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Impact of the Diffusion of Automotive-Safety Technologies in Japan: Preliminary Study

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Abstract:

The objective of this paper is to understand quantitatively the extent to which strengthened automotive safety standards, and the resulting incorporation of new technologies into existing vehicles, contributed to reducing traffic-accident losses in Japan. Our major findings, in this paper, is that the increasing sophistication of passive-safety technologies, and their increasingly widespread adoption, are important contributing factors to the significant decrease in traffic-accident losses in Japan in recent years. Nonetheless, the additional contributions of these factors in reducing traffic-accident losses is gradually decreasing. We conclude that increased adoption of *active*-safety technologies—which reduce accidents themselves—will play an important role in achieving further reductions in losses due to traffic accidents in the future.

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1. Introduction

Automotive safety provisions in Japan have been implemented by the following two ways. One is regulations designed to ensure safety—affecting factors such as the structure of the vehicle body, on-board devices, maximum passenger capacity, and maximum cargo capacity—and implemented in the form of safety standards based on Japan's Road Vehicle Transport Law. Tests during vehicle inspections have been ensured compliance with regulations. The other is a system of driver licensing and traffic rules, based on the Road Traffic Law, to ensure safe use of automobiles (Sano et al., 2008). Safety standards regarding the body of the automobile itself have been in place since 1951 and have since been revised or expanded, including a major revision in 1968. This major revision followed the 1966 enactment of the U.S. National Traffic and Motor Vehicle Safety Act and the public announcement in 1967 of the Federal Motor Vehicle Safety Standards (FMVSS) based on that legislation; in 1968, Japan's Transport Ministry announced *automotive safety standards* and mandated a revision and strengthening of *safety standards for road transport vehicles*. Subsequently, in 1972—following the recommendations of the Council for Transport Technology "Motor Vehicle Safety Measures" (「自動車の安全確保のための技術的方策について」) which describes about the concept and target of *automotive safety standards*—automobile safety standards have been revised based on the recommendations.

The objective of this paper is to understand quantitatively the extent to which these strengthened automotive safety standards, and the resulting incorporation of new technologies into existing vehicles, contributed to reducing traffic-accident losses.

The structure of this paper is as follows. In Section 2, we discuss advantages and disadvantages of the methods used by Japan's Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in its assessments—conducted every 5 years—of the efficacy of automotive safety provisions. In Section 3, we discuss the methods used in this paper to assess effectiveness and the data we use in our analysis. Section 4 presents the results of our analysis.

2. MLIT's assessments of the effectiveness of automotive safety provisions

In Japan, the effectiveness of automotive safety provisions is assessed every 5 years as part of the *automotive safety-provision cycle*, a plan-do-check-act (PDCA) cycle （「自動車の安全対策のサイクル（PDCA）」）recommended in 1999 by the Council for Transport Technology. The most recent evaluation was conducted in 2016 as an interim assessment of progress toward the goal established by the Council of Transport Policy (2011)—*to introduce automotive safety standards that reduce traffic fatalities within 30 days by 1,000 in 2020 compared to 2010 levels*—and the results of this evaluation have been collected by the Council of Transport Policy (2016).

The effectiveness tests conducted by the Council of Transport Policy specify particular safety technologies and specific types of accidents—involving specific types of vehicles—that may be prevented by those technologies. For active-safety technologies, the assessments consider numbers of accidents and numbers of fatalities as variables for evaluating effectiveness. For passive-safety technologies, the assessments consider only numbers of fatalities as variables for evaluating effectiveness. The impact of a safety technology is taken to be the difference between the actual numbers of accidents and fatalities in 2014 and the numbers of accidents and fatalities that would be expected assuming that the diffusion rate of individual technology remains the same as that in 2010. This method of assessing effectiveness has the advantage that the effectiveness of each technology can be evaluated. However, this method is problematic for following reasons. First, among the various severity classes of personal bodily injuries due to automobile accidents, only reductions in *fatalities* are taken into account. The impact of safety technologies in reducing the severity of other classes of bodily injury—reducing *serious injuries* to *minor injuries* and *minor injuries* to *no injuries*—is entirely neglected. Second, in some cases, the prevention of a single accident is attributed to multiple technologies simultaneously, posing the risk of overestimating the overall effect when accumulating the effect of individual technology.

Compared to the methods used by the Council of Transport Policy (2016), the methods used in this paper do not allow assessment of the impact of individual technologies, and in this sense, they are inferior to the methods of the Council of Transport Policy (2016). On the other hand, our analytical methods solve the two problems noted above, and in this sense, they are in fact superior to the methods of the Council of Transport Policy (2016).

3. Methods for analyzing contributing factors and sources of statistical data

In this paper, we adopt a top-down approach to assessing the effectiveness of automotive safety technologies, decomposing results from previous years on the year-by-year evolution of traffic-accident losses into individual contributing factors to identify the contributions of technologies. In this section, we discuss the methods we used to perform this decomposition (3.1), the relationship between technologies and the individual factors we identify (3.2), and our sources for the data we use (3.3).

