

Exploratory analysis of motorcycle holding time heterogeneity using a split-population duration model

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Abstract

This study integrated the samples taken in 2000 for motorcycle usage and their corresponding records registered in the Taiwan's Vehicle Registration System to observe the survival process of motorcycle ownership. The specific heterogeneity of censored observations that failed to demonstrate actual ownership status in the registration system was corrected by employing a split-population duration model with a Weibull hazard function. The results indicated that around 11% of all observations would never experience an eventual registration termination and that the hazard rates of terminating motorcycle ownership grew at a slightly increasing rate as the holding time increased. Ways of enhancing the accuracy of the motorcycle registration system and accelerating the elimination mechanisms for old motorcycles should be carefully examined.

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1. Introduction

Holding duration for private vehicles is connected not only with transportation planning and management strategies, but also with issues of environmental protection and traffic safety improvements. Automobile holding duration has been extensively studied by a lot of research (Gilbert, 1992; De Jong, 1996; Yamamoto and Kitamura, 2000). However, little has been noted about motorcycle holding time for prior studies.

The importance of motorcycles in daily transportation for many Asian countries such as Japan, Malaysia, and Taiwan is no less than automobiles. The number of motorcycles per thousand persons for Taiwan was as high as 538 and the amount of motorcycles made up around two-thirds of all of Taiwan's motor vehicles at the end of 2003 (Taiwan's Ministry of Transportation and Communications, MOTC, 2004a). In terms of the ownership rate, Taiwan takes first place worldwide. Motorcycles were not only heavily used (i.e. 5.2 days per week

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and 12.2 km per day on average); they also had substantial substitution with other transportation means (i.e. 50.5% and 28.6% of the motorcycle riders also respectively reported using passenger cars and public transit as their daily means of transportation) (MOTC, 2004b).

However, the life span of a motorcycle in Taiwan may extend to ten years or more, leading to problems with pollution emissions, energy consumption, and even traffic safety. Many studies have indicated that emissions levels may be positively correlated with the age of four-wheeled vehicles (Anilovich and Hakkert, 1996; Bin, 2003) as well as with the age of motorcycles (Lu and Lee, 2001). In addition, there is a higher likelihood of accidents with older vehicles and thus being one of the key issues in accident prevention, although this is relatively difficult to identify when compounded by drivers' behavior in traffic safety research. Therefore, it is essential to uncover the determinant factors influencing motorcycles holding duration, so that the effective interventions for eliminating old motorcycles could be developed.

An integration of the sampling survey of motorcycle usage conducted by MOTC in 2000 and the corresponding registration information for these sampled motorcycles in the Taiwan's Vehicle Registration System (VRS) was applied. Both the precise registration time for specific events and the censored time at the end of the observation could be recognized via employing the VRS records. However, around 10.2% of the samples that may actually have been terminated but not been registered in the VRS was identified by the owners' self-report survey (MOTC, 2004b). The specific heterogeneity for registration holding duration, which could inflate the average holding time, revealed that we should employ a special statistical method to formulate our problem.

A split-population duration model is specially developed to estimate and revise the survival time for a population in which some elements will never experience events eventually (Schmidt and Witte, 1989; Bando-padhaya and Jaggia, 2001). Prior transportation research that employed duration models with possible applications for a split-population method is sparse. However, a portion of observations never experiencing events, postulated in the split-population model, may elaborate on the possibility that some motorcycle owners may not alter their motorcycle registration status in the VRS, even though a specific terminating ownership event, such as a stolen vehicle or a disposal, has occurred.

Consequently, two purposes were established for this study. First, we attempted to develop an appropriate design to better catch ownership information about motorcycle holding duration. Second, a split-population duration model was applied to explore the heterogeneity of holding duration, caused by motorcycle ownership terminations that had not been accurately recorded in the VRS.

2. Research design

2.1. Definition of motorcycle holding duration

Our research design was developed through the integration of the data sampled in 2000 from the MOTC and the corresponding registration information for these sampled data from the VRS. The MOTC's sampling survey, focusing on motorcycle usage conditions, was administered through a stratified and systematic sampling method on December 15, 1999. The sample size was 10,780 and sampling error was $\pm 1\%$ under a 0.95 confidence coefficient (MOTC, 2000).

