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Title:

**Household car and motorcycle ownership in Bangkok and Kuala Lumpur in
comparison with Nagoya**

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Abstract

This study investigates household car and motorcycle ownership behaviours in the Asian metropolises of Bangkok and Kuala Lumpur (developing countries), and of Nagoya (developed country). Mode choice models are first estimated to calculate accessibility measures, and then car and motorcycle ownership models are estimated using bivariate ordered probit models with the accessibility measures as explanatory variables. Inter-regional comparisons and spatial transferability analysis are conducted. Results suggest that: (i) accessibility measures and car and motorcycle ownership behaviour are correlated; (ii) car and motorcycle ownership is substitutable in Bangkok and Kuala Lumpur, but is complementary in Nagoya; (iii) car and motorcycle ownership behaviour in Bangkok and Kuala Lumpur is similar and quite distinct from Nagoya; and (iv) car and motorcycle ownership behaviour in Nagoya in 1981 was closer than ownership behaviour in Nagoya in 1991 and 2001 to the behaviour in Bangkok and Kuala Lumpur. Policy implications are also discussed.

Keywords

car and motorcycle ownership, accessibility, bivariate ordered probit model, Asian metropolises, spatial transferability

1. Introduction

Private vehicle ownership in developing countries has been steadily increasing since the 1960s due to economic development and related rapid urbanisation. As described by Goodwin (1997), a private vehicle is a symbol of power, status, control, and freedom. If users consider a car or a motorcycle as a necessity, then it will be difficult to reduce the level of ownership. However, the level of vehicle ownership may also be driven by increasing demand for travel, rising income levels, and people's attitudes to alternative public transport services which may offer insufficient supply and inferior quality.

Growing vehicle ownership leads to increased vehicle use. This in turn generates hyper congestion on the road network, leading to poorer lives and a degraded environment. Yet carefully planned policies are needed if long-term targets aimed at reducing road traffic are to be achieved. Some possible measures to achieve such targets are greater investment in the road infrastructure and public transport systems, as well as regulations aimed at reducing vehicle ownership and usage. Investigations of vehicle ownership behaviour are a key requirement for successful policy measures of these types. Moreover, vehicle ownership is a basic input for transport models, such as car allocation models. (See Anggraini et al. 2012, for example.) Therefore, accurate ownership forecasts are essential.

Most previous investigations in this field have paid attention only to car ownership. Even where rare attempts have been made to develop disaggregate models that analyse both household car and motorcycle ownership, they are often highly advanced (so as to take account of the interdependencies between them) and involve considerable modelling complexities. The bivariate ordered probit (BOP) model has been found to be an appropriate modelling technique for such studies, rather than the commonly used multinomial logit (MNL) model with independence of irrelevant alternatives (IIA) restrictions. One of the limited examples in which car and motorcycle ownership is analysed simultaneously is Lee

and Shiao (1995), where diffusion modelling techniques are adopted. Another example is Senbil et al. (2007), who applied BOP model to car and motorcycle ownership modelling for the Jabotabek (Indonesia), Kuala Lumpur (Malaysia), and Manila (Philippines) metropolitan areas. Sanko et al. (2009) also applied BOP models.¹ More applications of BOP models are summarised in Greene and Hensher (2010).

This study attempts to investigate household car and motorcycle ownership in Asian metropolises by developing BOP models. The case study considers two cities in developing countries, Bangkok and Kuala Lumpur, and one in a developed country, Nagoya. In the case of Nagoya, data are analysed at three time points, 1981, 1991, and 2001, which makes possible a comparison of ownership behaviours in two decades. In the developing countries of Asia, the motorcycle is treated both as a main mode of transport and an intermediate mode before switching to a car. In Japan, on the other hand, the motorcycle might be considered a complementary mode. The level of public transport services in urban areas in Japan is already very high, but such services are also improving in developing countries. Accordingly, a comparative analysis between cities in developing countries and in developed countries is of interest, which is one of the themes of this study. Further, it is believed that accessibility measures are correlated to vehicle ownership behaviour.²

The main aims of this research are to (1) investigate the relationships between accessibility measures and vehicle ownership, (2) investigate the complementary or substitutability relationship between car and motorcycle ownership, and (3) find a context

¹ Yamamoto (2009) applied the trivariate binary probit model to household car, motorcycle, and bicycle ownership.

² Land use policy in Japan is not suitable to compact city, and suburbanisation often happens, resulting in more vehicle ownership and usage.

that provides better spatial transferability³.

This paper is structured as follows. In the next section, previous studies on vehicle ownership are reviewed. Then the methodology is presented and the case study cities are briefly described. Finally empirical findings are reported followed by the concluding remarks.

2. Previous studies on vehicle ownership

The growth in vehicle ownership has received substantial attention in recent years due to its long-term impact. Asian countries, in particular, suffer serious traffic congestion, making deterrent measures vital. Even though a number of investigations on vehicle ownership and usage in developing countries have been conducted on an aggregate and disaggregate basis over two decades (Button et al. 1993, Matas et al. 2009, Nolan 2010, Said 1992, Stanovnik 1990, Vasconcellos 1997), car ownership and usage continue to grow to the detriment of the local and global environments.

Car ownership and public transport usage are highly interrelated. There have been a number of investigations that set out to clarify the relationship between them and to investigate appropriate policy options aimed at sustainable transport (Dissanayake 2008, Dissanayake and Morikawa 2002, 2008, Goodwin 1997, Kitamura 1989, Matas et al. 2009). Dissanayake and Morikawa (2002) investigated possible transport policies for developing countries emphasising the “push and pull” concept in which a vehicle tax for car and motorcycle travel in city centres is considered in conjunction with fare reductions on public

³ Sanko and Morikawa (2010) analysed the relationships between context and transferability. Most transferability analyses has been done in developed countries, and their application to developing countries is very limited. (See Dissanayake et al. 2012, Santoso and Tsunokawa 2005, for example.)

transport. However, the reduction in vehicle usage resulting from such policies has been reported to be inadequate, since traveller attraction to private vehicles is remarkably high. As mentioned by Goodwin (1997), the quality of public transport services depends not only on the current level of car ownership but also on changes in the level of car ownership and public transport use. Accordingly, it has been proposed that longitudinal survey data could be more helpful in investigating correlations between car ownership and public transport usage than cross-sectional surveys or aggregate time series data (Goodwin 1997, Kitamura 1989). Kitamura (1989) conducted an investigation to observe the causal factors relating to car ownership and public transport usage and reported that car usage determined public transport usage.

The decision to own a vehicle is usually made at a household level, so the disaggregate approach is selected as an appropriate technique for modelling behaviour (Ben-Akiva and Lerman 1985, Bhat and Pulugurta 1998, Chu 2002, Dissanayake and Morikawa 2002, Matas et al. 2009, Pendyala et al. 1995). In models of vehicle ownership, the number of cars or motorcycles owned by a household is generally used as the dependent variable, while explanatory variables may include all other household-related information, such as the number of household members, household income, availability of public transport, number of workers in the household, and information about individual household members including gender, age, and occupation.

The disaggregate vehicle ownership models so far developed can be divided into two main categories: (1) non-ordered discrete choice models like the multinomial logit model, in which the number of vehicles owned is considered as a discrete value (Bhat and Pulugurta 1998, Matas and Raymond 2008, Potoglou and Kanaroglou 2008); and (2) ordered response models in which a latent propensity measure is assumed to determine the level of vehicle ownership (Bhat and Pulugurta 1998, Chu 2002, Matas et al. 2009, Pendyala et al. 1995). The

non-ordered discrete choice models are more flexible than ordered response models in the error structure among alternatives in the choice set. Bhat and Pulugurta (1998) and Potoglou and Susilo (2008) compared a multinomial logit model and an ordered response logit model, and suggested that the non-ordered discrete choice model outperforms the ordered response model from the viewpoint of goodness-of-fit with their dataset. However, non-ordered discrete choice models cannot properly account for the ordinal nature of the number of vehicles owned. This shortcoming is the main reason why many researchers have applied ordered response models when investigating household vehicle ownership. In addition, Cameron and Trivedi (2005, p. 682) state that, for analysing count data, “unordered models such as multinomial logit . . . are not parsimonious and more importantly are inappropriate.” They suggested using “a sequential model that recognises the ordering of the data,” and “one such model is an ordered model.” There is a trade-off between parsimony and flexibility, but the authors placed more emphasis on parsimony and adopted ordered models in the present case. Count models are also capable of considering the ordinal nature of the data, but the application of such models in the field of vehicle ownership is rare. One exception is the work by Zhao and Kockelman (2002), who applied a multivariate negative binomial model to the number of vehicles by type. They obtained reasonable estimation results with their dataset, showing the applicability of the model structure. Count models, such as the bivariate Poisson regression model and the bivariate negative binomial regression model, implicitly assume equal intervals. For example, when an intensity parameter is doubled, the average number of occurrences of the event is also doubled. However, this does not mean that the average number of occurrences of the event is always proportional to independent covariates, since the intensity parameter can include higher power terms of independent covariates. On the other hand, ordered models can express uneven intervals by estimating the threshold values. A comparison of ordered response models and count models remains as a further research

task.

