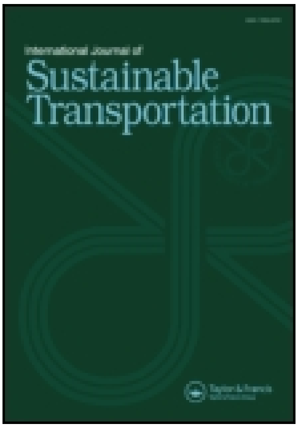

International Journal of Sustainable Transportation
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ujst20

An Analysis of Car and Motorcycle Ownership in Macao

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Published online: 01 Oct 2012.

International Journal of Sustainable Transportation, 7:204–225, 2013

ISSN: 1556-8318 print/1556-8334 online
DOI: 10.1080/15568318.2013.710057

An Analysis of Car and Motorcycle Ownership in Macao

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ABSTRACT
Reducing automobile dependency is one of the key challenges in the development of a sustainable transportation system. However, to evaluate the effectiveness of a policy, it is necessary to understand the factors that would influence the choice behavior of travelers. In this paper, the impacts of urban characteristics to the household vehicle ownership level for cars and motorcycles in Macao are investigated. A discrete choice approach is used to estimate the number of vehicles that a household would own using disaggregate household survey data. The result reveals that whereas income has positive effect on both car and motorcycle ownerships, the demographic attributes of the residential locations have different effects to the ownerships of the two vehicle types. We also propose that the motorcycle ownership should be represented at a personal decision level instead of a household level.
Key Words: car ownership, discrete choice models, motorcycle ownership, urban characteristics

1. INTRODUCTION

The traffic congestion, energy consumption, and environment issues are main concerns in many Asian cities, which have been enjoying the rapid economic growth since the last few decades. As demand for mobility and traffic increase with income and development, the purchasing power for private vehicles increases at the same time, causing more serious traffic congestion problems. Accessibility is a major index in the sustainable development of a city, and how to reduce the need

Received 11 April 2011; revised 4 October 2011; accepted 6 June 2012.
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and dependences of automobile is one of the key challenges in the development of a sustainable transportation system.

The motorization process in cities in Asia is dissimilar from that of Western countries (Hook and Replogle 1996). Most Asian cities have the characteristics of high population density, rapid growth in gross domestic product (GDP), and a mixture of private transportation modes, including cars, motorcycles, bicycles, and walking. Only a few cases, such as Japan, Singapore, Hong Kong, and Korea, have managed to control motorization. Public transportation could reach a larger modal share if the transit system and land-use pattern are integrated before automobile dependencies are established (Heilbrun and McGuire 1987).

To evaluate the effectiveness of a policy towards vehicle ownership control, it is necessary to understand the factors that influence household preferences and needs regarding the ownership of private vehicles. In this study, we analyze the impacts of urban characteristics to car and motorcycle ownership, and a discrete-choice model is proposed using disaggregate data from surveys at the household and personal levels. Whereas the private car is a safe, comfortable, and reliable mode of travel, motorcycles and scooters are more popular in some countries—such as Taiwan, Malaysia, and Japan—due to these modes' high efficiency and convenience in intra-city commuting. Intuitively, the factors for car ownership and motorcycle ownership are different, but cars and motorcycles are substitutions for each other and therefore their ownership levels may be interrelated. Motorcycles are often considered to be a stepping-stone to car ownership, and we have to understand the attributes of the owners and users in order to derive efficient policies towards vehicle ownership and usage controls.

This article contributes to the literature with the empirical investigation for the case of Macao, which is a city having unique characteristics. Macao has a population of 550,000 people and a land area of 29.7 km^2, and is one of the cities with the highest population density in the world. In 2000, there were 55,000 registered cars and 58,000 registered motorcycles in Macao, and these numbers increased to 88,000 and 104,000 in 2010, a growth of 60% and 79%, respectively, over the last 10 years. Since 2002, tourism and gaming industries became the main economic development directions of the city, and the GDP per capita increased by 150% to $39,000 USD in 2009. As one can expect, the development of the city and significant boost in household incomes are the main reasons for the rapid increase in private vehicle ownership. Furthermore, the history of Macao's urban growth leads to mixed-land areas, characterized by historic buildings and monuments, old town and newly developed districts coexisting in the limited land size. The changing urban form adds further challenges to formulating effective land-use and transportation policies towards sustainable development (Loo and Chow 2008).

The rest of the article is organized as follows. An overview of the literature on vehicle ownership and use is given in Section 2. Section 3 presents a brief introduction of urban growth and the transportation system in Macao. The dataset collected from a household survey interview will be used in this study, and is described in Section 4. Section 5 presents the modeling structure, and the estimation results are discussed in Section 6. Concluding remarks, policy implications of our results, and suggestions for future research directions are given in Section 7.

2. OVERVIEW OF RELATED WORKS

Many researches have investigated the modeling of vehicle ownership and use, which aims at predicting the future growth of the ownership or understanding the behavior of households for the type or number of vehicles one would own (de Jong et al. 2004). Previous studies using aggregate model approaches compared the ownership levels across countries and cities with the aggregated characteristics such as area, population density, and urbanization level to derive the vehicle saturation level (in terms of number of vehicles per thousand population), and there is strong evidence that car ownership is related to income level (Dargay and Gately 1999; Dargay, Gately, and Sommer 2007). These models are good for estimating future growth of vehicle ownership in the city or country. However, they are not able to identify the factors or characteristics of the individuals affecting ownership levels, which are important in the evaluation of transportation policies.

Discrete-choice modeling approaches, employing personal or household survey data with socioeconomic and demographic variables, have the explanatory power to enable the policy makers to derive a better policy towards sustainable transportation for less energy consumption and emissions (Salon 2009; Chiou et al. 2009). These approaches are used to explain the policy-sensitive variables such as vehicle ownership cost, usage cost and transit availability that are relevant to the ownership and usage level.

