COST-BENEFIT ANALYSIS OF VEHICLE SAFETY REGULATIONS

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ABSTRACT: Vehicle safety regulations promote R&D activities, and the R&D costs are ultimately reflected in vehicle prices. While the vehicle itself becomes safer, drivers may drive less carefully because they feel safe. It is unclear whether drivers and/or fellow passengers actually become safer. The regulations also result in an increase in vehicle weights. Heavier vehicles negatively impact fuel economy. This paper presents an empirical cost-benefit analysis of vehicular regulations in Japan by considering these issues simultaneously. We find a 2- to 3-year lag between R&D activities, an increase in parts cost, and the setting of regulations. The cost-benefit ratio appears to be

almost 1.

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1. INTRODUCTION

Road traffic injuries are a huge public health and development problem, resulting in almost 1.2 million deaths per year and injuring or disabling approximately 20 to 50 million people annually (WHO, 2004). To reduce the number of accidents that result in death or injury, governments have introduced vehicle safety regulations in addition to driver education, road improvements, and insurance systems. Recently, safety belts, air-bags, and safer (energy absorbing) body structures have been introduced in Japan (Table 1). These technologies are often referred to as passive technologies. The basic concept of these technologies is to minimize human damage after an accident; however, they do not lower the probability of an accident, which is what automobile makers are currently focusing on.

[Table 1 about here]

[Figure 1 about here]

Post 1993 in Japan, the number of accidents resulting in fatalities has displayed a declining tendency, although casualties have been increasing (Figure 1, top). Taking into account the increase in vehicle ownership, we calculated the accident rates per vehicle (Figure 1, bottom). Given the above, we infer that while casualties show a slight increase, fatalities have been decreasing. Since driving conditions such as the average speed on road and traffic signals per road length have been mostly constant after 1993, the reduction in fatalities can be largely attributed to safety regulations [1].

Vehicle safety regulations promote R&D activities in the automobile industry, and the R&D costs are ultimately reflected in vehicle prices. This study aims to determine whether or not these vehicle regulations have been cost effective. While the vehicle itself may become safer, there is a possibility that drivers may drive less carefully because they feel safe. Moreover, it is unclear whether or not drivers and/or fellow passengers have actually become safer. Hence, cost effectiveness should be determined from the viewpoint of the actual change in the number of accidents and not from that of the vehicles' attributes. In addition, vehicle safety regulations increase vehicle weight, and heavier vehicles have a negative impact on fuel economy. This negative impact needs to be taken into account when determining the cost effectiveness of vehicle safety regulations.

This study examines the cost effectiveness of Japan's passive vehicle regulations after 1993. In the US, regulatory impact assessment is mandated, and the National Highway Traffic Safety Administration (NHTSA) shows the added vehicle cost and weight resulting from the implementation of the federal motor vehicle safety standards (Tarbet, 2004). In the case of Europe, a review of the effectiveness of the casualty reduction measures in the UK between 1980 and 1996 showed that passive safety or crash protection improvements to vehicles were the greatest contributors to reducing casualties (Broughton et al., 2000). Another review suggested that the improved standards for crash protection could reduce deaths and serious injuries on European roads by as much as 20% (ETSC, 1993). However, in Japan, the decision-making process with respect to regulations is unclear, and the cost effectiveness of regulations has not been publicly discussed.

In this study, we will address the following issues in order to evaluate cost effectiveness:

1. Timing of R&D activities triggered by regulations
2. Costs of vehicles and their parts resulting from efforts to comply with regulations

3. Costs and benefits of regulations

The remainder of this paper is organized in the following manner. Section 2 describes the study methodology. Section 3 presents the data used for analysis; section 4, the results. Finally, the concluding remarks and the scope for further research are provided in section 5.

2. METHODOLOGY

Addressing the abovementioned 3 issues is not an easy task; this is because unlike the US, Japan has no system for regulatory impact assessment, and therefore, automobile makers do not respond positively when asked for cost data. In addition, the following issues should also be considered:

* R&D: Automobile makers invest in R&D regardless of the regulations.

* Cost: Costs of vehicles and their parts are affected by material and other capital costs and are prone to fluctuation.

* Effectiveness: Drivers and driving conditions also influence accidents.

