Doshisha University

Safety and Fuel Economy of Passenger Cars

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Abstract:

In the United States, while there exists a result of analysis that shows tighter fuel efficiency requirements leading to lighter vehicle bodies would increase the number of fatal accidents, other recent works argue that fuel economy is not relevant to the occurrence rate of fatal accidents. This research is aimed at examining the relationship between fuel economy and the occurrence rates of accidents in Japan.

Traditionally, the safety of passenger cars has been assessed through the use of laboratory data from the viewpoint of risk of death and injury under the assumption that accidents have already occurred and results have been published in New Car Assessment. On the other hand, we examined safety by vehicle type from the perspective of the occurrence rates of accidents resulting in death (fatal accidents) and accidents resulting in injury or death (hereinafter “accidents”). We conducted negative binominal regression analyses of the occurrence rates of fatal accidents and accidents, taking into consideration the influence of driver-related factors, vehicle characteristics on these occurrence rates. The results of our analysis demonstrate that there is no important difference in the adjusted occurrence rates of fatal accidents and accidents, which excludes the effects of driver-related characteristics, among vehicle types other than minivans and sport and specialty cars; further, it has been clarified that the adjusted occurrence rate of fatal accidents is not necessarily strongly correlated with the score in New Car Assessment. While the adjusted occurrence rate of fatal accidents exhibited a tendency to decrease inversely with the increase in the weight of the vehicle, we obtained an opposite result for sport and specialty cars, which have a high adjusted occurrence rate of fatal accidents. There is a possibility that the interior volume or the vehicle shape would have a greater influence on the occurrence rate of fatal accidents.

Keywords: safety, accident, fatal accident, fuel economy, negative binominal regression

JEL codes: K29, R49

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Ross (University of Michigan). In compiling the database for analysis, we gained the cooperation of Mr. Hiroshi Takahashi (who graduated from Chuo University in 2005) and received valuable advice from Mr. Hisashi Imanaga (Japan Automobile Research Institute), the participants of the above conference, and anonymous referees. I would like to take this opportunity to extend a special thanks to all of them.

Safety and Fuel Economy of Passenger Cars

Masayoshi Tanishita/ Hiroaki Miyoshi

1. Introduction

In connection with the restriction of the Corporate Average Fuel Economy (CAFE) in the United States, while Crandall and Graham (1989) show that tighter fuel efficiency requirements leading to lighter vehicle bodies would increase the number of fatal accidents, other recent works (Ahmad and Greene, 2005; Noland, 2005; Wenzel and Ross, 2003) argue that fuel economy is not relevant to the occurrence rate of fatal accidents. This research is aimed at examining the relationship between fuel economy and the occurrence rate of accidents resulting in death (fatal accidents) and accidents resulting in injury or death (hereinafter "accidents") in Japan. It would also be important to clarify the relationship between vehicle characteristics and the occurrence rates of fatal accidents or accidents for the future examination of fuel efficiency requirements or safety regulations in Japan. Three factors—vehicle characteristics, driver-related characteristics, and the driving environment (the road structure, the traffic volume, etc.)—are relevant to traffic accidents, and a number of research studies have been carried out on the relationship between each factor and traffic accidents. In this paper, we will focus on the characteristics of vehicles and drivers. With regard to vehicle characteristics, factors such as the engine size and the weight of the vehicle affect the acceleration performance, while factors such as the interior volume or the center of gravity have an impact on the ease of driving, the risk of overturn, and the ease of engaging in avoidance behaviors. These factors are relevant to the occurrence rates of accidents and the gravity of damage in accidents. On the other hand, with regard to driver-related characteristics, experience and character are said to influence the occurrence rates of accidents.

As concrete indicators of safety related to vehicle characteristics, the Ministry of Land, Infrastructure and Transport and the National Agency for Automotive Safety & Victims' Aid evaluated the collision safety performance of each type of vehicle through collision tests and published the results in New Car Assessment. In addition, Japan Automobile Research Institute examined the relationship between the score presented in New Car Assessment and the mortality and serious injury rates in actual accidents; it concluded that while there is a correlation between these factors, the statistical significance is low (Tominaga et al., 2004). While they have examined safety on the presupposition that accidents have already occurred, we can also consider the occurrence rate of accidents, which is calculated by dividing the number of accidents that have occurred by the number of vehicles as one of indicators for evaluating vehicle safety. Thus, this paper will focus on the occurrence of "actual" accidents as the indicator for safety.

The data on the number of actual accidents is published by Institute for Traffic Research and Data Analysis. However, the values in this data do not exclude driver-related characteristics and the influences of the driving environment; further, they do not directly reflect the safety of the vehicle itself. In addition, it should also be noted that there is a possibility that drivers' overestimation of safe vehicles caused a moral hazard for them and increased the number of accidents.

This paper is aimed at estimating the safety of passenger cars from the viewpoint of the probability of accidents, by controlling for driver-related factors, such as the rate at which the seatbelt is worn and the rate of alcohol consumption, and analyzing the relationship between the results of our estimation and those of the evaluation in New Car Assessment or the fuel economy.

In this paper, we will first explain the data and method used in the next section. With regard to the method, we show that it would be inappropriate to apply the ordinary regression analysis as we intend to deal with a rare phenomenon, namely, accidents; thus, we use the negative binominal regression that further generalizes the Poisson regression. In the third section, we present the regression results obtained using the abovementioned method. In the fourth section, we discuss the regression results and demonstrate the following: (i) the level of safety is the highest in the case of minivans and the lowest in the case of sport and specialty cars, but there is no important difference among other types of vehicle; (ii) the occurrence rate of actual fatal accidents is not necessarily strongly correlated with the assessment score in New Car Assessment; and (iii) while the rate of fatal accidents tends to decrease inversely with the increase in the weight of the vehicle, we have obtained the opposite result for sport and specialty cars, which have a high occurrence rate of fatal accidents; further, there is a possibility that the interior volume, which is a variable representative of the number of passengers, or the vehicle shape would have a greater influence on the occurrence rate of fatal accidents. Finally, in the concluding section, we explain the importance of promoting the development of technologies for improving both fuel economy and safety.