Many studies on car ownership for cities where a private car is a necessary good focused on the choices of vehicle type (Cao, Mokhtarian, and Handy 2006; Choo and Mokhtarian, 2004; Mohammadian and Miller 2003; Zhao and Kockelman 2000). These studies investigated the factors that would inference which of the (four-wheeled) vehicle types, including passenger cars, SUVs, pickup trucks, and minivans that a household would own. Zhao and Kockelman (2000) found that large-household families prefer minivans over SUVs, and prefer SUVs over passenger cars, whereas pickup trucks are more popular in lower–population density areas.

However, for cities and metropolitan areas where population density is high and the public transportation system is developed, the question of car ownership is whether to own a car or how many cars a household would own (Bhat and Pulugurta 1998). In contrast, a diverse but particularly important issue in Asian cities is the ownership and use of motorcycles. The motorcycle is considered to be an efficient mode of private transportation, with its relative low cost of ownership, operation, and maintenance. A number of investigations towards the modeling of motorcycle ownership were proposed recently (Burge et al. 2007; Leong and Sadullah 2007; Sillaparcharn 2007; Tuan and Shimizu 2005). These studies suggested that motorcycle users may switch to cars for the higher-income group, and the introduction of high ownership taxes could be an effective policy to manage the rapid increase in motorcycle ownership.

The sole modeling of motorcycles ignores the interrelation with the ownership and usage level of private cars. The motorcycle is suggested to be a substitution for cars for lower-income groups, but the exact relationship is still unclear. Since the natures of car and motorcycle modes are different, the models developed for the vehicle-type choices may not be applicable. Yamamoto (2009) compared the vehicle ownership behavior of the Osaka metropolitan area, Japan, and Kuala Lumpur, Malaysia, by analyzing the simultaneous vehicle-ownership combinations of multiple vehicle types, including cars, motorcycles, and bicycles. It was found that, in general, population density has a negative effect on car ownership. However, whereas the bicycle is more popular in high–population density districts in the Osaka area, the level of bicycle ownership is higher at lower–population density areas in Kuala Lumpur, showing the difference of behavior and usage patterns among cities. One possible reason is that Osaka has a dense and well-developed rail network and the bicycle is used for transfer purposes. In the case of Taiwanese cities, Hsu and Lin (2007) suggested that cars and motorcycles have a relation of substitution for households which have the economic capacity to own both. Hsu, Tsai, and Lin (2007) further elaborated the conclusion that income level has a negative influence on motorcycle ownership, which is also affected by the provision of public transportation services. The factors related to the utility of motorcycle usage are its travel-time reliability, convenience, and safety. Lai, Lu, and Chiang (2006) proposed a car and motorcycle mixed-demand model using a nested logit framework, and showed that the correlation between the number of cars and the number of motorcycles owned by a household is not statistically significant. However, the usage among vehicles in a multiple-vehicle household has a substitution effect, meaning that the total vehicle-usage rate decreases with the number of vehicles owned in the household.

Furthermore, there is recent interest in understanding how vehicle ownership and usage levels are affected by land use development strategies. The built environment has been shown to have a strong impact on the behavior of travelers, and balancing urban growth for mixed land uses can result in significant benefits to the transport sector by reducing the demand for transportation (Cervero and Kockelman 1997; Cervero 2002). Mokhtarian and Cao (2008) reviewed and compared several alternative models proposed in the literature in modeling the influences of the residential built environment on travel behavior, and identified several casual-influence relationships (e.g., causality or association) and the extent between the built environment and travel behavior implied by the modeling structure. Zegras (2010) examined the relationship between built environment characteristics and a household's likelihood of car ownership, and found a strong relationship with locational characteristics, such as distance to the central business district and transit stations.

On the methodology employed, most of the above mentioned vehicle ownership studies that adopted a multinomial logit (MNL) formulation. The multinomial logit model is a discrete-choice model developed based on the random utility theory (Ben-Akiva and Lerman 1985), which has an unordered-responsive choice mechanism and can be used in deriving the relationship between the explanatory variables and vehicle ownership level for disaggregate data analysis. Other modeling forms such as ordered-response choice models were also applied to the problem (Bhat and Pulugurta 1998; Chu 2002). More advanced discrete-choice modeling approaches are also available. Combining mixed-revealed preference and stated preference data, Wen (2010) proposed an alternative tree modeling structure for problems with multinomial and nested-choice hierarchy. Zito et al. (2011) considered an ordered probit-demand model to estimate the public transport demand enhanced by the advanced traveler-information system. These models based on utility theory assume a utility function with observed variables and a random component capturing the unobserved factors that affect the individual's choice, and the random component may follow some assumed distributions. Dia and Panwai (2010) argued that assumptions of perfect information and decision-making capability of individuals in the discrete choice model may not be satisfied in some problems, and the complex relationship of imperfect input should be better modelled with other approaches. Their paper proposed an artificial neural network (ANN) model, and showed that ANN is superior to, in terms of classification rate, the discrete-choice models for the prediction problem of driver compliance with traffic information. More recently, Wang and Li (2011) extended for a multiple discrete-continuous choice model for the modeling of activity choices and time allocations.

3. LAND USE, URBAN GROWTH, AND TRANSPORT SYSTEM IN MACAO

3.1. History of Urban Development and Urban Form

The urban development of a city is characterized by the change of urban form and land-use patterns. Since the arrival of the Portuguese explorers in the fifteenth century, Macao has received enormous impacts on its culture, landscape, and population compositions (Tang and Sheng 2009). Macao has limited land but a high population growth, and by the twentieth century, most of the farmland and villages were gradually absorbed for urban growth. Since then, land reclamation became the only solution for further growth. The changes to the urban form during the last decades were initialized by the concession rights and obligations for operating the gaming industry in 1966. The promotion of gambling activity brought up the tourism and associated service industries, and casinos, hotels, and new blocks of buildings appeared. The improvement to the economy brought wealth to the city, and spaces for development were desired. Edmonds and Kyle (1998) discussed the change of land use, population, and economic activities during the 1972–1994 period. Table 1 displays the change of the land area and length of roadways in Macao during the last century, and the map of Macao is given in Figure 1. It is noted that the Cotai area is an inter-island reclamation area between Taipa and Coloane island, which started to form since 1998.

