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Safety Impacts due to the Incompatibility of SUVs, Minivans, and Pickup Trucks

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Abstract. This research sets out to estimate the effects of vehicle incompatibility on the risk of death or serious injury to drivers involved in two-vehicle collisions. Based on data for 3,153,813 drivers, logistic regression was used to model the risk of driver death or serious injury. Our analyses show that pickup trucks, minivans and SUVs are more aggressive than cars for the driver of the other vehicle and more protective for their own drivers. The effect of the pickups is more pronounced in terms of aggressivity, while the minivans turn out to be the most protective vehicle type. The point estimates are comparable to those in the Toy and Hammitt study (2003), but, in contrast to that study, we are now able to establish that a greater number of these effects are significant with a bigger sample size. Like vehicle mass and type, other characteristics of drivers and the circumstances of the collision influence the driver's condition after impact. Male drivers, older drivers, drivers who are not wearing safety belts, collisions occurring in a higher speed zone and head-on collisions significantly increase the risk of death. Except for the driver's sex, all of these categories are also associated with an increased risk of serious injury in a collision. For this risk, a significant increase is associated with female drivers.

Keywords. Aggressivity, crash severity, crashworthiness, incompatibility, light trucks and vans, logistic regression, mass ratio.

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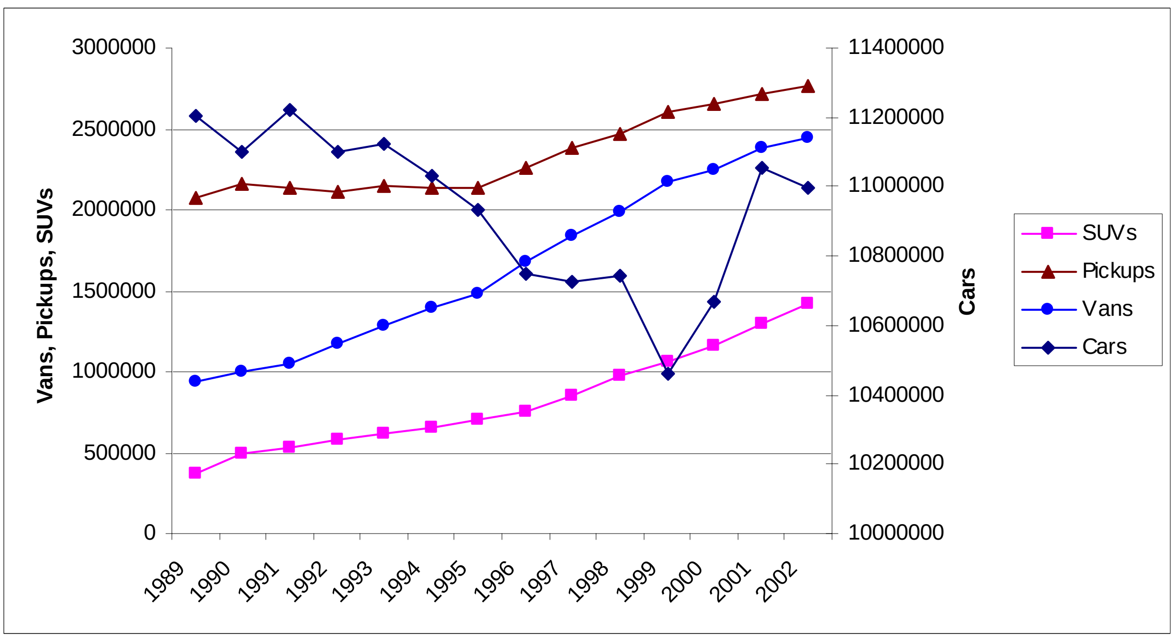
1. Introduction

Since the early 1990s, the light duty vehicle fleet has seen major change in North America with amazing growth in sport utility vehicles (SUVs), and an appreciable increase in the number of pickup trucks and minivans. These three types of vehicles form a category generally known as Light Trucks and Vans (LTV). For example, Figure 1 shows this trend in the fleet in Canada between 1989 and 2002. We point out that SUVs have seen dramatic growth (287%), followed by minivans (160%) and pickup trucks (34%). Over the same period, the number of passenger cars fell by 2%.