2. Data and Methods

2.1. Data

We have used the integral data on traffic accidents prepared and managed by Institute for Traffic Research and Data Analysis for a period of six years in total—from 1996 to 1998 and from 1999 to 2001—to extract the following statistics: the number of vehicles by common name, the number of vehicles in which passengers were killed, the number of vehicles involved in accidents, the rate of alcohol consumption, the accident history, and the rate at which the seatbelt is worn in vehicles involved in fatal accidents and accidents. In this case, the number of vehicles involved in accidents implies the cases in which the passenger(s) of the vehicle concerned was (were) killed or injured. With respect to the number of vehicles in which passengers were killed, we counted as one car when at least one of the passengers of the vehicles involved in an accident was killed even if several passengers were killed. While we are aware that in order to describe the vehicle characteristics, it may be more appropriate to deal with fatal accidents and accidents in which the vehicle concerned has the maximum rating blame, we did not consider this in this study; it remains as a challenge for future research.

By doing so, we obtained macro data on these items by common names (names used in catalogs, such as “Corolla” or “Crown,” which can be different from those appearing on vehicle inspection certificates). 8 types of vehicles, 238 common names, and 363 samples. We excluded vehicles with less than 50 thousand registered number from the samples to ensure reliability. Vehicle Types and the number of common names considered in the analysis are presented in Table 1 (the names within parentheses represent the common names of the relevant vehicle type).

Table 1 Vehicle Types and the number of common names considered in the analysis

Vehicle type	Number of common names
Light family cars (Wagon R)	30
Sedan A (Engine size of less than 1500 cc: March)	28
Sedan B (Engine size of less than 2000 cc: Corona)	36
Sedan C (Engine size of more than 2000 cc: Mark II)	28
Sport and Specialty (Celica)	23
Wagon (Corolla Wagon)	42
Minivan (Estima)	30
RV/SUV (Pajero)	21

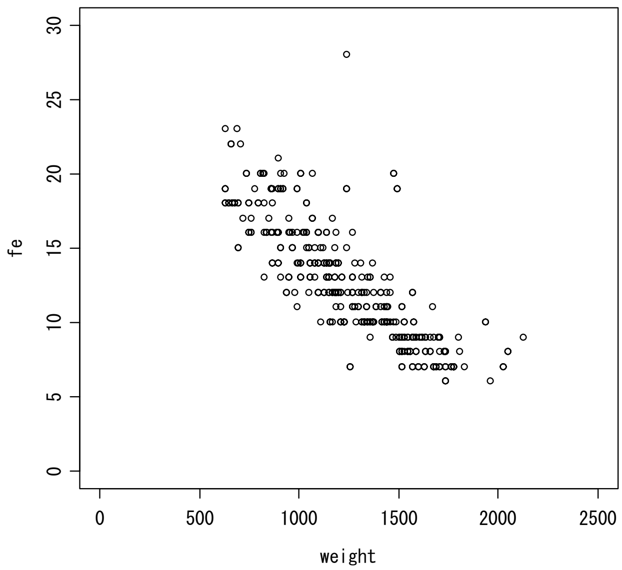
For the above samples, using the Japanese Motor Vehicles Guidebook, we have also compiled data such as the price, the weight of the vehicle, fuel economy, the interior volume (= length of the vehicle * width of the vehicle * height of the vehicle), as well as the degree of instability (= height of the vehicle / (width of the vehicle * length of the vehicle)) in view of the risk of overturn during collision. As the weight of the vehicle may alleviate the acceleration performance or the impact at the time of collision, it is expected to have a negative influence on the occurrence rate of fatal accidents and accidents. Likewise, fuel economy will have a positive correlation with the occurrence rates of fatal accidents and accidents because it decreases as the weight of the vehicle increases. These are the arguments of automakers in the discussion related to tighter restrictions on fuel economy in the United States. While we have employed the interior volume as one of indicators showing the ease of driving due to our belief that drivers can derive greater relaxation in spacious cars, we should also be aware of its effect as a representative indicator of the number of passengers. In other words, the driver will become more safety conscious when he or she has one or more fellow passengers, thereby reducing the occurrence rates of fatal accidents and accidents. (In contrast, we can assume that the possibility that passengers sustained injuries in the accident will increase in the case of a greater number of fellow passengers). While elements such as the engine size, the horsepower/weight, and the brake performance are also important variables, in this paper, we consider them as dummy variables for vehicle types. With regard to the data on the performance indicator of passenger cars, we have employed the median value in the case where one common name of vehicle has several models. The descriptive statistics related to the abovementioned variables are listed in Table 2.

Table 2 Summary statistics for the key variables

Variables	Min.	Mean	Max.	Variance
a. # of vehicles involved in fatal accidents	0	17.9	147	464.5
b. # of vehicles involved in accidents	563	4595	55055	6.72E+07
c. # of registered vehicles	51000	417240	2683000	1.92E+11
Occurrence rate of fatal accidents (= a / c)	0	0.0035	0.028	1.34E-05
Occurrence rate of accidents (= b / c)	1.05	1.84	2.94	1.00E-01
Weight (kg)	6.30E+02	1.25E+03	2.13E+03	1.04E+04
Interior volume (m^3)	0.99	3.25	5.71	9.70E-01
Degree of instability (= height / (width*length)) (m^{-1})	2.60E-04	4.60E-04	1.02E-03	1.29E-08
Fuel economy (l/km)	6	12.68	28	1.60E+01
Drinking rate (%)	0	2.17E+01	1.00E+02	331.07
Accident history rate (%)	0	9.9	50	1.34E+02
Seatbelt wearing rate (%)	84.4	93.58	98	8.47

2.2. Method

With respect to the occurrence rate of fatal accidents (= the number of accidents in which passengers were killed / the number of vehicles registered) and the occurrence rate of accidents (= the number of vehicles involved in accidents resulting in injury or death / the number of vehicles registered), we will conduct regression analyses with four categories of variables as the explanatory variables. The first is driver-related characteristics that comprise the rate of alcohol consumption, accident history, and the rate at which the seatbelt is worn. The second is vehicle characteristics that span the weight of the vehicle, the interior volume, the degree of instability, and the dummy variables for vehicle types (we set recreational vehicle (RV) as zero). The third is the dummy variable for the time points that reflect the technological improvement between the periods 1996–1998 and 1999–2001 as well as the changes in the driving environment. As indicated in Figure 1, it should be noted that fuel economy has a strong correlation with the weight of the vehicle. Therefore, in order to avoid the problem of multicollinearity, we will not consider fuel economy as an explanatory variable at this stage, but we examine this in section 4.