Pendyala et al. (1995) modelled vehicle ownership as an ordered response probit model at six time points so as to observe the income elasticity of car ownership over time. According to their investigation, the relationship between car ownership and income varies over time, while the variations depend on the type of household structure. Additionally, the impact of accessibility measures on car and motorcycle ownership is believed to be high and many models include accessibility measures as one of explanatory variables. For example, Chu (2002) and Matas et al. (2009) considered accessibility measures, based on travel times between origins and destinations by each mode, which are weighted by the number of workers in each destination zone. Accessibility measures can be categorised as gravity-based, utility-based, and so on, and activity-based accessibility is an expansion of utility-based accessibility. (Dong et al. 2006; See also Bhat et al. 2000.) A detailed review of car ownership models can be found in De Jong et al. (2004). Although some studies estimate both vehicle ownership and usage (Fang 2008, Spissu et al. 2009, for example), the authors focus on ownership behaviours.

Researchers recently have shown particular interest in using ordered response models to investigate vehicle ownership behaviours. When analysing both car and motorcycle ownership behaviours, researchers consider BOP models. Sanko et al. (2009) estimated BOP models for Nagoya using data collected in 1981, 1991, and 2001 and used the estimated models to explore temporal transferability. Senbil et al. (2007) estimated BOP models for three cities in developing countries. Comparisons of BOP estimates in developed and developing countries are rare, and the authors extended the analysis in Sanko et al. (2009) for their detailed comparison in this paper, which is one of the themes of this study⁴. In addition

⁴ Travel behaviours for multiple time points in a specific metropolitan area have also received an attention and have been analysed by researchers, such as Kitamura and Susilo

to inter-regional comparisons, this paper examined spatial transferability. Ownership models commonly incorporate accessibility measures, and the authors adopt utility-based accessibility measures. Utility-based accessibility measures are appropriate for considering many of the factors affecting accessibility measures. (A more detailed explanation is given in Subsection 3.1.)

3. Methodology

The methodology consists of four main steps. The first step is the development of mode choice models for analysing the travel demand in the cities concerned. (MNL models on a trip basis; see Ben-Akiva and Lerman 1985, for example.) The second step is to calculate the accessibility measures based on the expected maximum utility of the mode choice models estimated in the first step (see Subsection 3.1). The third step is to estimate the car and motorcycle ownership models, including the accessibility measures calculated in the second step as explanatory variables. (BOP models on a household basis; see Subsection 3.2.) The final step repeats the earlier steps for each case study city, compares the results inter-regionally, and investigates the spatial transferability (see Subsection 3.3).

3.1. Accessibility measures

Accessibility measures are calculated based on the utility functions of mode choice models. In gravity-based accessibility measures, the denominator is usually a function of the travel times or travel costs between a specific zone and the zone of destination, and the numerator is usually the unity or population in the zone of destination. This type of accessibility can be affected only by travel times, travel costs, and population. However, it is reasonable to assume that the younger generation, which is not allowed to drive, and the older generation,

(2005).

which is able to drive, can have different accessibility. In order to influence these kinds of factors, utility-based accessibility measures rather than gravity-based accessibility measures are adopted. Utility-based accessibility measures can be derived at the individual level.

The maximum utility, a log-sum term, can be used as an accessibility measure (Ben-Akiva and Lerman 1985). Note that log-sum values represent not the sum of the utility of each mode but the expected highest utility of each mode. According to existing studies, accessibility measures are based on both of (1) the attractiveness of a location and (2) a resistance factor for travel. Sánchez-Silva et al. (2005) mention that many researchers define accessibility measures based on these two factors. Chu (2002) uses accessibility measures of this type in a car ownership model.

The following factors are considered for an individual n residing in zone z_n , where $z_n = 1, \dots, Z$, and Z : number of zones in the study area.⁵

(a) additional accessibility of car availability

$$WAAC_n = \sum_{z=1, z \neq z_n}^Z [w_{RBCz} \ln(\exp(V_{Rzn}) + \exp(V_{Bzn}) + \exp(V_{Czn})) - w_{RBz} \ln(\exp(V_{Rzn}) + \exp(V_{Bzn}))] \quad (1a)$$

(b) additional accessibility of motorcycle availability

$$WAAMC_n = \sum_{z=1, z \neq z_n}^Z [w_{RBMcz} \ln(\exp(V_{Rzn}) + \exp(V_{Bzn}) + \exp(V_{MCzn})) - w_{RBz} \ln(\exp(V_{Rzn}) + \exp(V_{Bzn}))] \quad (1b)$$

⁵ “Accessibility by public transport (accessibility by transit)”

$WAT_n = \sum_{z=1, z \neq z_n}^Z w_{RBz} \ln(\exp(V_{Rzn}) + \exp(V_{Bzn}))$, is also considered, but is not reported here. This is because BOP models including “accessibility by public transport” as explanatory variables have worse model fit compared to BOP models including “additional accessibility of car availability” and “additional accessibility of motorcycle availability” in the majority of case study cities.

where:

$$w_{RBz} = (Q_{Rz} + Q_{Bz}) / \sum_{z=1, z \neq z_n}^Z (Q_{Rz} + Q_{Bz}) \quad (2a)$$

$$w_{RBCz} = (Q_{Rz} + Q_{Bz} + Q_{Cz}) / \sum_{z=1, z \neq z_n}^Z (Q_{Rz} + Q_{Bz} + Q_{Cz}) \quad (2b)$$

$$w_{RBM Cz} = (Q_{Rz} + Q_{Bz} + Q_{MCz}) / \sum_{z=1, z \neq z_n}^Z (Q_{Rz} + Q_{Bz} + Q_{MCz}) \quad (2c)$$

where, V_{Rzn} , V_{Bzn} , V_{Czn} , and V_{MCzn} denote the systematic components of the utility functions of mode choice models when individual n travels between zone z_n and zone z by rail, bus, car, and motorcycle, respectively; and Q_{Rz} , Q_{Bz} , Q_{Cz} , and Q_{MCz} denote the traffic volume (obtained through surveys) between zone z_n and z by rail, bus, car, and motorcycle, respectively. (Only destination zones are mentioned in the suffixes of V , w , and Q . The origin zone is always the zone of residence of individual n ; that is, z_n , and is removed for simplicity.)

The ratio of trip count (trip count means the number of trips between zone z_n and z by all respondents) is used as an indicator of attractiveness, assuming that a more attractive area has a higher count. If the attractiveness of the entire study area is considered, the number of trips generated and attracted to and from the entire study area should be considered. However, in Eq. (1), the trip count to and from a zone of residence is considered, since the case study cities have relatively large survey areas (see Section 4). One of the disadvantages of this accessibility measure is that, when the trip count is concentrated in the area close to the zone of residence, an area that is very attractive but not travelled to and from the zone of residence is not included in the calculation. More theoretically, mode and destination choice models can be estimated to calculate weights, but for simplicity travel count data are used.

To sum up, two additional accessibility measures indicate travel convenience if an individual is able to use these alternatives in addition to public transport (rail and bus), which is usually available to all citizens. The higher the additional accessibility, the higher the intensity of vehicle ownership.