This major change in the vehicle fleet composition is thought to affect road safety. There is concern about the safety of occupants involved in collisions between two light duty vehicles of differing geometry and mass, a phenomenon better known as "vehicle incompatibility." According to Gabler and Hollowel (2000), a vehicle's incompatibility is the combination of its self-protective capacity and aggressivity when involved in collisions with another vehicle. Self-protection centres on a vehicle's chances of shielding its occupants in a collision, whereas aggressivity is measured by causality affecting the occupants of the other vehicle in the collision. As the relative composition of the fleet of vehicles is altered, negative effects on road safety might appear.

Figure 1: Census of light duty vehicles (passenger cars and LTVs) in Canada between 1989 and 2002.



This figure uses data from the *Canadian Vehicle In Operation Census* database.

A literature review reveals that a number of factors increased by this major change in the car fleet actually affect passenger safety in collisions. A number of studies acknowledge the influence of mass and geometry on the risk incurred by passengers: the difference in masses increases the self-protection and aggressivity of the heavier vehicle, whereas geometric incompatibility (e.g., of a passenger car versus an LTV) generally penalizes the car driver. These factors were cited in recent studies by O'Neill and Kyrychenko (2004), Acierno *et al.* (2004), Broyles *et al.* (2003), Toy and Hammitt (2003), Mayrose and Jehle (2002), Joksch (2000), and Farmer *et al.* (1997).

The literature review also shows that a number of control variables must also be considered to fully gauge incompatibility. For example, the literature shows women as more at risk of serious injury than men and the use of safety devices (belts and/or airbags) remains salutary for both sexes. These factors were also cited in recent studies by Ulfarsson and Mannering (2004), Dissanayake and Lu (2002), Bedard *et al.* (2002), and Mercier *et al.* (1997).

The aim of this study is to estimate the LTV effects on road safety by comparing them with the effects of passenger cars, using an analysis of the risk of death and/or serious injury to the drivers of vehicles involved in two-vehicle collisions. In general, we will compare our results with those of Toy and Hammitt (2003), since their study had the same objectives as ours and the methodology used is comparable on several levels. However, our big sample size (3,158,813 vs. 6,481) allows us to more accurately pinpoint the statistical significance of the estimated effects and use models that make more precise distinctions between the various types of vehicle incompatibility (the similarities and differences in these two studies will be described in greater detail in Section 3).