Note 1) "Fe" denotes "Fuel economy."

2) The result of the single regression is as follows:

$$\ln(\text{Fe}) = 9.40 - 0.97 \ln(\text{Weight}) \quad R^2 = 0.71$$
$$(40.43) \qquad (-29.75)$$

The values within parentheses are t-values.

Figure 1 Correlation between the weight of the vehicle and fuel economy

As the frequency of accidents is limited, it is not appropriate to apply the ordinary least squares (OLS) method that presupposes the homogeneous dispersion and normal distribution of the error term. Namawa and Shimamura (1998) conducted a Poisson regression analysis that presupposes that the average and the dispersion of the error term are equal. Initially, we attempted to adopt the Poisson regression as well. However, because the dispersion of the error item greatly exceeded its average, we decided to conduct a negative binominal regression analysis that further generalizes the Poisson regression (when the parameter of the Poisson distribution follows the gamma distribution, the Poisson distribution will correspond to the negative binominal distribution.) In this case, it can be described as the generalized linear model, and the parameters will be estimated by the maximum likelihood method.

We now briefly explain the negative binomial regression. Let us assume that Y—the number of accidents (the number of fatal accidents)—follows the negative binominal distribution. If three covariates (X) affects Y, the probability that we can obtain $Y = y$ will be indicated as below:

$$P(Y = y \mid X_1, X_2, X_3, k) = \frac{\Gamma(y+k)}{\Gamma(k)\Gamma(y)}\left(\frac{k}{k+\mu}\right)^k\left(\frac{\mu}{k+\mu}\right)^y \quad y = 0, 1, 2\ldots \text{(1)}$$

In this case, Γ is expressed as a gamma function, $\mu = E(Y)$ (the expectation of Y), and k is a parameter related to the dispersion. The dispersion of Y can be expressed as $V(Y) = \mu + \mu^2/k$ (in the Poisson distribution, $k = \infty$). Thus, assuming that the following link function $\eta = g(\mu)$ can be explained as the linear sum of the covariate (X), we estimate parameter β[3] as follows.

$$\eta = g(\mu) = \log(\mu) = x'\beta$$

$$\mu = \exp(x'\beta)$$

$$\text{where } x' = [1, X_1, X_2, X_3] \text{ and } \beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} \ldots(2)$$

While Y denotes the number of targeted vehicles, we obtain the occurrence rates of fatal accidents and accidents by using the number of vehicles registered as the offset variable (denominator).

3. Regression Redults

3.1.The occurrence rate of fatal accidents

Table 3 displays the estimated results of the occurrence rate of fatal accidents. Regression A shows the result of the regression based on the explanatory variables described above. On the other hand, regression B shows the result of the regression with the variables inclusive of the cross-term of the interior volume and the dummy variables. Figure 2 illustrates the residual plots corresponding to the estimated results on regression B of Table 3.

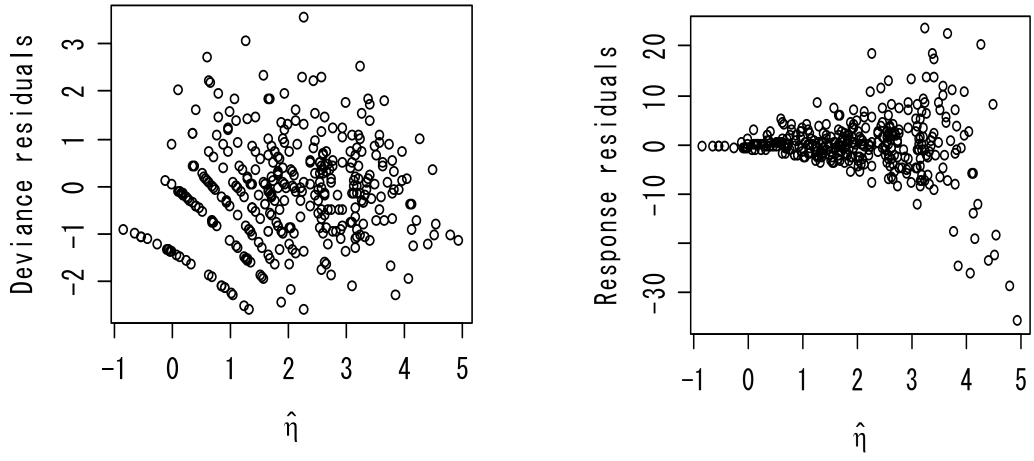
Table 3 Regression estimates of the occurrence rate of fatal accidents

Variable	Regression A			Regression B		
	Coefficient estimate	z-value	Significance	Coefficient estimate	z-value	Significance
Intercept	2.44	1.43		2.87	1.70	*
Rate of alcohol consumption (%)	0.17	2.43	**	0.12	1.76	*
Accident history (%)	0.055	4.02	****	0.057	4.30	****
Rate at which the seatbelt is worn (%)	–0.1402	–7.62	****	–0.1393	–7.832	****
Weight (kg)	–0.0005879	–3.297	****	–0.0005828	–3.287	***
Interior volume (m^3)	–0.04456	–0.607				
Interior volume * Mini dummy				–0.7072	–2.145	**
Interior volume * Sedan A dummy				–0.3771	–1.42	
Interior volume * Sedan B dummy				–0.5361	–1.534	
Interior volume * Sedan C dummy				–0.2563	–0.795	
Interia volume * Sport dummy				–0.5273	–2.667	***
Interior volume * Wagon dummy				–0.2253	–1.509	
Interior volume * Minivan dummy				0.12	1.40	
Degree of instability (= height / (width*length)) (m^{-1})	–11.48	–0.028		–1122	–1.725	*
Mini dummy	0.16	1.13		1.98	2.40	**
Sedan A dummy	0.28	2.18	**	1.27	1.66	*
Sedan B dummy	0.32	2.52	**	1.87	1.70	*
Sedan C dummy	0.057	0.50		0.80	0.73	
Sport dummy	0.71	5.67	****	1.96	4.13	****
Wagon dummy	–0.02915	–0.248		0.59	1.22	
Minivan dummy	–0.1632	–0.924		–1.149	–2.5	**
Time dummy	0.11	1.07		0.11	1.13	
k: dispersion	15.37	19.46		18.59	5.01	
Null deviance		1154.99			1233.13	
Residual deviance		409.36			409.41	