3.2. Bivariate ordered probit (BOP) model

For each household h , let j represent the number of cars owned ($j = 0, 1, \dots, J$), and let k represent the number of motorcycles owned ($k = 0, 1, \dots, K$). The equation system can be written as:

$$y_{1h}^* = \beta_1' \mathbf{x}_{1h} + \varepsilon_{1h}, \quad y_{1h} = j \text{ if } \mu_{1,j} < y_{1h}^* \leq \mu_{1,j+1}, \quad (3a)$$

$$y_{2h}^* = \beta_2' \mathbf{x}_{2h} + \varepsilon_{2h}, \quad y_{2h} = k \text{ if } \mu_{2,k} < y_{2h}^* \leq \mu_{2,k+1}, \quad (3b)$$

where y_{1h}^* and y_{2h}^* denote the propensity for household h to own cars and motorcycles, respectively; y_{1h} and y_{2h} denote the observed number of cars and motorcycles owned by household h , respectively; $\mathbf{x}_{1h}$ and $\mathbf{x}_{2h}$ are vectors of exogenous variables; β_1 and β_2 are corresponding vectors of parameters that are estimated with the threshold values (i.e. μ_1 and μ_2); and random error terms ε_{1h} and ε_{2h} are assumed to be distributed identically and independently across households in accordance with the standard normal distribution.

The interactions between the number of cars owned and the number of motorcycles owned can be incorporated into Eq. (3). In the BOP modelling approach, interactions can be divided into observed and unobserved ones. An observed interaction (called an *interaction*) is a direct relationship between car and motorcycle ownership. This study, specifically, attempts to include the numbers of cars owned and motorcycles owned in the functions of motorcycle

ownership and car ownership, respectively. On the other hand, an unobserved interaction (called a *correlation*) can be found in the error correlation between car and motorcycle ownership propensity functions. That is, unobserved factors that influence car ownership can be correlated with those that influence motorcycle ownership. A standard normal bivariate distribution function is specified such that:

$$\phi_2(\bullet) = \phi_2(\varepsilon_{1h}, \varepsilon_{2h}, \rho_{\varepsilon_{1h}, \varepsilon_{2h}}) \quad (4)$$

Likewise, the corresponding cumulative distribution function is given as:

$$\Phi_2(\bullet) = \Phi_2(\varepsilon_{1h}, \varepsilon_{2h}, \rho_{\varepsilon_{1h}, \varepsilon_{2h}}) \quad (5)$$

ρ represents the correlation between the random error terms.

From Eqs. (3) and (5), the joint probability that household h will own j cars and k motorcycles is:

$$\begin{aligned} P_{h,j,k} = & \Phi_2[\mu_{1,j+1} - \beta'_1 \mathbf{x}_{1h}, \mu_{2,k+1} - \beta'_2 \mathbf{x}_{2h}, \rho_{\varepsilon_{1h}, \varepsilon_{2h}}] \\ & - \Phi_2[\mu_{1,j} - \beta'_1 \mathbf{x}_{1h}, \mu_{2,k+1} - \beta'_2 \mathbf{x}_{2h}, \rho_{\varepsilon_{1h}, \varepsilon_{2h}}] \\ & - \Phi_2[\mu_{1,j+1} - \beta'_1 \mathbf{x}_{1h}, \mu_{2,k} - \beta'_2 \mathbf{x}_{2h}, \rho_{\varepsilon_{1h}, \varepsilon_{2h}}] \\ & + \Phi_2[\mu_{1,j} - \beta'_1 \mathbf{x}_{1h}, \mu_{2,k} - \beta'_2 \mathbf{x}_{2h}, \rho_{\varepsilon_{1h}, \varepsilon_{2h}}] \end{aligned} \quad (6)$$

The parameters to be estimated are the $J + K - 2$ threshold values ($\mu_{1,0}, \mu_{2,0} = -\infty$;

$\mu_{1,1}, \mu_{2,1} = 0$; $\mu_{1,J+1}, \mu_{2,K+1} = +\infty$), β_1 , β_2 , and ρ . The parameters are obtained by

maximising the log-likelihood function:

$$L^* = \sum_{h=1}^H \sum_{j=0}^J \sum_{k=0}^K Z_{hjk} \ln P_{hj} \quad (7)$$

where:

$$Z_{hjk} = \begin{cases} 1 & \text{if the household } h \text{ owns } j \text{ cars and } k \text{ motorcycles, and} \\ 0 & \text{otherwise.} \end{cases}$$

As mentioned, one of the advantages of BOP model is its ability to consider interactions. As noted above, observed and unobserved interactions are in this paper called *interactions* and *correlations*, respectively, in order to avoid confusion.

The elasticities of vehicle ownership probabilities are calculated for both car and motorcycle. Eq. (8a) shows the elasticity of probability of household h owning i ($=j$ for car; $=k$ for motorcycle) cars or motorcycles for continuous variables, while Eq. (8b) shows the corresponding pseudo-elasticity for discrete variables.

$$E_{x_{ahn}}^{\Pr(y_{ah}=i)} = \frac{\partial \ln \Pr(y_{ah}=i)}{\partial \ln x_{ahn}} = \frac{\phi(\mu_{a,i-1} - \beta'_a \mathbf{x}_{ah}) - \phi(\mu_{a,i} - \beta'_a \mathbf{x}_{ah})}{\Phi(\mu_{a,i} - \beta'_a \mathbf{x}_{ah}) - \Phi(\mu_{a,i-1} - \beta'_a \mathbf{x}_{ah})} \beta_{an} x_{ahn} \quad (8a)$$

$$E_{x_{ahn}}^{\Pr(y_{ah}=i)} = \frac{\left[\frac{\{\Phi(\mu_{a,i} - (\beta'_a \mathbf{x}_{ah} + \beta_{an})) - \Phi(\mu_{a,i-1} - (\beta'_a \mathbf{x}_{ah} + \beta_{an}))\}}{-\{\Phi(\mu_{a,i} - \beta'_a \mathbf{x}_{ah}) - \Phi(\mu_{a,i-1} - \beta'_a \mathbf{x}_{ah})\}} \right]}{\Phi(\mu_{a,i} - \beta'_a \mathbf{x}_{ah}) - \Phi(\mu_{a,i-1} - \beta'_a \mathbf{x}_{ah})} \quad (8b)$$

where, $a = 1$ for car ownership and 2 for motorcycle ownership; x_{ahn} and β_{an} are the n -th explanatory variable for household h and the corresponding parameter estimate; ϕ and Φ denote the probability density function and the cumulative distribution function of the univariate normal distribution, respectively.

3.3. Spatial transferability

Measures to evaluate model transferability can be divided into the following types: (1) tests of model parameter equality; (2) tests of disaggregate prediction; and (3) tests of aggregate – zonal level – prediction (see Koppelman and Wilmot 1982, for example). The measure used here consists of the third type, tests of aggregate prediction, since prediction at aggregate level is of primary interest to policy planners. The measure considered is absolute error (AE) of the share.

$$AE = \sum_{c,mc} |S_{c,mc}(\theta_{t1}) - S_{c,mc}(C_{t2})| \quad (9)$$

where, $S_{c,mc}(\theta_{t1})$ denotes the predicted share of households owning c cars and mc motorcycles in $t2$ context using parameter θ_{t1} estimated in context $t1$. $S_{c,mc}(C_{t2})$ denotes the observed share in context $t2$.

4. Case study cities

The case study cities examined in this study are briefly described in this section. The major characteristics of the surveys are summarised in Table 1.

***** Table 1 *****

4.1. Bangkok, Thailand

Bangkok Metropolitan Region (BMR) is located on the gulf of Thailand and is the capital of Thailand. Data used in this study were obtained from a household travel survey in BMR

taken during 1995/96. The database consists of all attributes of trips that were made on the date of the survey and information on household members.

4.2. Kuala Lumpur, Malaysia

Kuala Lumpur is located on the west of the Malay Peninsula and is the capital of Malaysia. During the process of industrialisation, an expanding economy has encouraged rapid urbanisation and motorisation, especially in the Klang Valley Region of which Kuala Lumpur is part. The data are obtained from a household travel survey that was conducted in 1997–1999. The database provides information related to households, individual members, and their trips.

4.3. Nagoya, Japan

Nagoya Metropolitan Region (NMR) centring on Nagoya city is the third largest metropolitan region in Japan. The data used in this study consist of household travel surveys conducted in 1981, 1991, and 2001.^{6,7} The dataset consists of information on household vehicle ownership, information on household members, and all trip records of household members made on the date of the survey.

