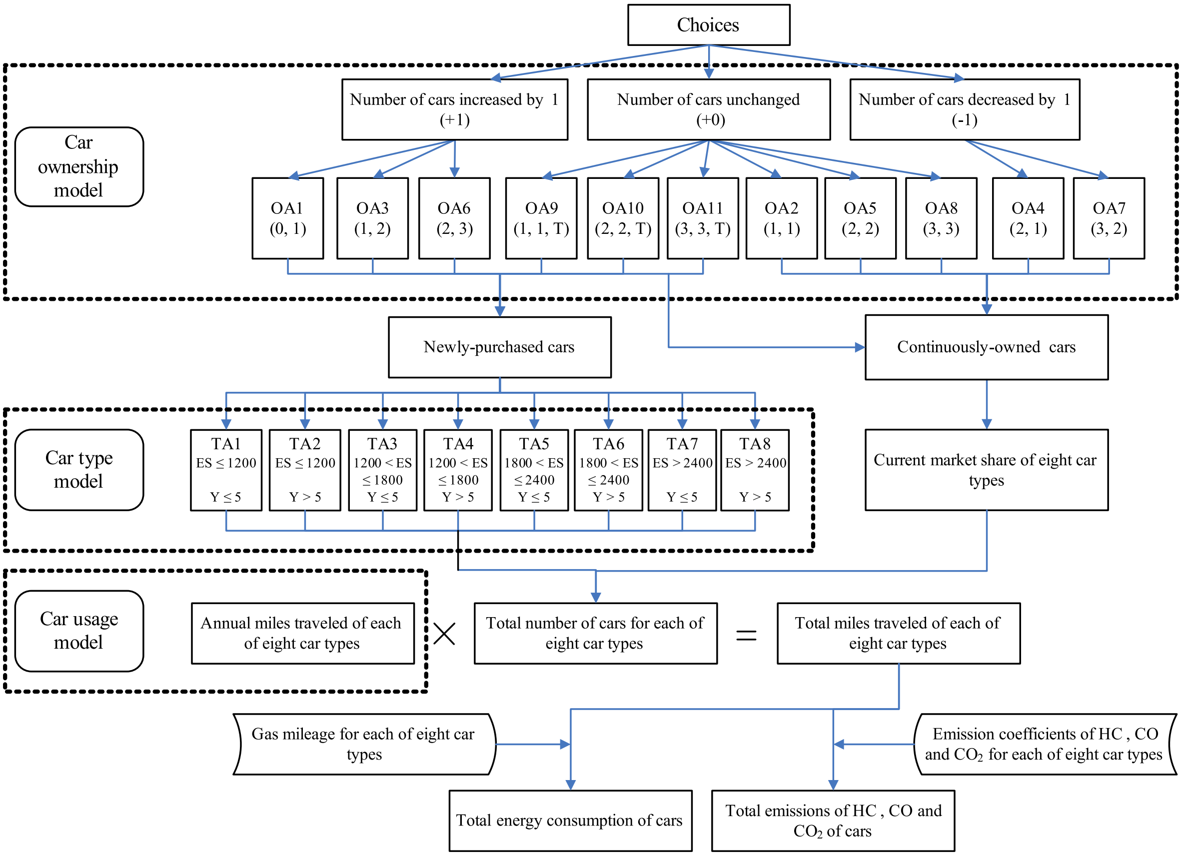

Fig. 1. Framework of the integrated car model.

3.1. Integrated car model

The car ownership model in Fig. 1 considers 11 alternatives, OA1–OA11, to represent annual changes in household car ownership status. Since few Taiwanese households possess more than three cars and replace more than one car within a year, the alternatives of owning more than three cars and making more than two car transactions annually are not considered here.

For the alternatives OA1–OA8, the left and right figures in parentheses represent the numbers of cars owned by households in years t and $t + 1$, respectively. The alternatives of OA9–OA11 are denoted by an additional T in parenthesis to represent households that replaced a car during the year. All ownership alternatives can be classified into three clusters of +1, +0 and −1 to represent changes in household car ownership. Since the questionnaire survey only targeted car owners, households with the alternative (1,0) are excluded. The choice structure of the proposed vehicle ownership model is remarkably more complicated than those of previously proposed ones. Two main distinctions could be noted: First, the proposed vehicle ownership model contains both behaviors of vehicle ownership (number of vehicles owned) and transaction (choice among do nothing, trade a vehicle, add a vehicle, and dispose of a vehicle), which were usually separately tackled in most of previous studies (e.g. Train, 1980; Hocherman et al., 1984; Mohammadian and Miller, 2003a,b; Kumar and Rao, 2006; Whelan, 2007). However, in the context of energy consumption and emissions estimation, the proposed model should be able to estimate not only the changes in total numbers of vehicles but also the changes in numbers of each type of vehicles. Second, it is widely known that the vehicle transaction behaviors would be significantly affected by the number of vehicles already owned by the household. Although most of traditional vehicle transaction models considered the number of vehicles either as a key explanatory variable (e.g. Hensher, 1998; Mohammadian and Miller, 2003a) or an exogenous model (e.g. Roorda et al., 2009). However, in this study, it is considered as different alternatives. Taking three alternatives of the car ownership model, OA(0,1), OA(1,2), and OA(2,3), for instances, they represent the same alterative of "add a vehicle" to the traditional vehicle transaction models but distinct alternatives to our model. In doing so, the behaviors could be explained in more details.

The car type model considers eight alternatives, TA1–TA8, based on various combinations of engine size (ES) and age (Y). Car sizes are divided into four categories: ES ⩽ 1200c.c. (cube centimeter), 1200c.c. < ES ⩽ 1800c.c., 1800c.c. < ES ⩽ 2400c.c., and ES > 2400c.c.; similar to the vehicle size classes of subcompact car, compact car, medium car, and large car, while cars are

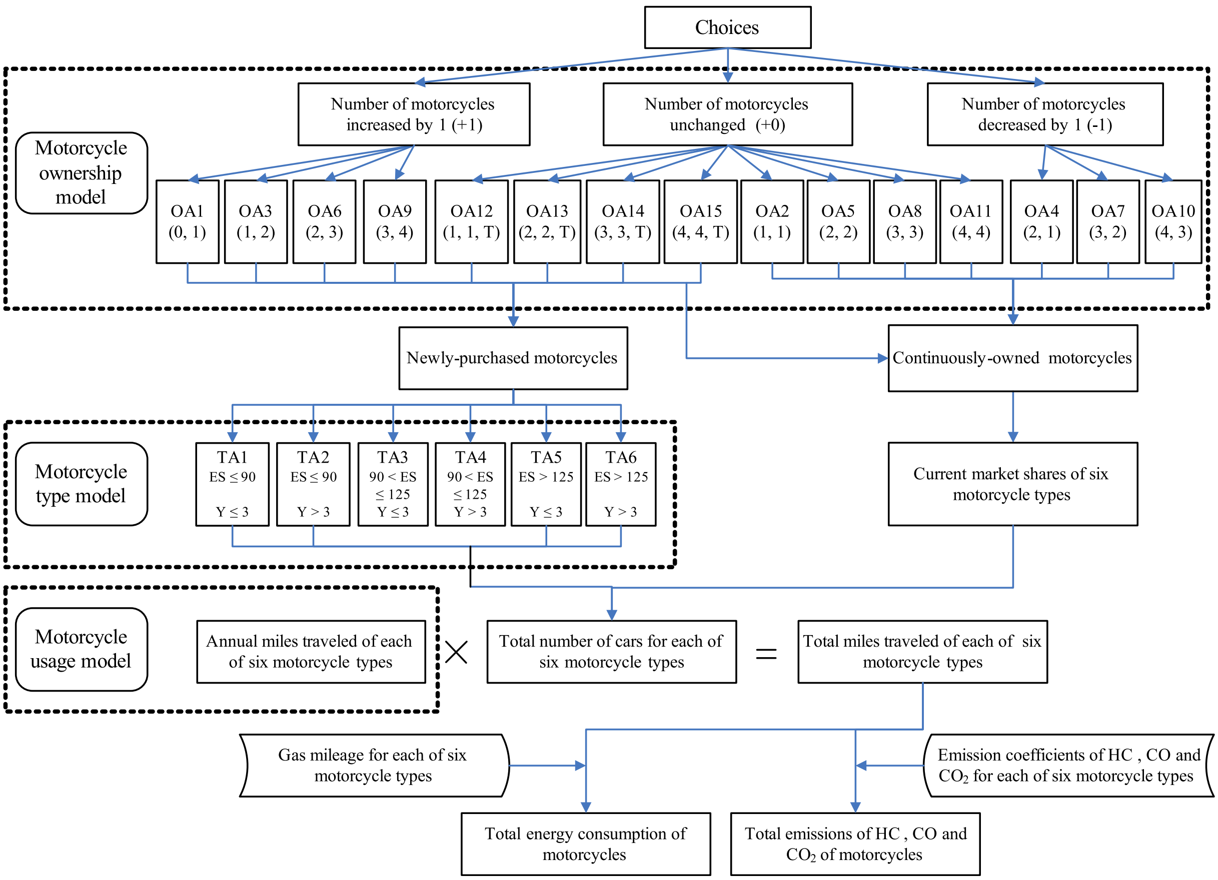

Fig. 2. Framework of the integrated motorcycle model.

classified according to age into two categories: $Y \leqslant 5$ years and $Y > 5$ years. In Taiwan, only cars aged over 5 years are required to undergo annual exhaust inspections.

The car type model is only applied to newly-purchased cars of the ownership alternatives of OA1, OA3, OA6, OA9, OA10, and OA11 which acquire at least one car. By multiplying the choice probability of the corresponding ownership alternatives and that of the type alternative as in Eq. (1), it is possible to determine the market shares of newly-purchased cars in the year. For continuously-owned cars of all alternatives, except for OA1 and OA9 having none continuously-owned car, the types are determined based on the original market shares of eight types of cars. Figures on original market share were obtained from official statistical reports published by the Ministry of Transportation and Communications (MOTC).

$$TN_i = TH \times \Pr_{TAi} \times (\Pr_{OA1} + \Pr_{OA3} + \Pr_{OA6} + \Pr_{OA9} + \Pr_{OA10} + \Pr_{OA11}) \quad \text{for } i = 1,2,\ldots,8 \tag{1}$$

$$TO_i = TH \times MS_{TAi} \times (\Pr_{OA2} + \Pr_{OA3} + \Pr_{OA4} + 2\Pr_{OA5} + 2\Pr_{OA6} + 2\Pr_{OA7} + 3\Pr_{OA8} + \Pr_{OA10} + 2\Pr_{OA11}) \quad \text{for } i = 1,2,\ldots,8 \tag{2}$$

$$TT_i = TN_i + TO_i \text{for } i = 1,2,\ldots,8 \tag{3}$$

where TN_i is the total number of newly-purchased type i cars. TH is the total number of households which own at least one car. Pr_{TAi} represents the choice probability of the alternative TAi, estimated by car type model. Pr_{OAi} represents the choice probability of the alternative OAi, estimated by car ownership model. TO_i is the total number of continuous-owned type i cars. MS_{TAi} represents the original market share of type i cars. TT_i is the total number of type i cars which sum up total numbers of newly-purchased and continuously-owned type i cars.