2. Methodology

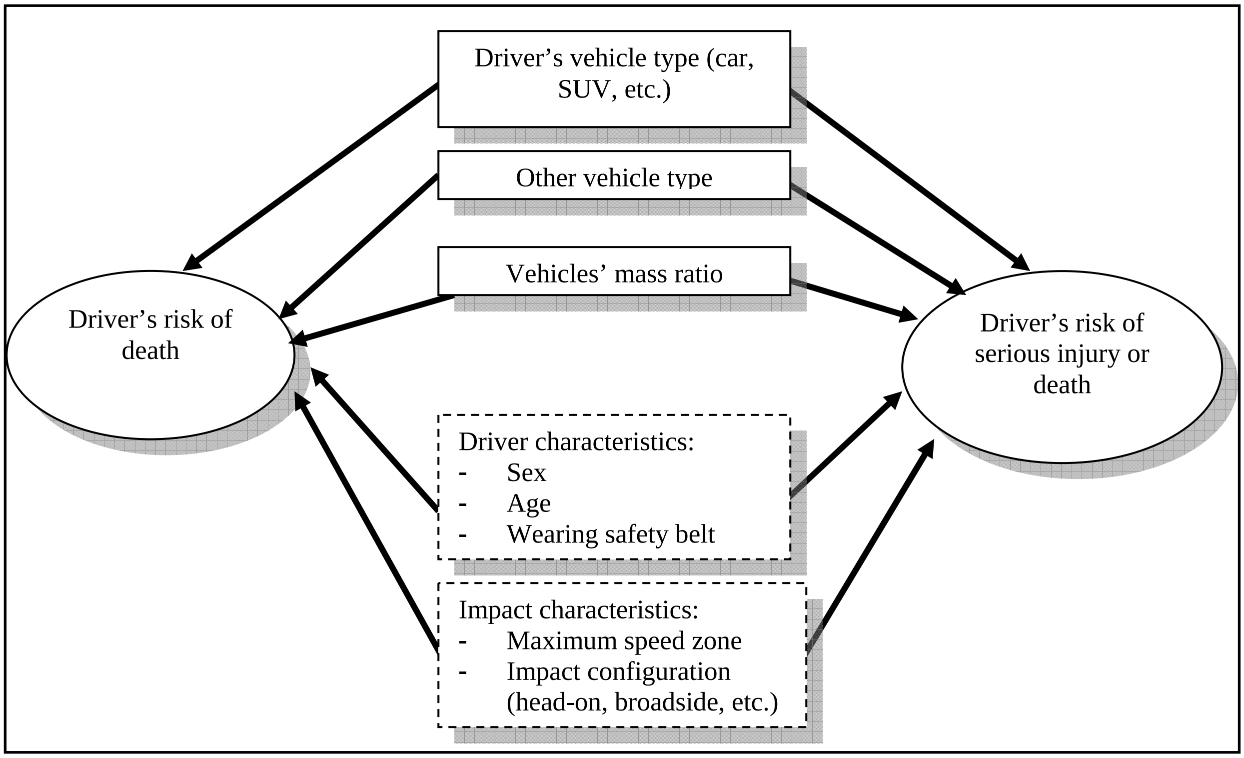
2.1 Data source

The data used in our study come from Transport Canada. They were chosen from the NCDB (National Collision Database). This database contains information on all collisions reported by police in Canada. This made it possible to analyse two-vehicle collisions occurring between 1993 and 2001 in seven Canadian provinces or territories: Alberta, Prince Edward Island, Ontario, Quebec, Newfoundland, Saskatchewan and Yukon. We indexed 3,153,815 drivers involved in two-vehicle collisions.

2.2 Conceptual development

Unlike Toy and Hammitt (2003), who used only one criterion variable (the risk of severe injury or death in a collision), we will consider two criterion variables: the risk of death in a collision and the risk of severe injury or death in a collision. Both criterion variables being binary, we will use logistic regression to model them. Figure 2 shows the kinds of available variables that will be used to model these criteria. Note that the variables in the dotted rectangles represent control variables.

Figure 2: Modelling conceptualization



The first two variables will allow us to evaluate the geometric aspect of vehicle incompatibility on the risk of serious or fatal injury in an impact. The first variable is the driver's vehicle type (passenger car, SUV, pickup truck, minivan, other), which will allow us to determine the self-protection each of these vehicle types gives the driver. The second variable is the type of the other vehicle involved in the collision, which will allow us to determine the aggressivity of these vehicles. In addition to geometric incompatibility, we can use our third variable to evaluate the effect of the incompatibility caused by difference in vehicle mass. This variable will be the mass ratio of both vehicles involved in the collision in 5 categories: the driver's vehicle is at least two times lighter (0, 0.5], two times to 20% lighter (0.5, 0.8], the difference is less than 20% (0.8, 1.2], 20% to two times heavier (1.2, 2] and at least two times heavier (2,+∞).

The control variables used in earlier studies and available from our database are the driver's sex, the driver's age (classified in four groups: under 25, 25-44, 45-64, and 65 and over), whether or not a safety belt was worn, maximum authorized speed where the collision occurred (under 50 kph, 50-70 kph, 80-90 kph, and 100 or more kph), and impact configuration (head-on, rear-end, broadside, same direction, etc.). We will use all these variables in our model.

3. Results

3.1 Descriptive analyses

Table 1 shows the marginal distribution of our study's target variables, while the conditional distributions that reflect the different categories of independent variables are presented in the Appendix.

Table 1: Distribution of the variable for driver injury severity

Injury severity	Frequency	Percentage
None (no hospital admission)	2,919,223	92.56%
Minor (admission but no hospitalization)	211,608	6.71%
Major (hospitalization but no death within 30 days)	18,949	0.60%
Fatal (death within 30 days)	4,033	0.13%
Total	**3,153,813**	**100.00%**

3.2 Logistic regression analysis results

We begin with the results for risk of death and go on to present the results for risk of serious injury or death. In each case, 5 different models will be shown. The first model covers only the types of the two colliding vehicles and the additional variables will appear in subsequent models: the second model will control for driver characteristics (sex, age and safety belt), the third model will be adjusted by adding the vehicles' mass ratio, the fourth model will include the maximum authorized speed where the collision occurred, and the fifth model will add the collision configuration. This five-model iterative process was also used by Toy and Hammitt (2003). Note that for each variable, a category representing the missing values was created and included in the regression models. However, the corresponding estimated effects are not of interest and are thus not presented in Table 2.