The analysis of this paper is restricted to accidents involving vehicle-vehicle collisions between 4-wheel vehicles other than special purpose vehicles.

other than special purpose vehicles.

3.1. Decomposing year-by-year variations in traffic-accident losses into various contributing factors

Figure 1 is a schematic depiction of our framework for decomposing year-by-year variations in traffic-accident losses into various contributing factors.

First, as an initial step, we decompose the year-by-year variation in traffic-accident losses into three primary factors using the following formulas:

$$S = D \cdot A \cdot L \tag{1}$$

$$\frac{\Delta S}{S} = \frac{\Delta D}{D} + \frac{\Delta A}{A} + \frac{\Delta L}{L} + R \tag{2}$$

where,

S is the total loss due to traffic accidents (computed, for each year, as the product of the loss per accident in Table 2 and the number of victims),

D is the total number of kilometers traveled.

A is the number of accidents per kilometer traveled,

L is the amount of the losses per accident, and

R denotes the indecomposable residual (A).

Based on this model, the relative year-by-year variation in losses due to traffic accidents may be approximated by the sum of the relative variations in three quantities: total kilometers traveled, accidents per kilometer traveled, and losses per accident.

Next, as a second step, we further decompose the variations in each of these three quantities into various contributing factors, as follows. First, the total number of kilometers traveled is the product of the number of vehicles owned and the travel distance per vehicle, and thus—in analogy with Eq. (2)—the majority of the relative variation in the *total number of kilometers traveled* may be decomposed into the relative variations in the *total number of vehicles owned* and the *number of kilometers traveled per vehicle.* We refer to any residual variation in the *total number of kilometers traveled* not captured by this two-factor decomposition as the *indecomposable residual* (B). Going further, it is possible to identify the portion of the year-by-year variation in kilometers traveled per vehicle that is attributable to *variation due to changes in the composition of the vehicle fleet* (i.e. to variations in the relative proportions of the various vehicle types among all vehicles owned). We refer to any residual variation in the *total number of kilometers traveled per vehicle* as *variation due to other factors* (A). Here the *variation due to changes in the composition of the vehicle fleet* is computed as follows:

$$\left(\frac{\sum_{i=1}^{6}\left(\frac{d_{i,t}}{m_{i,t}} * m_{i,t+n}\right)}{\sum_{i=1}^{6} m_{i,t+n}} - \frac{\sum_{i=1}^{6} d_{i,t}}{\sum_{i=1}^{6} m_{i,t}}\right) / \frac{\sum_{i=1}^{6} d_{i,t}}{\sum_{i=1}^{6} m_{i,t}}, \qquad (3)$$

Where

$d_{i,t}$ is the *total number of kilometers traveled* by vehicles of type i in year t. For vehicle types, we use the 6-category classification scheme of Japan’s Road Transport Vehicle law: one category of buses (both standard-size and small), three categories of cargo vehicles (standard-size, small, and light), and two categories of passenger vehicles (standards-size/small and light),

$m_{i,t}$ is the number of vehicles of type i owned in year t,

n is the number years elapsed since initial year t. In this study, we consider the values n=3 or n=5.

Next, within the *variation in the number of accidents per kilometer traveled* it is possible to identify the contribution of the *variation in the number of vehicles owned, in the composition of the vehicle fleet, and in the number of kilometers traveled by each vehicle type.* After subtracting this contribution, we refer to any additional contributions to the *variation in the number of accidents per kilometer traveled* as the *variation due to other factors* (B). The *variation in the number of vehicles owned, in the composition of the vehicle fleet, and in the number of kilometers traveled by each vehicle type* is computed as follows:

$$(\frac{\sum_{i=1}^{6}\sum_{j=1}^{6}(a_{ij,t} * d_{i,t+n} * d_{j,t+n})}{\sum_{i}^{6} d_{i,t}} - \bar{a}_t)/\bar{a}_t, \tag{4}$$

where

$a_{ij,t}$ is computed by dividing the number of accidents in year t in which vehicles of types i and j were respectively the primary and secondary vehicle by the product $d_{i,t} \times d_{j,t}$ of the total distances traveled by vehicles of types i and j in year t. Here the primary party in a vehicle-vehicle accident is the driver or vehicle judged to be more at fault for the accident (or, if both parties are equally at fault, the driver or vehicle for whom personal bodily injuries are less severe). The *secondary* party is the party judged to be less at fault, or (if both parties are equally at fault) the party whose bodily injuries are more severe,

$\bar{a}_t$ is the weighted average of $a_{ij,t}$ over all vehicle types.