The car usage model is used to estimate annual miles traveled by each car type. The total annual miles traveled by each car type can be computed as:

$$TM_i = TT_i \times AM_i \quad \text{for } i = 1,2,\ldots,8 \tag{4}$$

where TM_i represents the total annual miles traveled by type i cars. AM_i represents the average annual miles traveled by type i cars, estimated by the car usage model. Based on the estimated total annual miles traveled by each car type, the energy consumption and emissions are computed as:

$$EC_i = g_i \times TM_i \quad \text{for } i = 1, 2, \ldots, 8 \tag{5}$$
$$HC_i = h_i \times TM_i \quad \text{for } i = 1, 2, \ldots, 8 \tag{6}$$
$$CO_i = c_i \times TM_i \quad \text{for } i = 1, 2, \ldots, 8 \tag{7}$$
$$CO2_i = k_i \times TM_i \quad \text{for } i = 1, 2, \ldots, 8 \tag{8}$$

where EC_i represents the total motor fuel consumed by type i cars (liter, l). g_i is the amount of fuel consumed per unit distance of type i cars (l/km), a reciprocal of gas mileage. Lower value of g_i represents higher fuel economy. h_i, c_i, and k_i are the coefficients associated with HC_i, CO_i, $CO2_i$ emitted per unit distance traveled by car type i, respectively (g/km). The total energy consumption and emissions of cars by simply summing up all fuel consumed and exhausts emitted by each type of cars:

$$TEC = \sum_{i=1}^{8} EC_i \tag{9}$$

$$THC = \sum_{i=1}^{8} HC_i \tag{10}$$

$$TCO = \sum_{i=1}^{8} CO_i \tag{11}$$

$$TCO2 = \sum_{i=1}^{8} CO2_i \tag{12}$$

where TEC, THC, TCO, and $TCO2$ represent the total energy consumption and HC, CO, and CO_2 emissions.

3.2. Integrated motorcycle model

Similar to the car model, Fig. 2 shows the framework of the integrated motorcycle model. Notably, there are two differences between the integrated motorcycle and integrated car models, namely the numbers of alternatives in ownership and type models. For the motorcycle ownership model, the questionnaire survey revealed few households possessing more than four motorcycles or replacing more than one motorcycle annually, and thus the motorcycle ownership model considers 15 alternatives, OA1–OA15. For the motorcycle type model, motorcycle types are divided into six alternatives by considering three engine size categories ($ES \leqslant 90$c.c.; $90\text{c.c.} < ES \leqslant 125$c.c.; $ES > 125$c.c.) and two age categories ($Y \leqslant 3$ years and $Y > 3$ years). In Taiwan, only motorcycles aged over 3 years require annual exhaust inspections. Total miles traveled, total fuel consumption, and total emissions of HC, CO, and CO_2 for each motorcycle type, and the total annual fuel consumption and exhaust emissions for motorcycles can be estimated accordingly.

4. Data collection

4.1. Questionnaire design

For estimating the above models, a nationwide questionnaire survey of car and motorcycle owners was conducted. Based on the explanatory variables commonly adopted in related studies, two questionnaires, dealing with cars and motorcycles, respectively, are designed, each containing four parts: (1) household characteristics, including household location, age and gender of head of household, family size, number of family members aged below 18 years old, number of family members aged over 65 years old, average household income, number of family members in work, number of cars, motorcycles, and bicycles owned, number of car and motorcycle licenses, distance from home to nearest public transport stop (including bus, subway, rail), and purchases or sales of cars and motorcycles during October 1, 2006 to September 30, 2007. (2) Principal driver/rider demographics, including gender, age, occupation, educational level, income, driving experience, commuting mode and travel time. (3) Vehicle characteristics, including year of production, year of acquisition, brand-new or second-hand, brand, purchase price, engine size, gas mileage, annual miles traveled, cumulated miles traveled, major area in use, weekly commuting days, weekly recreational days, total annual usage costs (fuel, maintenance, parking, road tolls, and insurance). (4) Responses to management strategies for mitigating ownership and use of private vehicles, including increased gas prices, in-town congestion charges, transit fare discounts, shortened exhaust inspection period, subsidization of purchases of alternative fuel vehicles, and compulsory ownership of parking spaces for new car buyers.

4.2. Questionnaire dissemination

The questionnaires were mailed by post to owners of cars and motorcycles nationwide, with 45,000 samples for each vehicle type being randomly drawn from Taiwan's Vehicle Registration (VR) Database, which is maintained by the Directorate General of Highways (DGH), MOTC. The VR Database contains information that includes vehicle license plate numbers, names, addresses, and telephone numbers of vehicle owners, as well as some vehicle characteristics, and while the information is confidential, it can be used for designated purposes with the permission of the DGH. Since this study was sponsored by the Institute of Transportation, Ministry of Transportation and Communications, we were permitted to access to the VR Database for purposes of contacting potential subjects by post.

A proportional stratified random sampling method is adopted, and car and motorcycle questionnaires are independently disseminated to car and motorcycle owners in 23 cities/counties in Taiwan proportionally to the numbers of cars and motorcycles registered in those jurisdictions during September 1–30, 2007. A total of 5906 valid questionnaires were returned, including 3450 car owners and 2536 motorcycle owners. This dataset is used to calibrate the car/motorcycle ownership and usage models. Furthermore, for the calibration of car/motorcycle type model, owing to sampling owners who had newly purchased a motor vehicle within the past year being insufficient for model building, the sample set was expanded to include those who had purchased a motor vehicle during the past three years, from October 1, 2004 to September 30 2007, under the assumption that the background of owners was unlikely to have changed significantly during the past three years. The final sample comprised 1419 car owners and 1249 motorcycle owners.

4.3. Descriptive statistics

Tables 1 and 2 list demographic breakdowns of the sampled vehicle owners as well as the sampled cars and motorcycles, respectively. From Table 1, most car and motorcycle owners are male, but for cars the proportion of male ownership is 10% higher than for motorcycles. The age of car owners evenly distributed among the 31–40, 41–50, and 51–60 year old age

Table 1
Demographic breakdowns of sampled car and motorcycle owners.

Item	Level	Car owner		Motorcycle owner	
		Sample	Percentage (%)	Sample	Percentage (%)
Gender	Male	2655	77.0	1653	65.2
	Female	795	23.0	883	34.8
Age	⩽20	11	0.3	131	5.2
	21–30	359	10.4	683	26.9
	31–40	909	26.3	558	22.0
	41–50	1005	29.1	594	23.4
	51–60	818	23.7	437	17.2
	61–70	266	7.7	95	3.7
	⩾71	82	2.4	38	1.5
Education	Primary or below	131	3.8	165	6.5
	Junior high	213	6.2	196	7.7
	Senior high	1019	29.5	750	29.6
	University	1707	49.5	1174	46.3
	Master	330	9.6	238	9.4
	Ph.D.	50	1.4	13	0.5
Monthly income (NT$ 1000)	>20	469	13.6	806	31.8
	20–40	1071	31.0	1016	40.1
	40–60	1054	30.6	505	19.9
	60–80	480	13.9	127	5.0
	80–100	164	4.8	43	1.7
	100–120	99	2.9	26	1.0
	>120	113	3.3	13	0.5
Work or school mode choice	None	493	14.3	364	14.4
	Walk	130	3.8	75	3.0
	Car	1814	52.6	294	11.6
	Motorcycle	865	25.1	1693	66.8
	Bicycle	42	1.2	31	1.2
	Bus	48	1.4	29	1.1
	Metrorail	41	1.2	34	1.3
	Rail	15	0.4	16	0.6
	Taxi	2	0.1	0	0.0
	Air	0	0.0	0	0.0
Driving experience (year)	⩽10	867	25.1	939	37.0
	11–20	1341	38.9	807	31.8
	21–30	961	27.9	571	22.5
	31–40	239	6.9	177	7.0
	⩾41	42	1.2	42	1.7
Daily commuting time (minute)	⩽15	1541	44.7	1340	52.8
	16–30	1267	36.7	837	33.0
	31–45	397	11.5	208	8.2
	46–60	198	5.7	117	4.6
	⩾61	47	1.4	34	1.3

Table 2
Characteristics of sampled cars and motorcycles.

Items	Car			Motorcycle		
	Level	Sample	Percentage (%)	Level	Sample	Percentage (%)
Produced year	Prior to 1990	427	12.4	Prior to 1990	35	1.4
	1991–1995	591	17.1	1991–1995	396	15.6
	1996–2000	906	26.3	1996–2000	701	27.6
	2001–2005	884	25.6	2001–2005	781	30.8
	2006–2007	642	18.6	2006–2007	623	24.6
Purchased year	Prior to 1990	316	9.2	Prior to 1990	30	1.2
	1991–1995	455	13.2	1991–1995	291	11.5
	1996–2000	872	25.3	1996–2000	650	25.6
	2001–2005	1051	30.5	2001–2005	863	34.0
	2006–2007	756	21.9	2006–2007	702	27.7
Engine size (c.c.)	600–1200	100	2.9	以下	469	18.5
	1201–1800	1987	57.6	51–100	286	11.3
	1801–2400	1115	32.3	101–125	1664	65.6
	⩾2401	248	7.2	以上	117	4.6
Annual miles traveled (1000 km)	<5	454	13.2	<2.5	557	22.0
	5–10	856	24.8	2.5–5.0	943	37.2
	10–20	1235	35.8	5.0–7.5	458	18.1
	20–30	594	17.2	7.5–10.0	395	15.6
	30–40	175	5.1	>10.0	182	7.2
	>40	106	3.1	–	–	–
Cumulated miles traveled (1000 km)	<10	470	13.6	<10	726	28.6
	10–50	812	23.5	10–25	789	31.1
	50–100	784	22.7	25–50	588	23.2
	>100	1384	40.1	>50	433	17.1
Gas mileage (km/l)	0–5	130	3.8	0–15	244	9.6
	6–10	2235	64.8	16–25	931	36.7
	11–20	1054	30.6	26–35	1041	41.0
	⩾21	31	0.9	⩾36	320	12.6

groups, while the age of motorcycle owners is equally distributed among the 21–30, 31–40, and 41–50 year old age groups, suggesting motorcycle owners are roughly ten years younger than car owners. Both car and motorcycle owners display similar educational levels, but car owners have substantially higher incomes than motorcycle owners. Regarding choice of transport mode for traveling to work or school, most car owners choose cars (52.6%), followed by motorcycles (25.1%), while most motorcycle owners choose motorcycles (66.8%), followed by cars (11.6%). By excluding owners who do not have to work or go to school, the probability of choosing private vehicles as the commuting mode is nearly 94% for both car and motorcycle owners, indicating high dependency on private motor vehicles.