In this study, we assume that the cost increase resulting from safety regulations is directly proportional to the percentage of patents related to safety regulations. Needless to say, this is a bold assumption; however, we believe this can be a first-order approximation in the case where information on the costing of vehicle parts is unavailable. In addition, to control the cost fluctuation, we estimate the cost change with/without using the moving average (5 years). With regard to the estimation of the reduction in fatalities, we were unable to separate the effects of the change in drivers from those of the change in driving conditions; however, we separated the effects of vehicle age from those of vehicle model year.

Given the above, we adopted the following steps for the purpose of this study (Figure 2):

1. Data collection on the total number of patents and the percentage of patents related to vehicle safety regulations
2. Estimation of the increase in the cost of vehicles and their parts as a result of safety regulations
3. Analysis of accident data according to vehicle type and vehicle age

[Figure 2 about here]

3. DATA

Table 2 presents the data collected. In this study, we focused on the costs of the vehicle body, air-bags (including head restraints), and safety belts, following the implementation of safety regulations. However, other vehicle parts such as lamps and tires were excluded because we found that there was almost no change in the cost. Further, we categorized the cars into the following 2 brackets: compact cars (less than 2000 cc) and large cars (more than 2000 cc). In this paper, fatality is defined as death within 24 hours of the accident. In addition, the injury cases were also divided into 2 groups: serious injury cases (procurement with more than 30 days) and minor injury cases.

[Table 2 about here]

4. RESULTS

1) Regulations, patents, and costs

First, we interviewed some of the people in charge of regulations at the Toyota Motor Corporation. All the interviewees admitted that in Japan, automobile makers begin investing in R&D activities shortly after they notice the regulators' efforts to set or reinforce regulations. By analyzing traffic accidents data, regulators examine the efforts taken by overseas regulators on regulations and attempt to set or reinforce regulations. The representatives of automobile makers maintain constant correspondence with the regulators. Subsequently, closed meetings between regulators and automobile makers are held several times. During this period, automobile makers invest in R&D activities and develop new technologies to comply with the new standards. Finally, the regulators announce the new standards. In sum, R&D activities resulting from safety regulations in fact take place before the new standard is implemented. Thus, when a new standard is announced, almost all new cars in Japan are in compliance with the standard.

Therefore, we collected patent data not only after the regulations were implemented but also from 5 years before. Subsequently, we investigated the relationships among regulations, patents, and the cost of parts (Figure 3).

An almost 2- to 3-year lag between the implementation of patents and an increase in the cost of parts is evident. In addition, a 2- to 3- year lag between the change in cost and the setting of the regulation is also indicated. Following the implementation of a new technology, automobile makers as well as makers of automobile parts attempt to reduce costs and/or improve functions. In general, the cost of parts with the same technology decreases and that of parts with the new technology introduced by R&D activities increases over time. As a result, the cost of parts fluctuates. Therefore, we estimated the cost change with/without using the moving average (5 years).

[Figure 3 about here]

Furthermore, it is obvious that in order to maximize profits and promote sales, automobile makers will always invest in R&D activities, for example, in areas of body design and amenity equipments, regardless of the regulations. Therefore, we need to survey not only the number of patents but also their contents. For this purpose, we divide the patents into two categories—patents related to safety regulations and other patents—based on their keywords. Figure 4 shows the change in the percentage of patents related to safety regulations. Although there are fluctuations, almost 30% of patents are related to safety regulations. Thus, on average, 30% of the total number of patents are related to safety regulations. Based on the analysis conducted in this paper, we assumed that 30% of the increase in the cost and weight of vehicles results from safety regulations.

[Figure 4 about here]

2) Increase in the cost of vehicles as a result of safety regulations

By adding the costs of safety belts and air-bags and considering the number of units as well as 30% of the vehicle body cost, we can estimate the increase in the cost of vehicles resulting from the implementation of safety regulations (Figure 5). With regard to the calculation of vehicle body cost, we consider the average weight increase because vehicles become heavier as they move into the large car category from the compact car one.

[Figure 5 about here]

The average vehicle price has increased by about 0.55 million yen. It is estimated that about 30% of the cost increase (0.14–0.26 million yen) is a result of safety regulations.