Via linking the plate number of the above sampled data to the registration records in the VRS, the VRS's motorcycle records, such as the original issue date of a licensing plate, the name of the owner, and the "transfer" or "disposal" record and its date, if any,¹ offered a basis for observing the time-to-event history of motorcycle ownership. The end of the observation period was set as February 15, 2004. As a result, the duration termination occurred if either a transfer or disposal event was identified, otherwise regarded as censored data during the more than four-year observation period (from December 15, 1999 to February 15, 2004). The research design is demonstrated in Fig. 1.

However, some of the censored holdings may actually have been terminated, but not been registered in the VRS. About 13.2% of holders, from a current large-scale sampling survey, self-reported that their motorcycles

¹ Note: "transfer" means when a motorcycle owner transfers his/her motorcycle to another owner and changes the registration record in the VRS; while "disposal" means a motorcycle owner ends his/her motorcycle registration in the VRS and, hence, the motorcycle can no longer be used on the roads.

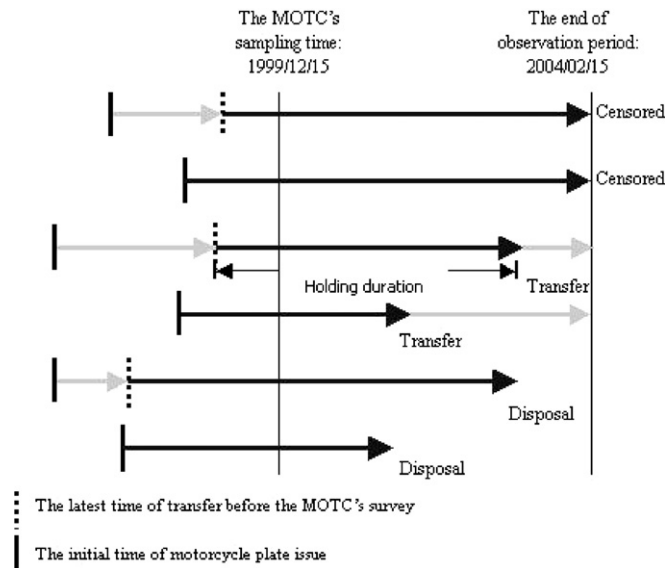


Fig. 1. Tracing and follow-up design for holding duration observation.

had been stolen or discarded; of these stolen or discarded motorcycles, 78% had not been recorded in the VRS (MOTC, 2004b). That is, around 10.2% of registered motorcycles were no longer in the possession of their registered owners; this could not be adequately demonstrated by the VRS, however.

The specific type of heterogeneity for the holding duration, which partly came from inaccurate registration records, revealed that a special statistical method for formulating this problem should be considered. Thus, to revise the specific heterogeneity of these censored data, a split-population duration model was employed to reduce any possible bias.

2.2. Independent variables and research hypotheses

Three categories of covariates, including vehicle, motorcycle usage, and aggregate socioeconomic attributes, were introduced to the duration models in this study. The notation and description of these independent variables as well as the expected association between independent variables and hazard rates are summarized in Table 1. The association assumptions on the hazard rates are individually illustrated as follows.

2.2.1. Vehicle variables

2.2.1.1. Used motorcycle. A used vehicle at purchase revealed a higher probability of being replaced sooner (De Jong, 1996; Yamamoto and Kitamura, 2000), because of the lower reliability and higher repair cost (De Jong, 1996). Similarly, the holding duration of a used motorcycle was expected to be shorter (i.e. the hazard rate of terminating ownership would be higher).

2.2.1.2. Motorcycle age. Vehicle age at purchase was also found to be positively associated with the hazard of being replaced (De Jong, 1996; Yamamoto and Kitamura, 2000). Therefore, we assumed that the older a used motorcycle at purchase, the higher the instantaneous termination of the motorcycle ownership.

2.2.1.3. Engine size. In general, motorcycles over 150 cc have a longer holding duration not only because of their higher value, but also because of their scarcity resulted from the long-standing registration prohibition in Taiwan due to the oil crisis since 1980. Since a higher engine size may represent a higher motorcycle replacement cost, we speculated that the higher the engine size was, the lower the termination hazard generated.