Note) ****, ***, **, and * indicate significance at the 0.1%, 1%, 5%, and 10% levels, respectively.

At this point, we compile the information obtained although the estimation accuracy is not very high since in certain samples, the number of fatalities is zero.

- All the variables that we considered as driver-related factors (the rate of alcohol consumption, accident history, and the rate at which the seatbelt is worn) are significant at the 10% level, and their signs are as we expected.
- With respect to the dummy variables for the types of vehicles, the coefficient of sport and specialty cars is particularly greater than that of the others; this shows that the number of fatalities for sport and specialty cars is large. The coefficient of the dummies for light family cars and sedans are also relatively high. On the other hand, the coefficient of minivans is small.
- Among vehicles of the same type, the larger the weight, the smaller the number of fatalities.
- As regards the result of regression A in Table 3, the interior volume and the degree of instability, a variable representative of the height of the center of gravity, are not significant; this is probably due to their strong correlation (the correlation coefficient is equal to –0.8). However, when we use the cross-term of the interior volume and the dummy variables for each type of vehicle as an explanatory variable, the regression result showed statistically significant values particularly for vehicles with a small interior volume such as light family cars and sport and specialty cars, as in regression B of Table 3. Among these types of vehicles, the larger the interior volume, the smaller was the occurrence of rate fatal accidents. Simultaneously, the degree of instability is significant at the 10% level, and we obtained the result that higher the height of the vehicle against the value of the product of the width and length of the vehicle, the smaller was the occurrence rate of fatal accidents. This may be because cars with greater vehicle height provide drivers with a wider field of view and make it easy for them to drive and engage in avoidance behavior. On the other hand, the risk of overturn can be greater as the center of gravity will be higher. Further considerations will be required for each effect.
- With regard to the cross-term of the weight of the vehicle and the dummy for the types of vehicle, we omit the explanation of the regression results since it was not statistically significant.



Note 1) The panel on the left-hand side shows the deviance residuals, while that on the right-hand side shows the response residuals.

2) The deviance residual is the normalized value of the margin between μ, estimated using the contribution ratio with respect to the log likelihood and the observed value of Y, and shows the fitness of the generalized linear model. On the other hand, the response residual simply shows the margin between the assumed μ and the observed Y. We have expressed the latter in a form that is easier to understand. For the details, please refer to McCullagh and Nelder (1989) as well as Agresti (1996).

Figure 2 Residual plots

It is appropriate to add the assessment score of New Car Assessment as one of the explanatory variables. However, the number of samples for which scores could be collected in this study is limited to 46 and is inadequate for the estimation. For reference we indicated the result obtained from the limited number of variables excluding the dummy for the types of vehicles in Table 4. The coefficient of the assessment score is negative, and we can interpret the occurrence rate of fatal accidents is smaller as the score is higher, albeit statistically insignificant.

Table 4 Negative binominal regression estimate on the occurrence rate of fatal accidents with the assessment score

Variable	coefficients estimates	z-value	Significance
Intercept	4.03	1.33	
Assessment Score	–0.0019717	–0.182	
Weights (kg)	–0.0009332	–3.673	****
Rate at which the seatbelt is worn (%)	–0.0696212	–2.325	**
Rate of alcohol consumption (%)	0.014	2.14	**
Accident history (%)	0.0024	0.33	
k:dispersion	1.31	3.20	
Null deviance		81.8	
Residual deviance		51.3	

Note) ****, ***, **, and * indicate significance at the 0.1%, 1%, 5%, and 10% levels, respectively.

3.2. The occurrence rate of accidents

Table 5 and Figure 3 present the estimated results of the occurrence rate of accidents. Likewise, we will explain the results obtained as below.

- As in the case of the occurrence rate of fatal accidents, driver-related factors—the rate of alcohol consumption, accident history, and the rate at which the seatbelt is worn—have considerable influence on the occurrence rate of accidents. However, with regard to the rate of alcohol consumption, in contrast with the case of fatal accidents, we obtained a negative coefficient. While we can ascertain that the rate of alcohol consumption is not really relevant in the case of accidents without fatalities, we will need to review this interpretation in the future.
- With respect to the dummy variables for the types of vehicles, as in the case of fatal accidents, the coefficient of sport and specialty cars is particularly greater than that of the others; on the other hand, that of minivans is small. It is highly possible that small children are often on board in minivans, and this might encourage safe driving.

・ Among cars of the same type of vehicle, the larger the weight, the fewer the accidents.

・ The larger the interior volume, the fewer the accidents. This shows that the interior volume becomes a representative variable for the number of passengers, and drivers attempt to drive safely when they have fellow passengers. In addition, as the interior volume increases, the field of view becomes relatively wider and manifests the possibility for drivers to drive more safely.