Finally, within the *variation in losses per accident* it is possible to identify the contribution of the *variation in numbers of accidents for each primary-secondary vehicle-type pair*; we refer to any residual variation in the *losses per accident* as *variation due to other factors* (C). Here the *variation in numbers of accidents for each primary-secondary vehicle-type pair* is computed as follows.

$$(\frac{\sum_{i=1}^{6}\sum_{j=1}^{6}(s_{ij,t} * a_{ij,t+n})}{\sum_{i=1}^{6}\sum_{j=1}^{6} a_{ij,t+n}} - \bar{s}_t)/\bar{s}_t, \tag{5}$$

Where

$s_{ij,t}$ is the loss incurred per individual accident for accidents in year t in which vehicles of types i and j were respectively the primary and secondary vehicle.

$\bar{s}_t$ is the weighted average of $s_{ij,t}$.

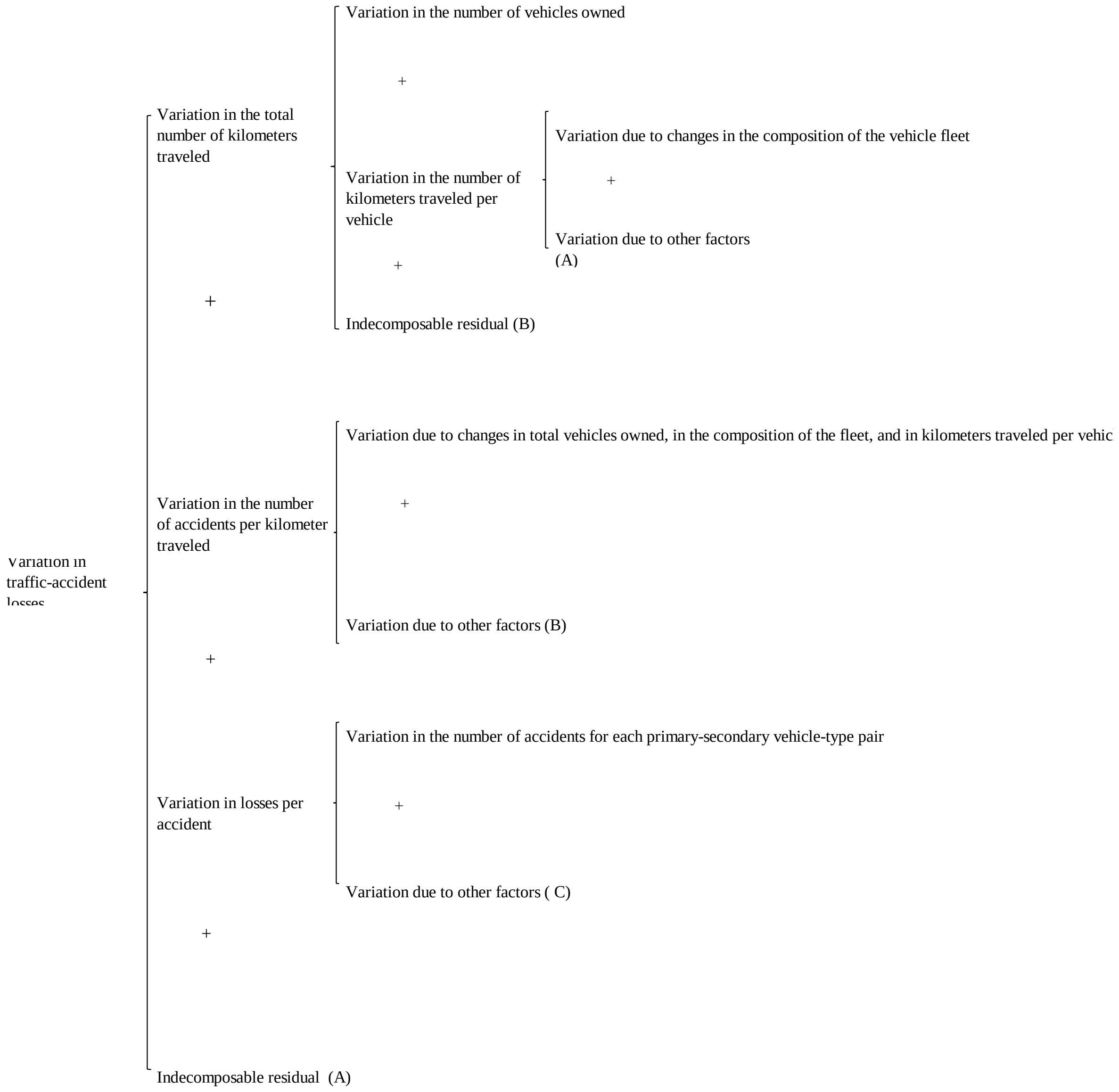


Figure 1: Decomposing the year-by-year evolution of traffic-accident losses into various contributing factors

3.2. Relationship between technology systems and the various contributing factors

Having analyzed the various factors affecting traffic-accident losses per the framework of Figure 1, we now discuss the extent to which the various factors in this decomposition are affected by increased adoption of safety technologies.