Macao has experienced a very rapid economic boom since reunification with China in 1999. Under the "one country two systems" framework, Macao was the only city in China to permit legalized casino gambling. Under the limitation of land and human resources, the government defined Macao's long term economic strategy as "gaming-led tourism" in 2002, and massive numbers of visitors were expected. In 2003, the China central government introduced the individual visit schemes, which permits mainland travelers to visit Hong Kong and Macao on an individual basis. This further boosted tourism and resulted in a tremendous increase of visitors since then. For that reason, the gaming and service economy received the first priority in the land use development strategy. For instance, the center of the Cotai area (now known as Cotai strip) is now dedicated for the infrastructures of casinos, hotels and resorts, and convention centers. However,

Table 1. Change of land area and length of roadways in Macao.

	Land area (km^2)					Length of roadway (km)			
Year	Macao Peninsula	Taipa Island	Cotai	Coloane Island	Total	Macao Peninsula	Taipa and Cotai	Coloane Island	Total (including bridges)
1912	3.4	2.3	–	5.9	11.6	n/a	n/a	n/a	n/a
1936	5.2	2.6	–	6.0	13.8	n/a	n/a	n/a	n/a
1957	5.5	3.3	–	6.3	15.1	n/a	n/a	n/a	n/a
1986	5.8	3.7	–	7.1	16.6	n/a	n/a	n/a	n/a
1991	6.5	4.0	–	7.6	18.1	n/a	n/a	n/a	n/a
1996	7.7	5.8	–	7.8	21.3	n/a	n/a	n/a	n/a
2000	8.5	6.2	3.1	7.6	25.4	173.2	75.9	54.3	324.2
2005	8.9	6.5	5.2	7.6	28.2	182.4	107.1	57.3	368.2
2010	9.3	6.8	6.0	7.6	29.7	198.8	132.2	61.2	413.4

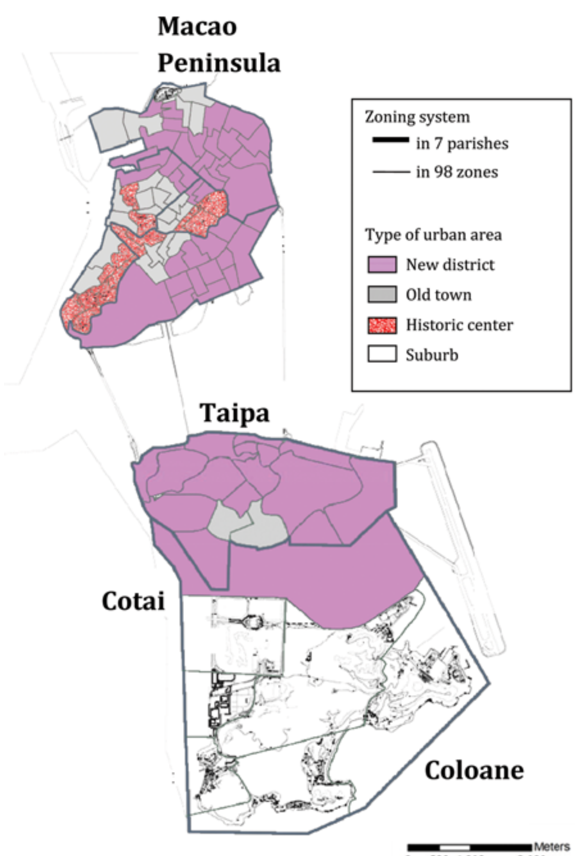

Figure 1. **The urban development area of new district, old town and historical center area in Macao. (Figure appears in color online.)**

transportation planning and policy were ignored to tackle the rapid growth of transportation demand.

3.2. Cross-Border and Local Public Transport

Macao is a typical city facing the congestion problem, with the demand for transport increasing more rapidly than the construction of ports and road infrastructure. There is a strong demand for transportation between mainland China, Hong Kong, and Macao, given their close proximity and interactions of economic activities. Macao has also established herself as a link between the Pearl River delta (PRD) and other fast-growing economic regions of the world, providing efficient direct links to neighboring regions.

In 2009, the annual number of arrivals through border checkpoints reached 53 million persons, of which 25 million were Macao residents, 16.8 million were from mainland China, and 7.5 million were from Hong Kong. The border checkpoints connect Macao to her hinterland cities in mainland China and Hong Kong by road transport and ferry, whereas the international airport has flights between Macao and major cities in China and other Asian countries. The border checkpoints and the corresponding annual arrivals are listed in Table 2 (FSM 2010). Particularly, the Barrier Gate at the north of the peninsula connecting to Zhuhai of mainland China is the busiest checkpoint. On average it handles 110,045 arrivals per day, which is more than one-fifth of the population. This high value is due to the close economic activities (e.g., business, entertainment, shopping) between Macao and Zhuhai. Most of the visitors from Mainland China will arrive through

Table 2. The border checkpoints of Macao.

Checkpoint	Opening year	Transportation	Annual arrivals	To and from
Barrier Gate	1874[a]	Road (by walk, car or coach)	40,166,000	Zhuhai, China
Macao Outer Harbour ferry terminal	1993[b]	Sea	7,179,000	Hong Kong, Shenzhen and Guangzhou, China
Macao International Airport	1995	Air	1,813,000	Major cities in China and Asian countries
Cotai Frontier Post (Lotus Port)	2000	Road (by car or coach only)	1,165,000	Hengqin and Zhuhai, China
Taipa (temporary) ferry terminal	2007[c]	Sea	2,663,000	Hong Kong, Shenzhen and Jiangmen, China
Macao Inner Harbor ferry terminal	2008	Sea	397,000	Zhuhai, China

[a] The Barrier gate was firstly built in 1574 connecting to mainland China, and later relocated by the Portuguese in 1874.
[b] The Outer Harbour ferry terminal was firstly built in 1960's, and relocated in 1993 for expansions.
[c] The Taipa ferry terminal is a temporary terminal for passengers, and will be fully operated at 2012.

the Barrier Gate. The Macao Outer Harbour ferry terminal, mainly to Hong Kong and Shenzhen, China, also handles a large number of arrivals (19,670 per day), and most are visitors coming from Hong Kong. Because the gaming industry is 24 hours, the ferry service, and thus the custom office at the Macao terminal, also operate 24 hours a day. Since the opening of the Taipa ferry terminal in 2007, visitor arrivals are diverted and the traffic pressure of the Outer Harbor ferry terminal is much reduced. As one can see, there is a large pressure for cross-border traffic, and the government is seeking alternatives to expand the capacities of the ports and extend their hours of operation.