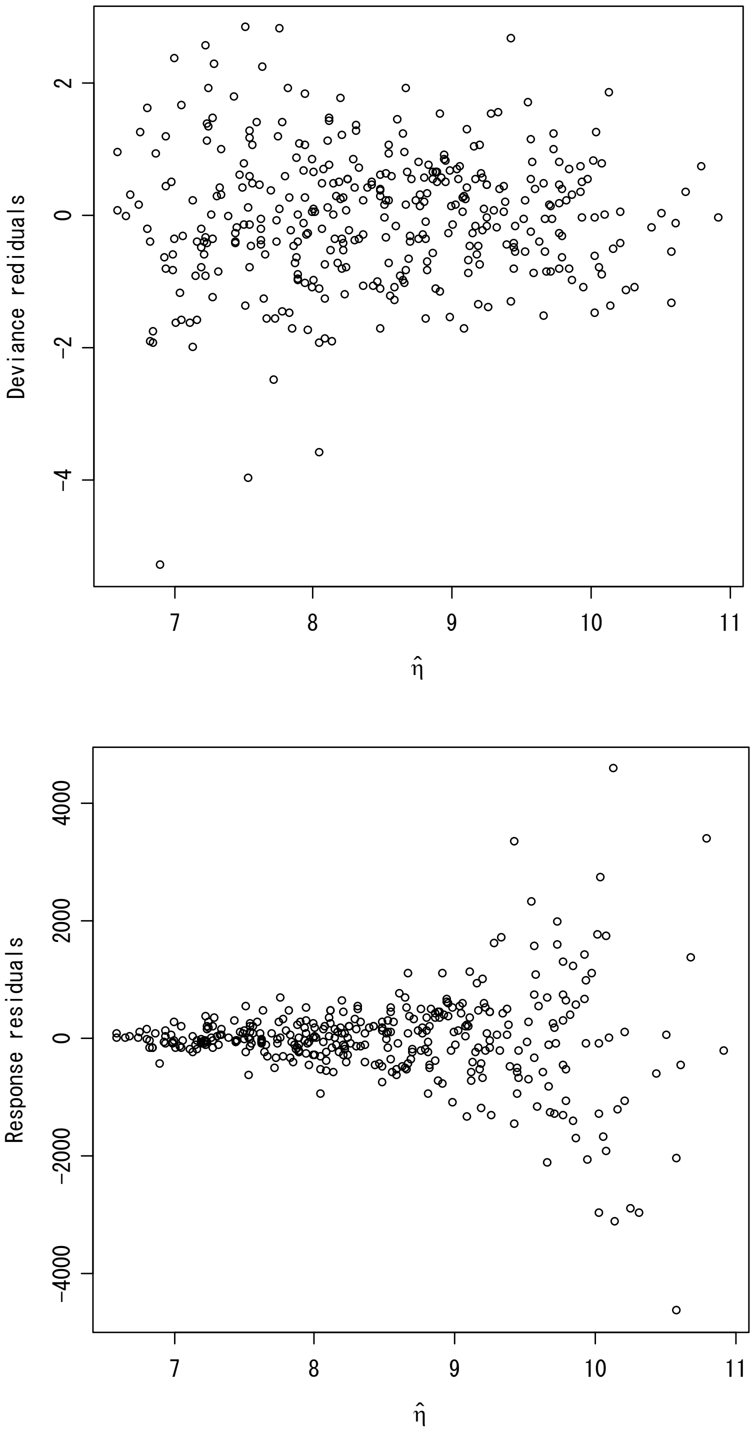
・ As the degree of instability becomes greater, fewer accidents occur as in the case of the occurrence rate of fatal accidents.

・ Considering the technological advancement and the differences in the road condition, we have introduced a dummy for the time points. However, as in the case of fatal accidents, it was not statistically significant.

Table 5 Regression estimate of the occurrence rate of accidents

Variable	Coefficient estimate	z-value	Significance
Intercept	6.76	17.43	****
Rate of alcohol consumption (%)	–0.05518	–3.947	****
Accident history (%)	0.030	9.93	****
Rate at which the seatbelt is worn (%)	–0.03538	–8.621	****
Weight (kg)	–0.000186	–5.105	****
Interior volume (m^3)	–0.06909	–4.585	****
Degree of instability (= height / (width*length)) (m^{-1})	–652.5	–7.044	****
Mini dummy	–0.06874	–2.281	**
Sedan A dummy	0.025	0.91	
Sedan B dummy	–0.01412	–0.536	
Sedan C dummy	–0.04618	–1.94	*
Sport dummy	0.076	2.77	***
Wagon dummy	0.038	1.59	
Minivan dummy	–0.1372	–3.954	****
Time dummy	0.017	0.68	
k: dispersion	116.56	12.82	****
Null deviance		1228.62	
Residual deviance		369.27	

Note) ****, ***, **, and * indicate significance at the 0.1%, 1%, 5%, and 10% levels, respectively.



Note) The panel on the left-hand side shows the deviance residuals, while that on the right-hand side shows the response residuals. To some extent, there are samples whose deviance residual is large.

Figure 3 Residual plots

4. Discussion

In this section, based on the formulas estimated in the previous section, we analyze the relationship between the adjusted occurrence rate of fatal accidents and the other variables. Here, the adjusted occurrence rate implies the estimated occurrence rate that has been adjusted by excluding the effects of driver-related characteristics. When excluding these effects, we calculated the average of each driver-related variable by assuming that the characteristics are the same for all types of vehicles, and we assign these values to the result of Regression B in Table 3.