4.4. Comments and other statistics

The modal shares in these case study cities are found in Figure 1. Transport modes considered

⁶ The survey was also conducted in 1971. Since the motorcycle and bicycle were in the same category in 1971, the analysis of 1971 was omitted.

⁷ Among four survey time points (1971–2001), due to the urban area expansion and the policy of the survey designers at that time, the survey area is changed. In this study, the analysis is limited to the 1971 survey area, which is included in all four survey time points.

are limited to motorised modes; that is, rail, bus, car, and motorcycle. In Bangkok and Kuala Lumpur, motorcycle usage is not negligible. The bus has almost a 50% share in Bangkok.

***** Figure 1 *****

The sample distribution of the household car and motorcycle ownership is indicated in Figure 2. The number of households owning at least one car increased in Nagoya between 1981 and 1991. Between 1991 and 2001, the number of households owning at least one car remained at the same level, but the number of households owning more than one car increased. Motorcycles are much more commonly owned in Bangkok and Kuala Lumpur.

***** Figure 2 *****

Trend data on vehicle ownership is difficult to find, but there is available data on a national basis. (That is, the data is not on the metropolitan level but on the national level.) Concerning car ownership per 1,000 people, the figure has been increasing in the three countries: 33 cars in 1999 and 84 cars in 2003 in Thailand; 170 cars in 1999 and 219 cars in 2004 in Malaysia; and 201 cars in 1981 and 412 cars in 2001 in Japan (ASEAN-Japan Centre undated, AIRIA undated, PSOSJ undated a). Concerning motorcycle ownership per 1,000 people, the figure is increasing in Thailand and Malaysia, while it is decreasing in Japan; 141 motorcycles in 1994 and 206 motorcycles in 2004 in Thailand; 198 motorcycles in 1994 and 268 motorcycles in 2004 in Malaysia; and 127 motorcycles in 1994 and 104 motorcycles in 2004 in Japan (ASEAN-Japan Centre undated).

The age distribution of the population of Japan has been changing like in other developed countries and is also very different from that in developing countries. The elderly

population (65 years old and over) increased from 9.34% in 1981 to 17.97% in 2001 (PSOSJ undated a, b). This may cause significant changes to household characteristics in Japan.

Tables 2 and 3 are descriptive statistics for the explanatory variables used in the mode choice models and the BOP models, respectively. Table 2 lists the statistics for trip makers. Travel time and travel cost by mode m are calculated by selecting individuals who chose mode m ; or selecting individuals whose choice set includes mode m . (Note that mode m is considered not to be available in the origin-destination where no trip by mode m is recorded by the survey.) The authors have travel cost data for Nagoya for 1991 and 2001. The travel costs for rail and bus in 1981 are calculated from the data for 1991, but take into consideration the changes in the starting fare and the fare for travelling 10 km. The travel costs for car and motorcycle in 1981 are calculated from the data for 1991, but take into consideration the changes in the petrol price and the petrol mileage. The travel time and cost means and standard deviations must be dealt with carefully since these resulted in different values by the two methods, and a detailed examination is bypassed here. The Bangkok data includes travel cost information, but the Kuala Lumpur data does not. In all of the datasets, majority of the trip makers are males. The Nagoya datasets show a decreasing trend for male trip makers between 1981 and 2001, suggesting that females may have become more active. In Nagoya, the number of trips made by people aged 65 years or older increased each year, suggesting that older people may have become more active and/or that society has aged. This $\text{Age} \geq 65$ dummy is included to express the travel behaviours of “elderly citizens” but is not included for Bangkok and Kuala Lumpur, since the age distribution in a population differs in developing and developed countries. The percentage of Nagoya city residents decreased between 1981 and 2001, suggesting that the population might have become suburbanised. The city dummy is not included for Kuala Lumpur since the surveyed area as a whole can be considered a central city. The slightly smaller student mean and slightly larger mean for the

number of people aged 20 years or older in 2001 may suggest a low birthrate. For Bangkok, the larger student mean and smaller mean for the number of people aged 20 years or older may suggest that the population is younger. The student dummy is not included in the mode choice model for Kuala Lumpur because it is alternative-specific to rail, which is not available there.

***** Table 2 *****

Table 3 shows the statistics for household information. All of the variables categorised by age and gender show a decreasing trend in Nagoya, suggesting that household sizes are decreasing. The number of household members aged 20 – 65 and 20 – 29 is greater in Bangkok and Kuala Lumpur than in Nagoya.

***** Table 3 *****

5. Empirical findings

5.1. Mode choice models

Estimation results obtained with mode choice models using revealed preference data are presented in Table 4. The choice set includes rail, bus, car, and motorcycle, but Kuala Lumpur does not have rail. The line-haul modes obtained from the survey are modelled. The Bangkok and Kuala Lumpur models are estimated, while the Nagoya 1981, 1991, and 2001 models are updated to include travel cost information from an earlier study by the authors (Sanko et al. 2009). In the Nagoya models, 15,000 samples are drawn randomly to save computation time. An investigation into the historical trend of estimates in Nagoya can be found in Sanko et al. (2009). In order to make comparison easier, models are basically

estimated with the same set of explanatory variables and some of the variables not estimated as significant are retained. Driver's license information is not included because some researchers do not include driver's license ownership since it is closely related to vehicle ownership and the two are regarded as endogenous to some extent. Female and student dummies are excluded in the Kuala Lumpur model since the choice set does not include rail. Based on the reasons described in the previous section, travel cost and the $\text{Age} \geq 65$ dummy are not included for some of the cities concerned. Moreover, the city dummy is not included for the Kuala Lumpur model, and this effect can be included in the constant.

***** Table 4 *****

The adjusted ρ^2 is low for Bangkok. However, the Bangkok model is retained, since comparing models with the same set of explanatory variables has value. One possible reason for the lower goodness-of-fit in the Bangkok model is the exclusion of the taxi alternative and some explanatory variables. Dissanayake et al. (2012) developed an MNL model that takes into account the taxi alternative and a different set of explanatory variables and reported a higher goodness-of-fit with their dataset. A visual comparison of the models suggests that there is very little difference in their respective parameter estimates. All parameter estimates for level of service and socio-economic variables have the same sign across the five models, with the exception of the city and the student dummies. Travel time and travel cost have significant negative effects on all modes, as expected.

Three socio-economic variables are found to have effects on car and motorcycle usage. The $\text{Age} \geq 20$ and male dummies have significant positive effects. Although the legal age for driving cars and motorcycles differs in each country, usually it is in the late teens. (For example, the legal age for driving cars is 18 years and for driving motorcycles is 16 or 18

years old (depending on the size of the motorcycle) in Japan; however, the Age ≥ 20 dummy is used since the age information is given as categorical data in Nagoya 2001.) This legal system and the higher income of adults promote car and motorcycle usage. The attractiveness of cars and motorcycles for males and their higher income levels can explain the presence of the male dummy. A city dummy has a negative effect on car usage in Nagoya, suggesting that people hesitate to drive in very crowded cities. Also, in central areas, public transport accessibility might be high, which might induce an inclination toward public transport. A possible reason for the insignificant city dummy estimate in Bangkok is congestion not only inside the city but also outside.

The other three socio-economic variables are found to have effects on public transport usage. The female dummy has a negative effect on rail usage, suggesting that females are less likely to travel by rail. (This does not mean that females are reluctant to travel by rail, but that men are more likely to travel by rail, probably for commuting purposes.) Taking into account the positive coefficient estimate of the male dummy for car and motorcycle, the result suggests that females have a higher probability of choosing a bus than males. Moreover, the student dummy has a significant positive impact on rail usage in Nagoya, but has a negative impact in Bangkok. The dense railway network in Nagoya attracts students to rail usage. However, the poor railway network in Bangkok is not attractive to them. In addition, the Age ≥ 65 dummy has a significant positive impact on bus usage in Nagoya. Shorter access and egress times to and from bus stops and free bus tickets, which have been offered to Nagoya city residents aged 65 years and over by the Nagoya city government since 1973, explain the strong relationship between elderly travel and bus use.