3) Change in traffic accidents and benefits resulting from safety regulations

[Figure 6 about here]

Figure 6 illustrates the change in traffic accidents per car according to the type of accident. Clearly, the number of fatalities and serious injury cases decreases and that of minor injury cases tends to increase. However, these values may be incorrect because they may be simultaneously influenced by both the model year and the vehicle age. To separate the effects of the two, we assumed a two-way loglinear model (simple fixed effect model) and estimated the parameters (β_i, γ_j).

$$\ln(Y_{ij}) = \alpha + \beta_i + \gamma_j + \varepsilon_{ij}$$

Here, Y_{ij} is the number of accidents per million registered cars, depending on the accident type (fatality, serious injury, and minor injury); β_i is the model year; γ_j is the vehicle age; and ε_{ij} is the error term ~ $N(0, \sigma^2)$.

The ANOVA tables for large cars are presented in Table 3. Similar results were obtained for compact cars. The results indicated that model year has statistically significant effects on the number of accidents; further, car age was also statistically significant except in the case of fatalities.

Figure 7 illustrates the fixed effects of model year and vehicle age; the declining tendency of the number of fatalities and serious injury cases after 1993 is evident. On the other hand, the number of minor injury cases displayed a tendency to increase. Interestingly, it was seen that new cars were safer than used cars and that car drivers drove more carefully. In this analysis, we have not included the impacts of changes in road conditions, drivers, and travel distance; this is because in comparison to the increase in the number of cars, there were no considerable changes in these factors. However, a closer investigation of these factors should be conducted in future research. Based on these fixed effects, we estimated the reduction in traffic accidents.

[Table 3 about here]

[Figure 7 about here]

The Japanese government provides the values for traffic fatality prevention (VFP) and the values for injury prevention (VIP) for the cost-benefit analysis of transport infrastructure improvement projects. However, these values are based on labor loss and are considerably different from willingness to pay to reduce the probability of fatality/serious injury. In general, hedonic wage or the contingent valuation method is used to obtain the value of statistical life (VSL). Blaeij et al. (2003) show the result of a meta-analysis for VFP in road safety. On average, a VPF of about 3.46 million (1996 US dollars) for Stated Preference (SP) studies and about 1.19 million (1996 US dollars) for Revealed Preference (RP) studies was obtained, although the range of estimates that they reviewed varied from 392,000–30,838,000 (1996 US dollars). In Japan, Imanaga

(2000) estimated VFP as well as the value of serious injury cases using contingent valuation. In this study, we applied 300 million yen for VFP and 200 million yen for serious injury cases. With regard to minor injury cases, we assumed 5 million yen per accident as VIP.

By adding the change in β from 1993 to 2004, VFP, and VIP, we estimated the benefits of safety regulations. In this study, we assume that all cars are used for 10 years. The 10-year benefits are calculated based on a 3% discount rate.

4) Change in fuel economy

In general, an increase in the weight of a vehicle reduces its fuel efficiency. Since 1993, the average vehicle weight has increased by about 50 kg. Since we assume that the effect of regulations is 30% of the total effect, that is, 15 kg, we can state that safety regulations result in a 1% increase in the weight of the vehicle. In Japan, the fuel economy elasticity of vehicle weight is almost –1 (Figure 8). Therefore, safety regulations increase fuel cost by about 1%. With regard to other emissions such as NOx and PM, we have excluded these from the analysis because almost all Japanese cars are powered by gasoline, and it is not the weight but the fuel quality that has a major impact on emissions.

[Figure 8 about here]

5) Cost effectiveness of safety regulations

Table 4 summarizes the benefits as well as the costs of safety regulations in Japan. We are unable to state with certainty whether or not the Japanese safety regulations were cost effective, although it depends on VFP/VIP. In addition, if we overestimate the increase in vehicle cost due to a misassumption, B/C will be improved.