We first consider three contributing factors which are most likely *not* affected by automotive safety provisions but affected by the acquisition, ownership, and travel behaviors of vehicle users. These are, 1) *Variation in the total kilometers traveled,* 2) *Variation due to changes in total vehicles owned, in the composition of the fleet, and in kilometers traveled per vehicle type in variation in the number of kilometers traveled per vehicle,* and 3) *variation in the numbers of accidents for each primary-secondary vehicle-type pair in variation in losses per accident.* It is not possible to say that those behaviors of vehicle users are not affected by vehicle safety technologies. It is, however, assumed to be mainly affected by socioeconomic conditions.

The primary factors that are related to automotive safety provisions are *variations due to other factors* (B) and *variations due to other factors* (C) . First, *variations due to other factors* (B), which give rise to variations in the *number of accidents per kilometer traveled,* exert influence on many variables, including individual personal factors such as the extent to which drivers drive safely, infrastructure factors such as the condition of roads, the increasing sophistication and widespread adoption of active-safety technologies that prevent accidents themselves, and distortions arising from our assumption that numbers of accidents are proportional to total travel distance. Unfortunately, in this manuscript we are not able to isolate the impact of active safety technologies—and their increasing sophistication and widespread adoption in the future—as an individual factor.

Next, *variations due to other factors* (C) include all contributions to the *variation in losses per accident* that remain after subtracting *variation in the number of accidents for each primary-secondary vehicle-type pair,* and thus correspond to a pure measure of *variations in losses per accident.* Some of these variations may be due to improvements in the conditions under which collisions occur (such as reduced speed at collision time), which are already included in *variations due to other factors* (B). However, we believe that a considerable portion of these variations may be attributed to the increasing sophistication of collision-safety systems and other passive-safety technologies and their increasingly widespread installation in existing vehicles.

3.3. Data

We next discuss the sources of the data used in our analysis of contributing factors.

3.3.1. Loss amounts per individual traffic-accident victim

According to Japan’s Cabinet Office (2012), total losses due to traffic accidents amounted to 6.3 trillion yen. Losses may be broadly divided into monetary losses—those for which compensation in the form of monetary payment is possible—and non-monetary losses; total monetary and non-monetary losses in 2009 were approximately 4 trillion and 2.4 trillion yen respectively. The term “non-monetary losses” here refers to physical and emotional pain, suffering, and other hardship experienced by victims of traffic accidents; of the 5 categories of non-monetary losses defined by Japan’s cabinet office (2012) and listed in Table 1.

Table 2 lists monetary and non-monetary losses per individual victim for personal bodily injuries of various degrees of severity used in this study. Here we have used 2009 values as established by Japan’s Cabinet Office (2012) and adjusted to 2015 yen amounts using a GDP-deflator. Here we note that, whereas the Cabinet Office (2012) classifies personal bodily injuries into three severity classes—death, residual disability, and injury—the the *Japan Traffic Accident Database,* J-TAD (Macro) uses a different set of three categories: death, serious injury, and slight injury. Here we have performed calculations on the assumption that ITARDA’s categories of serious injury and slight injury correspond respectively to the residual disability and injury categories in the Cabinet Office classification. Table 2 reflects these results.

Table 1 Categories of non-monetary losses

Party	**Description**
Victim	Pain, suffering, or other hardship due to a traffic accident experienced by the victim of the accident
Friends and relatives of victim	Pain, suffering, or other hardship experienced by persons other than the victim due to the victim’s involvement in a traffic accident
Party responsible for causing the accident	Reduced quality of life experienced by the party responsible for causing the accident associated with factors such as downgraded credit or termination of employment due to having caused the accident
Friends and relatives of party responsible for causing the	Pain, suffering, or other hardship experienced by persons other than the party responsible for causing an accident due to that party’s

accident	involvement in the accident
Third parties	Sadness experienced upon learning of the accident; or other similar hardship

Source: Based on the definitions on page 17 of Japan’s Cabinet Office (2012).

Table 2: Monetary losses for personal bodily injuries of various degrees of severity

(Thousand yen)

	Death	Serious Injury	Slight Injury
Monetary Losses	31,122	9,546	1,599
Non-monetary losses	210,326	8,479	234
Total	241,449	18,025	1,833