As for car and motorcycle characteristics, 29.5% and 17.0% of cars and motorcycles, respectively, were produced prior to 1996, implying a considerable percentage of cars and motorcycles aged over 12 years remain in use in Taiwan. Notably, energy consumption and emissions are believed to be higher in older vehicles. Cars with engine sizes of 1201–1800 c.c. have a lion's share (57.6%) of the car market, while the motorcycle market is dominated by engine sizes of 101–125 c.c. (65.6%). Cars mostly traveled 10,000–20,000 km annually (35.8%), followed by 5000–10,000 km (24.8%). Motorcycles mostly traveled 2500–5000 km annually (37.2%), followed by 0–2500 km (22.0%). In terms of cumulated miles traveled, cars had mostly traveled over 100,000 km (40.0%), while most motorcycles had traveled 10,000–25,000 km (31.1%). As for gas mileage, most cars achieved 6–10 km/l (64.8%) while for motorcycles the figure was 26–35 km/l (41.0%), indicating that motorcycles achieved 3–5 times better gas mileage than cars.

5. Model estimations: integrated car model

5.1. Car ownership model

Four car ownership model structures, as depicted in Fig. 3, were estimated and compared in Table 3, where MNL and NL represent the multinomial logit and nested logit models, respectively. The explanatory variables considered in the models are mainly derived from the questionnaire survey, except for three variables: urbanization (defined as the proportion of the population employed in the manufacturing and service industries), road density (defined as kilometers of roads per capita), transit density (defined as transit vehicle-kilometer per capita), which are determined depending on the city/county of residence of the respondents. That is, respondents living in the same city will share the same values for these three variables. These three variables reflect differences in transportation environment among counties and cities in Taiwan.

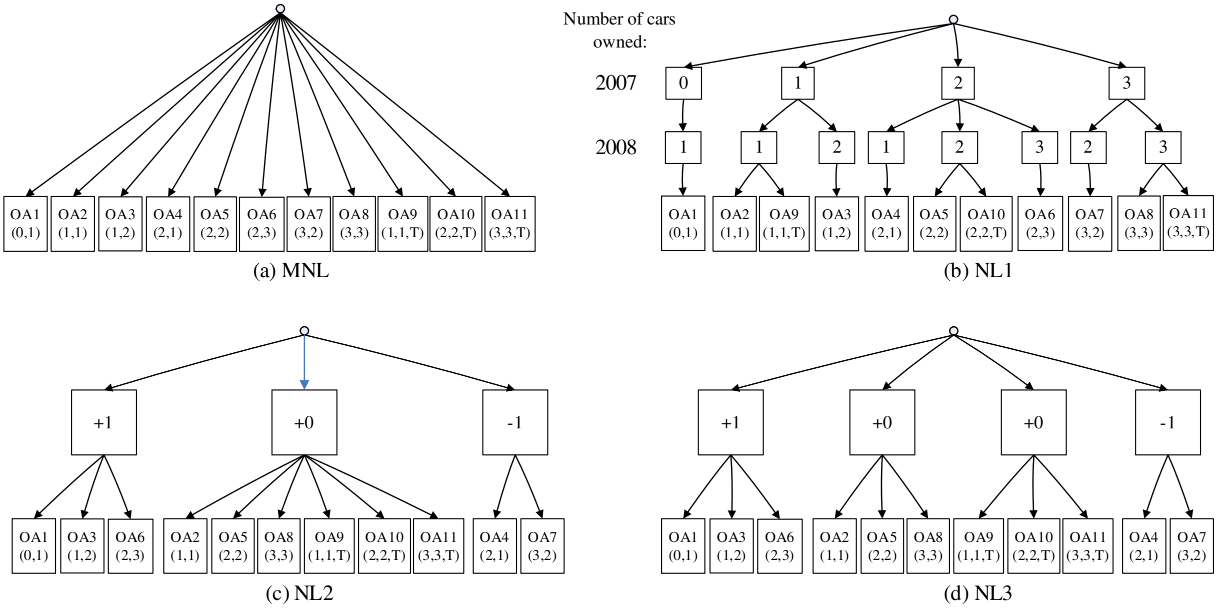

Fig. 3. Four choice structures of the car ownership model.

In Table 3, the inclusive value of NL1 model is larger than 1 as indication of the inappropriateness of the nested structure. The NL2 and NL3 models have the inclusive values that lie within the 0–1 range and are statistically different from 1, but only the NL2 model outperforms the MNL model, using the likelihood ratio test at the 0.05 level of significance. Consequently, the NL2 model is selected as the preferred car ownership model. Notably, except for alternative specific constants, the estimated parameters of all explanatory variables are significantly different from zero at the 0.01 level in the models of various structures. As noted from the estimation result of the NL2 model, the generic variables, namely, fixed cost (car price, license tax plus fuel fee) and variable cost (fuel cost) in owning and using cars, are all negative. When a parameter coefficient has a negative value, it indicates that increasing the value of this variable will reduce the utility of the alternative, and thus the probability of the alternative being chosen, provided all else remains unchanged. As expected, negative coefficients were associated with fixed or variable costs, suggesting car ownership reduces with increasing fixed or variable costs. In terms of magnitude of coefficients, (license tax + fuel fee)/household income shows the largest and most significant effect on car ownership, followed by fuel cost/household income. Car price/household shows the smallest coefficients.

The remaining explanatory variables are treated as alternative specific. The urbanized degree variable has four coefficient estimates for the OA5(2,2), OA8(3,3), OA10(2,2,T), and OA11(3,3,T) alternatives, which are statistically significant and negative, representing that inhabitants of higher urbanized areas tend not to own multiple cars (2 or 3 cars). In contrast, the coefficients for the road density variable specific to the OA5(2,2), OA6(2,3), and OA10(2,2,T) alternatives are positive, suggesting that higher road density encourages car ownership. However, the transit density variable exhibits two negative coefficients associated with the OA8(3,3) and OA11(3,3,T) alternatives, indicating that more convenient transit service reduces car ownership.

The number of employed family members positively and significantly affects the OA2(1,2) and OA6(2,3) alternatives, meaning that as more household members work, more cars are required to meet their travel needs. Regarding the effects of the number of family members aged below 18 on car ownership, the literature contains contradictory conclusions. For instance, Ben-Akiva (1973) showed that an increase in the number of household members aged below 18 years old increased family expenses and decreased disposable income, which may negatively affect car ownership. Conversely, de Jong (1990) concluded that increasing numbers of family members aged below 18 increases travel demand and thus car ownership. The estimated results presented in this study show that the coefficient is significantly positive for OA5(2,2), OA8(3,3), OA10(2,2,T), and OA11(3,3,T), suggesting that families with more members aged below 18 are likely to own more cars. Numbers of motorcycles owned significantly and negatively affects OA5(2,2), OA8(3,3), OA10(2,2,T), and OA11(3,3,T), indicating high substitution effect between cars and motorcycles. Number of car licenses significantly and positively affects OA3(1,2), OA5(2,2), OA6(2,3), OA8(3,3), OA10(2,2,T), and OA11(3,3,T), indicating that car ownership increases with number of family members holding car licenses.

5.2. Car type model

Three choice structures of the car type model, as shown in Fig. 4, are compared. Table 4 lists the estimation results.

From Table 4, the inclusive values of nested logit models in both NL1 and NL2 structures are either larger than 1 or not significantly different from 1, indicating the inappropriateness of nested structures. Consequently, the MNL structure is

Table 3
Estimation results for the car ownership model.