Table 1
Notations of independent variables and expected association on hazard rates

Variable notation	Variable description	Expected association
<i>Vehicle attributes</i>		
(a) Used motorcycle	The holder possessing a second-hand motorcycle at purchase is equal to 1 and otherwise 0	+
(b) Age of motorcycle	The value of the vehicle age of a motorcycle at purchase is counted and the value for a new motorcycle is set to be 0	+
(c) CC(1)	The engine size of a motorcycle equaling 50 cc or under is set to be 1 and otherwise 0	+
(d) CC(2)	The engine size of a motorcycle ranging from 51 cc to 150 cc is set to be 1 and otherwise 0	+
<i>Motorcycle usage attributes</i>		
(a) Maintenance costs	The log of the total year's maintenance cost of the sampled motorcycle	+
(b) Holder's age	Age of the sampled motorcycle holder	–
(c) Running mileage	Running mileage per week of the sampled motorcycle	+
(d) Household's fleet size	The sampled motorcycle holder possessing only one motorcycle and no passenger cars in his/her household is set to be 1 and otherwise 0	–
<i>Aggregate socioeconomic attributes</i>		
(a) Unemployment rate	Unemployment rate in the registration area of the sampled motorcycle in 1999	–
(b) Motorcycle density	Numbers of motorcycles per thousand persons in the registration area of the sampled motorcycle in 1999	+
(c) Passenger car density	Numbers of passenger cars per thousand persons in the registration area of the sampled motorcycle in 1999	–
(d) Engel's coefficient	Percentage of the average food-and-drink expenditure over the average consumption expenditure of the households in the registration area of the sampled motorcycle in 1999	–
(e) Consumption propensity	Percentage of the average consumption expenditure over the average disposal income of the households in the registration area of the sampled motorcycle in 1999	+

2.2.2. Motorcycle usage variables

2.2.2.1. *Maintenance costs.* A motorcycle with a higher maintenance cost was more likely to arouse its holder's intention to replace or dispose of it. Therefore, the increase of motorcycle maintenance cost was assumed to raise the hazard of ending ownership.

2.2.2.2. *Holder's age.* Older people tended to possess cars for a longer period, possibly due to the formation of stronger habits (De Jong, 1996). Vehicles used by older primary users also revealed a longer ownership period (Yamamoto and Kitamura, 2000). Therefore, younger people were hypothesized to be more likely to replace their motorcycles and thus their motorcycles had a raised termination hazard. For comparison, the age of these sampled holders was adjusted to the time the event had occurred or was censored.

2.2.2.3. *Running mileage.* Higher vehicle miles traveled showed a higher hazard for terminating vehicle ownership (De Jong, 1996; Yamamoto and Kitamura, 2000). Similarly, vehicles with higher odometer readings also revealed a higher terminating hazard (Gilbert, 1992). As expected, a higher running mileage was likely to increase attrition and risk of motorcycle damage so as to accelerate holding termination.

2.2.2.4. *Fleet size of household.* The household fleet size was negatively correlated with the holding duration of the observed vehicle (De Jong, 1996; Yamamoto and Kitamura, 2000). We set a binary variable in this study, denoting whether the sampled motorcycle was the only vehicle in the holder's household. Based on previous studies, if a motorcycle was the only vehicle in a household, the hazard rate of terminating the motorcycle's holding would be lower.

2.2.3. Aggregate socioeconomic variables

Several socioeconomic variables in terms of the Taiwan's twenty-three administrative areas for motorcycle registration were also introduced via employing the officially published socioeconomic index. These included

the unemployment rate, motorcycle density, passenger car density, Engel's coefficient, and the consumption propensity reported in these administrative areas. The socioeconomic variables for the year 1999 were employed to relate to the year that the MOTC's inventory conducted. Since these five aggregate covariates did not reveal substantial variations across the observation period, our concern over the influence of these covariates on holding duration mainly came from the variations across areas, but not across time.

2.2.3.1. Unemployment rate. Gilbert (1992) indicated that a higher unemployment rate caused a decline in the hazard for vehicle disposal. Therefore, it was assumed that a soaring jobless rate would, on average, make consumers more conservative in their consumption behavior, thus decreasing the holder's intention to replace or dispose of their motorcycles in these areas.

2.2.3.2. Motorcycle density. Areas having a high motorcycle density revealed that motorcycles were more likely to be the principal transportation mode within these areas, with, on average, a higher likelihood of intensive usage, which was assumed to lead to a higher possibility of ending motorcycle ownership.