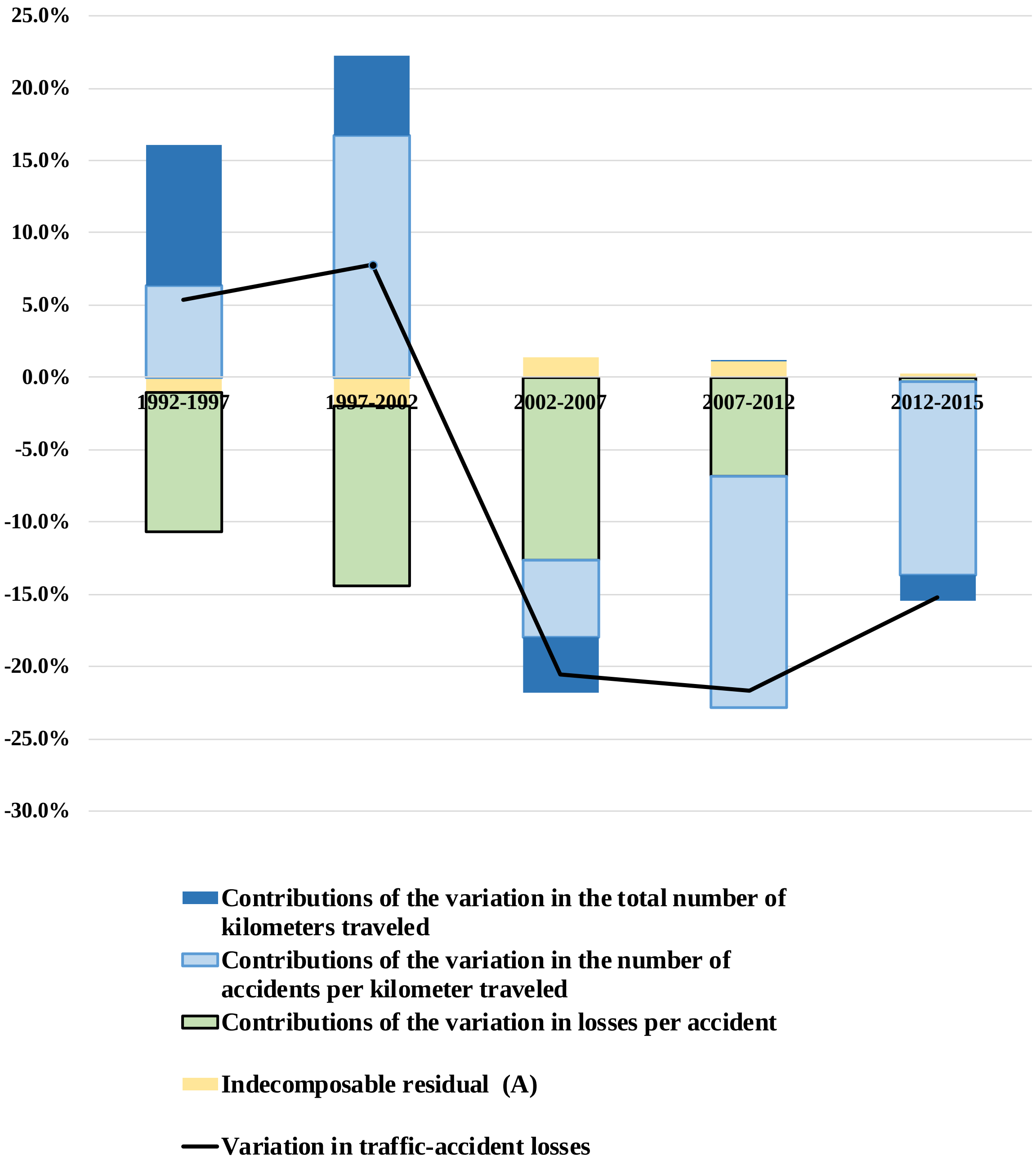
Source: Data taken from Japan Cabinet Office (2012) Table 6-4, “Loss amounts per individual victim (not excluding compensation for emotional suffering)” and multiplied by GDP deflator to convert to 2015 values.

3.3.2. Kilometers traveled, vehicles owned, accident counts and numbers of victims of personal bodily injuries of various severities

For numbers of kilometers traveled by vehicles of various types, we used data from the *Monthly Statistics on Motor Vehicle Transport* prepared by Japan's Ministry of Land, Infrastructure, Transport, and Tourism. For numbers of vehicles of various types owned, we used individual statistical data sets from the *Monthly Report of Vehicle Ownership Statistics* prepared by Japan's Automobile Inspection and Registration Information Association. For numbers of traffic accidents and numbers of victims of personal bodily injury of each severity class, we used data from J-TAD (Macro), which reports numbers of fatalities per 24-hour period.