3.2.1 Driver death risk results

Table 2 presents the odds ratios (ORs) obtained for the five logistic regression models in terms of probable risk of death for drivers involved in two-vehicle collisions. Note that this criterion variable was not used by Toy and Hammitt (2003) because the likelihood of dying in a collision is so small (about 0.13%: see Table 1) that a huge sample size is needed to estimate the model's parameters.

Model 1

In this model, only the categories of the two vehicles involved in the collision were used for the risk of fatal driver injury. Except for pickup trucks, where self-protection differed insignificantly from the passenger car reference category, the probability of fatal driver injury is reduced by about 44% for minivans (OR= 0.56) and 40% for SUVs (OR= 0.60).

As regards the “other vehicle” variable (other vehicle involved in the collision), all vehicle types in this model are associated with statistically significant aggressive effects compared to the reference category. Drivers colliding with pickups are 3.40 times more likely to die. With SUVs and minivans, the likelihood of death is, respectively, 2.08 and 2.05 times greater. *A priori*, we have some reservations about these results since the other factors were not present in this model.

We also point out that, in this model and subsequent models, uncategorized “other” vehicles are generally very aggressive and will be found to be significantly self-protective in subsequent models. These results reflect the fact that this category includes vehicles heavier than 4,356 kg (e.g., heavy trucks and buses).

Model 2

The three additional variables for driver characteristics were introduced: these are age, sex and the wearing of the safety belt. Except for pickup self-protection, which became significant (the OR went from 1.05 to 0.82), LTV self-protection and aggressivity (pickup trucks, minivans and SUVs) remained generally the same.

With respect to the new variables introduced, we point out that the risk of death for men rose by 25% compared to the risk for women. As for age, we note first that there is no significant difference between the under 25 and 25-44 age groups, but the risk of death increases with age thereafter. Finally, not wearing the safety belt increases the driver’s risk of death dramatically (48 times).

Model 3

Adding the mass ratio of the two vehicles colliding in Model 3, we see some effect on LTV self-protection and aggressivity, since all these effects were reduced (e.g., the odds ratios all grew slightly closer to 1).

With respect to mass ratio as such, we see this variable has a significant effect: the higher the ratio, the smaller the risk of dying in the collision. For example, the driver of a vehicle with a ratio under 0.5 is almost 23 times (3.49/0.15) more likely to die than the driver of the other vehicle (provided all other variables for these two drivers are identical).

Model 4

We now add the maximum authorized speed where the collision occurred. As vehicles' exact speed is not available in the database, we emulated Joksch (2000) in using this limit as a proxy variable. The results show the speed limit as a highly significant factor in estimating drivers' risk of death. We see right away that a collision where the speed limit is less than or equal to 40 kph reduces the drivers' risk of death by 67% (OR= 0.33) compared to the reference category (speed limit of 50 to 70 kph). Drivers colliding in an 80-90 kph zone are 15 times more likely to die. It is interesting to note that the risk in this model is much less on a freeway (≥ 100 kph limit) than in an 80-90 kph zone (OR= 7.14 vs. 15.0). We will see in the next model that this is mainly due to the configuration of the collisions. Note too that introducing the speed limit substantially reduces the effect of the safety belt, though its effect is still clearly significant (OR goes from 46.9 to 24.1).

Model 5

We finally add the collision configuration to our model. This confirms that head-on collisions are definitely the most deadly. For example, drivers involved in a head-on collision are about 7 times (1/0.14) more likely to die than in a rear-ender. Note too that introducing the collision configuration appreciably reduces the gap between 80-90 kph and 100 kph + speed zones. In Canada, the 80-90 kph roads are generally undivided highways and the 100 kph are divided highways; It is therefore not surprising that the risk be higher on 80-90 kph speed zones than on 100 kph zones.

In this final model, we see LTVs differing significantly from passenger cars in terms of aggressivity and self-protection. Compared to car drivers, the probability of fatal injury is reduced by about 36% for minivan drivers (OR=0.64) and 29% for drivers of pickups or SUVs (OR= 0.71). As to aggressivity, drivers colliding with a pickup truck instead of a car are 2.55 times more likely to die. Drivers colliding with SUVs and minivans are, respectively, 2.15 and 1.86 times more likely to die than if they had collided with cars.

