MODELLING CAR OWNERSHIP IN HONG KONG: A DISCRETE CHOICE APPROACH

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Abstract: In this paper, disaggregate car ownership choice models are developed for Hong Kong using the results of a survey with both revealed preference and stated preference questions. The car ownership choice (logit-type) models are calibrated to classify households into non-car owning and car owning households, and one-car owning and multi-car owning households. The revealed preference survey results show that monthly household income, accessibility to employment, monthly car ownership and usage costs are statistically significant to car ownership choices. On another hand, from the stated preference survey results, it was found that monthly household income, vehicle license fee, home-end parking fee and car usage costs are the key factors of owning cars in Hong Kong.

1. INTRODUCTION

Car ownership forecast plays an important role in both transport planning and traffic management. Over recent years, car ownership has become one of the major determinants of travel behaviour. It is recognised that the level of car ownership in a city or country is one of the key factors influencing the level of demand for transport facilities including roads, junctions and parking spaces. An increase in car travel contributes more to congestion, and hence to demand for additional roadspace. Thus, transport and fiscal policies for controlling car ownership growth become more important in many countries. These measures can affect many dimensions of travel behaviour but are likely to be most significant in terms of travellers' choice of car ownership.

The previous studies on car ownership can be generally divided into two approaches: aggregate and disaggregate. Aggregate car ownership forecasting models are estimated on the basis of area-wide time series or cross-sectional data on car ownership per capita or per household and various independent variables (Tanner, 1977). Disaggregate forecasting models are usually developed on the basis of household-level data and stratify households into categories of zero-car, one-car and two-or-more car households (Prevedouros and Schofer, 1992). The disaggregate models are structurally more behavioural compared to aggregate models and are better able to capture the causal relationship between car ownership determinants and car ownership levels (Oi and Shuldiner, 1963; Schor, 1989). Consequently, disaggregate methods have become the preferred approach to model car ownership choice

(Bhat and Pulugurta, 1998). This is because car ownership is a categorical variable, and disaggregate car ownership models usually take the form of discrete choice models.

Household car ownership is usually related to household income and household structure. Pendyala *et al.* (1995) developed ordered-response probit models that describe the changes in the relationship between household car ownership and income by household type. Kitamura (1987, 1988) proposed several model systems of household car ownership, trip generation and modal split. The main driving force of household car holdings in Kitamura's models is socio-demographic characteristics of the households, such as household income and the number of licensed drivers. Train (1986) developed a logit model system of household car ownership, vehicle type choice and utilization. The explanatory variables, such as household income, household size, and the number of workers in the household, are used in the car ownership sub-model.

In Hong Kong, there is about 276 vehicles per kilometre of road, which is one of the highest vehicle densities in the world. The number of licensed vehicles has grown from 266,000 in 1980 to 500,000 in 1997 (Hong Kong Transport Department, 1998) representing an increase of 88% over the past 17 years or an average annual growth rate of 3.8%. Figure 1 shows the past trend of licensed vehicles from 1980 to 1997. With this growth, the transport authority is certainly faced with a great challenge to handle the increasing travel demand. Thus, there is a need to better understand the choice of car ownership and to forecast the car available households by zone in Hong Kong for strategic planning purpose.