[Table 4 about here]

5. CONCLUSIONS

In this study, we focused on Japan’s passive safety regulations with regard to vehicles and estimated the cost effectiveness of these regulations on the basis of the patents resulting from R&D activities. Further, not only changes in traffic accidents but also changes in fuel economy were considered in the analysis. The following results were obtained:

- There is a 2- to 3-year lag between price change and the implementation of a regulation; a similar lag exists between price change and R&D investment. Japanese regulations are determined through negotiation between the industry and government. By the time a regulation is implemented, the new technology has almost been established. Therefore, we should consider this fact for the regulation analysis. We considered a 5-year lag for the cost.
- About 30% of the total increase in cost results from regulations. This percentage is considerably high in comparison with that derived by previous studies (Sperling, 2004 and Tarbet, 2004). This may be a result of our bold assumption that the percentage of regulation-related cost increase is directly proportional to the percentage of regulation related patents. This needs to be analyzed further.
- The cost-benefit ratio appears to be almost 1, although it depends on the VFP and VIP; moreover, traffic fatality rates have been decreasing since 1993.

As mentioned previously, the Japanese vehicle safety regulations are passive measures. At present, automobile makers have been developing active technologies such as lane keeping, brake-assist, and caution systems to inform the driver of approaching obstacles, pedestrians, fleets, and so on. These active accident prevention measures should be encouraged as opposed to passive ones.

However, the assumptions made in this paper are extremely strong. In particular, the assumption that the percentage of cost increase resulting from safety regulations is directly proportional to the percentage of patents related to safety regulations should be verified carefully. Although we interviewed some people in charge of the regulations at the Toyota Motor Corporation, we were unable to obtain accurate values. In future research, not only outside researchers but also those from within the company should be involved. Further, it is necessary to provide a breakdown in cost according to the costs of parts including material cost change, for example, adopt the activity-based costing approach. Moreover, the Japanese government should introduce regulatory impact analyses including cost effectiveness surveys.

In addition, we assumed that the benefits, that is, the reduction in fatalities and serious injury cases when using new cars after 1993, are a result of safety regulations. This assumption is reflected in the fact that driving conditions such as travel speed and road safety facilities are almost constant and that the total ambulance activity time has not improved since 1993. However, the drivers' attitude toward safety and safety consciousness may have improved. There is a need to further analyze the traffic accident data together with the Institute of Traffic Accident Research and Data Analysis.

One remaining question is whether further regulation is required to promote these active technologies. If consumers can obtain accurate information, such regulations are unnecessary. In the 1980s and 90s, automobile makers did not have a positive attitude toward improving safety due to the accompanying increase in cost. However, at present, safety has become one of the key issues for sales promotion. Therefore, consumer behavior with regard to car purchase should also be analyzed.

Finally, an international comparison is extremely important not only with regard to the cost effectiveness of regulations but also relating to the contents of these regulations. As mentioned in the first section, Japan shows a declining trend in the case of fatalities; however, casualties are increasing. The cause of this widening gap needs to be analyzed systematically.

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TABLES

Table 1. Vehicle safety regulation regarding vehicle body and safety belts in Japan after 1993

Year	Body[a]	Safety belts
1993		Rear safety belt and alarm system for non-safety belt drivers
1996	Standards for frontal impact protection	
1999	Standards for side impact protection	
2000	Standards for offset impact protection	

[a] Air-bags are essential in order to be in compliance with the standards relating to the body of the vehicle

Table 2. Data list

	Data	Source or Organization
Patents	Number of patents by type	Japan Patent Office
Cost, weight, and fuel economy	Parts	Machinery statistics Shipment survey
	Vehicle	Japanese Motor Vehicle Guidebook: Annual report on the number of automobile registrations
Traffic accidents	Number of vehicles by age	Vehicle registration statistics
	Number of fatalities and injury cases	Institute for Traffic Accident Research and Data Analysis

Table 3. ANOVA tables for large cars

ANOVA table of death rate					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	25	511.69	20.47	3.445	1.25E-06
Age	14	128.51	9.18	1.545	0.1013
Residuals	154	914.96	5.94		

ANOVA table of serious injury rate					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	25	31.377	1.255	19.315	< 2.2e-16
Age	14	14.791	1.057	16.260	< 2.2e-16
Residuals	154	10.007	0.065		

ANOVA table of minor injury rate					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	25	9.114	0.365	12.478	< 2.2e-16
Age	14	11.972	0.855	29.268	< 2.2e-16
Residuals	154	4.499	0.029		

