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Regional motorcycle age and emissions inspection performance: A Cox regression analysis

Hsin-Li Chang, Tsu-Hurng Yeh *

Department of Transportation Technology and Management, National Chiao Tung University, Hsinchu 300, Taiwan

Abstract

This work combines a motorcycle usage survey from the year 2000 with corresponding records from Taiwan's Vehicle Registration System to study the relationship between motorcycle disposal age and the implementation of motorcycle inspection and maintenance programs at the regional level. Two models are used to represent the quality of inspection and maintenance program implementation, and analyzed separately. After controlling for other independent predictors, analysis of the first model shows that districts with good inspection performance had a 15% higher hazard rate of motorcycle disposal. Under the second model, a 1% increase in the inspection rate and 1% decrease in the ineligibility rate were also found to raise the hazard rate by 2% and 4% respectively.

Keywords: Motorcycle emissions inspections; Disposed motorcycles; Censored observations; Cox regression model

1. Introduction

The use of older vehicles can lead to increased air pollutant emissions. Many studies have shown that the emissions of four-wheeled vehicles (Bin, 2003; Beydoun and Guldmann, 2006) and motorcycles (Lu and Lee, 2001) are positively correlated with their age. Older vehicles may produce higher emissions because of poor maintenance (Anable et al., 1997), backward technology (Anable et al., 1997), or both.

Motorcycles are as important as automobiles for daily transportation in many Asian countries. Taiwan, in particular, has the highest rate of motorcycle ownership in the world (Internal Road Federation, 2003). Registered motorcycles accounted for about two-thirds of all motor vehicles at the end of 2003, according to the Taiwan Ministry of Transportation and Communications (MOTC) (2004a). Motorcycles with small engines less than 150 cc are especially popular, because of their high accessibility and low fuel consumption.

Older, more polluting motorcycles may be easy to identify, but little has been done to investigate whether regional motorcycle inspection and maintenance (I/M) policies and their implementation have any impact on the motorcycle age distribution. The regional perspective is important because local I/M programs have

* Corresponding author.
E-mail address: barryyeh7@hotmail.com (T.-H. Yeh).

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adopted different strategies to deal with older motorcycles. In particular, regions with poorly implemented programs may allow older motorcycles to remain in service, thus aggravating the emissions problem. This study explores the relationship between average motorcycle age and regional I/M performance measures such as inspection rate, ineligibility rate, and CO and HC emission levels.

The motorcycle usage survey conducted by MOTC in 2000 and registration information for the sampled motorcycles from the Vehicle Registration System (VRS) are combined here. Precise disposal dates for retired motorcycles are likewise obtained from VRS records. Since motorcycle age is a censored duration variable, a Cox regression model based on proportional hazards is applied to establish its degree of association with the regional I/M program performance measures and investigate the disposal hazard rate of older motorcycles.

2. Taiwan's motorcycle I/M program

The motorcycle I/M programs issued by Taiwan's Environmental Protection Administration (EPA) demand that motorcycles in use undergo a yearly mandatory idle testing[1] inspection for carbon monoxide (CO) and hydrocarbon (HC) emissions. The standards for CO and HC values are nationally consistent, and have been tightened by the EPA five times since 1988. As a result, they are the strictest standards worldwide[2] (Environmental Protection Administration, 2002).

Some of 16.1% motorcycles failed to meet emission standards during the annual inspection in 2004. Motorcycles less than three years old had only a 7% rejection rate, while the rate reached 24.3% for motorcycles aged ten years or over (Environmental Protection Administration, 2005). Even though older motorcycles only have to comply with standards dating from their year of manufacture, they still display a disproportionately high ineligibility rate.

The actual inspection is implemented by local Environmental Protection Bureaus in each of Taiwan's 23 administrative districts. Regional implementation of motorcycle I/M programs appears to be inconsistent. The average inspection rate was only 51% of all registered motorcycles in 2004, with the southern and eastern regions of Taiwan revealing rates lower than average. The lowest disqualification rate in the 2004 annual inspection was 10.4% in Taipei city, while the highest were 21.8% and 21.5% in the cities of Kaohsiung and Taichung, respectively.