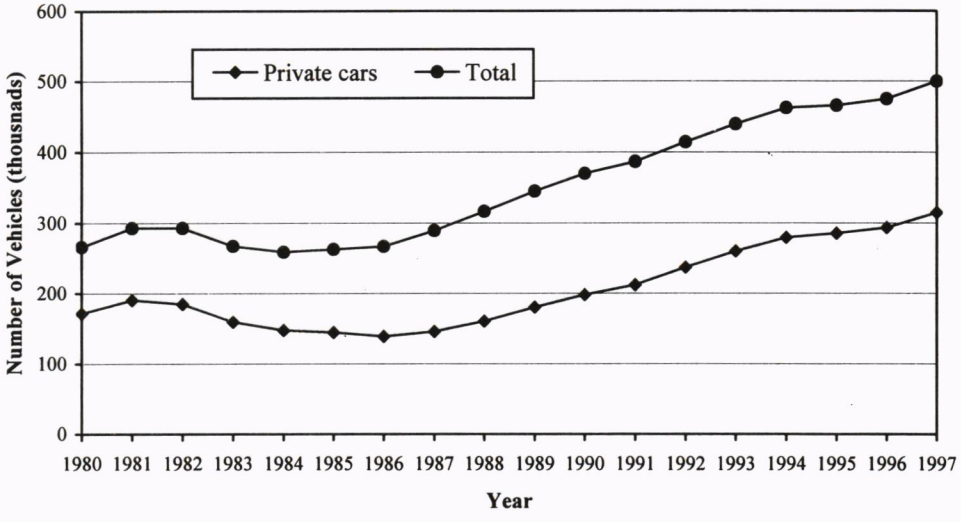

Figure 1. Trends of Licensed Vehicles in Hong Kong, 1980 - 1997

Aggregate approach is usually adopted for forecasting Hong Kong car ownership in the previous related studies. A car ownership model that relates various factors (e.g. population, gross domestic product, monthly household disposable income, first registration tax and annual license fee) to the number of licensed private cars in Hong Kong was calibrated by Tam and Lam (1997a). Another study of Hong Kong car ownership (Prevedouros and An,

1998) considered lagged gross domestic product and railway passenger mileage are the potential factors influencing car ownership.

The existing car availability model used in Hong Kong is a part of the enhanced Second Comprehensive Transport Study (CTS-2) model by Hong Kong Transport Department and Wilbur Smith Associates (1995). The input factors of this model include household income distribution, public transport accessibility, residential parking supply, car ownership costs and car usage costs.

This paper identifies factors that would affect the choices of car ownership in Hong Kong's households. The influences of monthly household income, household size, accessibility to employment, residential car parking availability, monthly car ownership cost and monthly car usage cost are examined. Disaggregate data was collected from a survey which contains both revealed preference and stated preference (Kroes and Sheldon, 1988) questions. Binary logit models (Ben-Akiva and Lerman, 1985) are calibrated for modelling car ownership choice-making behaviour. The levels of non-car available households, one-car available households and multi-car available households can be forecasted in each zone by the developed models.

This paper is organized as follows. Section 2 presents a description of the survey conducted in the early of 1998. Section 3 shows the results of the survey. The proposed car ownership choice model is presented in Section 4. In Section 5, the proposed model is calibrated using revealed preference data, in which the factors that affect car ownership choice can be identified. The influence of changes of economic and fiscal measures on car ownership using stated preference data is investigated in Section 6. Conclusions drawn from the analysis are presented in Section 7, together with recommendations for further study.

2. THE SURVEY

The survey was designed to collect relevant data for analyzing car owning choices of Hong Kong residents. In order to identify the factors affecting car ownership in Hong Kong, two pilot surveys were conducted in 1996 and 1997. The first pilot survey studied the influence of personal income and parking rents on car ownership (Tam and Lam, 1997b). The second pilot survey studied the effect of two fiscal restraint measures, annual license fee and electronic road pricing, on car ownership and usage (Ng and Lam, 1998). From the pilot surveys, the information of sample frame, sample size required and factors were used for the design of the main survey. Additional factors such as purchase cost of private cars, monthly fuel costs, insurance fee and others are also considered in the main survey.

The main survey was conducted in the four licensing offices of Transport Department in Hong Kong in April 1998. Survey targets are individual who entered the survey sites and over the age of 18 as they could obtain valid driving licenses according to the laws in Hong Kong. Simple random sampling method was used for selection.

Questionnaire contains both Revealed Preference (RP) and Stated Preference (SP) questions. Revealed preference questions are to collect valuable data relating to characteristics of the persons surveyed and their households. Stated preference questions are designed for assessing the effects of varying the factors that would contribute toward the decision of car owning. Stated preference is a factorial design procedure in which hypothetical

combinations of attributes are varied in order to reveal their role in influencing the individual's preferences for alternative attribute levels (Kroes and Sheldon, 1988). People are asked for making decision on owning a car or additional cars, or disposing their cars, under a set of hypothetical scenarios. Each scenario describes the hypothetical level of their household income, car purchase cost (including first registration tax), annual vehicle license fee, home-end parking fee and car usage cost. The response bases itself on a "trade off" decision made between various attribute combinations.