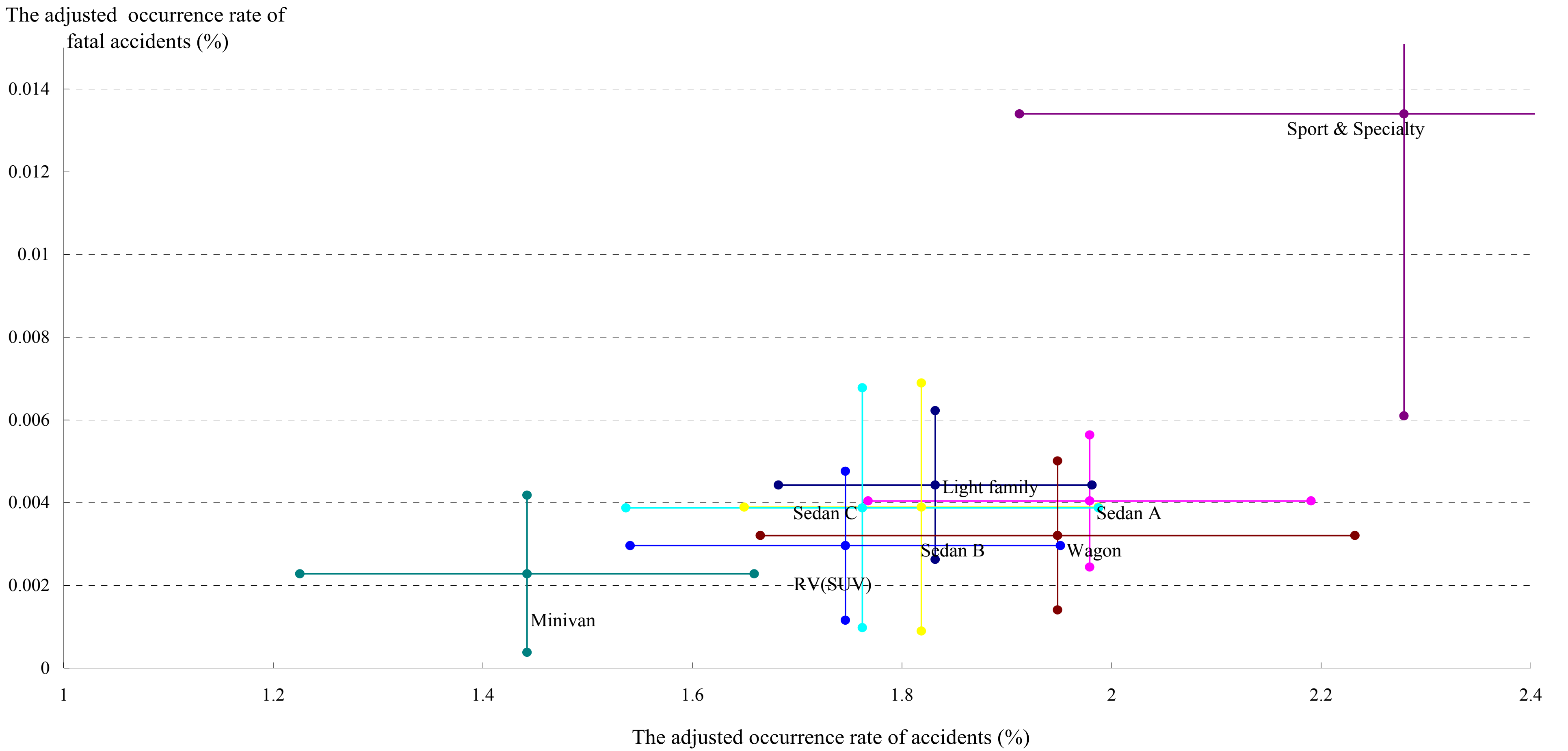
4.1. Relationship between the occurrence rates of fatal accidents and accidents

As indicated in Figure 4, the occurrence rates of both accidents and fatal accidents are the lowest in minivans and by far the highest in sport and specialty cars. The rates for the other types of vehicles are located somewhere between the above two, and the differences among them are extremely small.

4.2. Relationship between the occurrence rate of fatal accidents and the score of New Car Assessment

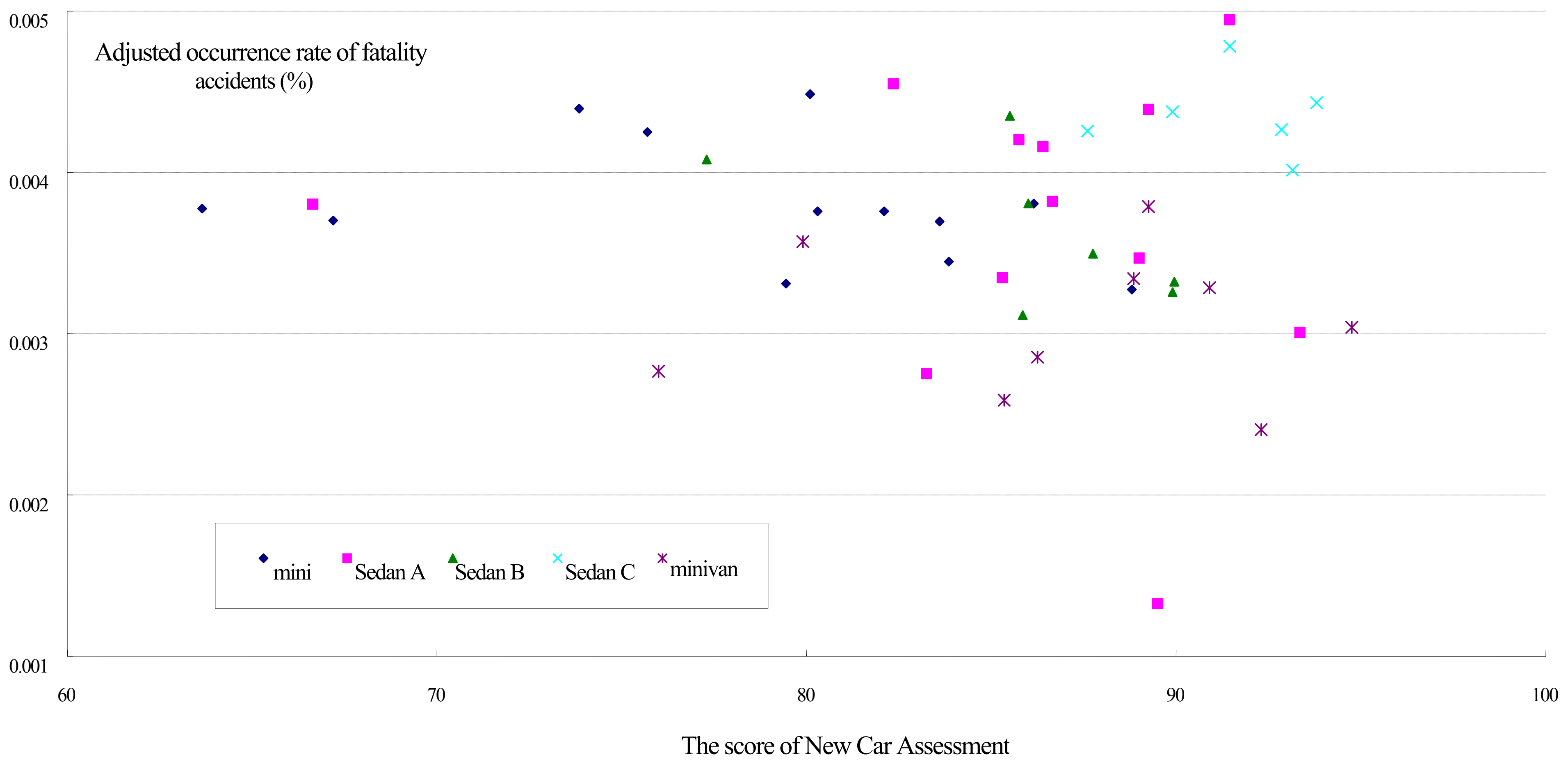
In the evaluation method in New Car Assessment, frontal crash tests and side-impact tests are conducted and are scored from 0 to 100. A score of 0 means that there is a risk of receiving serious injuries in all body parts, such as the head, in both the tests, whereas a score of 100 means that there is a considerably low risk of sustaining serious injuries in all body parts in both the tests. The evaluation indicates that the light family car has a low score and, consequently, a higher risk of injury in the case of an accident under the same condition.