Table 4. Benefits and Costs of Safety Regulations in Japan

Benefit	Thousand yen/10 years	Costs	Thousand yen/10 years
Reduction in fatalities	90	Increase in vehicle cost	140–260
Reduction in serious injury cases	120	Increase in fuel cost[a]	8.3
		Increase in the cost of minor injury cases	15
Total	210	Total	163–283
B/C	0.74–1.29		

[a] Travel distance: 100,000 (km/10 years); fuel economy: 12 (km/L); gasoline price: 100 (yen/L)

FOOTNOTE

[1] Needless to say, this gap could be a result of the emergency medical care system. However, the statistics of the fire defense agency show that the time required to transport casualties to the hospital after receiving an emergency call has been increasing and that the total ambulance activity time has not improved. Therefore, we assume that safety regulations have played a major role in the reduction of fatalities after 1993.

CAPTIONS

Figure 1. Changes in the number of traffic accidents (top) and in the traffic accident rate per vehicle (bottom)

Figure 2. Estimation flow of the benefits and costs of safety regulations

Figure 3. Percentage of patents and the cost of vehicle parts (safety belt)

Figure 4. Change in the percentage of patents related to safety regulations

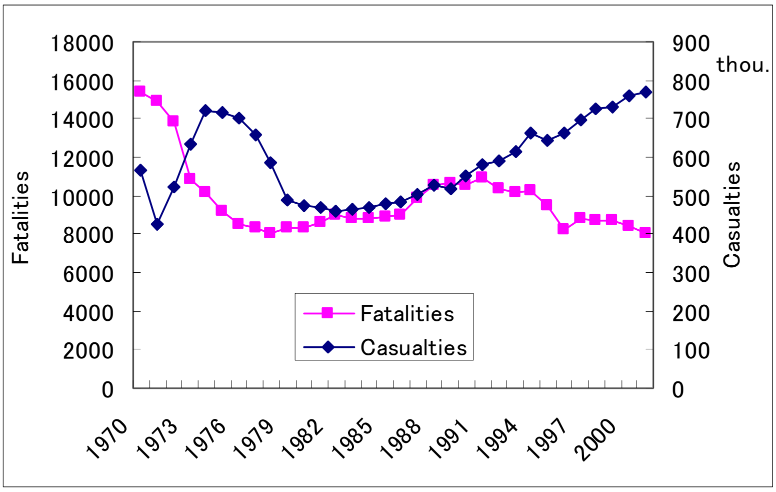
Figure 5. Increase in the cost of vehicles as a result of safety regulations

Figure 6. Change in the traffic accidents per vehicle (%) according to accident type

Figure 7. Fixed effects of safety improvements according to model year and vehicle age

Figure 8. Relationship between vehicle weight (kg) and fuel economy (km/L)

FIGURES



18000
16000
14000
12000
10000
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Fatalities
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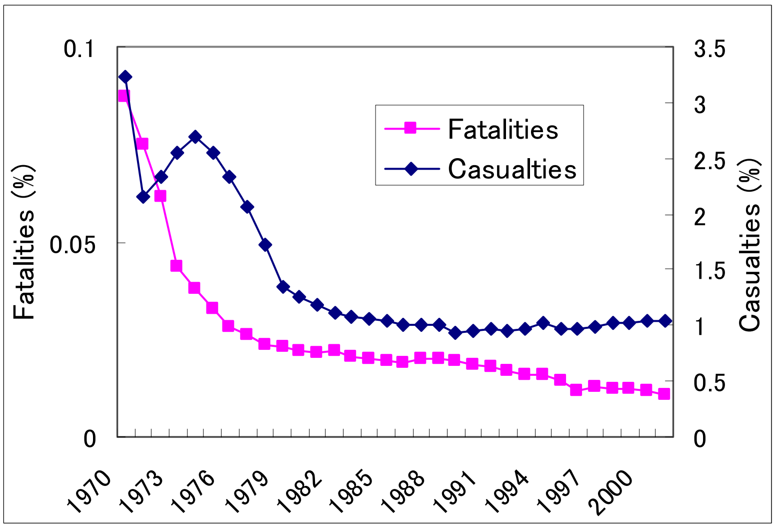