2.2.3.3. Passenger car density. Since passenger cars may have a partial substitution effect on motorcycles, areas with a higher ownership rate of passenger cars were more likely to reduce the average usage frequency of motorcycles. Therefore, this variable was expected to have a negative influence on hazard rate.

2.2.3.4. Engel's coefficient. A higher Engel's coefficient meant that on average the households in this area spent more on food-and-drink, thus spending less on durable goods such as motorcycles. We speculated that a higher Engel's coefficient in an area discouraged the purchase of durable goods, thus extending the average holding duration of motorcycles in the area.

2.2.3.5. Consumption propensity. We speculated that the stronger the consumption propensity, the more likely the decision to replace or dispose of a motorcycle, thus positively connecting to the hazard rate for motorcycle termination.

3. Methods

Different formulations of standard parametric and semi-parametric duration models have been raised by many statistical references (Kalbfleisch and Prentice, 1980; Lawless, 1982; Allison, 1995; Le, 1997). The hazard function $h(t)$, defined as the instantaneous rate of a holder terminating his/her motorcycle holding in a very small time, is expressed as (1).

$$h(t) = \lim_{\Delta t \rightarrow 0} \frac{\Pr(t \leq T < t + \Delta t | T \geq t)}{\Delta t} = \lim_{\Delta t \rightarrow 0} \frac{\Pr(t \leq T < t + \Delta t)}{\Delta t \times \Pr(T \geq t)} = \frac{f(t)}{S(t)}, \quad \forall t \geq 0 \quad (1)$$

where $f(t)$ and $S(t)$ are the density and survivor function, respectively. According to the hypothesis about the change of the hazard rate with time, different formulations such as the exponential, Weibull, and log-logistic methods may be applied. An implicit assumption made in standard duration models is that the event will eventually occur, which in this context implies that all motorcycle holders will eventually terminate their holding in the long run. However, the holding period was obtained from the VRS records, where some holders may not have cancelled their motorcycle registration when holding had actually been terminated. Estimation errors, produced by these partially incorrect VRS records, were corrected using a split-population duration model that took into account the possibility that the event may never occur (Schmidt and Witte, 1989). The split-population model estimated the instantaneous rate of the motorcycle population that would eventually terminate, as well as the subpopulation that would never experience a termination event.

The density, survivor, and hazard functions in the duration model are denoted by $f(t; X)$, $S(t; X)$, and $h(t; X)$, respectively. The duration variable, T , denotes the length of time from the initial holding of a motorcycle to the holding termination. The independent variable X , which is conditional on these functions, can be introduced to establish a regression model. To estimate the corresponding parameters of the independent variables, the general likelihood function form is given by

$$L = \prod_{i=1}^N [f(t; X)]^{C_i} [S(t; X)]^{(1-C_i)}, \quad (2)$$

where N is number of observations and C_i is an indicator variable that equals 1 when the motorcycle holding termination occurs by time t and 0 otherwise. Therefore, the density function captures the fact that the observation experiences a motorcycle termination event by time t , whereas the survivor function catches the fact that the duration of a motorcycle holding is at least as long as the censoring point, time t .

Since the split-population duration model allows the possibility that some censored observations may never encounter a registration termination, to illustrate the split-population duration model, let U be an unobservable variable that equals 1 for those who will eventually terminate their motorcycle registration and 0 otherwise. Then

$$P(U = 1) = \delta, \quad P(U = 0) = 1 - \delta, \quad (3)$$

where δ is the “split-population parameter” that denotes the probability of eventual termination of motorcycle registration. If $\delta < 1$, then a proportion of the censored observations will never experience this termination. Therefore, a split-population may be viewed as two different parts of a survival experience. For the first part, if a holder has terminated his/her motorcycle registration, we have $T = t$ and $C_i = 1$, the appropriate density for such a holder is therefore

$$P(U = 1)f(t; X, U = 1) = \delta f(t; X, U = 1). \quad (4)$$

For the second part, a censored observation $C_i = 0$ reveals simply that ownership of the motorcycle has not been ended during the observation period; we cannot, however, identify whether this censored data will never experience that event, or whether the observation time is simply not long enough to capture the event. Thus, we may consider the following two possibilities, (a) that this motorcycle will never undergo a change in ownership registration or (b) that registration of the motorcycle would have been terminated if it had been followed for a longer time. Specifically, this censored condition can be expressed as

$$P(U = 0) + P(U = 1)P(T > t; X, U = 1) = 1 - \delta + \delta S(t; X, U = 1). \quad (5)$$

Therefore, the likelihood function for the split-population duration model consists of expressions (4) and (5) above for completed and censored durations respectively. The specific likelihood function form can be determined once the hazard function is parameterized. In this study, we speculated that the chance of a motorcycle being disposed of or transferred increased over time. As a result, a Weibull hazard function was appropriate to our question, as it possesses a flexible property that can determine the estimated model with a constant, decreasing, or increasing hazard rate.