On the local transport modes, the public transportation system is composed of buses and taxi services. Currently there are over 40 bus lines serving about 315,000 passengers per day. About 85% of the passengers are local residents, and the remaining 15% are visitors (DSAT 2010). Conversely, taxis providing convenient door-to-door service can be called by phone or hailed on the street. Currently there is a taxi fleet of 980 vehicles. Due to the tourism industry, most of the vacant taxis will stay at the taxi stands of hotels and casinos to wait for customers, and there is a difficulty in finding a vacant taxi in the city center.

Another feature of the local transportation in Macao is the free shuttle bus services. Since the deregulation of the gaming industry, many casinos have opened and the number of visitors has increased sharply, so that the existing bus fleet is not able to fulfil the transportation need. Hotels and casinos equip a large fleet of luxury coaches and offer their own free point-to-point transportation between the main border checkpoints and casinos/hotels. Appearance of the shuttle buses caused positive and negative impacts to the whole transportation system (Wan and Wong 2010). In overall, the free shuttle bus services provide up to 70% of the capacity of the public bus services departing from the Barrier Gate and Macao Outer Harbor ferry terminal, and alleviate the high transportation demand of visitors.

3.3. Challenges for Balanced Urban Development

The Macao government has the objective to develop Macao into a world-class city suitable for living and leisure, in order to meet the expectations of its citizens. Currently, the developed area of the city is composed of a mixture of historical-heritage buildings, old buildings of two to five storeys, as well as modern and high-rise buildings. Since the city was awarded “World Cultural Heritage” status in 2005, heritage conservation is one of the objectives in the city planning. This adds further challenges to the development of a sustainable policy and planning for land use and transport. A recent policy paper proposed a three-layer conceptual framework for balanced urban development between old and new areas (DSAT 2009). The urban areas can be classified as historic core centers, old town areas, and new town districts, as displayed in Figure 1, and each has different characteristics of urban form and thus goals for city planning. The conceptual framework is illustrated in Figure 2. In the inner layer, the theme of planning for historical centers is slow walk and leisure, whereas the issues in old town areas are comfort and mobility for the community. In the outer layer, the planning goals of the new district are to provide fast and timely connections between districts.

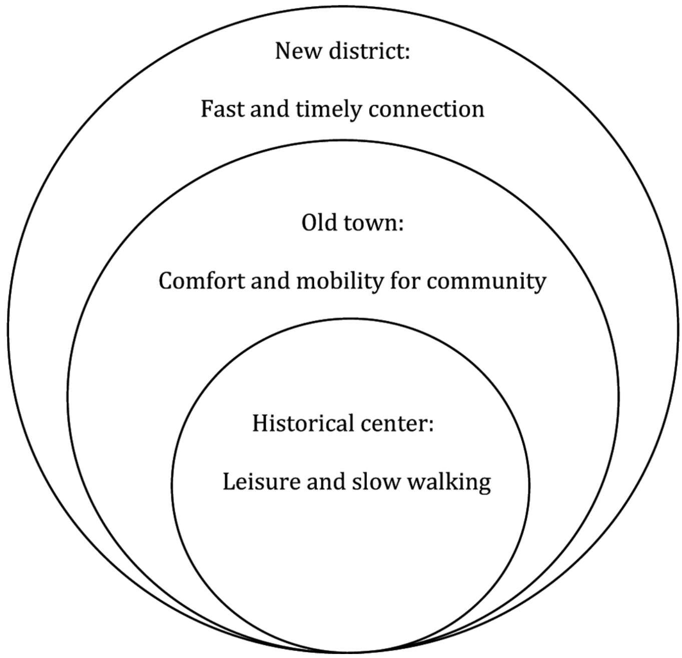

Figure 2. Balanced urban development between old and new areas in a three-layer conceptual framework (DSAT 2009).

Most of the historical buildings and structures are geographically distributed in the central to southwest district of the peninsula (see Fig. 1). According to the "Operational Guidelines for the Implementation of the World Heritage Convention" regulated by the United Nations Educational, Scientific and Cultural Organization (UNESCO), the World Cultural Heritage has to be protected with buffer zone areas. A buffer zone is defined to be the area surrounding a heritage site, preserving the importance, uniqueness and the original nature of the region, and the land-use purposes and height of buildings are regulated by the UNESCO committee (ICM 2011). Therefore, the population density and volume of through-traffic are low, but a high intensity of visitors is expected, and accessibility for tourism is the main concern in the traffic planning of the region.

The old town area has been the central district for social and economic activities and domestic business. The area was planned and developed much earlier, and most of the buildings inside are rather old. The area is characterized by the high density of population and residential buildings, local shops, and restaurants for the daily living needs of residents. Although there is no official definition for the old town area, most of the old communities are identified to be close to the historical buffer district. In this area, the roads are usually narrow and one-way, and there is a lack of off-street parking. Furthermore, public bus service has limited capacity because of the narrow roads and upslope hills. Private vehicles circulating for parking and traffic jams are common problems in this area. To this end, the government has initiated redevelopment projects for the old town area to improve the living quality of residents, and redesign the land use for sustainable development of the city (CCRBAM 2011). In contrast, the new town districts are developed more recently through land-use redevelopment and land reclamation. High-rise commercial and residential buildings are found in these areas, and the network has wider roads with a modern rectangular grid pattern, which is capable of accommodating increasing demands of traffic. The transportation demand and behaviors of travelers are different for the old and newly developed areas, and it is necessary to take these urban characteristics into account in vehicle ownership modeling.