0.1
0.05
0
Fatalities (%)
3.5
3
2.5
2
1.5
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Casualties (%)
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1973
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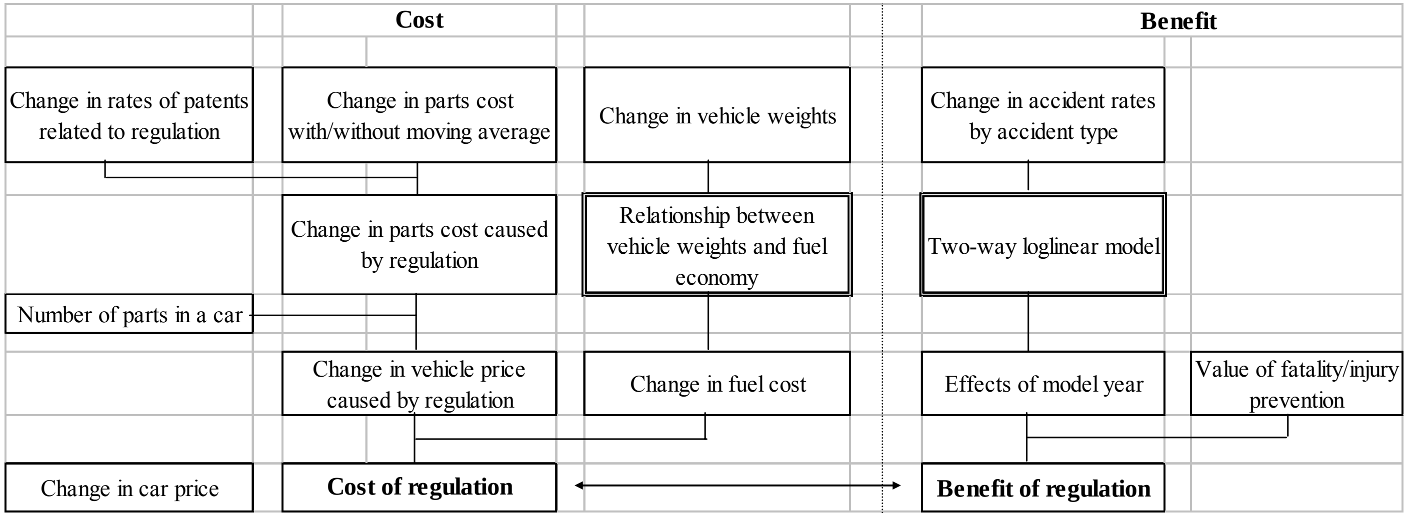
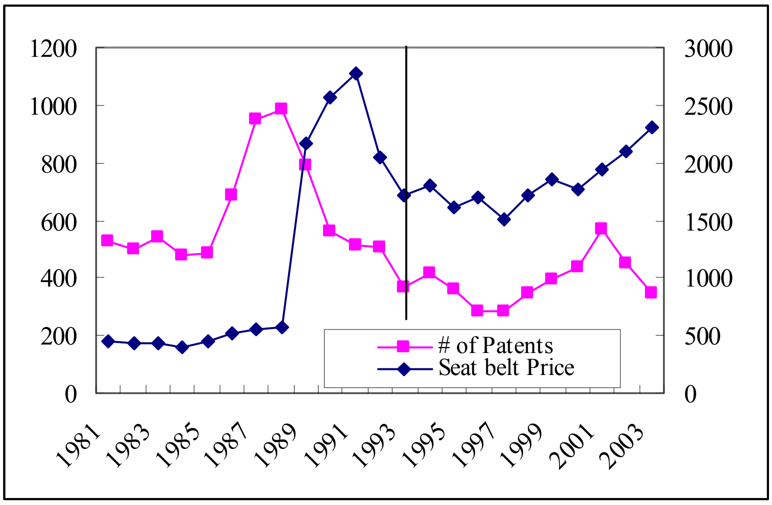
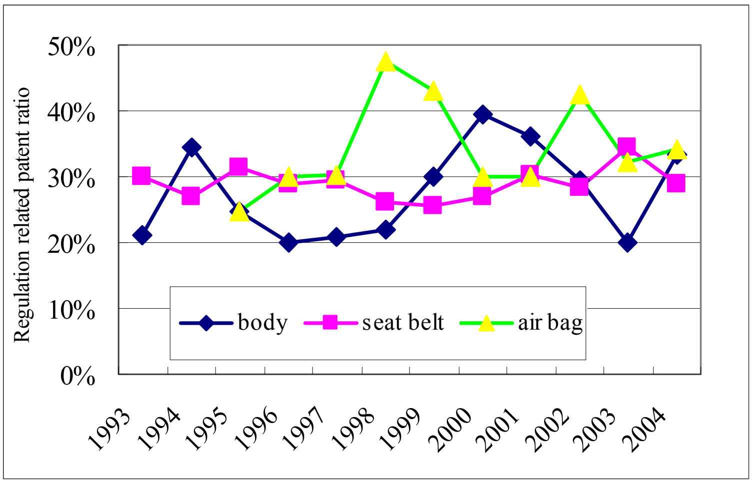