A sample of 422 was successfully interviewed on the four survey sites. The average response rate is 52%. However, about 9% samples were eliminated because their questionnaires were incomplete. The remaining valid 384 samples were used for further analysis. The following information is collected in the revealed preference questions of this survey:

- number of private cars owned by household;
- monthly household income;
- household size;
- household living location;
- car ownership cost (including purchase cost, first registration tax, annual license fee, insurance and home-end parking fee); and
- car usage cost (including fuel cost, maintenance cost and attraction-end parking fee).

Household living location is asked so as to relate the accessibility and parking availability information to the respondents' residential locations. In order to be compatible with the input data used in the Second Comprehensive Transport Study (CTS-2), the breakdown of the car ownership costs and usage costs are not considered in the revealed preference analysis.

In the stated preference questions of the survey, each respondent was asked for five to ten hypothetical scenarios. As a result, a database of 3438 observations was created from the valid SP samples. The following attributes are considered in the stated preference survey:

- monthly household income;
- car purchase cost;
- annual vehicle license fee,
- home-end parking fee; and
- car usage cost.

Car purchase cost, annual vehicle license fee and home-end parking fee are broken down from the car ownership costs so as to assess the effect of each of the components of car ownership costs on car ownership choices.

3. SURVEY RESULTS

Among the 384 observations, there are 217 car owning households and 167 non-car owning households. The number of cars owned by households is shown in Table 1. From the selected samples, the average number of cars per household is 0.70.

Table 1. Number of Cars Owned by Households

Number of Cars	Number of Respondents	Proportion of Total (%)
0	167	43.49
1	178	46.36
2	30	7.81
3	4	1.04
4	5	1.30
Total	384	100.00

The monthly household income for car owning and non-car owning households is illustrated in Figure 2. There is about 72% of non-car owning households in the income ranges of less or equal to HK$40,000[1]. The percentage of car owning households in the high-income ranges (above HK$40,000) is about 63% which is comparatively higher than that of non-car owning households 28%. The average household income of the car owning households is about HK$59,100 per month, and HK$35,300 per month for the non-car owning households.

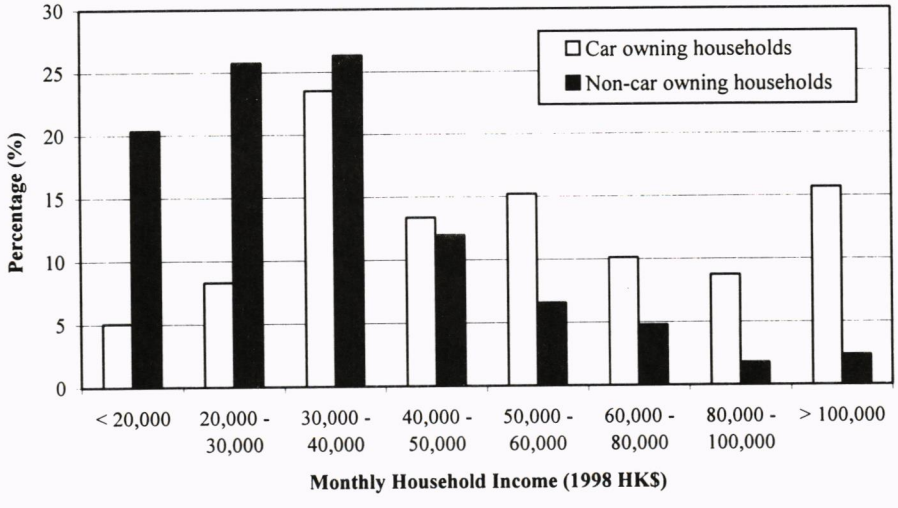

Figure 2. Monthly Household Income Distribution

A comparison of the average car ownership cost and usage cost in the survey and the Second Comprehensive Transport Study (CTS-2) is given in Table 2. When compared to the results of CTS-2, it was found that the percentage of capital cost including first registration tax of car ownership cost is reduced by 11.5%. However, the proportion of home-end parking fee to the ownership cost is greatly increased by nearly 12%. This shows that the parking rent becomes an important component of car ownership costs. The big differences in those components of car ownership costs are mainly due to the fact that CTS-2 was used the data collected in a travel characteristics survey in 1992, which is now updated to 1998 prices by