4. DATA COLLECTION

In this study, we investigated the attributes and characteristics of private vehicle ownership. The data source was from a largescale household survey conducted in Macao in 2009 (DSAT 2010; Wan, Wong, and Kao 2009). This is the first database available to the city for transportation-related analyses such as for transportation-modeling and planning purposes. In the survey, a total of 2,684 households (1.3% of population) were successfully interviewed regarding travel characteristics, and incorporated a 24-hour travel diary chronicling family members' travel behavior. Samples were chosen using the stratified sampling method, and household addresses were proportionally distributed in the geographical area divided into seven parish zones. For analysis purposes, all locations, such as household addresses, trip origins, and destinations, were further categorized into a 23-zone system and a 98-subzone system. Interviews with household members were carried out indoors by scheduled appointment. Therefore, there was a very high success rate for interviews out of the chosen addresses, and bias due to non-response of households was minimized.

The database recorded socioeconomic and demographic variables as well as travel characteristics at the household and personal levels. Household characteristics included variables such as property type, ownership level of vehicles, and private parking space availability; and for each of the household members, gender, age, occupation, education level, income level, and a travel diary with commuting locations, modes and travel times were recorded. In our analysis, we also combined other data sources mainly geographically referenced to determine the independent variables based on individuals' residential location (DSEC 2010).

Some basic information about Macao city and its travel characteristics is summarized in Table 3. Macao has a population density of 18,370 people per square kilometers (ppl/km^2) on average, which is ranked the top in the world-wide comparison. The Macao peninsula and island of Taipa and Coloane are connected by three bridges of less than 5 km (2.2 to 4.7 km) in length. The population density and vehicle-ownership levels are quite different across the urban area types, as illustrated in Figure 1. As Macao is a small city, many trips are within walkable distances, and a high proportion of commuting is completed by walking. On average, each person produces 1.52 walking trips and 1.53 mechanized trips (trips excluding walking and bicycling) per day. Most of the mechanized trips are completed by

Table 3. Some information of Macao and survey samples.

Area (km^2)	29.5	
Population		545,000
Number of registered cars		88,000
Number of registered motorcycle		104,000
Sample size		
Household	2684	
Population		6,979 (1.3%)
Modal share of mechanized trips (%)		
Bus	36.4	
Car	21.5	
Motorcycle	33.4	
Others	8.7	
Total	100	

bus (36.4%), car (21.5%), and motorcycle (33.4%), showing a high reliance on private transportation. Currently, car and motorcycle ownership level are 162 and 191 per thousand people, respectively.

Table 4 displays the sample distribution of household vehicle ownership for cars and motorcycles. Of households, 27.8% own one car, and 4.6% own two or more cars. Since the city is small and parking is limited, car-passenger trips are quite common and only a small number of families have two cars. In contrast, there is a higher ownership level for motorcycles, with 32.3% of households having one motorcycle, and 14% having two or more motorcycles. Further analysis of the data (not shown in the table) retrieves the fact that 19.4% of the sampled households (i.e., 520 households) possess both cars and motorcycles.

The explanatory variables used in the vehicle-ownership models are shown in Table 5. Referring to the literature, the number of family members (further separated into working adults, non-working adults, and youths) and household income are the common factors that would affect decisions on the vehicle-ownership level. Number of children (aged below 5) is also considered, as a family with a newborn baby is more likely to own a car, since private cars offer luggage space, air-conditioning, and a private environment. Therefore, it is expected that the number of children would be significant to car ownership but not to motorcycle ownership.

Table 4. Sample distribution of household vehicle ownership.

	Car owning household		Motorcycle owning household	
No. of vehicles	**Sample**	**Percentage (%)**	**Sample**	**Percentage (%)**
0	1,815	67.6	1,440	53.7
1	745	27.8	867	32.3
2 or more	124	4.6	377	14.0
Total	2,684	100	2,684	100

Table 5. Sample distribution of explanatory variables.

Explanatory variables	Mean	SD
Number of working adults	1.791	0.908
Number of non-working adults	0.489	0.656
Number of youths (aged below 18)	0.584	0.776
Number of children (aged below 5)	0.288	0.600
Monthly household income in $1,000 MOP	20.989	9.816
Population density in 10,000/km^2	9.713	4.490

Vehicle-ownership decisions would also depend on attributes related to the residential location of households. Population densities and the type of urban area at residential locations are considered. The values of population density are calculated using data from the geographical information system, aggregating the city into 23 zones, and the average population density of the samples is 9.713 (in 10,000 ppl/km^2). It is noted that this value is much higher than the average of the city, as we divided the aggregation level into small zones, and there are more samples from zones with higher population densities. Furthermore, it would be interesting to see the effect of type of urban area on the vehicle-ownership level, as the urban form can be representative and correlated to the availability of parking, public transport accessibility, and mixed-land use, which are difficult to be quantified in our case. A land-use-type dummy is introduced, with a value of 0 for new town area, and 1 for old town and historical area.

5. METHODOLOGY

In this study, multinomial logit model (MNL) is used for vehicle-ownership modeling. MNL assumes that each individual will choose the alternative within the choice set with the highest utility value. For a vehicle-ownership model, let $\mathrm{U_{nj}}$ be the utility of individual n choosing alternative j, where $j=0$ for owning no vehicles, 1 for owning one vehicle and 2 for owning two or more vehicles for the household. A linear form of utility function is assumed with a deterministic component and a random component,

$$U_{nj} = V_{nj} + \varepsilon_{nj} \quad \text{and} \quad V_{nj} = \alpha_j + \beta_{nj} x_n, \tag{1}$$

where x_n is the vector of explanatory variables of individual n, α_j and β_{nj} are the parameter vectors to be estimated, and ε_{nj} is the random variable in the utility which is not observable. The probability that household n chooses alternative i is given by

$$P_{ni} = \Pr\left(U_{ni} > U_{nj}, \forall j \neq i\right) \tag{2}$$

The MNL assumes that the random variable ε_{nj} are independently and identically distributed and follows a Gumbel distribution, such that

$$P_{ni} = \frac{\exp(V_{ni})}{\sum_j \exp\left(V_{nj}\right)} \tag{3}$$

In this study, the discrete-choice model is estimated by the maximum-likelihood approach, and the software Biogeme (Bierlaire 2003, 2008) is used for the estimation purpose.