The inspection rate also decreases as motorcycle age increases (Ministry of Transportation and Communications, 2004b), and the average disposal age of motorcycles in Taiwan is 13 years (Chang and Yeh, 2005). The problem of pollution from older motorcycles, which are both loosely monitored and the greatest potential source of emissions, should therefore be given careful consideration. It is important to know to what extent differences in regional I/M policy implementation inflate the disposal age of motorcycles.

3. Data sources

To determine the age of the disposed motorcycles, we linked the MOTC sampling survey to the registration records of the sampled motorcycles in the VRS. The MOTC survey, which focuses on motorcycle usage parameters such as maintenance cost, frequency and purpose of use, mileage, and basic information about the owners, was administered through a systematic, stratified sampling method on December 15, 1999. The sample size was 10,780, with a sampling error of ±1% at a 0.95 confidence level (Ministry of Transportation and Communications, 2000). By linking the plate numbers of the sampled motorcycles to the VRS, the original date of manufacturing, the name of owner, and the "disposal" record (if any)[3] were also obtained. These data offer a basis for determining an event history over the life span of a motorcycle.

Second-hand motorcycles can also be identified by examining the "latest transfer" record, which may list a date before the sampling time of the survey. To determine the complete life span of the sampled motorcycles,

[1] An idle test measures the concentration of pollutants emitted by a gasoline-powered motorcycle using a testing pipe 60 cm long and 4 cm wide on the inner diameter, while the motorcycle is idling.

[2] The latest revision of emissions standards (i.e. CO < 3.5% and HC < 2000 parts per million) took effect at the beginning of 2004.

[3] "Disposal" means that an owner ends their motorcycle's registration in the VRS, and hence the motorcycle can no longer be used on the roads.

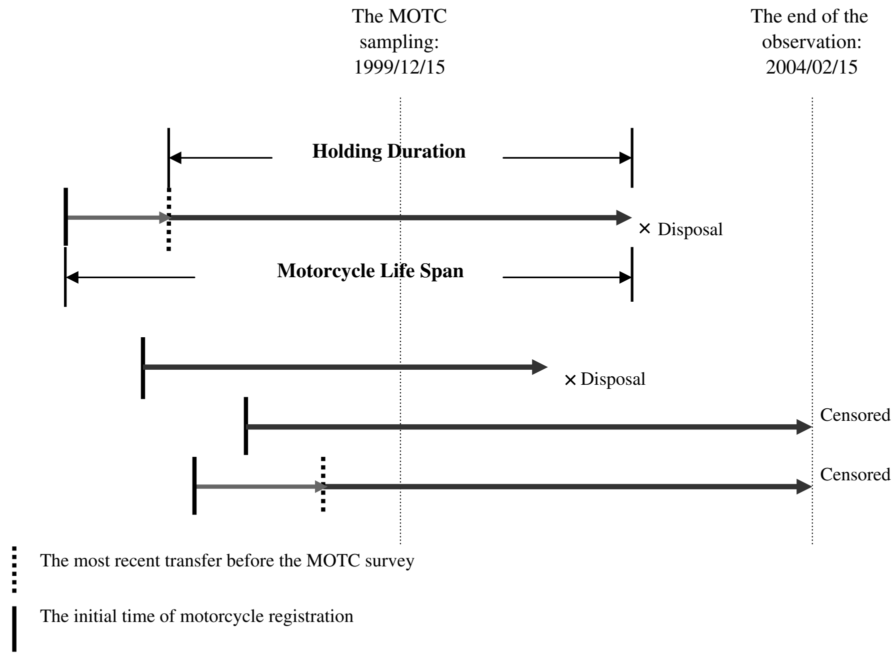

Fig. 1. Research design for observing the life span of motorcycles.

VRS disposal records were examined for all dates up to February 15, 2004. Fig. 1 illustrates the different life span histories of sampled motorcycles, which can be identified in the VRS records as either completed (i.e., the registration was terminated) or censored (i.e., the registration was not terminated).