[1] Current exchange rate: US$1.00 = HK$7.76

an inflation rate for comparison. As it was found that only about 1.5% growth of annual license fees from 1992 to 1998, it is more reasonable for using current annual license fee to compare with the fee obtained from the survey. With reference to the car usage costs, the proportion of the three components (i.e. fuel expenses, maintenance and attraction-end parking costs) found in the survey is similar to that in CTS-2.

It was also found in the survey that the average car ownership cost and usage cost is just 15.47% of the average monthly household income of car ownership households, but it is 25.91% of the average monthly household income of non-car ownership households.

Table 2. Comparison of Average Car Ownership and Usage Costs in the Survey and CTS-2 in Hong Kong

Cost Item	Survey in 1998		CTS-2*	
	Monthly Cost (1998 HK$)	Percentage (%)	Monthly Cost (1998 HK$)	Percentage (%)
Ownership Costs				
Capital cost (including First Registration Tax)	3584	59.89	5795	71.46
Annual License Fee	475	7.94	473#	5.83
Insurance	339	5.67	679	8.37
Home-end parking fee	1586	26.50	1163	14.34
Sub-total	5984	100.00	8110	100.00
Usage Costs				
Fuel expenses	1781	56.32	1535	54.84
Maintenance and spares costs	354	11.20	414	14.79
Attraction-end parking fee	1027	32.48	850	30.37
Sub-total	3162	100.00	2799	100.00
Total	9146		10909	

* CTS-2 model (Hong Kong Transport Department and Wilbur Smith Associates, 1995) was calibrated on the basis of the data collected in a travel characteristics survey in 1992.
\# Weighted average of current annual license fees.

4. PROPOSED CAR OWWNERSHIP CHOICE MODEL

The basic form of car ownership choice model is a logit-type discrete choice equation. The form of the model is

$$P_i = \frac{1}{1+e^{-Z}} \qquad i = 1, \ldots, 5 \tag{1}$$

where P_1 = probability of a household owning one-or-more cars;
P_2 = probability of a car owning household owning two-or-more cars;
P_3 = probability of a car owning household to retain his car(s);
P_4 = probability of a car owning household to own an additional car;
P_5 = probability of a non-car owning household to own a car;
$Z = C_0 + C_1X_1 + C_2X_2 + \cdots + C_iX_i$ is the utility function in a linear formulation;
$C_0, C_1, C_2, \ldots, C_i$ = model coefficients; and
$X_1, X_2, \ldots, X_i$ = model variables.

The model assumes that the utility of owning a car is a function of the following factors (or variables):

- monthly household income;
- household size;
- accessibility to employment;
- residential car parking availability;
- monthly car ownership cost; and
- monthly car usage cost.

Household income is an important element in affecting the desire of owning cars. It may be expected to be the most important variable for explaining variation in car ownership levels. Most of the previous related studies, such as Lerman and Ben-Akiva (1976) and Bhat and Pulugurta (1998), both included household income in their car ownership models.

The impact of household size on car ownership is twofold. On one hand, larger household implies higher trip frequency and thus has higher mobility expectation. On the other hand, more household members may have greater expenditure on essentials such as food, clothing. Therefore, less income will be available for automobile.

The influence of public transportation facilities on the level of car ownership can be assessed by the accessibility index of residential location. In this paper, accessibility is measured by the average public transport generalised cost to reach the closest 600,000 employment opportunities (Hong Kong Transport Department and Wilbur Smith Associates, 1995). On this basis, the accessibility was converted to as set of categories for use in the CTS-2 model, as shown in Table 3.