6. RESULTS

The household ownership decisions for cars and motorcycles have very different motivations. Previous studies in the literature suggested that the household car ownership, household motorcycle ownership, and their joint household ownership decision can be formulated as a discrete-choice model approach. However, this conclusion is empirical, and private modes could be necessary goods or luxury goods in a city. Furthermore, in some cases motorcycles are considered to be inferior to cars, but few investigations discussed the joint-ownership decision and the substitution effects between the two modes.

In this section, first of all, the model estimations for car ownership and motorcycle ownership at the household level will be performed separately. We will later show that the motorcycle-ownership level is not significantly correlated to the household attributes, but related to the decision of an individual person. Since we will make use of the attributes of the household members in the analysis, a subset of the database presented in Section 4 will be used, and those household samples with at least one member not successfully interviewed are excluded. Out of the 2,684 household samples interviewed, there are 1,976 households for which all household members were successfully interviewed, and there was no statistical bias and no significant differences between the attributes of the selected samples and that of the total sampled households.

6.1. Car Ownership Model

The estimated coefficients for the car ownership model are showed in Table 6. Most of the coefficients are statistically significant, except the number of non-working adults and the number of youths for two or more vehicles. Modeling with “zero vehicle” as the relative option, most of the coefficient estimates have the expected signs. The alternative specific constants for “one vehicle” and “two or more vehicles” are −0.943 and −3.78, respectively, with a higher (negative) value for “two or more vehicles”. These values are negative because the relative alternative “zero vehicle” has no alternative specific variables associated with the utility function. The negative alternative specific constants can be seen as a barrier that a household has to overcome, such as a higher-income household has a higher probability of owning a car (or two cars or more) as relative to not to have a car.

The coefficients for the alternative specific variables display the utility contributed from the attributes for the households. As expected, the monthly household income is positive, implying that a household with high income has a high chance of owning cars. The number of working adults, number of non-working adults, and number of youths have negative coefficients. Therefore, at the same income level, a household with more household members has a smaller probability of owning a car, as it may reduce the purchasing power of the household. Most of the empirical studies for the western cities (where public transportation is limited) indicated that the household size has positive effect on car ownership, but there are also findings

Table 6. Estimation results for the household car-ownership model.

Explanatory variables	Coefficient	t-Statistics
Alternative specific constants		
Zero vehicle	fixed	
One vehicle	−0.943	−3.59**
Two or more vehicles	−3.78	−5.9**
Alternative specific variables		
Number of working adults (one veh.)	−1.170	−9.83**
Number of working adults (two or more veh.)	−1.100	−4.23**
Number of non-working adults (one veh.)	−0.559	−5.4**
Number of non-working adults (two or more veh.)	−0.286	−1.22
Number of youths (one veh.)	−0.409	−4.94**
Number of youths (two or more veh.)	−0.183	−.99
Number of children (one veh.)	0.911	5.84**
Number of children (two or more veh.)	0.807	2.45**
Monthly income in $1,000 MOP (one veh.)	0.161	15.34**
Monthly income in $1,000 MOP (two or more veh.)	0.210	10.09**
Population density in 10,000/km^2 (one veh.)	−0.058	−4.56**
Population density in 10,000/km^2 (two or more veh.)	−0.129	−4.69**
Land use type dummy (0 = new town; 1 = old town and historical area) (one veh.)	−0.325	−2.83**
Land use type dummy (0 = new town; 1 = old town and historical area) (two or more veh.)	−0.596	−2.29*
Summary statistics		
Sample size		1976
Lok-likelihood at zero		−2170.858
Log-likelihood at convergence		−1217.351
ρ^2		.439

*Significant at 5%.
**Significant at 1%.

in Asian cities that this could be positive or negative (Yamamoto 2009). This can be interpreted that a private car is not necessary goods for most people in Macao. Interestingly, the coefficients for the number of children show a high positive effect on car ownership. Since there is no mass transit in Macao, and bus is the only reliable public transportation service, private cars provide a comfortable and convenient environment for family travel with babies or young children.

On the residential location-related explanatory variables, population density has a negative coefficient, showing that a household in a high-density area is expected to have a smaller chance of owning a car. In these areas there should be more traffic but better access to public transport services. The coefficients of land-use type also derive from the fact that households living in the old town and historical area are averse to owning a car. This can be explained by the fact that off-street and indoor parking within the old town area are very limited, and a vehicle spending half an hour circulating for an on-street parking space is not uncommon. Overall, the modeling result shows good estimation and is representative of the survey data.

6.2. Motorcycle Ownership Model

The estimation results of the motorcycle-ownership model are displayed in Table 7. The estimated alternative specific constants show a similar result as compared to the car ownership model. In the model, "zero vehicle" is used as the relative alternative, and the alternative-specific constants for "one vehicle" and "two or more vehicles" are −2.07 and −4.98, respectively, which are negative as expected.

Most of the coefficients of alternative-specific variables display different signs as compared to the car-ownership modeling result. Whereas monthly household income is positive to motorcycle ownership as expected, however, the number of working adults (except for one vehicle), number of non-working adults, and number of youths have positive coefficients; and number of children has negative coefficients. Contrary to the car-ownership modeling, a household with more members is more likely to own a motorcycle, but it is unlikely to commute with a child (less than 5 years old) riding a motorcycle. The population density at

Table 7. Estimation results for the household motorcycle ownership model.