Next, accessibility measures are discussed based on the model estimation results. The model specification in Table 4 suggests that the accessibility measures depend on travel time, travel cost, and demographic characteristics. The BOP models can consider the effects of

these factors by including accessibility measures on vehicle ownership. Of course, accessibility weightings (w_{RBz} , w_{RBCz} , and w_{RBMcz}) are also found to have an impact. As people age, the number of members in each category changes, so accessibility measures also change.

5.2. Bivariate ordered probit models

In total three BOP models are estimated for each case study city and time point⁸, taking into account a combination of correlation and/or interaction estimates.⁹ In order to make comparison easier, models are estimated with the same set of explanatory variables and some of the variables not estimated as significant are retained. To save computation time, 3,000 samples are drawn randomly. Four categories are set for car ownership (0, 1, 2, and 3+ cars) and three for motorcycle ownership (0, 1, and 2+ motorcycles) based on the information obtained in the databases (see Figure 2). The Bangkok and Kuala Lumpur estimate models are new, while the Nagoya 1981, 1991, and 2001 estimate models, already developed by the authors (Sanko et al. 2009), were updated to influence the accessibility measures calculated by the mode choice models in this study. An investigation of the historical trend in estimates for Nagoya also can be found in Sanko et al. (2009). The three models for each case are explained in footnote 9. Concerning the interaction term, the number of motorcycles owned is included in the function of car ownership since this has given better results than including the number of cars owned in the motorcycle ownership function in Bangkok and Kuala Lumpur. Table 5 shows the estimates when estimating correlation but not interaction. Compared with

⁸ 3 models for Bangkok, 3 for Kuala Lumpur, 3 for Nagoya 1981, 3 for Nagoya 1991, and 3 for Nagoya 2001 (in total, 15 models).

⁹ The three models for each case are: estimating neither correlation nor interaction; estimating correlation but not interaction; and estimating both correlation and interaction.

models estimating neither correlation nor interaction, the likelihood ratio test (L1 in Table 5) indicates that these two kinds of models are significantly different in three out of five cases. Compared with models with both correlation and interaction, the likelihood ratio test (L2 in Table 5) indicates that inclusion of the interaction term does not lead to model improvement in four out of five cases. On the other hand, in Kuala Lumpur, the inclusion of interaction has led to significant model improvement. Similar ownership levels of cars and motorcycles (see Figure 2) suggest that there can be a direct interaction between car and motorcycle ownership. (Based on the judgment of L1 and L2 in Table 5, the models estimating correlation but not interaction are adopted.)

***** Table 5 *****

The choice of explanatory variables was guided by findings from previous research and intuitive arguments: (1) accessibility measures (see Subsection 3.1); (2) number of workers in the household; and (3) number of household members based on gender and age information. For car ownership, the number of males and females aged between 20 and 65 years and those aged less than 20 or over 65 are employed, considering the legal age for driving and lifestyle. For motorcycle ownership, the number of males and females aged between 20 and 29 years and those aged less than 20 or over 29 are adopted, considering the attraction younger people have towards motorcycles. The results obtained based on this selection of variables provide the best model among those estimated. The income variable is not included in all of the databases due to lack of information. Driver's license information is not included for the same reason as described in the section on mode choice models.

First, the result of estimating the car ownership function is examined. The additional accessibility of car availability is estimated to be positive (sometimes significantly and

sometimes insignificantly) as expected. Most of the socio-economic characteristics are estimated as positive and significant. The larger the household size, the larger the demand for cars.

Next, the result of estimating the motorcycle ownership function is examined. The additional accessibility of motorcycle availability is estimated to be positive (sometimes significantly and sometimes insignificantly) as expected. Socio-economic characteristics are estimated to be positive and significant, or insignificant. The larger the household size, the larger the demand for motorcycles. The estimates for females younger than 20 or older than 29 are insignificant in all models but retained in order to explicitly consider the differences between males/females and car/motorcycle ownership.

The additional accessibility of car availability has a more significant effect than that of motorcycle availability, except in Kuala Lumpur, where neither has a significant effect. Households tend to own cars more significantly when owning a car provides additional accessibility than to own motorcycles when owning motorcycles brings additional accessibility.

The worker variables are more significantly estimated for the car ownership function than for motorcycle ownership function in Kuala Lumpur and Nagoya, suggesting that workers with income tend to own cars. However, the opposite result is obtained in Bangkok. The relatively smaller income level in Bangkok shows that income is not high enough to purchase cars.

The correlation is estimated to be negative in Bangkok and Kuala Lumpur, while it is positive in Nagoya. This suggests that unobserved factors that influence car ownership are negatively (positively) correlated with unobserved factors that influence motorcycle ownership in Bangkok and Kuala Lumpur (Nagoya). One interpretation of this is that different factors exist related to both car and motorcycle ownership, such as a propensity to

own either a car or a motorcycle, the different transport environmental factors that are not completely captured by the accessibility measures, and the desire for personal convenience in Bangkok and Kuala Lumpur. One interpretation of this as it relates to Nagoya is that common factors exist related to both car and motorcycle ownership, such as a propensity to own both cars and motorcycles, common transport environmental factors that are not completely captured by the accessibility measures, and the desire for personal convenience. That is, there is a substitutability (complementary) relationship between car and motorcycle ownership behaviour in Bangkok and Kuala Lumpur (Nagoya). The adjusted ρ^2 (base = $L(c)$) is not very low relative to that reported by Senbil et al. (2007). In addition, the adjusted ρ^2 (base = $L(0)$) is higher. Taking into account the uneven distribution of vehicle ownership (see Figure 2), the constants and threshold values can explain a large part of ownership behaviours, with the remaining behaviours explained by explanatory variables. This is one advantage that ordered models have over count models, which assume even intervals.

Table 6 lists the elasticities calculated for each variable. Among the number of members in a household categorised by gender and age, the elasticities are generally higher for Male 20 – 65 and Female 20 – 65. In the same kind of category defined by gender and age, motorcycle ownership generally has the two highest elasticities for Male 20 – 29 and males younger than 20 or older than 29. The elasticities for worker are relatively low. The elasticities for accessibility are relatively high for car ownership and relatively low for motorcycle ownership.

***** Table 6 *****

5.3. Assessment of spatial transferability

Spatial transferability as applied to the areas of Bangkok and Kuala Lumpur is examined.

Vehicle ownership in Bangkok is predicted using the Kuala Lumpur and three Nagoya models, while vehicle ownership in Kuala Lumpur is predicted using the Bangkok and three Nagoya models.

The adopted index is expressed by Eq. (9). The weights (w_{RBz} , w_{RBCz} , and $w_{RBM Cz}$) are the weights in the application context ($t2$ in Eq. (9)) rather than in the estimation context ($t1$ in Eq. (9)).

Tables 7 and 8 show the results. Better transferability of the Kuala Lumpur and Bangkok models as compared to the Nagoya models supports the theory that models estimated in similar contexts (developing countries) will have better transferability. Better transferability of the older models for Nagoya supports the theory that similar contexts (before motorisation in older time points) will also have better transferability. This is naturally expected, since the contexts (population, incomes, behaviours, tastes, and so on) are likely to be more similar between two cities in developing countries, and between cities in developing countries and cities decades ago in developed countries. The cost data in Nagoya 1981 is not exact, but of the three Nagoya models, Nagoya 1981 has the best transferability. The mode choice model for Bangkok includes the travel cost, but that for Kuala Lumpur does not. However, they have the best transferability between them.

***** Table 7 *****

***** Table 8 *****

6. Conclusions

In this study, BOP models are developed and analysed with the purpose of describing and predicting household car and motorcycle ownership behaviour in Bangkok and Kuala Lumpur as compared to Nagoya. Mode choice models are first estimated to calculate

accessibility measures, and then the car and motorcycle ownership models are estimated using bivariate ordered probit models, with accessibility measures included as explanatory variables. Especially, comparison of behaviours between developing countries and developed countries provided some interesting findings.