Table 2: Logistic regression for drivers' risk of death

	Odds ratios (confidence intervals of 95%)				
	Model 1	***Model 2***	***Model 3***	***Model 4***	***Model 5***
<u>Driver's vehicles</u>					
Cars	Ref	Ref	Ref	Ref	Ref
Pickups	1.05 (0.95-1.16)	**0.82 (0.73-0.91)**	0.91 (0.82-1.01)	**0.71 (0.64-0.80)**	**0.71 (0.64-0.80)**
Minivans	**0.56 (0.48-0.65)**	**0.57 (0.49-0.66)**	**0.65 (0.55-0.75)**	**0.62 (0.53-0.72)**	**0.64 (0.55-0.75)**
SUVs	**0.60 (0.49-0.73)**	**0.66 (0.54-0.81)**	**0.74 (0.60-0.91)**	**0.71 (0.58-0.88)**	**0.71 (0.58-0.88)**
Other	**1.18 (1.07-1.29)**	**0.72 (0.65-0.80)**	**0.68 (0.62-0.76)**	**0.43 (0.38-0.48)**	**0.50 (0.45-0.56)**
<u>Other vehicles</u>					
Cars	Ref	Ref	Ref	Ref	Ref
Pickups	**3.40 (3.08-3.74)**	**3.23 (2.92-3.56)**	**2.78 (2.51-3.07)**	**2.45 (2.21-2.71)**	**2.55 (2.30-2.83)**
Minivans	**2.05 (1.82-2.32)**	**2.08 (1.84-2.35)**	**1.75 (1.54-1.98)**	**1.83 (1.61-2.08)**	**1.86 (1.63-2.13)**
SUVs	**2.08 (1.77-2.43)**	**2.15 (1.83-2.53)**	**1.86 (1.58-2.19)**	**2.02 (1.71-2.38)**	**2.15 (1.81-2.54)**
Other	**6.36 (5.86-6.90)**	**5.94 (5.47-6.45)**	**5.30 (4.84-5.80)**	**4.51 (4.11-4.95)**	**5.20 (4.72-5.73)**
<u>Driver's sex</u>					
Female		Ref	Ref	Ref	Ref
Male		**1.25 (1.16-1.35)**	**1.27 (1.18-1.37)**	**1.18 (1.10-1.28)**	**1.13 (1.05-1.22)**
<u>Driver's age</u>					
Under 25		1.05 (0.96-1.14)	1.01 (0.93-1.10)	0.99 (0.91-1.08)	1.05 (0.96-1.15)
25-44		Ref	Ref	Ref	Ref
45-64		**1.41 (1.30-1.53)**	**1.43 (1.32-1.55)**	**1.34 (1.23-1.46)**	**1.40 (1.29-1.53)**
65 and +		**3.35 (3.07-3.67)**	**3.45 (3.15-3.77)**	**2.95 (2.69-3.24)**	**3.49 (3.17-3.83)**
<u>Safety belt</u>					
No belt		**48.2 (44.3-52.6)**	**46.9 (43.0-51.2)**	**24.1 (21.9-26.6)**	**21.5 (19.5-23.7)**
Safety belt		Ref	Ref	Ref	Ref
<u>Mass ratio</u>					
Less than 0.50			**3.49 (2.94-4.14)**	**3.24 (2.71-3.87)**	**3.68 (3.06-4.42)**
0.50 to 0.80			**1.55 (1.35-1.77)**	**1.58 (1.37-1.80)**	**1.65 (1.43-1.90)**
0.80 to 1.20			Ref	Ref	Ref
1.20 to 2.00			**0.51 (0.41-0.63)**	**0.53 (0.43-0.66)**	**0.52 (0.42-0.65)**
More than 2.00			**0.15 (0.07-0.33)**	**0.12 (0.05-0.27)**	**0.11 (0.05-0.25)**
<u>Authorized speed</u>					
Less than 50 kph				**0.33 (0.22-0.50)**	**0.30 (0.20-0.45)**
50-70 kph				Ref	Ref
80-90 kph				**15.0 (13.8-16.4)**	**9.50 (8.7 -10.4)**
100 kph and +				**7.14 (6.30-8.09)**	**8.56 (7.49-9.79)**
<u>Collision</u>					
Head-on					Ref
Rear-end					**0.14 (0.12-0.15)**
Broadside					**0.03 (0.02-0.03)**
Same direction					**0.05 (0.04-0.05)**
Other direction					**0.11 (0.10-0.12)**

3.2.2 Drivers' death or serious injury risk results

Table 3 shows the results of the five logistic regression models in terms of risk of death **or** serious injury for drivers involved in two-vehicle collisions. With one exception (see the paragraph below), using this new criterion variable does not change the interpretation or (in) significance of the variables analysed in the preceding section. However, we point out that almost all estimated odds ratios are closer to 1.