The relationship between regional implementation of the I/M program and motorcycle disposal age was established by collecting inspection-related data spanning the years 1999–2004. The emissions inspection data include average inspection rate, inspection station density, ineligibility rate, and idle testing values for CO and HC emissions for each of the districts.

4. Differentiation of regional inspection performance

A K-means cluster analysis based on five of the inspection-related variables just mentioned was applied to identify regional differences in policy implementation. The five inspection variables are defined as follows. The average inspection rate is measured as the percentage of vehicles participating in the annual mandatory emissions inspection. The inspection station density is calculated as the number of approved inspection stations per 1000 registered motorcycles. The average ineligibility rate is measured as the percentage of motorcycles failing to pass applicable standards for either CO or HC emissions. The average level of CO (%) and HC (ppm) emissions (which count as two separate variables) are measured for motorcycles inspected. Each variable is reduced to the average of all five annual values taken over the period 1999–2004, and is measured separately in each administrative district.

Overall means reveal 47.8% of registered motorcycles were inspected, 18.9% of inspected motorcycles were found ineligible, and only 0.13 inspection stations were available per thousand motorcycles. The average levels of CO and HC emission were 2.5% and 2741 ppm, respectively (Table 1). Only two regional clusters were defined, since additional groupings were found to have no further differentiation effect for the Cox regression model. Districts in cluster 1 had a slightly higher inspection rate and station density, a lower ineligibility rate, and lower CO and HC emission levels than those in cluster 2. Motorcycles in cluster 2 on average were 7.0% more likely to be found ineligible, had CO values 0.4% higher, and produced 893 ppm more HC than those in cluster 1.

The one-way MANOVA was also applied to test the mean differences of these five variables between the two cluster populations. The Wilks' Lambda (Λ) value, which was equal to 0.234, was transformed to a

Table 1
Regional cluster centers of emission-related variables

Variable	Overall (23 districts)	Cluster 1 (13 districts)	Cluster 2 (10 districts)
Inspection rate (%)	47.79 (4.34)	47.89 (3.60)	47.65 (5.35)
Ineligibility rate (%)	18.90 (4.54)	15.87 (3.26)	22.84 (2.38)
Inspection station density (stations per 1000 motorcycles)	0.130 (0.037)	0.139 (0.040)	0.119 (0.033)
CO Emissions (%)	2.46 (0.27)	2.27 (0.20)	2.69 (0.13)
HC Emissions (ppm)	2741 (525)	2353 (290)	3246 (243)

Note: Numbers in parentheses represent one standard deviation.

Table 2
Regional cluster membership by district

Administrative district	Cluster 1	Cluster 2
Yilan County	N	
Keelung City	N	
Taipei City	N	
Taipei County	N	
Taoyuan County	N	
Hsinchu City	N	
Hsinchu County	N	
Miaoli County	N	
Taichung City		C
Taichung County	C	
Changhua County	C	
Nantou County	C	
Yunlin County		C
Chiayi City		S
Tainan City		S
Chiayi County		S
Tainan County		S
Kaohsiung City		S
Kaohsiung County		S
Pingtung County		S
Taitung County	E	
Hualien County		E
Penghu County	OS	

Notes: "N", "C", "S", and "E" stand for North, Central, South and East Taiwan; "OS" stands for offshore Taiwan.

Rao statistic (= 11.12) following an $F_{5,17}$ distribution. This allows rejection of the null hypothesis that all five means were equal at $\alpha = 0.05$. In addition, individual ANOVA results between the two populations reveal that the mean differences in ineligibility rate, CO emissions, and HC emissions are statistically different from zero. The zero difference hypothesis could not be rejected, however, for the inspection rate and inspection station density.

Most of the districts with better implementation of the I/M program, districts in cluster 1, are located in the northern region of Taiwan or off-shore. The administrative districts belonging to each cluster are listed in Table 2.