Explanatory variables	Coefficient	t-Statistics
Alternative specific constants		
Zero vehicle	fixed	
One vehicle	−2.07	−8.31**
Two or more vehicles	−4.98	−12.15**
Alternative specific variables		
Number of working adults (one veh.)	−0.094	−0.96
Number of working adults (two or more veh.)	0.271	1.94*
Number of non-working adults (one veh.)	0.053	0.57
Number of non-working adults (two or more veh.)	0.573	4.27**
Number of youths (one veh.)	0.041	0.55
Number of youths (two or more veh.)	0.257	2.29*
Number of children (one veh.)	−0.116	−0.8
Number of children (two or more veh.)	−0.456	−2.34*
Monthly income in $1,000 MOP (one veh.)	0.065	7.64**
Monthly income in $1,000 MOP (two or more veh.)	0.102	8.84**
Population density in 10,000/km^2 (one veh.)	0.040	3.41**
Population density in 10,000/km^2 (two or more veh.)	0.024	1.46
Land use type dummy (0 = new town; 1 = old town and historical area) (one veh.)	−0.035	−0.34
Land use type dummy (0 = new town; 1 = old town and historical area) (two or more veh.)	−0.007	−0.04
Summary statistics		
Sample size		1976
Lok-likelihood at zero		−2170.858
Log-likelihood at convergence		−1759.38
ρ^2		0.19

*Significant at 5%.
**Significant at 1%.

residential locations has a positive coefficient. This is because the motorcycle is more popular as an efficient way of transport in population-dense areas, and parking for motorcycles may not be a problem. The land-use-type dummy has a negative coefficient, but the magnitude of the coefficient is small (less than 2% of the alternative specific constants), and the value is not statistically significant. Therefore, the motorcycle- ownership level is not correlated to zonal development and usage, but dominated by the population density.

In fact, the estimated motorcycle-ownership model is not satisfactory, as the ρ^2 value is small (0.19), and many of the coefficients have a very small value and are not significant. The coefficients associated with the number of household members for one vehicle is not statistically significant, and have small values (less than 5% of the constants for one vehicle). This means that the MNL model with the chosen explanatory variables cannot explain the behavior of the household motorcycle ownership.

We have also investigated a large number of candidate modeling structures and explanatory variables, including number of cars owned by the household, and number of male and female adults in a family, but the performance of the estimation could not be improved. This implies that the household ownerships of cars and motorcycles is not highly correlated. Therefore we conclude that the household attributes are not appropriate in modeling motorcycle ownership.

6.3. Attributes of Motorcycle Users

Fortunately, the database also includes the characteristics at the personal level and their trip itinerary, which allows us to identify travelers' mode-choice behavior for commuting. To illustrate the behavior differences for car and motorcycle usage, we categorized the sampled population into car drivers, car passengers, motorcycle users, and motorcycle passengers, and the numbers and corresponding ratios are displayed in Table 8. Out of all private car users, 62.7% are drivers and 37.3% are passengers. This suggests that household members traveling together in a car is very common. In contrast, the corresponding motorcycle user ratios are 86.4% and 13.6% for drivers and passengers, respectively, and most of the motorcycle riders are male. Since the ownership cost of a motorcycle is not high, it is likely that the owner of a motorcycle is the user of it, and there is no sharing among household members. We verified this by checking the number of motorcycle users and the number of motorcycles owned in a household, which has a high correlation value of 0.73. For this reason, motorcycle ownership should be better modelled on an individual level.

Table 8. Driver and passenger ratios of car and motorcycle users.

	Car driver	Car passenger	Subtotal	Motorcycle rider	Motorcycle passenger	Subtotal
Men	344 (78.5%)	94 (21.5%)	438	730 (93.5%)	51 (6.5%)	781
Women	143 (42.2%)	196 (57.8%)	339	303 (73.2%)	111 (26.8%)	414
Total	487 (62.7%)	290 (37.3%)	777	1033 (86.4%)	162 (13.6%)	1195

A binary logit model is applied to the disaggregate data of sampled population. Excluding the samples with age below 18 (with no driver's license), there are 5,566 observations. In addition to the monthly personal income, we considered the explanatory variables, including dummies for each of the six age groups (i.e., 19–24; 25–34; 35–44; 45–54; 55–64; ≥ 65), gender (i.e, male or female) and worker (i.e., worker or non-worker). The working location of the person is considered to represent if the residential location and location of work are both in Macao peninsula or the island of Taipa and Coloane (proximity), or otherwise the person has to cross the bridges between the two districts (cross-bridge). Commuting between the two areas by motorcycle is considered to be too far and uncomfortable, and there are also safety concerns.

The results are shown in Table 9. The estimated model has quite strong explanation power, and all coefficients are significant. The constant for being a motorcycle user is negative. Making the age group (19–24) the relative group, the dummies for all other age groups have negative coefficients. This means that persons aged 19–24 are more likely to be a motorcycle user, and the motorcycle usage is declining with the age. The coefficients of dummies for gender, work, and work location all are positive. Therefore, a male prefers using a motorcycle more than a does a female; a worker has a higher incentive to use a motorcycle than does a non-worker; and people use motorcycles for short-distance trips. These findings match the observations and intuitive explanations. Furthermore, location-based variables, such as population density and land-use types, were tested in the model, but similar to the household motorcycle model presented in the previous section, the additional coefficients are not able to enhance the performance of the model, and therefore are not being considered.

Table 9. Estimation results for motorcycle ownership of individual person.

Explanatory variables	Coefficient	t-Statistics
Constant	−2.97	−18.63**
Age dummy (19–24)	fixed	–
Age dummy (25–34)	−0.615	−4.94**
Age dummy (35–44)	−0.897	−7.28**
Age dummy (45–54)	−0.766	−6.58**
Age dummy (55–64)	−1.360	−8.71**
Age dummy ($\geq$65)	−3.190	−7.49**
Monthly personal income in $1,000 MOP	0.093	8.04**
Gender dummy (male = 1; female = 0)	1.110	14.23**
Worker dummy (worker = 1; non-worker = 0)	0.528	3.86**
Work location dummy (proximity = 1; cross-bridge = 0)	0.408	4.15**
Summary statistics		
Sample size		5566
Log-likelihood at zero		−3858.057
Log-likelihood at convergence		−2303.242
ρ^2		0.403

*Significant at 5%.

**Significant at 1%.

7. DISCUSSIONS AND CONCLUDING REMARKS

7.1. Summary

In this article, the influences of urban characteristics and household and personal attributes on private car ownership and motorcycle ownership in Macao are investigated. Because of the unique history, the city lacked a long-term land-use-development strategy and transportation-integrated planning until recently. Macao is a wealthy city but with very limited land area and high population density. The city is also characterized by its mixed land use, comprising historical center, old town, and new district linked together. Since the economic boom of the last decade, private transportation has become affordable to most households. Private vehicle ownership has been growing and there seems no sign of it slowing down. Understanding the factors that would influence the household decision to own a car or motorcycle, is essential in evaluating a transport policy, and policy makers can derive the relative importance of these factors from the sensitivities of the coefficients in the results.