Variables	MNL		NL1		NL2		NL3	
	Parameter	*t*-Statistic	Parameter	*t*-Statistic	Parameter	*t*-Statistic	Parameter	*t*-Statistic
Alternative-specific constants								
OA 1(0,1) (Base)	–	–	–	–	–	–	–	–
OA2(1,1)	2.110	26.665	1.277	5.626	3.146	4.517	2.854	5.131
OA3(1,2)	−0.591	−3.086	−1.409	−5.200	−0.696	−3.167	−0.670	−3.127
OA4(2,1)	−1.144	−7.524	−1.720	−8.240	−2.129	−3.031	−1.901	−3.158
OA5(2,2)	1.813	2.326	1.092	1.913	2.849	2.695	2.581	2.637
OA6(2,3)	−2.977	−7.237	−3.273	−8.439	−3.144	−6.929	−3.099	−6.965
OA7(3,2)	−1.468	−7.411	−1.551	−8.619	−2.430	−3.448	−2.202	−3.644
OA8(3,3)	−0.327	−0.347	−0.404	−0.635	0.719	0.607	0.472	0.421
OA9(1,1,T)	−0.170	−1.539	−1.004	−4.187	0.866	1.235	−0.329	−1.827
OA10(2,2,T)	0.131	0.167	−0.591	−1.026	1.167	1.101	0.020	0.024
OA11(3,3,T)	−1.937	−2.036	−2.013	−3.110	−0.890	−0.748	−2.046	−2.074
Alternative-specific variables								
Urbanization								
OA5(2,2)	−3.568	−2.102**	−2.441	−2.019**	−3.613	−2.050**	−3.653	−2.079**
OA8(3,3)	−4.623	−2.054**	−3.059	−1.947*	−4.667	−2.016**	−4.742	−2.055**
OA10(2,2,T)	−3.568	−2.102**	−2.441	−2.019**	−3.613	−2.050**	−3.653	−2.079**
OA11(3,3,T)	−4.623	−2.054**	−3.059	−1.947*	−4.667	−2.016**	−4.742	−2.055**
Road density								
OA5(2,2)	0.019	3.977***	0.012	3.349***	0.019	3.875***	0.019	3.921***
OA6(2,3)	0.013	2.182**	0.005	2.514**	0.015	2.742***	0.014	2.724***
OA10(2,2,T)	0.019	3.977***	0.012	3.349***	0.019	3.875***	0.019	3.921***
Transit density								
OA8(3,3)	−0.010	−2.739***	−0.007	−2.745***	−0.010	−2.900***	−0.010	−2.856***
OA11(3,3,T)	−0.010	−2.739***	−0.007	−2.745***	−0.010	−2.900***	−0.010	−2.856***
Number of employed family members								
0 A3 (1,2)	0.098	1.772*	0.052	1.935*	0.163	2.077**	0.150	2.003**
OA6(2,3)	0.289	3.477***	0.261	3.403***	0.370	3.474***	0.353	3.446***
Number of family members aged < 18								
OA5(2,2)	0.183	5.163***	0.130	4.414***	0.199	5.299***	0.195	5.241***
OA8(3,3)	0.344	6.798***	0.238	5.170***	0.364	6.818***	0.361	6.800***
OA10(2,2,T)***	0.183	5.163***	0.130	4.414***	0.199	5.299***	0.195	5.241***
OA11(3,3,T) ***	0.344	6.798***	0.238	5.170***	0.364	6.818***	0.361	6.800***
Number of motorcycles owned								
OA5(2,2)	−0.268	−5.708***	−0.198	−4.967***	−0.294	−5.845***	−0.294	−5.803***
OA8(3,3)	−0.226	−3.451***	−0.165	−3.459***	−0.259	−3.721***	−0.259	−3.698***
OA10(2,2,T)	−0.268	−5.708***	−0.198	−4.967***	−0.294	−5.845***	−0.294	−5.803***
OA11(3,3,T)	−0.226	−3.451***	−0.165	−3.459***	−0.259	−3.721***	−0.259	−3.698***
Number of car licenses								
0 A3 (1,2)	0.376	6.608***	0.387	7.064***	0.375	5.426***	0.376	5.646***
OA5(2,2)	0.485	11.230***	0.347	6.690***	0.508	11.097***	0.504	11.058***
OA6(2,3)	0.564	6.094***	0.488	5.446***	0.563	5.509***	0.564	5.631***
OA8(3,3)	1.064	17.175***	0.752	7.572***	1.090	16.799***	1.086	16.796***
OA10(2,2,T)	0.485	11.230***	0.347	6.690***	0.508	11.097***	0.504	11.058***
OA11(3,3,T)	1.064	17.175***	0.752	7.572***	1.090	16.799***	1.086	16.796***
Generic variables (GV)								
Car price/household income	−0.134	−2.574***	−0.083	−2.137**	−0.123	−2.344**	−0.123	−2.340***
(License tax + fuel fee)/household income	−7.041	−3.238***	−6.541	−3.971***	−8.247	−3.618***	−8.378	−3.599***
Fuel cost/household income	−0.865	−1.778*	−0.462	−2.135**	−0.848	−1.948*	−0.840	−1.835*
Inclusive value (*t*-statistic vs. 1)	–	–	1.552	2.128**	0.630	2.372**	0.688	1.962**
Log-likelihood at convergence								
LL(0)		−8272.739		−8272.739		−8272.739		−8272.739
ll(p)		−5703.541		−5698.195		−5701.230		−5701.901
Likelihood ratio index (ρ^2)		0.31056		0.31121		0.310841		0.31076
Log-likelihood value versus MNL						4.62 > 3.84**		3.28 < 3.84

* Significance at $\alpha = 0.1$.
** Significance at $\alpha = 0.05$.
*** Significance at $\alpha = 0.01$.

selected to represent the car type model. The likelihood ratio index of the MNL structure reaches 0.577, suggesting good model fit. Five generic variables related to car ownership and usage costs, including (fuel cost)$^{0.5}$, (license tax plus fuel

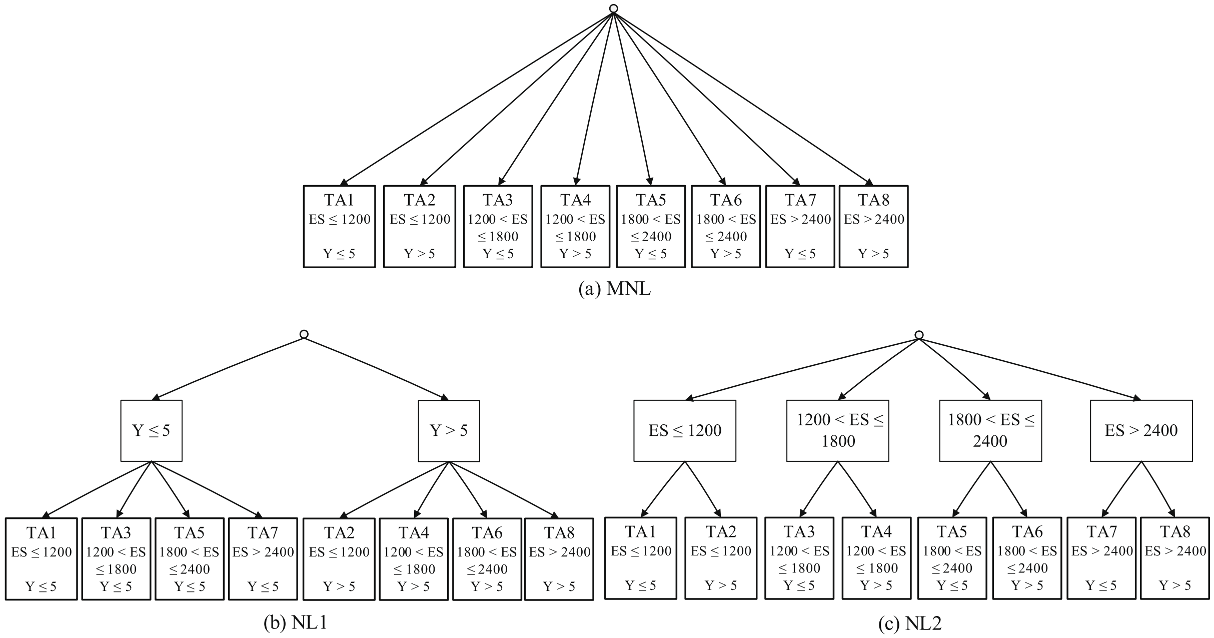

Fig. 4. Three choice structures of the car type model.

fee)/household income, *ln*(car price/household income), *ln*(insurance costs/household income), and *ln*(maintenance costs/household income), all appear to significantly and negatively affects car type choice. Since these costs usually increase with engine size, increases in these costs will reduce the probability of larger cars being chosen. However, fuel and maintenance costs increase with car age, making people tend to favor newer cars, but car price and insurance costs decrease with car age, leading to older cars being favored.

Regarding alternative specific variables, average monthly income of the principal driver is specified to the alternatives of Y > 5 (including TA2, TA4, TA5, and TA8) and has a negative coefficient, suggesting high-income drivers are more likely to acquire new cars than low-income drivers. Furthermore, the gender of the principal driver positively affects the alternative of ES > 1800c.c., suggesting that male principal driver are more likely to acquire a larger car than female principal drivers. Additionally, this variable also demonstrates a significant and negative coefficient on the alternative of $Y \leqslant 5$, indicating that female drivers have a stronger preference for newer cars than male drivers, because female drivers typically feel more awkward in dealing with car breakdown and hence prefer newer cars with lower breakdown probability. Finally, principal drivers with a master's level or higher education prefer cars less than five years old. This last finding is consistent with the findings of Mohammadian and Miller (2003a).

5.3. Car usage model

The car usage model was developed by stepwisely regressing *ln*(annual miles traveled) on explanatory variables, including household background, demographics and travel demand of the principal user, car characteristics, and ownership and usage costs. Various relationships, including linear, logarithmic, and exponential (powers of 1/2, 2, and 3) between explanatory and dependent variables were examined via the backward selection regression model, which started with all candidate variables in the model. The least significant variable is removed after each step. This process continues until no insignificant variables remain. Table 5 lists the final estimation results.

The coefficient of determination $R^2 = 0.610$ indicates good model fit. In addition, the variance inflation factor (VIF) for each variable is computed and used to detect the severity of multicollinearity. Results show all the VIF values fall below 5, indicating the low multicollinearity. The coefficients of corresponding variables are explained as follows. *ln*(household income) positively affects annual miles traveled, meaning that cars owned by higher income families are more intensively used (more miles traveled annually) displaying income elasticity of 0.039. The variables of (number of cars)^2 and number of motorcycles both possess negative coefficients, indicating usage substitution effects among cars and motorcycles within families. The positive coefficient of principal driver gender indicates that male drivers tend to undertake longer car journeys than females. (The coefficients of daily commuting time, weekly commuting days and weekly recreational days all positively affect annual miles traveled as anticipated. Car age negatively affects annual miles traveled, suggesting that older cars are less intensively used. Furthermore, the positive coefficient of engine size

Table 4
Estimation results for the car type model.

Variables	ML		NL1		NL2	
	Parameter	*t*-Statistic	Parameter	*t*-Statistic	Parameter	*t*-Statistic
Alternative-specific constants						
TA1(ES < 1200; Y < 5) (Base)	–	–	–	–	–	–
TA2(ES < 1200;Y > 5)	−3.221	−5.892***	−3.554	−3.830***	−3.690	−4.437***
TA3(1200 < ES < 1800; Y < 5)	4.796	18.337***	5.961	5.675***	5.003	15.215***
TA4(1200 < ES < 1800; Y > 5)	−0.395	−0.987	0.045	0.072	−1.517	−2.306**
TA5(1800 < ES < 2400; Y < 5)	4.490	13.827***	5.051	5.539***	4.860	12.154***
TA6(1800 < ES < 2400; Y > 5)	−0.480	−1.121	−0.821	−1.333	−1.317	−1.920*
TA7(ES > 2400; Y < 5)	5.429	12.323***	5.717	5.562***	6.310	11.856***
TA8(ES > 2400; Y > 5)	3.193	6.007***	3.671	3 481***	3.655	4 435***
Alternative-specific variables						
Monthly income of principal driver Y(age) > 5	−0.097	−3.037***	−0.099	−2.767***	−0.106	−2.305**
Gender of principal driver (male = 1; female = 0) ES > 1800	1.173	6.743***	1.874	4 474***	1.241	7.035***
Gender of principal driver (male = 1; female = 0) Y > 5	1.245	4 911***	1.566	4.889***	1.459	3 131***
Education of principal driver						
(above master degree = 1, below = 0) Y > 5	−0.801	−2.269***	−0.797	−1.850*	−1.126	−1.733*
Transit density ES > 1800	0.005	2.182**	0.007	1.910*	0.006	2.560**
Generic variables (GV)						
$(\text{fuel cost})^{0.5}$	−1.348	−3.305***	−1.399	−3.290***	−1.828	−5 533***
(license tax + fuel fee)/household income	−26.955	−3.710***	−26.941	−2.607***	−26.948	−3.963***
ln(car price/household income)	−1.037	−6.133***	−1.037	−5.029***	−1.260	−7.788***
ln(insurance cost/household income)	−1.239	−15.145***	−1.667	−6.224***	−1.515	−15.422***
ln(maintenance cost/household income)	−1.827	−19.831***	−2.450	−6.403***	−2.284	−17.560***
Inclusive value (t-statistic vs. 1)						
For y < 5	–	–	1.485	5.887***	–	–
For y > 5	–	–	1.396	4.313***	–	–
For ES < 1200	–	–	–	–	0.979	3.786***
For 1200 < ES < 1800	–	–	–	–	1.638	7 771***
For 1800 < ES < 2400	–	–	–	–	1.547	6.604***
For ES > 2400	–	–	–	–	1.175	1.174
Log-likelihood at convergence						
LL(0)		−2894.45		−2894.45		−2894.45
ll(p)		−1244.615		−1231.98		−1224.93
Likelihood ratio index (ρ^2)		0.576990		0.57436		0.57680

* Significance at $\alpha = 0.1$.
** Significance at $\alpha = 0.05$.
*** Significance at $\alpha = 0.01$.