5. Cox model and specification

5.1. Cox regression method

Since motorcycle age is a positive, censored variable with non-normal distribution, a duration (hazard rate) model was deemed appropriate in describing its behavior. A variety of standard formulations for parametric and semi-parametric duration models are available (Allison, 1995; Le, 1997). The hazard function $h(t)$ is defined as an individual's instantaneous rate of transition from one state to another, given that the transition has not yet occurred before time t. The equation for the function is

$$h(t) = \lim_{\Delta t \to 0} \frac{\Pr(t \leqslant T < t + \Delta t | T \geqslant t)}{\Delta t} = \lim_{\Delta t \to 0} \frac{\Pr(t \leqslant T < t + \Delta t)}{\Delta t \times \Pr(T \geqslant t)} = \frac{f(t)}{S(t)}, \quad \forall t \geqslant 0, \tag{1}$$

where $f(t)$ and $S(t)$ are called the density and survivor function of time t, respectively.

Although the survival time may also be formulated as a dependent variable, the hazard rate is more conventional as it highlights the instantaneous event rate. In this study, the hazard rate is calculated for motorcycle disposal events.

Various parametric models may be assumed to describe the hazard rate as a function of time, such as the exponential, Weibull, and lognormal formulations. The correct functional form, however, can usually not be acquired. The Cox proportional hazard model (also called Cox regression) is adopted because it is robust to approximate the results of a correct parametric model without needing to assume a specific functional form in advance (Kleinbaum, 1955).

The Cox regression model is comprised of two parts: the baseline hazard and an exponential component. Its functional form is expressed as

$$h(t|X, \beta) = h_0(t) \times e^{X \bullet \beta}, \tag{2}$$

where $h_0(t)$ is the baseline hazard function and X and β are vectors of the independent variables and their corresponding parameters.

The estimated parameters $\hat{\beta}$ are obtained by maximizing the joint probability of the partial likelihood function $L(\beta)$,

$$L(\beta) = \prod_{j=1}^{k} \left(e^{X_{(j)} \bullet \beta} \Big/ \sum_{l \in R_j} e^{X_l \bullet \beta} \right), \tag{3}$$

where k is the number of motorcycle disposal events during the observation period; R_j is the set of motorcycles at risk (the *risk set*) at the jth rank of time ($\leq k$) for disposed events, which represents the set of motorcycles that are not being disposed of before the jth rank of time; $X_{(j)}$ is the vector of independent variables corresponding to the disposed motorcycle occurring at the jth rank of time (number j in parenthesis represents the rank order of time); and X_l is the vector of independent variables corresponding to the lth set of motorcycles in R_j.

The estimated parameters $\hat{\beta}$ derived from the function, while not fully statistically efficient, are consistent and in large samples asymptotically normal and unbiased.

When comparing the relative hazard contribution of two distinct independent variable vectors, it is conventional to use the hazard ratio. This is expressed by Eq. (4), that is constant since $h_0(t)$ cancels out of the equation (the proportional hazard assumption).

$$HR = \hat{h}(t|X_1, \hat{\beta}) / \hat{h}(t|X_2, \hat{\beta}) = e^{(X_1 - X_2) \bullet \hat{\beta}}, \tag{4}$$

where X_1 and X_2 stand for the two values of the independent variable vector considered. If HR is significantly greater than 1, then the conditions described by X_1 are more likely to terminate a motorcycle's holding period than the conditions given by X_2. In other words, the motorcycle life expectancy is shorter under X_1.

5.2. Cox specification

To study the association between motorcycle age and regional emission-related attributes, several independent variables describing the vehicle, its holder, socioeconomic predictors, and regional inspection performance were introduced (Table 3).

- It has been shown that used vehicles are more likely to be replaced quickly (De Jong, 1996; Yamamoto and Kitamura, 2000) due to lower reliability and higher repair costs. These factors may reduce the duration of use, but it remains to be determined whether they affect the overall life span.