First, both accessibility measures are estimated as positive, suggesting that accessibility and vehicle ownership are positively related. The estimates are more significant in the function for car ownership except for Kuala Lumpur, where the estimates are insignificant. Second, the correlation is estimated to be negative in Bangkok and Kuala Lumpur, while it is positive in Nagoya. This suggests that the correlation means that unobserved factors that influence car ownership are negatively (positively) correlated with unobserved factors that influence motorcycle ownership in Bangkok and Kuala Lumpur (Nagoya). One interpretation of this is that different factors exist related to both car and motorcycle ownership, such as a propensity to own either a car or a motorcycle, the different transport environmental factors that are not completely captured by the accessibility measures, and the desire for personal convenience in Bangkok and Kuala Lumpur. In Nagoya, one interpretation of this is that common factors exist related to both car and motorcycle ownership, such as a propensity to own both a car and a motorcycle, the common transport environmental factors that are not completely captured by the accessibility measures, and the desire for personal convenience. In other words, a substitutability (complementary) relationship between car and motorcycle ownership behaviour exists in Bangkok and Kuala Lumpur (Nagoya). Third, the prediction of ownership behaviour in Bangkok and Kuala Lumpur is better when using models estimated for developing countries than those for Nagoya; that is, they have better transferability. Also, the Nagoya models for older time points have better transferability. Vehicle ownership behaviours in Bangkok and Kuala Lumpur are similar and quite distinct from Nagoya, while vehicle ownership behaviours for

older time points in Nagoya are similar to those in Bangkok and Kuala Lumpur.

The implications of the findings are summarised here. Transferability is analysed in this study in order to determine which model offers better transferability. First, the estimation context and application context must be similar. When predicting ownership behaviours in developing countries, models that are estimated using data collected in developing countries should be adopted. Income levels might be a criterion for selecting a similar context. The smaller income levels in Nagoya at older time points can explain the similarities with the developing countries. Although the number of workers is included in the model, income levels per worker vary. Incorporating income into the ownership models is one idea that has already been examined in other studies. (The authors could not incorporate income because it is not available for all cases.) Another idea is to estimate a model using multiple data sources. For example, when predicting ownership behaviours in Kuala Lumpur, estimate a model using data in Nagoya 1981, 1991, and 2001, and Bangkok and include a variable that expresses income level, such as gross domestic product per capita.

Among variables that the authors adopted for the BOP models, the socio-economic variables are difficult to manipulate. Only variables that the policy planners can manipulate are additional accessibility measures. Additional accessibility measures can explain ownership behaviours more than accessibility by public transport (see footnote 5). When policy planners control car- and motorcycle-owning behaviours, they must consider accessibility by both public transport and car/motorcycle. Accessibility measures actually have relatively high elasticities for car ownership. Making public transport services better and private transport services worse decreases car ownership levels. As mentioned in Subsection 5.1, accessibility measures are influenced by travel time, travel cost, and demographic characteristics. Hence, it is useful to increase the travel time and travel cost for private transport and decrease those for public transport. Relocation of the residence has an impact

on additional accessibility of car availability. In Nagoya 1981, relocation of the residence from outside the city to inside the city is equivalent to $0.87/1.82 \times 60$, or a 29-minute increase in car travel time, and to $0.87/2.40 \times 1,000$, or a 363-JPY increase in car cost (see Table 4). Another implication is a change in the household characteristics. As people age, ownership behaviours change. For example, imagine a household with a 19-year-old male. A year later, the male becomes 20 years old. In Nagoya 2001, estimates for Male 20 – 65 are greater than those for male aged less than 20 or over 65 by 0.37, suggesting that the household is likely to own more cars (see Table 5). Moreover, this also affects the accessibility measures, since Age ≥ 20 dummy is included in the mode choice models. The worsening accessibility measures for those aged over 19 has value by imposing higher cost for them. In other words, a concession for those travelling with aged less than 20 could be justified.

Finally, a number of subjects for future studies are recommended. One potential area for research is estimating count car and motorcycle ownership models and comparing them to ordered models. In this study, the same explanatory variables are used for the purposes of comparison, but estimating the best model in each case and then comparing them may reveal additional insights.

The authors conclude that, based on the transferability test, vehicle ownership behaviours at older time points in Nagoya are closer to those in Bangkok and Kuala Lumpur. This implies that vehicle ownership behaviour in Nagoya is a few decades ahead of that in Bangkok and Kuala Lumpur as a result of advancing motorisation. Many factors affect motorisation, such as the global economy, energy and fuel availability, politics, wars, and so on. These factors also must be incorporated into the analysis.

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Table 1
Brief description of surveys.

	Bangkok	Kuala Lumpur	Nagoya 1981	Nagoya 1991	Nagoya 2001
Survey period	1995/96	03/1997-02/1999	1981	1991	2001
Population (million) ^a	13 (in 2001)	3.77 (in 1997)	7.79 ^d	8.10 ^d	9.04 ^d
Survey area (km ²)	7,758	500	5,656 ^{b,d}	5,173 ^{b,d}	6,696 ^{b,d}
Population density (persons/km ²)	4,028 ^f	5,761 ^g	6,377 ^e	6,615 ^e	6,670 ^e
Number of households surveyed	7,657	6,235	102,266	81,178	97,543
Number of traffic zones	505	244	341 ^c	341 ^c	341 ^c
Survey conducted by	Urban Transport Database and Model Development (UTDM) Project (UTDM 1998); Bangkok Environmental Improvement Project (BEIP) (Environmental Atlas 1997)	Japan International Cooperation Agency (JICA); Strategies for Managing Urban Transport in Kuala Lumpur – SMURT-KL” (JICA 1999b)	Japanese government, Nagoya city, and Aichi, Gifu, and Mie prefectures	Japanese government, Nagoya city, and Aichi, Gifu, and Mie prefectures	Japanese government, Nagoya city, and Aichi, Gifu, and Mie prefectures
Survey region	Bangkok Metropolitan Area (BMA) and five adjacent provinces of Pathum Thani, Nonthaburi, Nakorn Pathom, Samut Sakorn, and Samut Prakan	Klang Valley Region (the federal territory of Kuala Lumpur and Selangor state)	Nagoya city and parts of the surrounding prefectures of Aichi, Gifu, and Mie	Nagoya city and parts of the surrounding prefectures of Aichi, Gifu, and Mie	Nagoya city and parts of the surrounding prefectures of Aichi, Gifu, and Mie

^a Population includes all people for Bangkok and Kuala Lumpur, while it consists of people aged 5 years old and over for Nagoya.

^b Survey area of 1971 Nagoya survey is 4,096 km². (See footnote 7.)

^c Zones in the area of Nagoya 1971 survey. This paper analyses the data collected in the Nagoya 1971 survey region. (See footnote 7.)

^d Source: CTSTKK (2003).

^e Source: City of Nagoya (undated). Population density of Nagoya city (only).

^f Source: Population and Housing Census 2000 (undated). Population density of Bangkok city (only).

^g Source: JICA (1999a). Population density of Kuala Lumpur city (only).

Table 2

Descriptive statistics for the variables used for the mode choice models.

	Bangkok		Kuala Lumpur		Nagoya 1981		Nagoya 1991		Nagoya 2001	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Travel time (Rail) [hr]	1.47 (1.49)	0.66 (0.57)	-- --	-- --	0.866 (0.789)	0.322 (0.329)	0.843 (0.775)	0.316 (0.305)	0.810 (0.743)	0.297 (0.292)
Travel time (Bus) [hr]	0.974 (0.982)	0.476 (0.497)	0.594 (0.635)	0.116 (0.128)	0.655 (0.637)	0.244 (0.241)	0.637 (0.602)	0.241 (0.245)	0.654 (0.631)	0.246 (0.251)
Travel time (Car) [hr]	0.806 (0.759)	0.424 (0.420)	0.790 (0.775)	0.233 (0.223)	0.405 (0.456)	0.224 (0.269)	0.421 (0.476)	0.219 (0.267)	0.387 (0.439)	0.213 (0.265)
Travel time (MC) ^a [hr]	0.505 (0.512)	0.277 (0.265)	0.540 (0.553)	0.139 (0.167)	0.314 (0.310)	0.176 (0.177)	0.345 (0.330)	0.203 (0.220)	0.345 (0.302)	0.190 (0.158)
Travel cost (Rail) ^c	0.111 (0.116)	0.107 (0.103)	-- --	-- --	0.243 (0.195)	0.123 (0.109)	0.371 (0.293)	0.192 (0.167)	0.310 (0.276)	0.140 (0.120)
Travel cost (Bus) ^c	0.0562 (0.0579)	0.0506 (0.0510)	-- --	-- --	0.137 (0.143)	0.086 (0.097)	0.202 (0.203)	0.113 (0.111)	0.302 (0.352)	0.228 (0.368)
Travel cost (Car) ^c	0.154 (0.145)	0.135 (0.131)	-- --	-- --	0.180 (0.212)	0.189 (0.237)	0.135 (0.164)	0.140 (0.192)	0.172 (0.208)	0.168 (0.214)
Travel cost (MC) ^{a,c}	0.0810 (0.0822)	0.0457 (0.0435)	-- --	-- --	0.139 (0.126)	0.159 (0.097)	0.110 (0.0971)	0.094 (0.0670)	0.160 (0.125)	0.133 (0.086)
Male dummy	0.572	0.495	0.742	0.438	0.676	0.468	0.594	0.491	0.557	0.497
Age $\geq$ 65 dummy	--	--	--	--	0.0283	0.1659	0.0407	0.1975	0.0992	0.2989
City dummy ^b	0.465	0.499	--	--	0.320	0.466	0.312	0.463	0.309	0.462
Student dummy	0.258	0.437	--	--	0.114	0.318	0.117	0.322	0.0985	0.2980
Age $\geq$ 20 dummy	0.744	0.436	0.877	0.328	0.884	0.321	0.885	0.319	0.914	0.280