Table 5
Estimation result for the car usage model.

Variable	Parameter	*t*-Statistic	VIF
Constant	8.855	70.421***	–
ln(household income)	0.039	3.726***	1.089
(Number of cars)[a]	−0.003	−1.677*	1.130
Number of motorcycles	−0.002	−2.123**	1.075
Gender of principal user (1 for male)	0.036	1.880*	1.041
Car age	−0.009	−7.480***	1.082
Engine size (per 100c.c.)	0.020	10.562***	1.113
Daily commuting time	0.005	10.715***	1.163
Weekly commuting days	0.015	4.832***	1.251
Weekly recreational days	0.010	1.689*	1.041
ln(fuel cost)	−0.451	−47.330***	1.070
ln(maintenance cost)	−0.129	−17.232***	1.316
Sample size	3450		
R^2	0.610		

* Significance at $\alpha = 0.1$.
** Significance at $\alpha = 0.05$.
*** Significance at $\alpha = 0.01$.
[a] VIF represents variance inflation factor.

means that larger cars are more intensively used. *ln*(fuel cost) and *ln*(maintenance cost) both have negative coefficients, indicating that the higher usage cost of cars reduces their usage intensity at elasticities of 0.451 and 0.129, respectively.

6. Model estimations: integrated motorcycle model

6.1. Motorcycle ownership model

The estimation results of the motorcycle ownership model under four choice structures, similar to the listing given for the car ownership model, are listed in Table 6. The inclusive value of NL1 model is larger than 1, indicating the inappropriateness of the nested structure. The NL2 and NL3 models obtain inclusive values within the 0–1 range and are significantly different from 1. Two NL models outperform the MNL model, using the likelihood ratio test at the 0.05 level of significance. To select a

Table 6
Estimation results for the motorcycle ownership model.

Variables	ML		NL1		NL2		NL3	
	Parameter	*t*-Statistic	Parameter	*t*-Statistic	Parameter	*t*-Statistic	Parameter	*t*-Statistic
Alternative-specific constants								
OA1(0,1) (Base)	–	–	–	–	–	–	–	–
OA2(1,1)	1.493	13.013	2.377	6.555	3.443	5.329	6.780	6.780
OA3(1,2)	0.904	7.018	1.803	0.915	7.063	0.930	7.140	7.140
OA4(2,1)	−2.048	−6.676	−1.026	−11.705	−2.985	−9.786	−5.718	−5.718
OA5(2,2)	2.022	17.478	3.059	7.086	3.721	5.872	7.463	7.463
OA6(2,3)	−0.920	−3.525	−0.095	−1.780	−4.983	−1.819	−5.167	−5.167
OA7(3,2)	−1.219	−5.357	−0.517	−10.869	−2.777	−8.928	−5.260	−5.260
OA8(3,3)	−0.502	−2.212	−0.453	4.515	2.349	3.316	4.049	4.049
OA9(3,4)	−2.339	−6.532	−2.429	−3.601	−7.173	−3.610	−7.372	−7.372
OA10(4,3)	−1.130	−4.834	−0.642	−10.772	−2.752	−8.819	−5.196	−5.196
OA11(4,4)	−1.976	−1.991	−2.819	3.347	1.531	2.381	1.794	1.794
OA12(1,1,T)	−1.165	−5.479	−0.282	3.901	2.040	−3.983	−5.733	−5.733
OA13(2,2,T)	−0.044	−0.282	0.994	5.021	2.633	−2.832	−4.175	−4.175
OA14(3,3,T)	−2.506	−9.501	−2.457	2.515	1.305	−5.439	−7.566	−7.566
OA15(4,4,T)	−3.059	−3.070	−3.901	2.267	1.036	−5.289	−4.293	−4.293
Alternative-specific variables								
Urbanization								
OA11(4,4)	3.511	2.082**	5.567	1.674*	2.443	2.426**	1.898	2.789***
OA15(4,4,T)	3.511	2.082**	5.567	1.674*	2.443	2.426**	1.898	2.789***
Road density								
OA8(3,3)	0.002	1.723*	0.001	2.111**	0.006	1.833*	0.006	1.946*
OA14(3,3,T)	0.002	1.723*	0.001	2.111**	0.006	1.833*	0.006	1.946*
Transit density								
OA11(4,4)	−0.018	−4.897***	−0.024	−4.501***	−0.019	−4.960**	−0.019	−4.887**
OA15(4,4,T)	−0.018	4.397***	−0.024	−4.501***	−0.019	−4.960**	−0.019	−4.887**
Number of employed family members								
OA8(3,3)	0.201	3.827***	0.216	3.267***	0.282	4.801**	0.281	4.798***
OA11(4,4)	0.723	14.947***	0.982	7.665***	0.807	14.686***	0.803	14.481***
OA14(3,3,T)	0.201	3.827***	0.216	3.267***	0.282	4.801**	0.281	4.798***
OA15(4,4,T)	0.723	14.947***	0.982	7.665***	0.807	14.686***	0.803	14.481***
Number of cars								
OA6(2,3)	−0.214	−1.954*	−0.293	−2.421**	−0.360	−2.394***	−0.352	−2.354**
OA8(3,3)	−0.136	−1.759*	−0.188	−1.763*	−0.131	−1.675***	−0.148	−1.884*
OA9(3,4)	−0.374	−2.567***	−0.423	−2.609**	−0.579	−3.027***	−0.571	−3.005***
OA14(3,3,T)	−0.136	−1.759*	−0.188	−1.763*	−0.131	−1.675***	−0.148	−1.884*
Number of motorcycle licenses								
OA6(2,3)	0.653	9.911***	0.763	9.155***	1.015	9.167***	1.038	9.612***
OA8(3,3)	0.541	10.191***	0.803	5.836***	0.472	8.894***	0.481	9.007***
OA9(3,4)	0.931	11.150***	1.237	7.547***	1.421	9.946***	1.438	10.447***
OA14(3,3,T)	0.541	10.191***	0.803	5.836***	0.472	8.894***	0.481	9.007***
Generic variables								
Motorcycle price/household income	−1.177	−2.993***	−1.387	−2.672***	−1.120	−3.000***	−1.371	−3.333***
Inclusive value (t-statistic vs. 1)	–	–	1.865	–	0.190	3.500***	0.219	2.277**
Log-likelihood at convergence								
LL(0)		−7367.615		−7367.615		−7367.615		−7367.615
ll(p)		−5416.707		−5413.582		−5387.967		−5389.484
Likelihood ratio index (ρ^2)		0.26480		0.26522		0.26870		0.26849
Log-likelihood value versus MNL						57.48 > 3.84**		54.45 > 3.84**

* Significance at $\alpha = 0.1$.
** Significance at $\alpha = 0.05$.
*** Significance at $\alpha = 0.01$.

preferred NL model, we performed non-nested tests based on an adjusted likelihood ratio index that corrects the likelihood ratio index for the number of parameters estimated (Horowitz, 1983; Ben-Akiva and Swait, 1986). By comparing the NL2 and NL3 model specifications under the null hypothesis that the model with an inferior likelihood ratio index is the true specification, the non-nested test produces an upper bound for the probability of incorrectly selecting the model with the greater likelihood ratio index as the true model. Given the difference in adjusted likelihood ratio indices of 0.0002, the probability of incorrectly selecting the NL2 model over NL3 is less than 0.04. Thus, we can conclude that the NL2 mode is statistically better than the NL3 model. These results provide the evidence that the NL2 model with $\rho^2 = 0.2687$ is the preferred model of motorcycle ownership. Furthermore, it can be observed that all explanatory variables are statistically significant in various structures. The only generic variable that exhibits a significant effect is the motorcycle price/household income variable. As expected, rising motorcycle prices reduce the utility of the alternatives and thus the probability of it being selected. The other two generic variables, namely, (license tax + fuel fee)/household income and fuel cost/household income, which are statistically significant in the car ownership model, are insignificant in the NL2 model. This difference occurs because in Taiwan, annual fuel fees are NT$4800, 6210 and 7200 for cars with engine sizes of 1201–1800c.c., 1801–2400c.c., 2401–3000c.c., respectively, while annual fuel fees are only NT$600, 900, 1200 for motorcycles with engine sizes of below 50c.c., 51–150c.c., and 151–250c.c., respectively. Additionally, annual license taxes for cars are NT$7120, 11,230 and 15,210 for cars with engine sizes of 1201–1800c.c., 1801–2400c.c., and 2401–3000c.c.; however, annual license taxes are 0 and NT$800 for motorcycles with engine sizes of below 150c.c. and 151–250c.c. Moreover, motorcycles have gas efficiency roughly three or four times that of cars. Thus, license taxes, fuel fees, and fuel costs do not significantly affect motorcycle ownership. The low ownership and usage costs of motorcycles in Taiwan explain its extremely high motorcycle ownership ratio.

Regarding the alternative specific variables (OA1(0,1) as the base), the urbanization and transit density both significantly and negatively affect the OA11(4,4) and OA15(4,4,T) alternatives, indicating that families living in more urbanized and high transit density cities have low rates of motorcycle ownership. However, the road density significantly and positively affects OA8(3,3) and OA14(3,3,T), indicating that people living in high road density areas tend to have higher rates of motorcycle ownership. The number of employed family members significantly and positively affects OA8(3,3), OA11(4,4), OA14(3,3,T), and OA15(4,4,T), implying that higher rates of family member employment create more work trips, increasing family motorcycle ownership rate. Number of cars owned significantly and negatively affects OA6(2,3), OA8(3,3), OA9(3,4),

Table 7
Estimation results for the car type model.