While the number of samples for which we could obtain assessment scores was limited, it is evident that the correlation between the assessment scores and the occurrence rate of fatal accidents is weak, as demonstrated in Figure 5; further, there are cars with a high occurrence rate of fatal accidents even among those with high assessment points.



Note) The horizontal and vertical width of each point is in the range of ±1σ for each type of vehicle. σ indicates the standard deviation.

Figure 4 Relationship between the adjusted occurrence rates of fatal accidents andthat of accidents

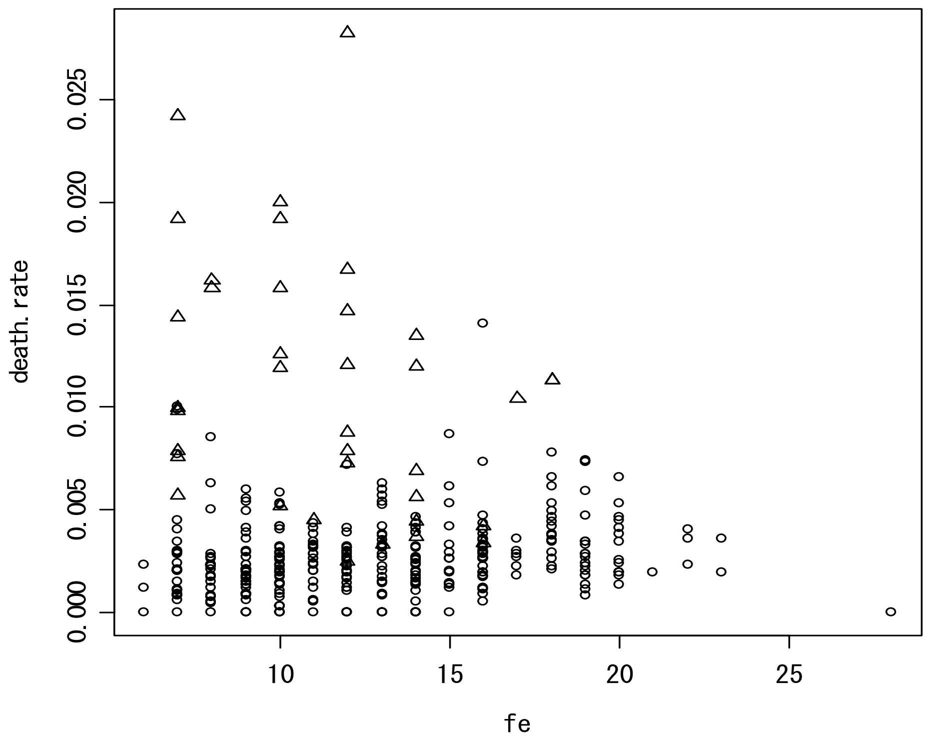


Note) The correlation coefficient is equal to 0.09.

Figure 5 Correlation between the score of New Car Assessment and the adjusted occurrence rate of fatal accidents

4.3. Relationship between the occurrence rate of fatal accidents and fuel economy

There is a high degree of negative correlation between the weight of the vehicle and fuel economy as in Figure 1. The lighter the weight of the vehicle, the higher is the fuel economy. Figure 6 illustrates the relationship between the fuel economy and the adjusted occurrence rate of fatal accidents.



Note 1) "Fe" denotes "Fuel economy," while "Death rate" refers to the occurrence rate of fatal accidents.

2) Δ represents sport and specialty cars.

3) The correlation coefficient is equal to –0.03.

Figure 6 Relationship between fuel economy and the adjusted occurrence rate of fatal accidents

In the previous section, we assumed that among cars of the same type of vehicle, the occurrence rates of fatal accidents and accidents decrease as the vehicle weight increases. However, for sport and specialty cars, we understood that the occurrence rate of fatal accidents decreases as fuel efficiency improves, as illustrated in Figure 6.

Thus, we analyzed the relationship between fuel efficiency and the occurrence rates of fatal accidents by using the mixture of regressions model (Turner, 2000); in this model, the parameters are estimated by the EM algorithm under the assumption that the figure of the distribution is a mixed distribution of several regression lines. Table 6 shows the result of this regression. We can assume three straight lines showing three different relations—downward sloping (safety increases as fuel efficiency improves), nearly constant (fuel efficiency is not related to safety), and upward sloping (safety decreases as fuel efficiency improves).

Table 6 Regression estimates of the adjusted occurrence rate of fatal accidents by using mixture of regressions model

Component	Intercept	β	σ^2	λ
1	0.0080	–1.99e – 04	4.40e – 06	0.16
2	0.024	–8.74e – 04	2.00e – 05	0.07
3	9.35e – 04	9.90e – 05	1.42e – 06	0.77

Note 1) The adjusted rate of the occurrence of fatal accidents

= Intercept + β (fuel efficiency) + ε, $\varepsilon \sim N(0,\sigma^2)$

2) AIC = –3395.934; AIC (of simple linear regression) = –3036.484; AIC is minimized when the number of components = 3.