The Weibull hazard function and survival function is respectively given by

$$h(t) = \lambda Q(\lambda t)^{Q-1}, \quad (6)$$

$$S(t) = \exp(-(\lambda t)^Q), \quad (7)$$

where $\lambda = \exp(\beta_i X_i)$, i.e. β_i is the i th estimated parameter of the i th independent variable X_i , and Q is the “shape parameter” that determines how the hazard rate is dependent with time. If $Q = 1$, the Weibull model reduces to the exponential model with a constant hazard rate. If $Q > 1$, the model demonstrates an increasing hazard rate over time; otherwise $Q < 1$ demonstrates a decreasing hazard rate.

4. Results

4.1. Descriptive statistics for holding duration

In terms of the status of motorcycle ownership at the end of the observation, two types of status were identified: censored and holding termination. Holding termination could be further divided into disposal or transfer, according to the VRS records.

Censored data made up approximately 70% (7215/10,349) of all observations during the observation spell, with the median and mean values for censored durations being greater than 8.78 years and 10.29 years respec-

Table 2
Descriptive statistics for duration of motorcycle holding

The end of observation	Number of observations	Duration descriptive statistics		
		Median	Mean	Standard deviation
Censored	7215	8.78+	10.29+	5.36
Holding termination	3134	7.52	8.75	5.58
(Disposal)	(1362)	(10.92)	(11.04)	(5.26)
(Transfer)	(1772)	(5.89)	(6.99)	(5.16)
Total	10,349	8.43+	9.82+	5.47

Note: “+” represents “greater than” in this table. (e.g. The median of the censored holding duration equal to “8.78+” years means greater than 8.78 years.)

tively (as shown in Table 2). The duration for terminated motorcycle ownership revealed different results for disposals and transfers. The median (10.92 years) and mean (11.04 years) duration for disposals were both obviously longer than the median (5.89 years) and mean (6.99 years) of those motorcycles transferred. In addition, since the coefficient of variation (i.e. the standard deviation divided by the mean) for the transfer events (0.74) was higher than the disposal events (0.48), the transfers appeared to have a wider variation in holding duration. The pooled holding duration for the two different events was compromised to become 7.52 and 8.75 years for the median and mean values respectively.

It may be noticed that the average duration for censored observations exhibited an extraordinary longer holding time, compared to the pooled events for motorcycles holding termination. If all the observations were randomly distributed, the central statistics for the censored data should be shorter than the events, because of the limited observation spell. That is, as a rule, the censored data that had not experienced termination simply because the observation time was not long enough; i.e. these censored observations would eventually have come to pass, had the observation spell been prolonged. This aroused our concern towards the heterogeneity of the censored data for it inflated the holding duration estimation errors. As explained in the previous sections, some records from the VRS probably did not reflect actual motorcycle holding status, because some of the owners had not registered the correct ownership status. Therefore, it appeared appropriate to employ the split-population duration model, in order to correct any possible estimation errors produced by incorrect registration records.

4.2. Estimation results for duration models

Two different duration models – the standard Weibull duration model and the split-population Weibull duration model were separately established. The estimated results for the two models are demonstrated in Table 3. The shape parameter for the standard Weibull model equaled 1.89 and was statistically significant, being greater than 1 at $\alpha = 0.01$. This revealed the fact that the instantaneous hazard of motorcycle termination was increasing at a decreasing rate (i.e. $1 < Q < 2$). However, the shape parameter rose to 2.05 after introducing the split-population duration model; thus, the hazard turned out to be growing at a slightly increasing rate (i.e. $Q > 2$). In addition, the split parameter was statistically significant at less than 1, equaling 0.89 in the split-population model. The proportion pointed out that around 89% of all observations would eventually experience registration termination and in contrast, 11% would perhaps never undergo such an event. After employing the split-population duration model, the median survival time for motorcycle holding was reduced from 11.81 years to 10.60 years.