Variables	ML		NL1		NL2	
	Parameter	*t*-Statistic	Parameter	*t*-Statistic	Parameter	*t*-Statistic
Alternative-specific constants						
TA1(ES ⩽ 90; Y ⩽ 3) (Base)	–	–	–	–	–	–
TA2(ES ⩽ 90; Y > 3)	−0.370	−1.449	−0.024	−0.067	−0.888	−1.804*
TA3(90 < ES ⩽ 125; Y ⩽ 3)	2.897	6.221***	3.703	4.671***	4.057	5.722***
TA4(90 < ES ⩽ 125; Y > 3)	1.997	4.077***	2.764	3.462***	2.100	2.667***
TA7(ES > 125; Y ⩽ 3)	2.039	3.963***	2.439	3.206***	4.153	5.049***
TA8(ES > 125; Y > 3)	2.439	3.657***	3.151	3.311***	4.885	3.513***
Alternative-specific variables						
Gender of principal driver (male = 1; female = 0) ES > 90	1.004	4.536***	1.204	3.283***	1.116	4.191***
Age of principal driver ES > 90	−0.021	−2.568**	−0027	−1.916**	−0.023	−2.064**
Annual miles traveled Y > 3	−0.803	−3.351***	−0.833	−3.178***	−0.884	−1.502
Annual miles traveled ES > 90	2.636	5.937***	3.132	4.115***	2.995	6.306***
Road density ES > 90	−0.023	−2.102**	−0.028	−1.601	−0.030	−2.173**
Generic variables						
$(\text{fuel cost})^{0.5}$	−1.658	−3.506***	−2.050	−4.563***	−2.734	−4.689***
ln(motorcycle price/household income)	−1.896	−8.192***	−2.110	−8.210***	−3.479	−9.308***
ln(insurance cost/household income)	−1.727	−11.170***	−2.157	−10.560***	−2.894	−10.710***
ln(maintenance cost/household income)	−1.424	−14.905***	−1.687	−11.333***	−2.256	−10.186***
Inclusive values (t-statistic vs. 1)						
For Y ⩽ 3	–	–	1.352	7.746***	–	–
For Y > 3	–	–	1.228	6.992***	–	–
for ES ⩽ 90	–	–	–	–	1.712	4.729***
For 90 < ES ⩽ 125	–	–	–	–	2.092	7.556***
For ES > 125	–	–	–	–	1.985	4.345***
Log-likelihood at convergence						
LL(0)		−2239.99		−2239.99		−2239.99
$LL(\hat{\beta})$		−1021.43		−1016.34		−989.24
Likelihood ratio index (ρ^2)		0.54400		0.54628		0.55837

* Significance at $\alpha = 0.1$.
** Significance at $\alpha = 0.05$.
*** Significance at $\alpha = 0.01$.

and OA14(3,3,T), indicating a high substitution relationship between cars and motorcycles. Furthermore, number of motorcycle licenses held by a family significantly and positively affects OA6(2,3), OA8(3,3), OA9(3,4), and OA14(3,3,T), indicating that families with more motorcycle licenses tend to have higher rates of motorcycle ownership.

6.2. Motorcycle type model

In Table 7, three choice structures of the motorcycle type model were also compared by setting TA1(ES $\leqslant$ 90; Y $\leqslant$ 3) as the base. Notably, the inclusive values of NL1 and NL2 are all larger than 1, indicating the inappropriateness of nested structures. Thus, the MNL structure is selected to represent the motorcycle type model, which has a likelihood ratio index of 0.544, indicating good model fit. Most generic variables significantly and negatively affect motorcycle type choices, except for (license tax plus fuel fee)/household income. The reason for the insignificance is similar to that for the motorcycle ownership model.

Regarding the alternative specific variables, principal driver gender has a positive effect, but the age variable negatively affects the alternative of ES > 90, implying that older male drivers prefer motorcycles larger than 90c.c. Annual miles traveled negatively affects the alternatives of Y > 3 and positively affects the alternatives of ES > 90, meaning that newer and larger motorcycles will be selected as annual mileage traveled increases. Notably, road density has a negative effect on the alternative of ES > 90, suggesting that families living in high road density cities prefer smaller motorcycles. This preference exists because increased road density encourages people to choose car as their main travel mode and motorcycle as a subordinate mode, and hence to prefer smaller motorcycles.

6.3. Motorcycle usage model

The motorcycle usage model is developed by stepwisely regressing *ln*(annual miles traveled) on explanatory variables, including principal user household background, demographics, and travel demand, motorcycle characteristics, and ownership and usage cost. Various relationships, including linear, logarithmic and exponential (powers of 1/2, 2, and 3) between explanatory variables and target variable are also examined. Again the backward selection model is used to sequentially remove insignificant explanatory variables. Table 8 lists the final estimation results. Notably, the coefficient of determination R^2 = 0.403. The VIF value for each variable is also computed. Results show all the VIF values fall below 5, indicating the low multicollinearity. The coefficients of corresponding variables are detailed below.

The logarithm of household income shows a negative effect on *ln*(annual miles traveled), in contrast to the car usage model, suggesting that motorcycle usage is inferior goods and the preference of higher income families for car usage over motorcycle usage. The number of employed family members positively affects *ln*(annual miles traveled), suggesting that larger numbers of members employed will result in higher travel demand and more intensive motorcycle usage. Numbers of cars and motorcycles both have negative coefficients, implying the existence of a substitution effect between them. Principal user gender and age respectively have positive and negative effects on motorcycle usage, suggesting that older and male riders are more intensive motorcycle users. Motorcycle age and engine size respectively negatively and positively affect *ln*(annual miles traveled), indicating that newer and larger motorcycles are used more intensively. The coefficients of daily commuting time, weekly commuting days and weekly recreational days of the principal user all show positive effects on annual miles traveled as expected, resembling the results of the car usage model. *ln*(fuel cost) has a negative coefficient, indicating that higher gas prices reduce motorcycle usage.

Table 8
Estimation results for the motorcycle usage model.

Variables	Parameters	*t*-Statistic	VIF
Constant	8.815	51.198***	–
ln(household income)	−0.083	−5.529***	1.152
Number of employed family members	0.018	2.069*	1.345
Number of cars	−0.012	−1.874*	1.173
(Number of motorcycles)[a]	−0.004	−2.671***	1.215
Gender of principal user (male = 1; female = 0)	0.128	5.500***	1.024
Age of principal user	−0.001	−1.993**	1.041
Motorcycle age	−0.011	−4.935***	1.056
Engine size (c.c.)	0.002	7.139***	1.066
Daily commuting time	0.004	7.007***	1.048
Weekly commuting days	0.057	12.963***	1.131
Weekly recreational days	0.037	5.599***	1.024
ln(fuel cost)	−0.389	−31.402***	1.165
Sample size		2536	
R^2		0.403	

* Significance at α = 0.1.
** Significance at α = 0.05.
*** Significance at α = 0.01.
[a] VIF represents variance inflation factor.

7. Estimating energy consumption and emissions

According to the variables presented in abovementioned models, the integrated car and motorcycle models are able to estimate energy consumption and emissions under the management strategies depicted in Table 9, which can be divided into three categories: increase ownership cost, increase usage cost and strengthen transit service.

To investigate the applicability of the proposed integrated models, the detailed estimation process for the changes in energy consumption and emissions under the three scenarios of base (unchanged), medium (10%) and large (30%) increases in gas price are compared.

7.1. Base scenario

Table 10 lists the number of sampled households adopting car ownership alternatives. The distribution can be used to compute the total number of cars owned by sampled households.

Cars that have been disposed do not consume fuel or emit pollutants, and thus can be ignored in the estimation process. Meanwhile, cars that are sold second-hand will re-enter the system via newly-purchased transaction. Therefore, to avoid double counting, this study only considers numbers of newly-purchased and continuously-owned cars. According to the total number of registered private owned passenger cars in Taiwan in 2007, namely 5555,839, numbers of newly-purchased and continuously-owned cars are estimated as being 878,138 and 4677,701, respectively. The car type model is then applied to the newly-purchased cars for estimating the number of cars belonging to each car type; meanwhile, the continuously-owned cars are split into various car types according to current market share. The total number of cars and miles traveled in various car types are computed and listed in Table 11.

Table 9
Applicable scenarios of the integrated models.

Policy	Management strategies	Manipulating models		Manipulating variables
		Car	Motorcycle	
Increase ownership cost	Increase license tax or fuel fee	Ownership Type	– –	(license tax + fuel fee)/household income
	Increase vehicle price 1. Levy vehicle registration tax 2. Mandatory requirements of parking lot	Ownership Type	Ownership Type	Vehicle price/household income
	Increase insurance cost	–	Type	Insurance cost/household income
Increase usage cost	Increase gas price 1. Levy energy tax	Ownership Type	– Type	Fuel cost/household income
	2. Fuel fee according to miles*	Usage	Usage	Fuel cost
	Level-up exhaust inspection standard or shorten exhaust inspection period	Type	Type	Maintenance cost/household income
		Usage	–	Maintenance cost
	Slow-down road construction	Ownership Type	Ownership Type	Road density
Strengthen transit service	Increase transit network and service frequency	Ownership Type	Ownership –	Transit density

* *Note*: Fuel fee in Taiwan is not levied on miles traveled, but on a lump-sum tax varying by engine size.

Table 10
Distribution of sampled household and cars under base scenario.

Alternative	Number of households		Number of cars		
	Household	Percentage (%)	Newly purchased	Continuously owned	Sold or disposed
OA1(0,1)	182	5.27	182	–	–
OA2(1,1)	1506	43.66	–	1506	–
OA3(1,2)	246	7.13	246	246	–
OA4(2,1)	57	1.66	–	57	57
OA5(2,2)	755	21.89	–	1510	–
OA6(2,3)	78	2.26	78	156	–
OA7(3,2)	30	0.88	–	60	30
OA8(3,3)	251	7.27	–	753	–
OA9(1,1,T)	154	4.46	154	–	154
OA10(2,2,T)	140	4.07	140	140	140
OA11(3,3,T)	50	1.46	50	100	50
Total	3450	100.00	850	4528	431

Note: – denotes no such a transaction under the alternative.

Table 11
Numbers of cars and total miles traveled in various car types under base scenario.

TA	Engine size	Age	Annual miles traveled (a)	Newly purchased			Continuously owned		
				Percentage (b)	Number of cars (c)	Total miles traveled (d)	Percentage (e)	Number of cars (f)	Total miles traveled (g)
1	ES ⩽ 1200	Y ⩽ 5	10,252	1.78	16,180	165,877,360	0.97	45,064	461,992,727
2		Y > 5	7881	0.62	5654	44,559,174	1.97	91,521	721,277,460
3	1200 < ES ⩽ 1800	Y ⩽ 5	11,698	47.91	436,240	5103,135,520	18.89	877,580	10,265,931,976
4		Y > 5	8795	7.54	68,653	603,803,135	38.53	1790,003	15,743,078,467
5	1800 < ES ⩽ 2400	Y ⩽ 5	11,602	29.25	266,378	3090,517,556	10.67	495,700	5751,115,476
6		Y > 5	10,145	3.7	33,677	341,653,165	21.75	1010,448	10,250,997,319
7	ES > 2400	Y ⩽ 5	13,136	6.79	61,852	812,487,872	2.38	110,569	1452,428,975
8		Y > 5	10,403	2.41	21,931	228,148,193	4.85	225,318	2343,986,707
	Sub-total		–	100	910,565	10,390,181,975	100	4645,739	46,990,809,106
	Total								57,380,991,081

Table 12
Shifting ratios of car users and motorcycle users under usage limitation and various gas price increases.