Table 3
Independent variable notation

Variable notation	Variable description
Used motorcycle	1 if the sampled holder possesses a second-hand motorcycle, otherwise 0
CC(1)	1 if the motorcycle's engine size is less than or equal to 50 cc, otherwise 0
CC(2)	1 if the motorcycle's engine size is in the range 51–150 cc, otherwise 0
Holder's age	Age of the sampled motorcycle's holder
Holder's sex	1 if the holder of the sampled motorcycle is male, 0 if female
Consumption propensity	The average consumption expenditure per household expressed as a percentage of the average disposable income, by district and averaged over the period 1999–2004
Motorcycle inspection Performance	(Dummy variable in Model 1): 1 if the motorcycle is registered in a district belonging to the cluster with higher overall inspection performance, otherwise 0 (Continuous variables in Model 2): Annual inspection rate, inspection station density, and annual ineligibility rate by district, averaged over the period 1999–2004

- A 1980 law prohibiting the import of motorcycles with an engine size over 150 cc was lifted on July, 2002 only because Taiwan joined the World Trade Organisation. Consequently, the majority of motorcycles in Taiwan are mopeds and 'light' motorcycles. In general, motorcycles over 150 cc have longer life spans not only because of their higher value and replacement cost, but also because of their scarcity as a result of having been banned for so many years. Three variables were defined to classify motorcycles into the following categories: 50 cc or under (mopeds), 51–150 cc (light motorcycles or motor scooters), and over 150 cc.
- Older owners tended to retain their cars longer, possibly due to stronger habits (De Jong, 1996). Vehicles with older primary users have also revealed a longer ownership period (Yamamoto and Kitamura, 2000). It was therefore assumed in this study that younger people replace their motorcycles at a faster rate (i.e., such vehicles have a higher disposal hazard). To make a fair comparison, the ages of sampled holders were adjusted to their vehicle disposal time or to the final observation year.
- The gender of a motorcycle owner may influence the timing of replacement or disposal.
- The consumption propensity in a district is an index measuring the average intensity of purchasing per household. It is defined as the ratio of a household's consumption expenditure to its average disposable income. We speculated that in districts with stronger consumption propensity, the decision to dispose of a motorcycle would be more likely. The average consumption propensity in each district was calculated over the period 1999–2004.
- As the principle variable of interest, motorcycle inspection performance was treated two different ways and the Cox model applied to each separately. First, we created a dummy variable to indicate membership in one of the two groups defined by the aforementioned cluster analysis. Second, the average inspection rate, inspection station density, and ineligibility rate were applied as continuous district variables (the average levels of CO and HC emission were excluded from the Cox model because they are highly correlated with the ineligibility rate).

6. Results

6.1. Motorcycle age statistics

At the end of the observation period, motorcycles were classified as either censored (i.e., no disposal record had appeared by 2004) or disposed of. Censored data, which make up 87.4% of observations, represent motorcycles that could still be in use in 2004. The median and mean durations reported in Table 4 should be treated as lower limits since the actual durations of these vehicles are higher. The median and mean durations for retired motorcycles were significantly longer, as expected; about half of all motorcycles were more than 13 years old. This is of major concern, as such vehicles emit high levels of pollutants.

Table 4
Descriptive statistics for motorcycle age

The end of the observation	Number of observations	Duration descriptive statistics		
		Median	Mean	Standard deviation
Censored	9415	9.88+	11.38+	5.77
(Cluster 1)	(5699)	(9.34+)	(11.10+)	(5.82)
(Cluster 2)	(3716)	(10.83+)	(11.82+)	(5.66)
Disposed	1362	12.99	13.30	4.18
(Cluster 1)	(855)	(13.01)	(13.15)	(4.05)
(Cluster 2)	(507)	(12.89)	(13.56)	(4.39)
Total	10,777	10.46+	11.63+	5.63
(Cluster 1)	(6554)	(9.08+)	(10.70+)	(5.58)
(Cluster 2)	(4223)	(11.30+)	(11.63+)	(5.58)

Note: "+" represents "greater than" in this table. (The median of the censored age of motorcycles is reported as "9.88+" years, meaning an unknown value greater than 9.88 years.)

All motorcycles from cluster 1 districts, which performed better inspections, had a shorter mean age. The mean age difference for disposed motorcycles between the two district clusters was 0.41 years, while the mean age difference for motorcycles still in service was 0.72 years. Individual ANOVA tests on these results reveal that the difference in censored motorcycles is statistically different from zero, at $\alpha = 0.05$. The difference in retired motorcycles was also mildly significant, at $\alpha = 0.1$.