^a MC denotes motorcycle.^b Central city resident dummy. Bangkok and Nagoya city resident dummy for Bangkok and Nagoya models.^c Unit is 100 THB and 1,000 JPY in Bangkok and Nagoya, respectively.

Note: For travel time and travel cost of each mode, figures without parentheses are calculated using individuals who chose that mode, and those within parentheses are calculated using individuals whose choice set includes that mode.

Table 3

Descriptive statistics for the variables used for BOP models.

	Bangkok		Kuala Lumpur		Nagoya 1981		Nagoya 1991		Nagoya 2001	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Male 20 – 65 (yrs old) ^{a,c}	1.13	0.70	1.29	0.84	1.07	0.76	0.980	0.642	0.860	0.673
Male – 19, 66 – (yrs old) ^{a,c}	0.431	0.683	0.462	0.738	0.579	0.816	0.472	0.713	0.439	0.657
Female 20 – 65 (yrs old) ^{a,c}	1.24	0.74	1.17	0.75	1.10	0.78	0.997	0.657	0.890	0.680
Female – 19, 66 – (yrs old) ^{a,c}	0.464	0.709	0.445	0.733	0.593	0.833	0.512	0.733	0.481	0.674
Male 20 – 29 (yrs old) ^a	0.356	0.612	0.431	0.777	0.234	0.475	0.222	0.460	0.181	0.427
Male – 19, 30 – (yrs old) ^a	1.21	0.93	1.32	0.96	1.41	1.18	1.23	0.93	1.12	0.84
Female 20 – 29 (yrs old) ^a	0.417	0.614	0.396	0.653	0.246	0.479	0.227	0.463	0.184	0.430
Female – 19, 30 – (yrs old) ^a	1.29	1.03	1.22	1.02	1.45	1.24	1.28	0.97	1.19	0.86
Worker ^a	1.85	0.96	1.76	1.05	1.61	1.17	1.58	1.03	1.37	1.02
WAT ^b	-0.109	0.045	-0.143	0.006	-2.46	0.42	-2.64	0.49	-2.95	0.56
WAAC ^b	0.483	0.187	3.21	0.82	1.37	0.60	1.70	0.71	2.00	0.84
WAAMC ^b	0.346	0.192	2.67	0.73	0.191	0.145	0.156	0.131	0.135	0.121

^a number of members in the household^b averaged over household members^c Following is applied to Nagoya 2001, since the age information is only available in a categorical data.

“Male 20 – 65” will be “Male 20 – 64”.

“Female 20 – 65” will be “Female 20 – 64”.

“Male – 19, 66 –” will be “Male – 19, 65 –”.

“Female – 19, 66 –” will be “Female – 19, 65 –”.

Table 4

Estimates of mode choice models.

Variable ^a	Bangkok		Kuala Lumpur		Nagoya 1981		Nagoya 1991		Nagoya 2001	
	Est.	<i>t</i> -stat.	Est.	<i>t</i> -stat.	Est.	<i>t</i> -stat.	Est.	<i>t</i> -stat.	Est.	<i>t</i> -stat.
Constant (R)	0	--	--	--	0	--	0	--	0	--
Constant (B)	0.05	0.2	0	--	-1.09	-17.0	-1.55	-19.2	-1.18	-12.3
Constant (C)	-1.50	-6.3	-0.92	-12.3	-1.77	-16.3	-1.42	-11.2	-0.34	-2.2
Constant (MC)	-1.73	-7.3	-1.63	-21.1	-4.41	-37.8	-4.31	-31.8	-3.62	-22.1
Travel time [60 min]	-0.15	-3.5	-0.24	-2.0	-1.82	-19.6	-1.87	-22.2	-2.08	-19.7
Travel cost [100 THB, 1,000 JPY] ^c	-0.46	-2.9	--	--	-2.40	-19.1	-1.60	-11.3	-2.82	-23.5
Male dummy (C, MC)	0.72	19.0	0.95	10.3	1.85	25.9	1.49	16.9	0.91	8.8
Age ≥ 65 dummy (B)	--	--	--	--	1.72	12.2	1.82	14.2	1.25	11.0
Female dummy (R)	-0.53	-1.7	--	--	-0.70	-8.8	-0.77	-8.1	-0.33	-3.0
City dummy (C) ^b	0.01	0.2	--	--	-0.87	-20.7	-0.85	-20.0	-1.09	-24.1
Student dummy (R)	-0.35	-0.9	--	--	0.73	9.3	0.96	11.1	1.03	9.6
Age ≥ 20 dummy (C, MC)	1.18	26.7	4.29	40.7	1.42	18.8	1.26	14.7	0.94	8.6
<i>Summary statistics</i>										
N	13,882		12,667		15,000		15,000		15,000	
L (β)	-11,429.3		-9,226.7		-10,078.3		-9,187.7		-7,891.3	
L (0)	-12,249.1		-13,434.0		-15,738.5		-15,140.8		-14,730.6	
Adjusted ρ ²	0.066		0.313		0.359		0.392		0.464	

0 in Est. column indicates a constant term set to zero.

-- in Est. and *t*-stat. indicates parameter not estimated and *t*-stat. not calculated, respectively.^a R, B, C, and MC in parentheses denote rail, bus, car, and motorcycle alternative specific. No letter after variable means generic.^b Central city resident dummy. Bangkok and Nagoya city resident dummy for Bangkok and Nagoya models.^c 100 THB in Bangkok; 1,000 JPY in Nagoya.

Table 5

Estimates of bivariate ordered probit models.