Shifting to	Car users			Motorcycle users		
	Gas price increase (%)		Usage limitation (%)	Gas price increase (%)		Usage limitation (%)
	10%	30%		10%	30%	
Car	–	–	–	3.76	0.94	13.01
Motorcycle	69.48	66.43	66.56	–	–	–
Bicycle	6.72	8.54	7.50	13.94	30.83	40.35
Bus	7.46	9.45	6.56	28.32	21.11	17.85
Subway	5.75	6.71	8.54	15.27	13.06	11.97
Rail	2.09	0.00	3.54	19.91	17.97	1.04
Taxi	0.37	0.27	1.15	1.11	0.10	0.97
Walk	6.12	5.53	5.73	9.96	13.38	14.39
Others	2.01	3.06	0.42	7.74	2.61	0.42
Total	100.00	100.00	100.00	100.00	100.00	100.00

Table 13
Ownership and usage of each car type under 10% and 30% increase in gas price.

Car type		Annual miles traveled	Newly purchased			Continuously owned			Total miles traveled	Total miles traveled + shifted motorcycle usage
Engine size	Age		Percentage	Number of cars	Total miles traveled	Percentage	Number of cars	Total miles traveled		
(a) 10% increase in gas price										
ES ⩽ 1200	Y ⩽ 5	9814	1.78	16,220	159,183,080	0.97	45,063	442,248,282	601,431,362	601,687,405
	Y > 5	7466	0.61	5594	41,764,804	1.97	91,521	683,295,786	725,060,590	725,369,265
1200 < ES	Y ⩽ 5	11,216	48.14	440,895	4945,078,320	18.89	877,576	9842,892,416	14,787,970,736	14,794,266,316
⩽ 1800	Y > 5	8287	7.53	68,558	568,140,146	38.53	1789,996	14,833,696,852	15,401,836,998	15,408,393,915
1800 < ES	Y ⩽ 5	11,053	29.17	265,136	2930,548,208	10.67	495,698	5478,949,994	8409,498,202	8413,078,319
⩽ 2400	Y > 5	9645	3.68	33,335	321,516,075	21.75	1010,444	9745,732,380	10,067,248,455	10,071,534,315
ES > 2400	Y ⩽ 5	12,445	6.73	60,696	755,361,720	2.38	110,568	1376,018,760	2131,380,480	2132,287,858
	Y > 5	9774	2.36	21,029	205,537,446	4.85	225,317	2202,248,358	2407,785,804	2408,810,854
Total			100.00	911,463	9927,129,799	100.00	4646,183	44,605,082,828	54,532,212,627	54,555,428,248
(b) 30% increase in gas price										
ES ⩽ 1200	Y ⩽ 5	8995	1.79	16,321	146,803,094	0.97	45,052	405,243,256	552,046,351	552,220,849
	Y > 5	6700	0.6	5471	36,652,792	1.97	91,497	613,033,099	649,685,891	649,891,252
1200 < ES	Y ⩽ 5	10,312	48.58	442,933	4567,530,188	18.89	877,354	9047,274,281	13,614,804,469	13,619,108,012
⩽ 1800	Y > 5	7357	7.51	68,473	503,757,708	38.53	1789,542	13,165,660,734	13,669,418,442	13,673,739,248
1800 < ES	Y ⩽ 5	10,031	29.01	264,502	2653,218,219	10.67	495,573	4971,089,066	7624,307,284	7626,717,274
⩽ 2400	Y > 5	8717	3.64	33,188	289,300,671	21.75	1010,188	8805,807,794	9095,108,465	9097,983,364
ES > 2400	Y ⩽ 5	11,172	6.6	60,176	672,288,797	2.38	110,540	1234,953,993	1907,242,790	1907,845,655
	Y > 5	8672	2.26	20,606	178,693,485	4.85	225,260	1953,457,209	2132,150,694	2132,824,652
Total			100.00	911,761	9048,244,955	100.00	4644,542	40,196,519,430	49,244,764,386	49,250,005,544

The figures in columns (a) and (b) are, respectively, estimated using the car usage and the car type models; while the figures in column (e) represent the current market share of each car type. The numbers of newly-purchased and continuously-owned cars over various car types can be computed by multiplying 878,138 and 4677,701 with columns (b) and (e), respectively. The total miles traveled by newly-purchased and continuously-owned cars, *namely* columns (d) and (g), can then be computed by multiplying columns (a) and (c) and columns (a) and (f). In Taiwan, total annual miles traveled by all cars in 2007 is estimated as 57,380,991,081 km.

Similar to the process for estimating annual miles traveled by cars, numbers of motorcycles and annual miles traveled are computed. Total miles traveled by motorcycles during 2007 reached 54,896,026,411 km, slightly lower than the figure for cars.

Due to the high substitution effect between cars and motorcycles within a household, the choice behaviors of cars and motorcycles should be better simultaneously surveyed and modeled. However, since it is our attempt to develop an integrated model for replicating the choice behaviors of private motor vehicles ranging from ownership, transaction, type and usage. With such an attempt, the questionnaire is rather lengthy already. To further simultaneously survey all private motor vehicles of a household will result in an unacceptable lengthy questionnaire for a post-mailed survey. Besides, if one attempts to model both car and motorcycle ownership, the number of private vehicles of a household in Taiwan will range from 0 to as high as 7 (three cars and four motorcycles). It would also cause the alternative structure of the disaggregate models too complicated to operate. Thus, this paper decided to model the choice behaviors of cars and motorcycles, separately and independently.

Anyhow, to consider the substitution effect between cars and motorcycles in a household, the numbers of cars and motorcycles are incorporated into each disaggregate model as instrumental variables of their usage. Besides, we also surveyed respondent responses under various scenarios. Shifting ratios (from discouraged car usage to the usage of other modes; likewise for discouraged motorcycle usage) under three scenarios are surveyed: (1) the management strategy of 10% increase in gas price; (2) the management strategy of 30% increase in gas price; (3) the management strategies which limit the usage of

Table 14
Ownership and usage of each motorcycle type under 10% and 30% increase in gas price.

Motorcycle type		Annual miles traveled	Newly purchased			Continuously owned			Total miles traveled	Total miles traveled + shifted car usage
Engine size	Age		Percentage	Number of motorcycles	Total miles traveled	Percentage	Number of motorcycles	Total miles traveled		
(a) 10% increase in gas price										
ES ⩽ 90	Y ⩽ 3	9814	1.78	16,220	159,183,080	0.97	45,063	442,248,282	601,431,362	601,687,405
	Y > 3	7466	0.61	5594	41,764,804	1.97	91,521	683,295,786	725,060,590	725,369,265
90 < ES	Y ⩽ 3	11,216	48.14	440,895	4945,078,320	18.89	877,576	9842,892,416	14,787,970,736	14,794,266,316
⩽ 125	Y > 3	8287	7.53	68,558	568,140,146	38.53	1789,996	14,833,696,852	15,401,836,998	15,408,393,915
ES > 125	Y ⩽ 3	11,053	29.17	265,136	2930,548,208	10.67	495,698	5478,949,994	8409,498,202	8413,078,319
	Y > 3	9645	3.68	33,335	321,516,075	21.75	1010,444	9745,732,380	10,067,248,455	10,071,534,315
Total			100.00	1961,142	8457,890,750	100.00	11,997,003	45,820,698,941	54,278,589,691	56,258,490,717
(a) 30% increase in gas price										
ES ⩽ 90	Y ⩽ 3	3677	5.88	115,315	424,013,589	4.94	592,652	2179,181,404	2603,194,993	2855,272,273
	Y > 3	2959	3.53	69,228	204,846,473	17.26	2070,683	6127,150,997	6331,997,470	6945,148,887
90 < ES	Y ⩽ 3	4431	64.6	1266,897	5613,620,988	16.23	1947,113	8627,657,703	14,241,278,691	15,620,315,915
⩽ 125	Y > 3	3705	18.57	364,184	1349,301,289	56.76	6809,499	25,229,193,795	26,578,495,084	29,152,191,931
ES > 125	Y ⩽ 3	5093	6.27	122,964	626,253,313	1.07	128,368	653,778,224	1280,031,537	1403,981,863
	Y > 3	4302	1.15	22,553	97,023,529	3.74	448,688	1930,255,776	2027,279,305	2223,588,476
Total			100.00	1961,141	8315,059,180	100.00	11,997,003	44,747,217,899	53,062,277,079	54,861,348,987

Table 15
Gas mileage and emission coefficients for each car and motorcycle type.

Vehicle	Engine size	Age	NO_x (g/km)	CO (g/km)	HC (g/km)	CO_2 (g/km)	Gas mileage (km/l)
Car	ES ⩽ 1200	Y ⩽ 5	0.12	0.37	0.31	175.15	12.92
		Y > 5	0.50	1.34	0.69	190.49	11.88
	1200 < ES ⩽ 1800	Y ⩽ 5	0.12	0.37	0.31	208.00	10.88
		Y > 5	0.50	1.34	0.69	219.07	10.33
	1800 < ES ⩽ 2400	Y ⩽ 5	0.12	0.37	0.31	240.49	9.41
		Y > 5	0.50	1.34	0.69	255.42	8.86
	ES > 2400	Y ⩽ 5	0.12	0.37	0.31	310.00	7.30
		Y > 5	0.50	1.34	0.69	349.23	6.48
Motor-cycle	ES ⩽ 90	Y ⩽ 3	0.15	1.23	0.69	83.60	27.07
		Y > 3	0.64	4.20	2.07	106.75	21.20
	90 < ES ⩽ 125	Y ⩽ 3	0.15	1.23	0.69	87.71	25.80
		Y > 3	0.64	4.20	2.07	111.20	20.35
	ES > 125	Y ⩽ 3	0.15	1.23	0.69	91.40	24.76
		Y > 5	0.64	4.20	2.07	116.83	19.37

Note: Emission coefficients of NO_x, CO, and HC are estimated by Mobile-Taiwan, which was revised from Mobile 6.1 (developed by Environmental Protection Administration, US) by considering the emission standard and vehicles mixes in Taiwan. Gas mileages are obtained from the questionnaire survey. CO_2 coefficient of each vehicle type is set as 2263 g/l divided by corresponding gas mileage.