Table 3. Accessibility to Employment

Accessibility Category	Generalised Cost Range (minutes)
1 Very High	Less than 15
2 High	16 to 24
3 Medium	25 to 30
4 Low	31 to 40
5 Very Low	Over 40

Car parking availability is closely related to household location. It can also reflect the accessibility to public transport. Lower parking availability implies that household may locate in the centre of the city and is thus of better accessibility to public transport. In this study, residential car parking availability is expressed as car parking spaces per household and was converted into a set of categories in a similar manner to that of accessibility. The categories used were shown in Table 4.

Table 4. Residential Car Parking Availability

Residential Car Parking Category	Parking Space Range (spaces/household)
1 Low	Less than 0.09
2 Medium	0.10 to 0.29
3 High	0.30 to 0.99
4 Very High	Above 1.00

Vehicle costs are partitioned into fixed ownership costs and variable usage costs. Ownership costs include purchase cost, first registration tax, annual vehicle license fee, insurance and home-end parking cost. Usage costs include gasoline expenses, maintenance and spares, and attraction-end parking fees. All these costs are converted to monthly basis in this study.

5. MODEL CALIBRATION USING REVEALED PREFERENCE DATA

In view of the limited size of the valid samples particularly for the multi-car owning households, binary logit model was adopted for calibration of the car ownership models. The model system developed in this study consists of two parts. The first part contains a binary logit model of car availability, which predicts whether a household has zero or one-or-more cars. The second part is another binary logit model (multi-car ownership choices) for car owning households, which splits households into one or two-or-more cars. Revealed preference data was used to calibrate these two binary logit models.

The calibration results of the car ownership model are presented in Table 5 in terms of the estimated coefficients, t-statistics and overall model goodness-of-fit statistics.

Table 5. Binary Logit Model of Car Ownership

Variable (X_i)	Coefficient (C_i)	t-statistics
Constant	-0.5425	-0.8109
Monthly household income (1998 HK$)	4.29×10^{-5}	7.1944
Household size (number of persons)	-0.0413	-0.4479
Accessibility index – category 2	0.6352	1.4542
Accessibility index – category 3	0.8293	1.7159
Accessibility index – category 4	1.7013	3.5518
Accessibility index – category 5	0.1201	0.2104
Residential car parking availability - category 2	0.0748	0.2327
Residential car parking availability - category 3	0.8235	0.7149
Residential car parking availability - category 4	-0.6475	-0.4553
Monthly car ownership cost (1998 HK$)	-0.0002	-3.4971
Monthly car usage cost (1998 HK$)	-0.0002	-2.0000
Chi-square	118.1520	
Goodness-of-fit	432.5620	
Number of samples	384	

The probability of a household owning one-or-more cars (P_1) can be obtained from the developed model, in which the t-statistics for each of the coefficients indicate their statistical significance. In order to assess how well the model fits, the predicted outcomes are compared to the observed values. The above model gives about 76% of accuracy for predicting the number of car owning and non-car owning households. It can be noted that monthly household income is highly significant to car ownership choices. As a result, car owning households increase with their monthly income. Household size and car parking availability have not demonstrated to be statistically significant. Accessibility, car ownership and usage costs are marginally significant to car owning choices. An increase in car ownership and usage costs would lead to a reduction in the willingness of car ownership.

As household size and parking availability are statistically insignificant, it is reasonable to eliminate them from the model. The revised model is calibrated and presented in Table 6.

Table 6. Revised Binary Logit Model of Car Ownership

Variable (X_i)	Coefficient (C_i)	t-statistics
Constant	-0.7159	-1.2766
Monthly household income (1998 HK$)	4.31×10^{-5}	7.4567
Accessibility index – category 2	0.7013	1.7389
Accessibility index – category 3	0.8873	2.0346
Accessibility index - category 4	1.7607	3.9310
Accessibility index - category 5	0.2147	0.4139
Monthly car ownership cost (1998 HK$)	-0.0002	-3.5556
Monthly car usage cost (1998 HK$)	-0.0002	-2.0000
Chi-square	117.0440	
Goodness-of-fit	433.5800	
Number of samples	384	

The revised model gives the accuracy of 76% for predicting the non-car and car owning households. The four factors, monthly household income, accessibility, car ownership cost and usage cost, included in the model are statistically significant except the last category of accessibility index. However, the variable of accessibility index – category 5 has still been included in the model for the completeness in representing the zonal accessibility. This is because it cannot be distinguished the accessibility of a zone in category 1 or 5, if this variable is excluded from the model. The revised model is recommended for the estimation of car owning households in Hong Kong.