Cost
Benefit
Change in rates of patents related to regulation
Change in parts cost with/without moving average
Change in vehicle weights
Change in accident rates by accident type
Change in parts cost caused by regulation
Relationship between vehicle weights and fuel economy
Two-way loglinear model
Number of parts in a car
Change in vehicle price caused by regulation
Change in fuel cost
Effects of model year
Value of fatality/injury prevention
Change in car price
Cost of regulation
Benefit of regulation



Note: The vertical line indicates the year when the regulation was implemented.


50%
40%
30%
20%
10%
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Regulation related patent ratio
body
seat belt
air bag
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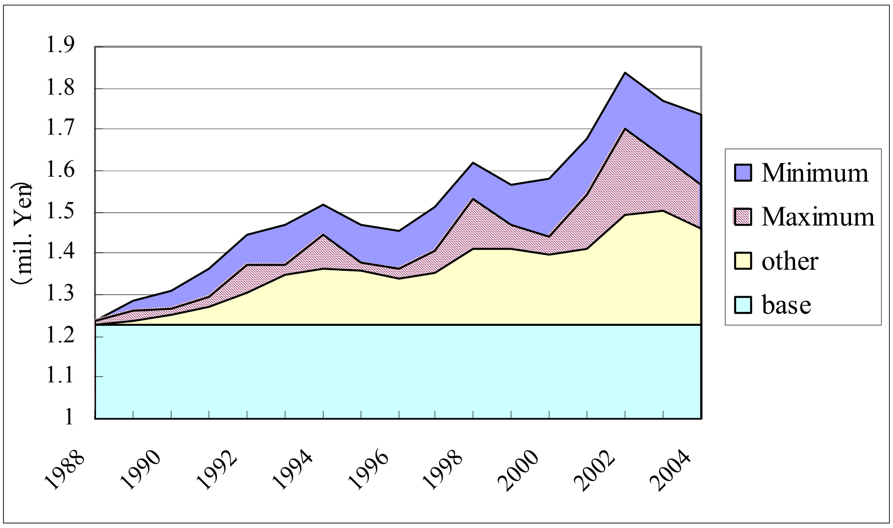
1.9
1.8
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1.6
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1
(mil. Yen)
1988
1990
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1994
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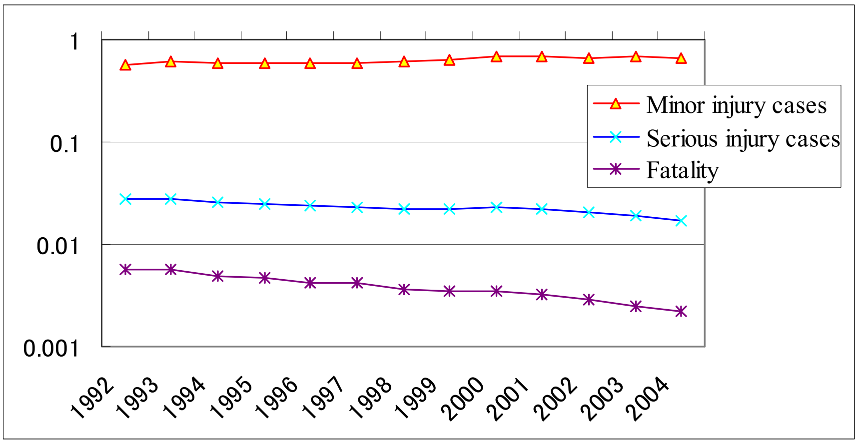
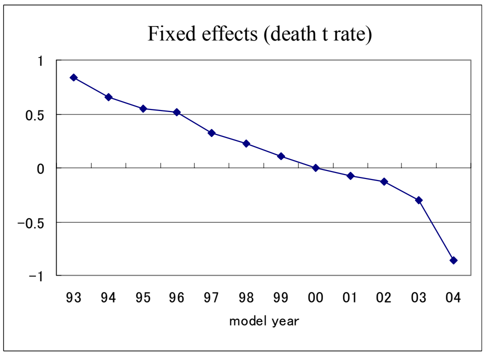