Variable	Bangkok		Kuala Lumpur		Nagoya 1981		Nagoya 1991		Nagoya 2001	
	Est.	t-stat.	Est.	t-stat.	Est.	t-stat.	Est.	t-stat.	Est.	t-stat.
<i>Car ownership</i>										
Constant term	-1.87	-18.0	-0.46	-2.4	-0.43	-6.8	-1.50	-19.4	-1.42	-19.0
Socio-economic characteristics										
Male 20 – 65 (yrs old) ^{a,c}	0.22	5.5	0.18	6.2	0.38	11.2	0.84	22.3	0.80	19.5
Male – 19, 66 – (yrs old) ^{a,c}	0.16	4.9	0.11	2.7	0.09	3.7	0.23	7.4	0.43	12.4
Female 20 – 65 (yrs old) ^{a,c}	0.22	6.0	0.17	5.7	0.07	2.1	0.64	16.8	0.69	18.1
Female – 19, 66 – (yrs old) ^{a,c}	0.26	7.6	0.07	1.7	0.07	2.6	0.30	10.0	0.30	9.5
Worker ^a	0.04	1.5	0.10	3.7	0.16	6.3	0.29	10.1	0.28	8.9
Accessibility measure										
WAAC ^b	1.41	9.3	0.03	0.5	0.26	6.7	0.41	12.5	0.43	16.2
Threshold values										
One and two cars	1.21	31.1	1.44	44.0	1.60	47.7	1.82	42.5	1.64	39.8
Two and three cars	2.00	27.7	2.33	42.9	2.43	54.3	3.14	57.5	3.17	58.6
<i>Motorcycle ownership</i>										
Constant term	-1.13	-12.8	-0.47	-2.9	-1.48	-21.2	-1.56	-20.3	-1.91	-22.7
Socio-economic characteristics										
Male 20 – 29 (yrs old) ^a	0.32	7.8	0.43	14.3	0.23	4.0	0.44	7.8	0.38	5.4
Male – 19, 30 – (yrs old) ^a	0.17	5.7	0.17	5.6	0.13	4.6	0.20	5.9	0.20	4.1
Female 20 – 29 (yrs old) ^a	0.02	0.4	-0.07	-1.9	0.02	0.4	0.15	2.6	0.06	0.8
Female – 19, 30 – (yrs old) ^a	-0.04	-1.5	-0.02	-0.8	0.00	0.2	0.03	0.9	0.03	0.9
Worker ^a	0.11	3.8	0.06	2.4	0.13	3.9	0.15	4.4	0.14	3.8
Accessibility measure										
WAAMC ^b	0.37	2.9	0.06	1.3	0.79	4.2	0.49	2.6	0.75	2.9
Threshold value										
One and two motorcycles	1.50	27.3	1.57	39.7	1.14	23.1	1.02	23.9	1.15	16.1
<i>Correlation</i>										
Correlation	-0.35	-13.7	-0.21	-9.0	0.17	6.4	0.05	2.0	0.01	0.4
<i>Summary statistics</i>										
N	3,000		3,000		3,000		3,000		3,000	
L(β)	-4,373.50		-5,688.17		-4,800.93		-4,594.32		-3,931.88	
L(c)	-4,664.91		-5,981.02		-5,250.86		-5,738.36		-5,096.07	
L(0)	-7,454.72		-7,454.72		-7,454.72		-7,454.72		-7,454.72	
Adjusted ρ^2 (base = L(c))	0.0597		0.0468		0.0832		0.1971		0.2259	
Adjusted ρ^2 (base = L(0))	0.4109		0.2346		0.3536		0.3813		0.4702	
L1 ^d	143.19		74.12		38.61		3.55		0.17	
L2 ^e	2.89		43.85		0.24		2.54		0.10	

^a number of members in the household^b averaged over household members^c Following is applied to Nagoya 2001, since the age information is only available categorically.

“Male 20 – 65” will be “Male 20 – 64”.

“Female 20 – 65” will be “Female 20 – 64”.

“Male – 19, 66 –” will be “Male – 19, 65 –”.

“Female – 19, 66 –” will be “Female – 19, 65 –”.

^d Likelihood ratio test compared to models estimating neither correlation nor interaction. $\chi^2(.05) = 3.84$. (d.f. = 1)^e Likelihood ratio test compared to models estimating both correlation and interaction. $\chi^2(.05) = 3.84$. (d.f. = 1)

Table 6

Elasticities of vehicle ownership models.

	Bangkok				Kuala Lumpur				Nagoya 1981				Nagoya 1991				Nagoya 2001			
	E_c^0	E_c^1	E_c^2	E_c^{3+}	E_c^0	E_c^1	E_c^2	E_c^{3+}	E_c^0	E_c^1	E_c^2	E_c^{3+}	E_c^0	E_c^1	E_c^2	E_c^{3+}	E_c^0	E_c^1	E_c^2	E_c^{3+}
Male 20 – 65 (yrs old) ^{a,c}	-0.13	0.19	0.49	0.79	-0.18	0.05	0.29	0.53	-0.42	-0.03	0.51	1.14	-0.81	-0.31	1.16	5.12	-0.79	-0.34	0.90	4.72
Male – 19, 66 – (yrs old) ^{a,c}	-0.10	0.14	0.35	0.54	-0.11	0.03	0.17	0.29	-0.11	0.00	0.11	0.20	-0.35	-0.09	0.23	0.63	-0.57	-0.20	0.41	1.55
Female 20 – 65 (yrs old) ^{a,c}	-0.13	0.19	0.49	0.79	-0.16	0.05	0.27	0.48	-0.08	0.00	0.08	0.15	-0.71	-0.24	0.81	3.02	-0.74	-0.30	0.75	3.53
Female – 19, 66 – (yrs old) ^{a,c}	-0.15	0.22	0.59	0.97	-0.07	0.02	0.11	0.19	-0.08	0.00	0.08	0.15	-0.44	-0.12	0.32	0.93	-0.44	-0.14	0.27	0.93
Worker ^a	-0.03	0.04	0.09	0.13	-0.09	0.03	0.15	0.26	-0.20	0.00	0.20	0.39	-0.43	-0.11	0.31	0.88	-0.42	-0.14	0.26	0.86
WAAC ^b	-0.42	0.56	1.25	1.82	-0.09	0.03	0.13	0.22	-0.51	-0.02	0.39	0.72	-1.45	-0.38	0.55	1.45	-1.83	-0.59	0.55	1.76
	E_{mc}^0	E_{mc}^1	E_{mc}^{2+}		E_{mc}^0	E_{mc}^1	E_{mc}^{2+}		E_{mc}^0	E_{mc}^1	E_{mc}^{2+}		E_{mc}^0	E_{mc}^1	E_{mc}^{2+}		E_{mc}^0	E_{mc}^1	E_{mc}^{2+}	
Male 20 – 29 (yrs old) ^a	-0.17	0.35	1.06		-0.36	0.18	1.11		-0.09	0.31	0.68		-0.19	0.59	1.49		-0.10	0.78	1.69	
Male – 19, 30 – (yrs old) ^a	-0.09	0.18	0.48		-0.15	0.08	0.36		-0.05	0.18	0.37		-0.08	0.25	0.53		-0.05	0.37	0.69	
Female 20 – 29 (yrs old) ^a	-0.01	0.02	0.04		0.06	-0.04	-0.12		-0.01	0.03	0.05		-0.06	0.20	0.40		-0.01	0.10	0.17	
Female – 19, 30 – (yrs old) ^a	0.02	-0.05	-0.10		0.02	-0.01	-0.05		-0.00	0.01	0.01		-0.01	0.04	0.07		-0.01	0.06	0.10	
Worker ^a	-0.06	0.12	0.29		-0.05	0.03	0.12		-0.05	0.18	0.35		-0.06	0.18	0.37		-0.03	0.26	0.47	
WAAMC ^b	-0.07	0.13	0.30		-0.14	0.08	0.29		-0.06	0.18	0.35		-0.03	0.09	0.17		-0.02	0.16	0.27	

Note: Elasticities for accessibility measures are calculated using Eq. (8a), while pseudo-elasticities for other variables are calculated using Eq. (8b). Sample means of

 $E_{x_{1hn}}^{\text{Pr}(y_{1h}=j)}$ and $E_{x_{2hn}}^{\text{Pr}(y_{2h}=k)}$ are represented by E_c^j and E_{mc}^k , respectively.^a number of members in the household^b averaged over household members^c Following is applied to Nagoya 2001, since the age information is only available categorically.

“Male 20 – 65” will be “Male 20 – 64”.

“Female 20 – 65” will be “Female 20 – 64”.

“Male – 19, 66 –” will be “Male – 19, 65 –”.

“Female – 19, 66 –” will be “Female – 19, 65 –”.

Table 7

Spatial transferability of vehicle ownership models (Bangkok).

	(a) Kuala Lumpur	(b) Nagoya 1981	(c) Nagoya 1991	(d) Nagoya 2001
<i>AE</i>	0.548	0.826	1.089	1.142

Table 8

Spatial transferability of vehicle ownership models (Kuala Lumpur).

	(a) Bangkok	(b) Nagoya 1981	(c) Nagoya 1991	(d) Nagoya 2001
<i>AE</i>	0.481	0.640	0.756	0.912

Figure 1
Modal distribution in the case study cities.

(a) Bangkok

(b) Kuala Lumpur

(c) Nagoya 1981

(d) Nagoya 1991

(e) Nagoya 2001

Figure 2

Vehicle ownership distribution in the case study cities.

Note: Cars and MCs stand for number of cars owned and number of motorcycles owned, respectively.