Using disaggregated data from a household interview survey, a multinomial logit model is employed to investigate household car ownership and household motorcycle ownership. An estimated car-ownership model shows good performance in explanation with the chosen explanatory variables. Whereas the number of household members has a negative effect, the number of children and household income have positive effects on car ownership. Households in the old town area and population-dense area have a lower car-ownership rate. In contrast, households residing on the island have a high probability of owning cars. Therefore, a further increase in car-ownership rates would be expected if more residents were to move their homes from the peninsula to the island as a response to the land-use policy in the future. Economic growth will further increase the household income and therefore amplify the private vehicle-ownership rates in the future. We also find that the household attributes do not explain the motorcycle-ownership level. This suggests that the motorcycle ownership behavior in Macao is quite different from that in previous studies. Instead, we adopt a binary logit model with explanatory variables at the personal level, and the estimated results can explain the observations. Interestingly, the motorcycle-ownership decision is not statistically correlated to the population density and land-use type of the residential location, but rather is affected by the distance between residential and work locations.

7.2. Policy Implications and Discussion

To develop a sustainable transportation system, the ownership of private vehicles must be reduced. Currently, the number of private vehicle ownerships in Macao has high growth rates, and the number of registered motorcycles is increasing even faster than that of registered cars. As our results show that the land-use and urban characteristics impact the level of car ownership, control on parking supplies could be an efficient policy to manage vehicle ownership for different zonal areas, and in a longer term the pattern of residential location choices can be changed. Because of the high population density and the rising level of vehicle ownership, spaces available for parking are limited and insufficient. Except for new high-rise buildings, most of the structures designed earlier do not have an indoor parking lot.

Conversely, the results show that the impact of urban characteristics on motorcycle ownership is insignificant. One possible explanation is that when a rider makes a decision to purchase a motorcycle, the difficulties of searching for a parking space is usually not taken into consideration—as one may have the impression that it is always possible to find a space to park, legally or illegally. Indeed, congested roadside parking for motorcycles has long been a critical social problem in Macao, as crowded parking can be obstacles for pedestrian footpaths. The results reveal that younger adults are more likely to be motorcycle riders, and therefore motorcycle-ownership control policies, promotions, and education will be more effective if the targets are the younger group and teenagers.

Success of vehicle ownership-control policies is also complementary with strategies for improving the public transportation system. Recently, the Macao government has announced the first land transport policy consultation paper, trying to define the goals, strategies, and policy actions towards sustainable transportation development for the next ten years (DSAT 2009). Emphasis is given to the public transport priority and green commuting. To encourage more travelers to make use of public transport, the government has spent 150 million MOP to subsidize 98 million bus riders in 2009. This measure has made the bus service more competitive. Furthermore, the walking environment is being improved, and an automatic walking system (a type of escalator built on or above the road), has been considered to be introduced in the city. All of these measures are intented to improve the accessibility as well as to reduce the usage of private transport. However, the bus service and the road space have already reached its carrying capacity in such a high-density and mixed-land-use area, and mass transit is the only way to relieve the increasing demand for transportation. To this end, a Light Rail Transit (LRT) has been planned to be constructed and expected to operate in 2014, and it will form the backbone of a future public transport system. It is noted that previous empirical studies showed that urban rail development may or may not result in a reduction in traffic congestion, and successfulness in solving the transportation problem would still rely on many factors. Development of urban rails will have a strong impact on the land use and urban expansion of cities, and therefore coordination between urban planning policies and transport investment plans is very important in the enhancement of the urban environment and the level of patronage (Babalik-Sutcliffe 2002; Loo and Cheng 2010).

7.3. Future Extensions

In Macao, car users and motorcycles users are two distinct groups, and they have very different characteristics as shown in our estimation using cross-sectional data. As we tested with different model forms and explanatory variables, the substitution effect between car ownership and motorcycle ownership is not observed. Some empirical studies suggested that a household may switch their vehicle ownership from motorcycle to car with increases of income level (Lai et al. 2006; Yamamoto 2009). This phenomenon cannot be confirmed in our study, and it may need to adopt a dynamic model with panel data in future investigations. Younger people prefer motorcycle, and the elder may switch to use cars when their income level and social status are improved. Indeed, there is hypothesis that one prefers motorcycle because of their attitudes, rather than the personal attributes, on issues such as perception of public transportation and the safety of motorcycle riding environment etc. In that case, the latent variables or user perceptions which are not directly observable can be modelled with other approaches such as Fuzzy logic approach (Zhang and Prevedouros 2011) and structural equation model (Tam, Lam, and Lo 2010).

Transportation policies towards vehicle ownership control must work together with proper strategies on reduction of vehicle usage. To tackle the problem of high vehicle ownership and usage, policy sensitivities parameters such as cost of private vehicle ownership and usage (such as taxes and tolls), costs and services of transit (i.e., substitutes), and availability of parking (i.e., complements) needs to be introduced, in additional to the socioeconomic and demographic variables in this study. In future extensions, more detailed attributes and specifications related to the built environment can be considered, and the connections between residential environments, vehicle ownerships and commuting behavior of travelers should be investigated to understand the interrelationships of the land use decisions, transport policies and urban growth in a longer-term aspect (Shay and Khattak 2012). Since Macao is a city of high walkability, benefits of improving the pedestrian orientation and walking environment can also be considered in the traveler behaviors (Cervero et al. 2009). Furthermore, the findings and implications of this article is only limited to the residents of Macao. Since there are a large number of visitors in Macao which have generated a significant transportation demand, the travel characteristics of visitors deserve further investigations.

ACKNOWLEDGMENTS

We would like to express our sincere thanks to the Transport Department of Macao Special Administrative Region Government for providing the database in our analysis. We also thank the three anonymous reviewers for their valuable comments that helped to improve the article. None of the views expressed in this article represents the views of the Transport Department of Macao SAR. All errors remain our own.

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