Interestingly enough, the effect of the driver's sex is negated if we look at risk of serious injury or death vs. risk of death in a collision. Comparing the effect of sex in the 5 models shown in Tables 2 and 3, we see that males are 13% more likely to die than women. Nonetheless, males are 21% less likely to be fatally or seriously injured in a collision.

Using the same criterion variable as Toy and Hammitt (2003), we can compare some of our results with that study. Here we compare our Model 5 in Table 3 with their Model 5 in Table II (p. 646). Note that the variables are not exactly the same in these two models. In their study, Toy and Hammitt (2003) found that only pickup trucks were significantly more protective and aggressive than cars. Our own conclusion is that all three types of LTVs are significantly more protective and aggressive than passenger cars. We might tend to assume that the results are divergent, but this is probably not the case, since our odds ratios are all, with one exception (pickup self-protection), within the 95% confidence intervals used in their study. Plausibly, this discrepancy in the two studies stems from the fact that our sample size was almost 500 times bigger than theirs (6,481 vs. 3,153,813). This advantage allowed us to obtain shorter intervals and thus more odds ratios that differ significantly from 1.

It is important to state that, although our sample is big, our parameters are not only statistically significant, but concretely so: our significant odds ratio closest to 1 is 0.88 (pickup self-protection), a difference of 12% that strikes us as significant in practice.

Table 3: Death or serious injury risk results

	Odds ratios (confidence intervals of 95%)				
	Model 1	***Model 2***	***Model 3***	***Model 4***	***Model 5***
Driver's vehicles					
Cars	Ref	Ref	Ref	Ref	Ref
Pickups	**0.94 (0.90-0.98)**	**0.87 (0.83-0.91)**	**0.95 (0.90-0.99)**	**0.84 (0.80-0.88)**	**0.85 (0.81-0.89)**
Minivans	**0.70 (0.66-0.73)**	**0.72 (0.68-0.76)**	**0.79 (0.75-0.84)**	**0.79 (0.74-0.84)**	**0.81 (0.76-0.86)**
SUVs	**0.71 (0.66-0.76)**	**0.76 (0.70-0.82)**	**0.82 (0.76-0.89)**	**0.85 (0.79-0.92)**	**0.88 (0.81-0.95)**
Other	1.00 (0.96-1.04)	**0.82 (0.78-0.85)**	**0.80 (0.76-0.83)**	**0.58 (0.55-0.61)**	**0.63 (0.60-0.66)**
Other vehicles					
Cars	Ref	Ref	Ref	Ref	Ref
Pickups	**1.84 (1.77-1.91)**	**1.78 (1.71-1.85)**	**1.63 (1.57-1.70)**	**1.56 (1.49-1.62)**	**1.63 (1.56-1.70)**
Minivans	**1.31 (1.25-1.37)**	**1.33 (1.27-1.40)**	**1.20 (1.14-1.26)**	**1.26 (1.19-1.32)**	**1.30 (1.23-1.37)**
SUVs	**1.20 (1.13-1.29)**	**1.23 (1.15-1.32)**	**1.13 (1.06-1.21)**	**1.24 (1.16-1.33)**	**1.32 (1.23-1.41)**
Other	**1.96 (1.89-2.03)**	**1.86 (1.79-1.93)**	**1.79 (1.72-1.86)**	**1.62 (1.55-1.69)**	**1.79 (1.72-1.87)**
Driver's sex					
Female		Ref	Ref	Ref	Ref
Male		**0.84 (0.82-0.87)**	**0.85 (0.82-0.87)**	**0.82 (0.79-0.84)**	**0.79 (0.77-0.81)**
Driver's age					
Under 25		**1.05 (1.01-1.08)**	1.02 (0.99-1.06)	0.97 (0.94-1.01)	0.99 (0.96-1.03)
25-44		Ref	Ref	Ref	Ref
45-64		**1.12 (1.08-1.16)**	**1.13 (1.10-1.17)**	**1.08 (1.04-1.12)**	**1.09 (1.05-1.13)**
65 and +		**1.81 (1.73-1.89)**	**1.84 (1.76-1.93)**	**1.62 (1.55-1.69)**	**1.67 (1.60-1.75)**
Safety belt					
No belt		**26.2 (25.2-27.3)**	**25.2 (24.2-26.3)**	**15.1 (14.5-15.8)**	**14.6 (13.9-15.3)**
Safety belt		Ref	Ref	Ref	Ref
Mass ratio					
Less than 0.50			**2.31 (2.13-2.50)**	**2.18 (2.00-2.38)**	**2.44 (2.24-2.66)**
0.50 to 0.80			**1.19 (1.13-1.25)**	**1.21 (1.15-1.28)**	**1.24 (1.18-1.31)**
0.80 to 1.20			Ref	Ref	Ref
1.20 to 2.00			**0.69 (0.64-0.73)**	**0.71 (0.66-0.76)**	**0.71 (0.67-0.76)**
More than 2.00			**0.36 (0.29-0.45)**	**0.30 (0.24-0.38)**	**0.29 (0.23-0.36)**
Authorized speed					
Less than 50 kph				**0.35 (0.31-0.40)**	**0.32 (0.28-0.37)**
50-70 kph				Ref	Ref
80-90 kph				**7.94 (7.66 -8.23)**	**5.71 (5.50 -5.94)**
100 kph and +				**3.21 (3.01-3.41)**	**3.92 (3.67-3.19)**
Collision					
Head-on					Ref
Rear-end					**0.21 (0.20-0.22)**
Broadside					**0.06 (0.06-0.07)**
Same direction					**0.07 (0.06-0.07)**
Other direction					**0.18 (0.17-0.19)**