Note: Logarithmic values are used in the vertical axis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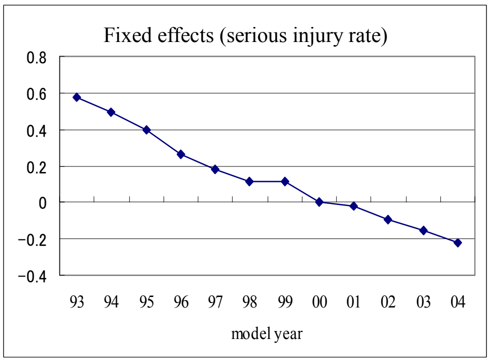
93 94 95 96 97 98 99 00 01 02 03 04
model year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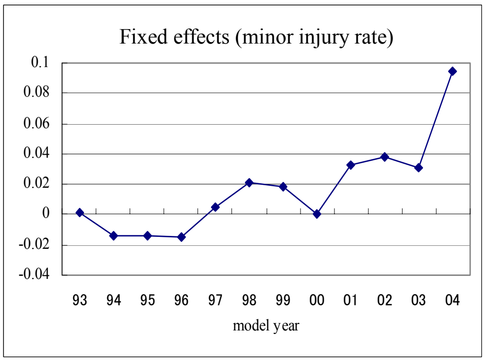
model year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0
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-0.04
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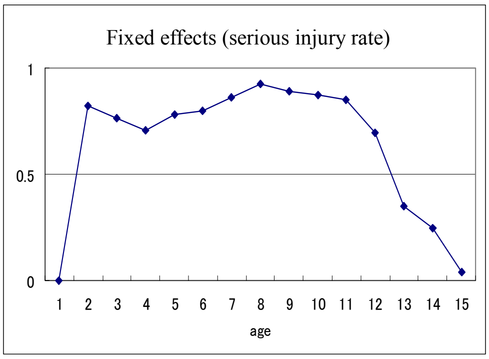
model year


Fixed effects (serious injury rate)
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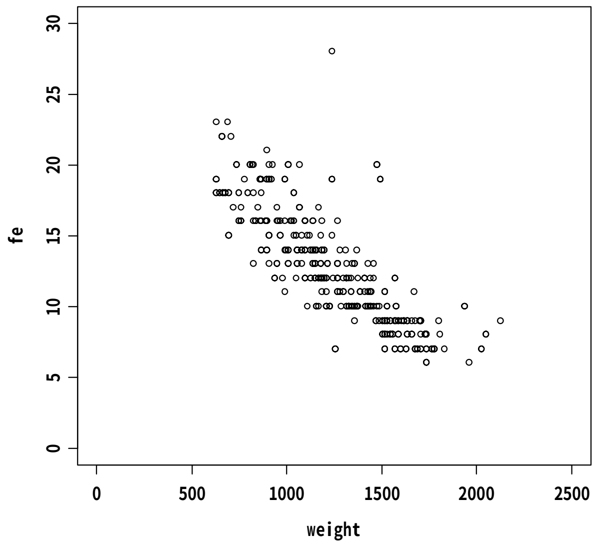
0.5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
age



Note: One outlier point over 25 (km/L) in fuel economy (fe) is Prius (Toyota).

The simple regression result is as follows:

ln(fe) = 9.40 – 0.97 * ln(weight) ; R2 = 0.71; number of samples = 361;

(40.43) (–29.75) (t-stats)