3) λ : Probability of each component

Why do sport and specialty cars show opposite tendencies? We would like to point out that the shape of the vehicle and the existence of fellow passengers are important variables.

Figure 7 shows the relationship between the interior volume and the occurrence rate of fatal accidents. In general, it is likely that drivers of cars with a small interior volume do not have fellow passengers, while those driving cars with a large interior volume are likely to have fellow passengers. We can imagine that drivers give less consideration to safety when they drive alone.

In addition, as explained above, there is a high degree of correlation between the interior volume and the degree of instability. It would therefore be possible to consider that it is the shape of the vehicle and not fuel economy that contributes to the decrease in the number of fatal accidents. We prove this by the fact that sport and specialty cars have high occurrence rates of fatal accidents as well as accidents.

Accordingly, we suggest that there is no universal relationship between the safety and the fuel economy of vehicles and the interior volume (the number of passengers on board) or degree of instability (width of field of view) is a more important variable relating to safety. Therefore, as in recent studies in the United States, we cannot necessarily accept Crandall and Graham's1 assumption that there would be more accidents when we reduce the vehicle weight in order to improve fuel efficiency.

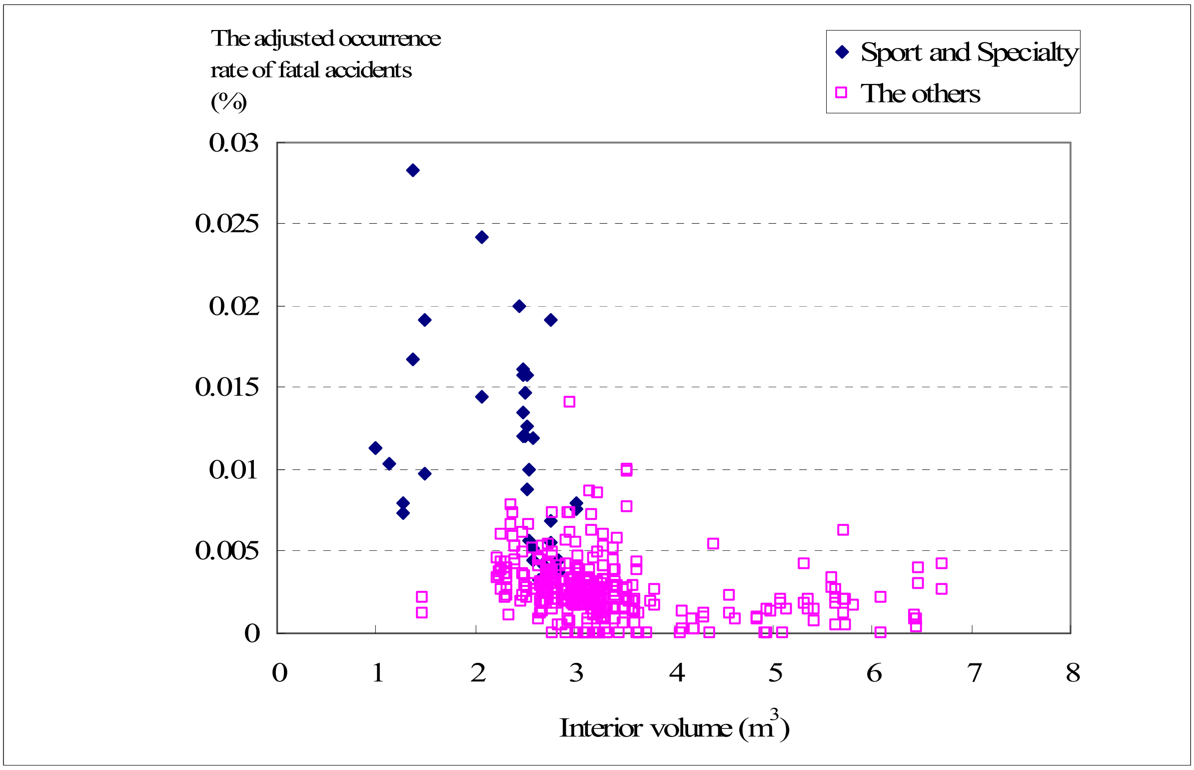


Figure 7 Relationship between the interior volume and the adjusted occurrence rate of fatal accidents

5. Concluding Remarks

Traditionally, the safety of passenger cars has been assessed using laboratory data from the viewpoint of risk of death and injury when accidents occur. This study is different from the previous studies in that we have examined the safety of each type of vehicle from the perspective of the occurrence rates of fatal accidents and accidents, based on the actual accident data adjusted by excluding the effects of driver-related characteristics. Thus, we demonstrated that apart from minivans that have the highest level of safety and sport and specialty cars that have the lowest safety level, there is no major difference among the other types of vehicles, and safety is not necessarily strongly correlated with the assessment result. Furthermore, the analysis suggests that it is possible that the occurrence rates of fatal accidents and accidents decreases as the weight of the vehicle increases (fuel efficiency deteriorates); however, sport and specialty cars exhibit the opposite correlation; further, the results state that it is highly possible that the shape of the vehicle, with respect to aspects such as the interior volume or the degree of instability(width of field of view), has a greater effect on the safety of passenger cars. Therefore, as suggested by recent studies in the United States, the assumption that fuel efficiency conflicts with safety is incorrect.

In this study, we suggested an assumption that the shape of the vehicle has a greater effect on the occurrence rates of fatal accidents and accidents than fuel economy. However, we should examine the validity of this assumption in considering variables that were used as dummy variables for each type of vehicle in this study (for example, horsepower, brake performance, collision-safe body, air-bag, intended purpose, factors related to the driving environment such as travel distance and the frequency of driving on highways, and the age of the driver). If this assumption is accepted, we will be able to improve the safety of passenger cars by modifying the design of the vehicle; further, we can expect future technological development that can improve both fuel efficiency and safety.

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