6.2. Cox regression results

Parameter estimations for the two Cox regression models (with different representations of inspection performance) are shown in Table 5. As the purpose here is to explore the relationship between motorcycle age and inspection performance, all the other independent variables in the model are controlled.

The disposal hazard rate was found to be independent of a motorcycle's used status, with $\alpha = 0.05$ for the relationship hypothesis in both models. Motorcycles with a larger engine size, however, had lower disposal hazard rates and similar hazard ratios under both models in agreement with expectations. In model 1, motorcycles with engine size under 50 cc and in the range 51–150 cc had, respectively, hazard rates 3.12 and 2.45

Table 5
Estimated parameters for the Cox regression models

Independent variable	Model 1		Model 2	
	β (SE)	e^{β}	β (SE)	e^{β}
Used motorcycle	−0.067 (0.060)	0.94	−0.076 (0.060)	0.93
CC (1)	1.137[a] (0.163)	3.12	1.169[a] (0.164)	3.22
CC (2)	0.894[a] (0.156)	2.45	0.939[a] (0.157)	2.56
Holder's age	−0.024[a] (0.002)	0.98	−0.024[a] (0.002)	0.98
Holder's sex	0.104 (0.064)	1.11	0.122[b] (0.064)	1.13
Consumption propensity	0.035[a] (0.006)	1.04	0.022[a] (0.007)	1.02
Inspection performance cluster	0.137[a] (0.059)	1.15	–	
Inspection rate	–		0.020[a] (0.009)	1.02
Ineligibility rate	–		−0.041[a] (0.007)	0.96
Inspection station density	–		−0.896 (0.972)	0.41
Number of observations	10,219		10,219	
Censored observations (rate)	8924 (82.8%)		8924 (82.8%)	
LL (β)	−10,259.2		−10,244.3	
LL (0)	−10,377.8		−10,377.8	
Degrees of freedom	7		9	

Notes: "a" and "b" denote that β is significantly different from 0 at the $\alpha = 0.05$ and $\alpha = 0.1$ levels, respectively.

times motorcycles with larger engines than 150 cc. The corresponding hazard ratios under model 2 were very similar, at 3.22 and 2.56.

As expected, older holders tended to dispose of their motorcycles later in both models. For each additional year in the holder's age, the disposal hazard decreases by 2%. Motorcycles owned by males had a disposal hazard rate 13% higher than those owned by females. The holder's gender, however, was only marginally associated with disposal age in model 2. Finally, a 1% increase in consumption propensity on average raised the disposal hazard rate by 4% and 2% respectively in the two models.

We now turn to the two measurements of regional motorcycle inspection performance previously discussed. Model 1, where inspection performance is classified by cluster membership, indicates that the districts with better inspection performance had a 15% higher disposal hazard rate after controlling for all other predictors.

Since the average CO and HC emission values were highly correlated with the ineligibility rate (with correlation coefficients of 0.99 and 0.89), these variables were excluded from model 2 to avoid multicollinearity. Both inspection rate and ineligibility rate were statistically significant predictors, at $\alpha = 0.05$, but the inspection station density was not significant. A 1% increase in the motorcycle inspection rate elevated the disposal hazard rate by 2%. A 1% increase of the motorcycle ineligibility rate, on the other hand, decreased the disposal hazard rate by 4%. These two predictors seem to confirm that districts with better implementations of the national motorcycle I/M program raise the disposal hazard rate.

7. Conclusions

Cluster analysis defined two district groups which exhibited significant differences in three motorcycle emission-related predictors: ineligibility rate, average level of CO emission, and average level of HC emission. Most of the administrative districts with better inspection performance were located in northern Taiwan, while districts with poorer performance were located in the south. The mean disposal age of motorcycles was about 13.3 years, indicating the possibility of a serious emission problem. In addition, the mean age of motorcycles in districts with inferior inspection performance was higher overall.

The quality of regional I/M implementation was represented in two ways using surrogate measurement variables. Cox regression models revealed that regional predictors of motorcycle inspection performance significantly influenced the disposal hazard rates of motorcycles. As expected, districts with poorer inspection performance inflated the mean disposal age.

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