Similarly, the multi-car ownership choice model for car owning households is calibrated and the results are shown in Table 7. The probability of a car owning household owning two-or-more cars (P_2) can be determined. This model gives overall accuracy of 83% to predict the one car or two-or-more cars owning households. However, the accuracy of the estimation of multi-car owning households is poor. The low accuracy may be due to the insufficient sample sizes (only 39 samples) for multi-car owning households. More samples should be collected in further study. The results found that household size, accessibility, car ownership and usage costs did not contribute significantly to the accuracy of the model. Thus household size, accessibility, car ownership and usage costs affect the initial decision to own

a car, but once the appropriate conditions are met, the decision to have more than one car is solely related to affordability and car parking availability.

Table 7. Binary Logit Model for Multi-Car Ownership Choices

Variable (X_i)	Coefficient (C_i)	t-statistics
Constant	-3.9094	-3.3621
Monthly household income (1998 HK$)	2.05×10^{-5}	3.1331
Household size (number of persons)	0.0996	0.7715
Accessibility index - category 2	-0.1192	-0.1253
Accessibility index - category 3	-0.6631	-0.6387
Accessibility index - category 4	0.3606	0.3670
Accessibility index - category 5	0.3997	0.3390
Residential car parking availability – category 2	0.7865	1.2872
Residential car parking availability – category 3	2.0911	2.4273
Residential car parking availability – category 4	1.7112	1.3903
Monthly car ownership cost (1998 HK$)	9.98×10^{-6}	0.1475
Monthly car usage cost (1998 HK$)	-4.70×10^{-5}	-0.4700
Chi-square	27.6820	
Goodness-of-fit	213.9580	
Number of samples	217	

The exclusion of the insignificant parameters produces a revised model presented in Table 8 with 83% of accuracy for predicting the multi-car owning households. It can be observed that eliminating the household size, accessibility, car ownership cost and car usage cost from the model has little effect on the significance of the remaining coefficients of the equation. The revised model is therefore recommended for modelling the multi-car ownership choices.

Table 8. Revised Binary Logit Model for Multi-Car Ownership Choices

Variable (X_i)	Coefficient (C_i)	t-statistics
Constant	-3.5272	-5.3313
Monthly household income (1998 HK$)	1.95×10^{-5}	3.4283
Residential car parking availability – category 2	0.7517	1.3980
Residential car parking availability – category 3	1.8748	2.3330
Residential car parking availability – category 4	1.6869	1.4627
Chi-square	23.6330	
Goodness-of-fit	209.3690	
Number of samples	217	

6. STATED PREFERENCE MODELLING

In order to assess the effects of economic changes and fiscal policies on car ownership choices, interviewers are asked to make response to the changes of car owning attributes in the stated preference questions of the survey. The attributes are monthly household income, car purchase cost, vehicle license fee, parking fee and car usage cost. The respondents make

decisions to own their cars, to own an additional car or to dispose their cars in view of these given attributes.

The choice of car ownership is modelled based on the results of the stated preference survey. For car owning households, the model is presented in equation (2) with 60% of accuracy for predicting the decision of retaining or disposing their cars. The number of samples for calibration of this model is 1438. It was found that monthly household income, car purchase cost per month, vehicle license fee per month, monthly home-end parking fee and monthly car usage cost are both statistically significant to car ownership choices. However, a positive effect of car purchase cost on car ownership is found. As cars are their assets in car owning households, an increase in car purchase cost would increase the probability of retaining their cars.

$$P_3 = \frac{1}{1+\exp(-0.35-9.31\times10^{-6}X_1-0.0001X_2+0.0009X_3+0.0003X_4+5.1\times10^{-5}X_5)} \quad \ldots (2)$$

t - stat. : *(-1.68)* *(-3.77)* *(-4.65)* *(3.00)* *(6.82)* *(1.75)*

where P_3 = probability of a car owning household to retain his car(s);
X_1 = monthly household income (1998 HK$);
X_2 = car purchase cost per month (1998 HK$);
X_3 = vehicle license fee per month (1998 HK$);
X_4 = home-end parking fee per month (1998 HK$); and
X_5 = car usage cost per month (1998 HK$).