The estimated parameters in both models had the same directions and similar effects on hazard rates. Compared with the standard Weibull model, most of the estimated parameters in the split-population model appeared to slightly expand the contribution effect on hazard rates. Therefore, we simply focused on the split-population model to illustrate the influence of the covariates on the hazard rates. The notation, e^β , in Table 3 represents the contribution to the hazard rate from changing one unit value for a specific independent variable, while controlling for other variables.

First, the association between vehicle variables and hazard rates were all in accordance with our original expectations. Holders possessing a used motorcycle raised the hazard rate by as much as 2.5 times, compared

Table 3
Estimated results of the two duration models

Independent variables	Standard Weibull model			Split-population model		
	$\beta \times 10^{-2}$	(S.E. $\times 10^{-2}$)	e^{β}	$\beta \times 10^{-2}$	(S.E. $\times 10^{-2}$)	e^{β}
Constant (β_0)	-409.10 ^a	(42.36)	-	-405.29 ^a	(46.24)	-
Used motorcycle (β_1)	83.75 ^a	(3.64)	2.310	91.61 ^a	(4.17)	2.500
Age of motorcycle (β_2)	3.62 ^a	(0.48)	1.037	5.27 ^a	(0.57)	1.054
CC(1) (β_3)	91.79 ^a	(8.29)	2.504	112.09 ^a	(9.42)	3.068
CC(2) (β_4)	70.49 ^a	(8.19)	2.024	86.54 ^a	(9.27)	2.376
Maintenance costs (β_5)	14.74 ^a	(1.37)	1.159	17.23 ^a	(1.51)	1.188
Holder's age (β_6)	-3.57 ^a	(0.10)	0.965	-3.86 ^a	(0.11)	0.962
Running mileage (β_7)	0.18 ^a	(0.02)	1.002	0.24 ^a	(0.02)	1.002
Household's fleet size (β_8)	18.54 ^a	(4.42)	1.204	25.68 ^a	(5.02)	1.293
Unemployment rate (β_9)	-9.35 ^a	(2.22)	0.911	-9.13 ^a	(2.42)	0.913
Motorcycle density (β_{10})	-0.22 ^a	(0.03)	0.998	-0.27 ^a	(0.03)	0.997
Passenger car density (β_{11})	-0.51 ^a	(0.06)	0.995	-0.65 ^a	(0.07)	0.994
Engel's coefficient (β_{12})	-1.98 ^a	(0.55)	0.980	-2.36 ^a	(0.62)	0.977
Consumption propensity (β_{13})	1.72 ^a	(0.36)	1.017	1.83 ^a	(0.39)	1.018
Q	1.89 ^b	(0.02)	-	2.05 ^b	(0.02)	-
δ	-	-	-	0.89 ^c	(0.01)	-
Number of observations	7650			7650		
LL(β)	-5024.50			-5024.50		
LL(0)	-6494.87			-6453.66		
Median survival time (years)	11.81			10.60		

Notes:

1. The standard errors (S.E.) of the estimated β 's are listed in parentheses.
2. e^{β} represents the contribution to hazard rate of changing one unit independent variable at a time.
3. Q is the "shape parameter" in the Weibull hazard function and δ is the "split parameter" in the split-population duration model.
4. ^aDenotes that β is significantly different from 0 at $\alpha = 0.01$; ^bdenotes that Q is significantly larger than 1 at $\alpha = 0.01$; and ^cdenotes that δ is significantly less than 1 at $\alpha = 0.01$.

to those possessing a new motorcycle. In addition, each used motorcycle with one more year old at purchase increased the hazard rate by 5.4% (=1.054-1). Compared to motorcycles over 150 cc, possessing an engine size of under 50 cc, or ranging from 51 cc to 150 cc, had 3.07 and 2.38 times the hazard rate respectively for ownership termination.

Second, motorcycle usage variables were generally consistent with expectations towards the association with hazard rates, except for "household's fleet size". The increase in maintenance costs by 2.72 times (i.e. equals one unit increase by taking log) raised the hazard rate by 19%. For each year's increase in the age of a holder, the hazard was reduced by 3.8%. The increase in riding mileage of 1 km per week increased the hazard rate by 0.2%. In addition, when the sampled motorcycle was the only vehicle in a household, the hazard rate increased by 29.3%, compared to a household with more than one vehicle.