4. Results of our analysis

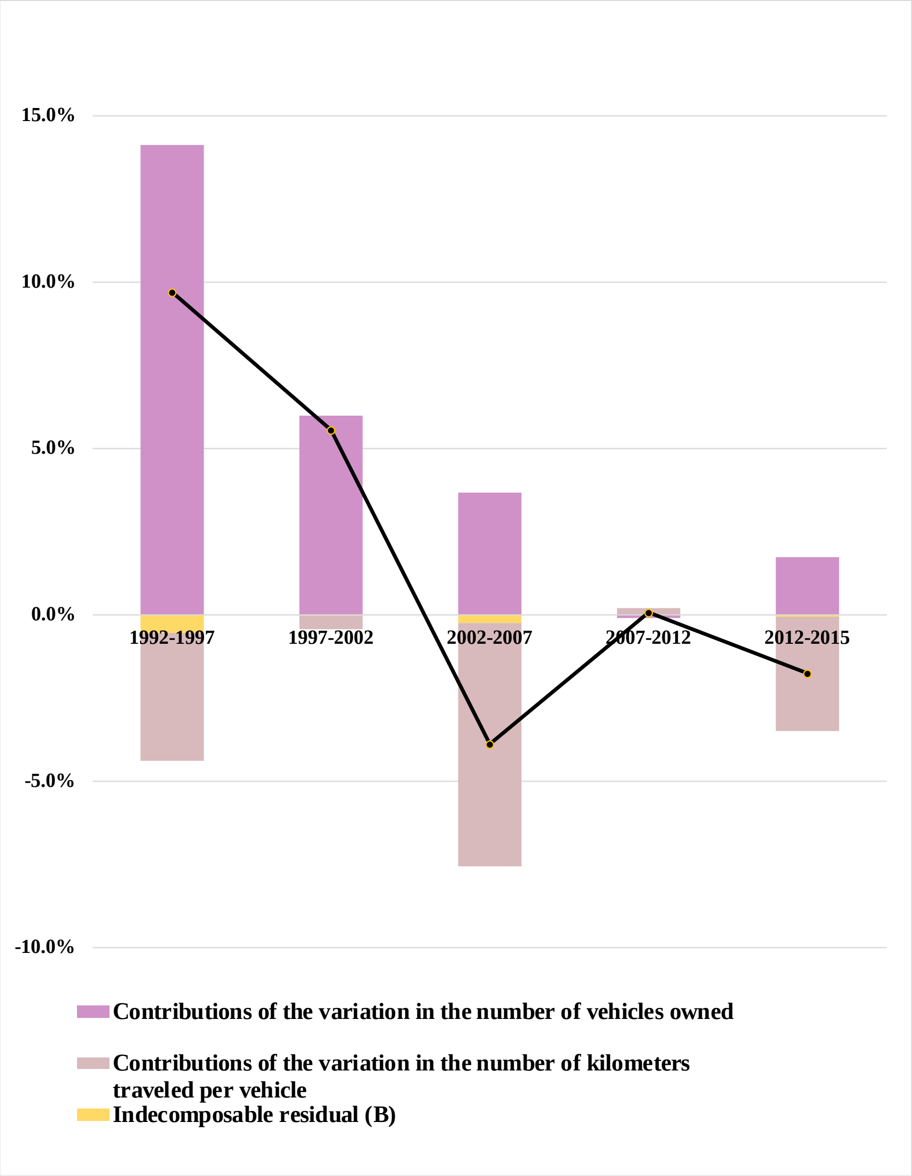
Figure 2 shows the results of the first stage of our contributing-factor decomposition based on equation (2). First, the relative *variation in traffic-accident losses* during the 5-year period between 1992 and 1997 was +5.3%; decomposing this total into the three primary contributing factors discussed above, we find the *variation in the total number of kilometers traveled* contributes +9.7%, the *variation in the number of accidents per kilometer traveled* contributes +6.3%, and the *variation in losses per accident* contributes -9.7%. The contribution of *indecomposable residua*l (A) was -1.0%. Although the increases in total travel distances and in accidents per kilometer traveled both tend to increase total accident losses, this is partially offset by a decrease in losses per accident. Dividing the 24 years between 1992 and 2015 into 5 intervals, we see that the *variation in the number of accidents per kilometer traveled* acted to increase total accident losses until 2002; however, since 2002 this factor has tended to decrease accident losses. In contrast, the *variation in losses per accident* has acted consistently to decrease total accident losses through the entire interval 1992-2015; however, the effect of this factor has gradually decreased over time, and makes almost no contribution to the reduction in total accident losses during the three-year interval 2012-2015.



Note: Losses due to accidents involving special purpose vehicles are not included

Figure 2: Factors contributing to year-by-year variation in traffic-accident losses (for vehicle-vehicle collisions involving 4-wheel vehicles)