In order to calibrate the multi-car ownership choice model, car owning households are asked to own an additional car under various hypothetical scenarios. The multi-car ownership choice model is shown in equation (3), which gives 65% of accuracy for predicting the choices of multi-car ownership. The number of samples for calibration of the model is 305.

$$P_4 = \frac{1}{1+\exp(-0.27-2.12\times10^{-5}X_1+0.0001X_2+0.0023X_3+0.0003X_4-0.0002X_5)} \quad \ldots (3)$$

t - stat. : *(-0.52)* *(-4.37)* *(3.00)* *(2.88)* *(3.00)* *(2.97)*

where P_4 = probability of a car owning household to own an additional car.

The results show that all the above five factors are statistically significant, whereas monthly household income is the most significant factor. The car purchase cost now negatively affects the choices of owning an additional car. However, the sign of car usage cost is incorrect. This may be due to the combined effects of fuel cost, maintenance fee and attraction-end parking fee. The sample sizes for owning an additional car may also be insufficient to calibrate the model. Therefore, further refinement of this model should be carried out with more representative survey samples. The revised model for deleting the incorrect sign variable X_5 is listed in the following equation (4).

$$P_4 = \frac{1}{1+\exp(-0.92-2.09\times10^{-5}X_1+8.70\times10^{-5}X_2+0.0025X_3+0.0002X_4)} \quad (4)$$

t - stat. : *(-1.94)* *(-4.40)* *(2.81)* *(3.13)* *(2.08)*

For the non-car owning households, the model is calibrated for the choices of owning a car and is presented in equation (5). The number of samples for calibration is 1473. 58% of accuracy is obtained from the model for predicting the choices of owning a car. Monthly household income, vehicle license fee per month, home-end parking fee per month and monthly car usage cost are found to be statistically significant. However, car purchase cost is insignificant. This may be partially due to the fact that the non-car owning households are inexperienced on car purchasing and so the effect of changing the car purchase cost could not be perceived properly.

$$P_5 = \frac{1}{1+\exp(-5.29-1.42\times10^{-5}X_1+4.10\times10^{-5}X_2+0.0020X_3+0.0011X_4+0.0007X_5)}$$

t - stat. : *(-6.87)* *(-6.46)* *(0.88)* *(2.86)* *(5.50)* *(7.00)*

... (5)

where P_5 = probability of a non-car owning household to own a car.

7. CONCLUSIONS

The findings presented in this paper are the results of the main survey conducted in the early of 1998 in Hong Kong, which takes into account the findings of the two pilot surveys in 1996 and 1997. The survey contains both revealed preference and stated preference questions, which considers the influence of monthly household income, household size, accessibility, parking availability, monthly car ownership and usage costs on car ownership choices. Based on the results of the survey, the probabilities of car ownership and multi-car ownership choices are estimated by the two binary logit choice models.

It was found from the revealed preference survey results that monthly household income, accessibility to employment, monthly car ownership and usage costs are statistically significant to the probability of car ownership choices. The proposed model shows that the more monthly income of a household, the higher is the probability of the household owning car(s). On another hand, increases in monthly car ownership and usage costs lead to a reduction in the probability of owning cars. In the multi-car ownership choice model, only monthly household income and residential car parking availability are found to be significant. From the stated preference survey results, it was found that monthly household income, vehicle license fee, home-end parking fee and car usage costs are the key factors on car ownership choices for both car owning and non-car owning households.

Further work will be conducted to refine the developed models by breaking down the components of the car ownership and usage costs in the revealed preference analysis. Another survey should be carried out so as to increase the sample sizes for both revealed preference and stated preference modelling, particularly the sample size for multi-car owning households. Multinomial logit choice model of car ownership can then be calibrated when more representative survey samples are collected.

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