Third, the effect of the aggregate socioeconomic variables was also in accordance with hazard rate expectations, except for "motorcycle density". An increase in unemployment rate of 1% reduced the hazard rate for motorcycle ownership termination on average by 8.7%. Increasing vehicle density in an area by one motorcycle and by one passenger car per thousand persons reduced the hazard rate by 0.3% and 0.6% respectively. Also, an increase in Engel's coefficient of 1% reduced the hazard rate by 2.3%; however, a 1% increase in consumption propensity raised the hazard rate by 1.8%.

5. Discussion

The estimated results from the two different models showed that factors raising the hazard rate for motorcycle ownership termination are as follows: a used motorcycle or a motorcycle with a higher vehicle age at time of purchase; a lower displacement type; higher maintenance costs; heavier riding mileage; and being the only vehicle as well as a stronger consumption propensity in a household. However, the increasing age of the holder

and motorcycle registration areas with higher unemployment rates, a higher density for both motorcycles and passenger cars, and a stronger Engel's coefficient tended to reduce the hazard rates for motorcycle ownership termination.

In terms of factors influencing holding duration, most of the estimated results were in agreement with our original assumptions, except for two variables—"household's fleet size" and "motorcycle density". First, a decrease in the size of a household's fleet reduced the hazard rate of observed vehicles being terminated ownership in past studies (De Jong, 1996; Yamamoto and Kitamura, 2000). However, in our study, when a motorcycle was the only vehicle in a household, the hazard rate of ownership termination increased. The reason for this may be that possessing only one motorcycle likely means heavier usage and increased wear and tear, resulting in a shorter holding duration. In contrast, households owning more vehicles increased the holding duration of the observed motorcycle, possibly because of the substitution effect contributed by the other vehicles.

Second, the increase in "motorcycle density" in an area, on average, decreased the hazard rate of motorcycle holding termination. Our speculation that motorcycles were more likely to be the principle mode of transportation in high dense areas for motorcycle ownership, which would result in heavier usage of motorcycles and produce a shorter holding duration, was not validated. In contrast, the correlation coefficient between motorcycle density and Engel's coefficient among various areas was 0.45, while between motorcycle density and consumption propensity, it was -0.32 . It appears that a higher motorcycle density may be highly associated with a lower consumption ability and a more conservative consumption propensity, thus increasing the average holding duration for motorcycles.

Interestingly, the standard Weibull duration model revealed that the hazard function increased at a declining rate over time, whereas the introduction of the split-population model changed the hazard rate to become growing at a slightly increasing rate, exhibiting the proportion of never experiencing registration termination to be 11%; this appears to be comparable to the self-reported results – 10.2% (MOTC, 2004b).

This 11% of sampled motorcycles (equivalent to 1.35 million of motorcycles at the end of 2003) failing to terminate registration, probably arose from the fact that the Vehicle Registration Agency does not enforce periodic vehicle examinations for motorcycles under 250 cc in Taiwan; thus, the agency has no appropriate mechanism, such as penalties or vehicle plate revocation, that would allow for an update in the accuracy of motorcycle registrations. In addition, although the annual emissions inspection on all types of motorcycles was implemented by the Environmental Protection Administration, the emissions examination system is not linked to the vehicle registration system. Therefore, the rather slack management of motorcycle registrations has created a bias in official records. These inaccuracies in motorcycle registration could result in errors when establishing strategies for transportation planning, management, environmental protection, and international comparisons.

After eliminating the subpopulation that would never experience an event, the median of holding years was still as high as 10.6. This means that over 50% of motorcycle holders will retain their motorcycles for more than 10 years (i.e. the motorcycle age would be even higher, since about 30% were second-hand vehicles). Passenger cars with a vehicle age of more than 10 years made up only 29% of the total in Taiwan at the end of 2003 (MOTC, 2004a). In addition, according to Anilovich and Hakkert (1996), the median vehicle age values for fleets in the USA (6.5 years), United Kingdom (5.3 years), Holland (6.8 years) and Israel (8.0 years) were quite a bit lower than the median motorcycle age in Taiwan. Since motorcycles are generally heavily used, this raises our concerns over the emissions, energy consumption and safety problems associated with the use of this large proportion of older motorcycles. The government should, therefore, carefully examine ways of accelerating elimination mechanisms for these older motorcycles.

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