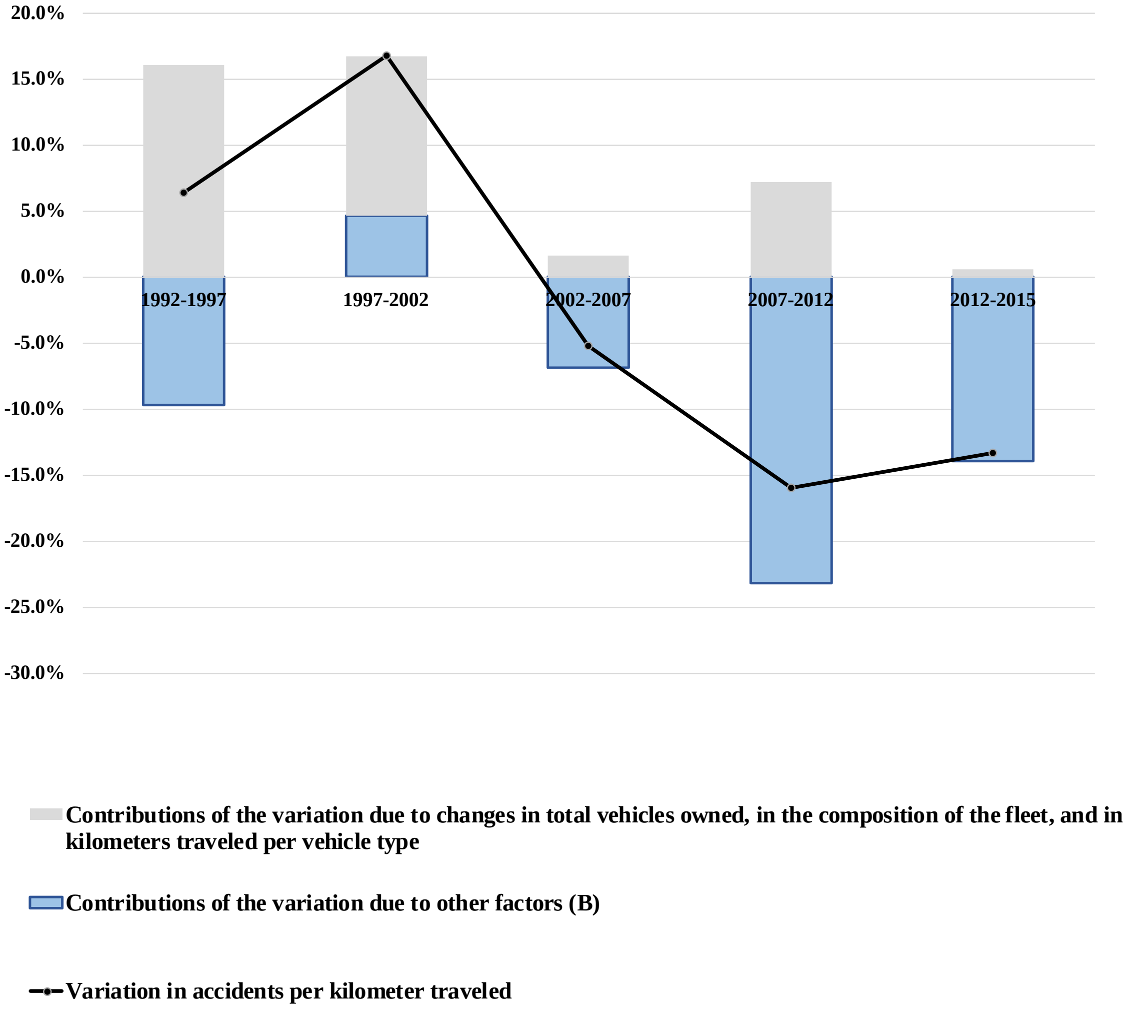
Figures 3-6 show results of the later stages of our contributing-factor decomposition. First, Figure 3 decomposes the *variation in the total kilometers traveled* into contributions from the *variation in the number of vehicles owned* and the *variation* *in the number of kilometers traveled per vehicle*. Excluding the period 2007-2012, the positive effect of the increase in numbers of vehicles owned is offset by the decrease in kilometers traveled per vehicle; in the intervals 2002-2007 and 2012-2015 the total travel distance decreased.



Note: Losses due to accidents involving special purpose vehicles are not included

Figure 3: Factors contributing to year-by-year variation in the total kilometers traveled (for vehicle-vehicle collisions involving 4-wheel vehicles)

Figure 4 decomposes the *variation in the number of accidents per kilometer traveled* into contributions from the *variation due to changes in total vehicles owned, in the composition of the fleet, and in kilometers traveled per vehicle type*, plus the contributions of *variation due to other factors* (B). The former factor acts consistently to increase accident losses; however, the *variation due to other factors* (B), which includes the effect of active-safety technologies, acts to decrease accident losses in all intervals except 2002-2007.