Table 16
The energy consumption and emissions of cars and motorcycles under various scenarios.

Item	Base scenario	10% increase		30% increase	
	Amount	Amount	Diff. (%)	Amount	Diff. (%)
Car usage (km)	57,380,991,081	54,532,212,627	−4.96	49,244,764,386	−14.18
Car usage + shift (km)	–	54,555,428,248	−4.92	49,260,330,305	−14.15
Motorcycle usage (km)	54,896,026,411	54,278,589,691	−1.12	53,062,277,079	−3.34
Motorcycle usage + shift (km)	–	56,258,490,717	2.48	58,200,499,344	6.02
EC (l)	8445,673,587	8209,828,527	−2.792	7743,290,552	−8.316
CO_2 (kg)	19,112,559,328	18,578,841,958	−2.792	17,523,066,520	−8.316
NO_x (kg)	44,464,735	44,096,438	−0.828	43,129,257	−3.003
CO (kg)	226,249,416	227,681,641	0.633	228,413,902	0.957
HC (kg)	117,412,719	117,967,086	0.472	118,022,616	0.519

Table 17
Results of 10% and 30% increase (or reduction) in important manipulating variables.

Policy	Manipulating variables	10%					30%				
		EC (l)	CO_2 (kg)	NO_x (kg)	CO (kg)	HC (kg)	EC (l)	CO_2 (kg)	NO_x (kg)	CO (kg)	HC (kg)
Increase ownership cost	Increase (license tax + fuel fee)	−0.004	−0.004	−0.001	0.002	0.002	−0.006	−0.006	−0.005	−0.003	−0.003
	Increase vehicle price	−0.013	−0.013	0.030	0.014	0.010	−0.039	−0.039	0.043	−0.014	−0.023
	Increase insurance cost	−0.004	−0.004	−0.001	0.002	0.002	−0.006	−0.006	−0.005	−0.003	−0.003
Increase usage cost	Increase gas price	−2.792	−2.792	−0.828	0.633	0.472	−10.124	−10.124	−6.560	−3.749	−4.031
	Increase maintenance cost	−0.142	−0.142	−0.011	0.074	0.064	−0.318	−0.318	−0.258	−0.136	−0.133
	Reduce road density	−0.010	−0.010	−0.032	0.022	0.017	−0.023	−0.023	−0.079	−0.049	−0.035
Strengthen transit service	Increase transit density	−0.006	−0.006	−0.005	0.003	0.003	−0.017	−0.017	−0.026	−0.022	−0.019

either cars or motorcycles, as shown in Table 12. Thus, taking motorcycle usage for instance, the total motorcycle usage is first estimated by the integrated model, and then adds the usage shifted from discouraged car usage. As shown in Table 12, most car users shift to using motorcycle (66.43% to 69.48%), while most motorcycle users shift to taking buses (28.32% for 10% increase in gas price) and bicycles (30.82% for 30% increase in gas price; 40.35% for motorcycle usage limitation). As anticipated, few motorcycle users shift to using cars. Notably, the shifting ratio from car usage to motorcycle usage or from motorcycle usage to car usage decreases with increasing gas prices. According to the shifting ratio, the extra total miles traveled by cars and motorcycles are induced from the shifting usage.

Accordingly, the total miles traveled by cars and motorcycles under 10% and 30% increases in gas price are estimated in Tables 13 and 14, respectively.

To estimate energy consumption and emissions, the gas mileage and emission coefficients for each car and motorcycle type are estimated as listed in Table 15.

From Eqs. (5)–(12), total energy consumption and emissions of cars and motorcycles can be estimated as listed in Table 16. Note that total miles traveled by cars decrease by 4.96% and 14.18%, respectively, under scenarios of 10% and 30% increase in gas price, indicating that the gas price elasticity of car users is 0.47–0.50; while total miles traveled by motorcycles decrease by 1.12% and 3.34%, respectively, under scenarios of 10% and 30% increase in gas price, indicating price elasticities of 0.11, which are less than one-fourth of those of car users, suggesting motorcycles are a comparatively gas price inelastic mode. With further incorporation of shifting ratio, total miles traveled by cars change only slightly, but total miles traveled by motorcycles increase significantly, even resulting in greater usage than in the base scenario, with increase percentages of 2.48% and 6.02%, respectively, due to the large percentage of discouraged car users (69.50% and 64.60% under 10% and 30% gas price increases, respectively) who turn to using motorcycles to make their journeys. Total fuel consumption and CO_2 emissions decrease by 2.79% and 8.32% under the scenarios of 10% and 30% increase in gas price. NO_x emissions also slightly reduce by 0.83% and 3.00% under the scenarios of 10% and 30% increase in gas price, respectively. In contrast, CO and HC emissions increase by 0.63% (0.96%) and 0.47% (0.52%), respectively, under 10% (30%) increase in gas price because of greater use of motorcycles, which are more polluting in terms of CO and HC. Clearly, even with sky-rising gas prices, reduction of energy consumption and emissions is limited. Accordingly, to propose sustainable management strategies based on usage cost to mitigate car and motorcycle usage, the low gas price elasticities of car and motorcycle usage and high shifting ratio (from cars to motorcycles) will neutralize the expected reduction in emissions. Unlike European and North American countries, motorcycles are very prevailing and competitive private vehicles in many Asian counties. Taking Taiwan for instance, the ownership ratio of motorcycles reaches 0.586 per capita, the highest level in the world. Therefore, because of higher emissions of motorcycles, implementation of the management strategies aiming at mitigating ownership and usage of cars might not result in less pollution, if no corresponding strategies for motorcycle usage control are simultaneously implemented, since large part of discouraged car usage would shift to use of motorcycles instead. The interpretation of the findings has been highlighted in the context.

The same estimation process is then applied to the scenarios of 10% and 30% increase (or decrease) in other manipulating variables and the results are reported in Table 17. As anticipated, the strategy of increase in gas price exhibits the highest effect on reducing energy consumption and emissions, followed by the strategy of increase in maintenance cost. Comparing to the effects of gas price and maintenance cost increase, the strategies associated with other manipulating variables contribute rather little to sustainability achievement. Based on this, the strategies to levy Energy Tax (increase in gas price) and to level-up exhaust inspection standard and shorten exhaust inspection period (increase in maintenance cost) are recommended.

8. Concluding remarks

This study, respectively, proposes integrated choice behaviors associated with ownership, type and usage of cars and motorcycles in Taiwan. The integrated models provide in-depth investigations of the above disaggregate choice behaviors in Taiwan. Based on such integrated models, reduction in energy consumption and emissions under various management strategies, designed to mitigate ownership or usage of cars and motorcycles, can be estimated and assessed. Scenarios involving gas price increases (base scenario, 10% and 30%) are first estimated and compared in more details. The scenario analysis is used to illustrate the integration and interaction among ownership, type and usage models. The results of the gas price increase scenarios indicate low gas price elasticity for usage of cars and motorcycles in Taiwan; especially, there is a high ratio of users shifting from car usage to motorcycle usage in response to high gas prices, suggesting high dependency upon cars, and even higher dependency on motorcycles. This phenomenon explains why Taiwan has the highest ratio of motorcycle ownership in the world. Furthermore, strategies associated with 10% and 30% increase in other manipulating variables are also estimated and compared. The results show that the strategy of gas price increase exhibits the largest effect on the reduction of energy consumption and emissions, followed by the strategy of maintenance cost increase. The countermeasures for reducing ownership and usage of cars and motorcycles are then recommended.

Of course, it is possible that the respondent of a household owning more than one private motor vehicle would alternatively use one of them for traveling to work or school; however, to avoid doubt counting, only the behaviors related to the sampled vehicle are considered. The trips of the respondent traveling with other vehicles are not considered in the proposed model, since we are modeling the annual miles traveled by a vehicle not by a person. In fact, other family members might also contribute to the annual miles traveled by the sampled vehicle, which has already been considered since the respondents were asked to provide the annual miles traveled by the sampled vehicle, not by the principal user alone. Besides, it is worth noting that for the households owning more than one vehicle, the usage intensities of these vehicles may also differ. Fortunately, with a systematically sampling technique, vehicles with high or low usage intensity will be chosen propositionally. The representativeness of the annual miles traveled by vehicles can be assured.

Since too many alternatives are designed in the ownership and type models of cars and motorcycles, creating difficulties in examining and interpreting alternative specific variables. A more simplified alternative structure of the models deserves further examination. Moreover, also because of the consideration of too many alternatives, this study developed separate car and motorcycle models. However, owing to the high substitution between cars and motorcycles within households, user behavior in relation to cars and motorcycles is best modeled simultaneously. Additionally, choice behaviors of car and motorcycle users may differ depending upon the transportation environment of the cities where they live. Cities with more convenient public transportation may reduce the dependency of their residents on private motor vehicles. Consequently, it is interesting to separately develop and compare integrated models of the car and motorcycle users living in different cities. To enhance the applicability of the proposed model, a mode choice model among cars, motorcycles, bikes, walk, transit, and paratransit, under various management strategies deserves to be developed for enhancing the comprehensiveness of the integrated model. The mode choice model can be used to explain which mode and to what extent the discouraged car or motorcycle usage is shifted to. For example, a comprehensive model proposed by Roorda et al. (2009) which combines vehicle ownership, vehicle type as well as activity scheduling/mode choice into an integrated dynamic vehicle transactions model. However, to simultaneous consider so many choice behaviors will lead to a very lengthy questionnaire. Therefore, it is suggested collecting the data through a home interview survey instead of a post-mail survey in future studies. Last but not least, a follow-up survey of the sampled car and motorcycle owners should be conducted to examine dynamic changes in choice behaviors in consecutive years. Based on such a survey, a dynamic modeling of these choice behaviors based on panel data can be developed and then used to provide more insightful information.

We acknowledge that modeling car and motorcycle ownership may adopt more complex discrete choice models such as the cross-nested logit (CNL) or generalized nested logit (GNL) model (Vovsha, 1997; Wen and Koppelman, 2001) that has a high degree of flexible correlation structure accommodating differential cross-elasticity of pairs of alternatives. However, in addition to utility function parameters, the CNL or GNL model requires estimating a large number of inclusive value and allocation parameters, which may result in computational burden. When the number of alternatives is large, difficulty in estimation can be extremely severe. We use the NL model because it can be feasibly estimated with a large number of alternatives and well serve for the purpose of policy simulations. Nevertheless, it may be worthwhile to adopt advanced discrete choice models such as CNL, GNL, and mixed logit models (Brownstone and Train, 1998; McFadden and Train, 2000) at a later stage of model development.

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