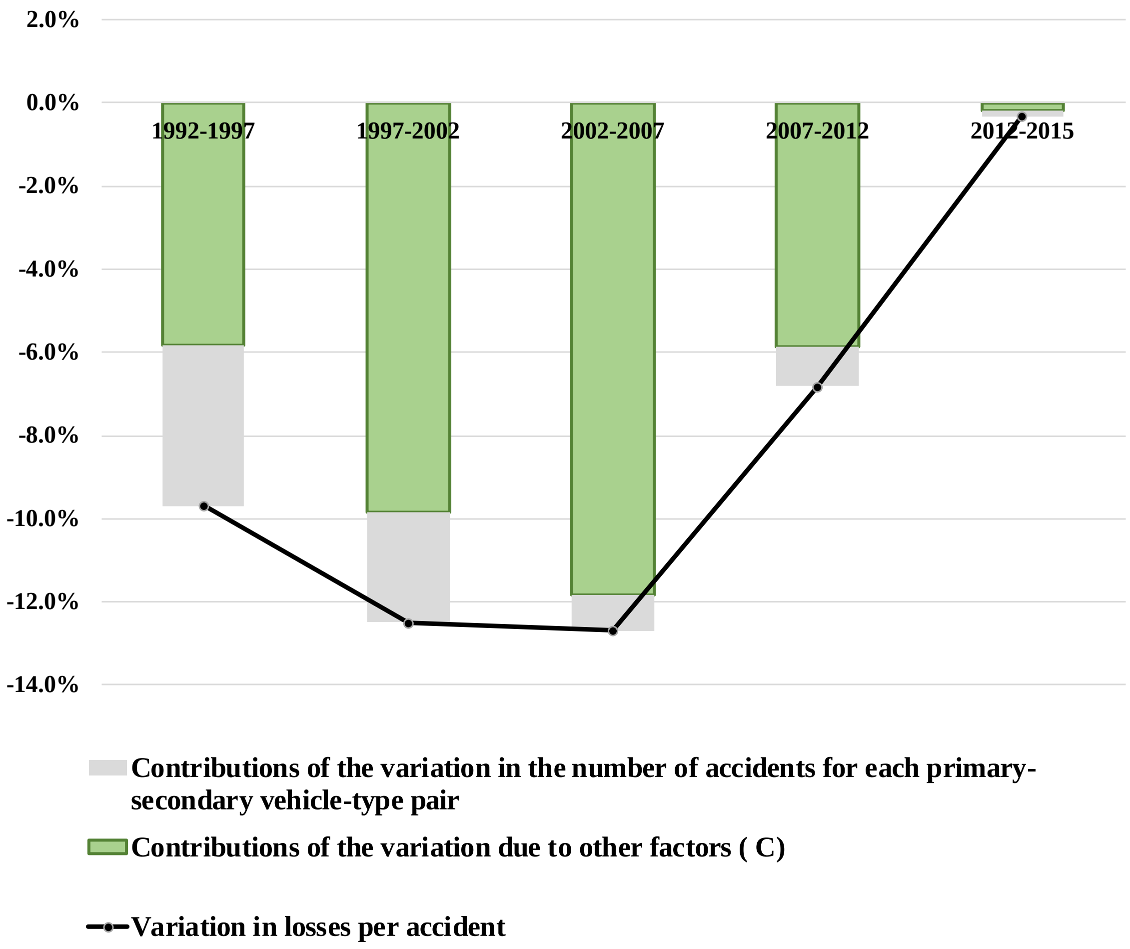


Note: Losses due to accidents involving special purpose vehicles are not included

Figure 4: Factors contributing to year-by-year variation in the number of accidents per kilometer traveled

Figure 5 decomposes the *variation in losses per accident* into the contribution of the *variation in the number of accidents for each primary-secondary vehicle-type pair* plus the *variation due to other factors* (C). Both of these factors act to decrease accident losses, but the *variation due to other factors* (C) is the dominant factor.

Inasmuch as regulatory standards governing collision safety were repeatedly strengthened throughout this interval, we may infer that the increasing sophistication of passive-safety technologies, and their increasingly widespread adoption in existing vehicles, played a significant role here.



Note: Losses due to accidents involving special purpose vehicles are not included

Figure 5: Factors contributing to losses per accident (for vehicle-vehicle collisions involving 4-wheel vehicles)

5. Conclusions and open problems

The analysis of this paper shows that the increasing sophistication of passive-safety technologies, and their increasingly widespread adoption, are important contributing factors to the significant decrease in traffic-accident losses in Japan in recent years.

Nonetheless, the additional contributions of these factors in reducing traffic-accident losses is gradually decreasing. In the future, increased adoption of *active*-safety technologies—which reduce accidents themselves—will play an important role in achieving further reductions in losses due to traffic accidents.

In the future, we hope to extend this study in three directions. First, the analysis of this paper was restricted to vehicle-vehicle collisions between four-wheel vehicles. We hope to expand our analysis to include two-wheel vehicles and to other types of traffic accidents including single-vehicle accidents, pedestrian-vehicle accidents. Second, the increasing frequency of traffic accidents caused by elderly drivers has become a societal problem in recent years, and the task of identifying ways in which technology can help to reduce accidents among the elderly is a particularly fascinating challenge. An analysis with focus restricted to accidents caused by elderly drivers would shed considerable light on this topic. Third, we hope to analyze and distinguish the various factors that, in this study, were lumped together in the categories *variations due to other factors* (B) (including the impact of active-safety technologies) and *variations due to other factors* (C) (including the impact of passive-safety technologies), and to identify the particular roles played by various types of technologies—such as collision-safety technologies and technologies offering reports to drivers—in reducing traffic-accident losses. To this end, we plan to conduct a regression analysis with *variations due to other factors* (B) and *variations due to other factors* (C) taken as the explained variables and the market-diffusion status of the various types of technology taken as the explanatory variables.

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