4. New representation of vehicle incompatibility

We are now going to represent vehicle incompatibility by looking at essentially all possible combinations of the variables we want to study where the 4 types of light duty vehicles (passenger car, pickup truck, minivan and SUV) are concerned: the driver's vehicle type, the other vehicle type involved in the collision, and a mass ratio categorization. As our sample is huge, each combination of these variables will have enough observations (between 976 and 343,898 observations per category) to attempt a fairly accurate estimate of the associated odds ratio. We now present this new representation and corresponding logistic regression model.

Table 4 shows, in decreasing order, the odds ratios (and 95% confidence intervals) of the risk of serious injury or death for 48 types of incompatibility. The total number of 48 combinations reflects our use of 4 categories to describe the driver's vehicle type (the "drive" column), 4 categories to describe the other vehicle type (the "impact with" column), and 3 categories to characterize the mass ratio (the "mass ratio" column). Note that the mass ratio was categorized as follows:

- **"Smaller":** the mass of the driver's vehicle is at least 20% smaller than the mass of the other vehicle (ratio<0.8).
- **"=":** there is a discrepancy of less than 20% between the masses of the two vehicles (0.8≤ratio≤1.2).
- **"Bigger":** the mass of the driver's vehicle is at least 20% greater than the mass of the other vehicle (ratio>1.2).

Note: all control variables in Model 5, Section 3.2.2, were also used in this regression. We also added all significant interaction terms and collisions with missing mass ratios were removed.

Studying Table 4, we find as follows:

- We point out in particular that most of the big odds ratios are associated with collisions where the driver's vehicle had a smaller mass than the other vehicle. Similarly, the combinations with the smallest odds ratios are associated with collisions where the driver's vehicle was heavier than the other vehicle.
- The aggressivity of pickup trucks is clearly established. For any mass ratio category, the most dangerous collisions are always the ones where the other vehicle is a pickup. Indeed, when we look only at the point estimates of odds ratios, we see that the four types of collisions where the other vehicle is a pickup are always the most dangerous collisions.
- The low aggressivity of passenger cars is also clearly established. For any mass ratio category, the collisions where the other vehicle is a car are generally among the least dangerous collisions for drivers.
- Collisions involving vehicles of the same type are not necessarily less dangerous: for any mass ratio category, the most dangerous collisions are those involving two pickups.

- When not colliding with pickups, pickups are highly protective. For any mass ratio category, pickup drivers are generally less at risk of serious or fatal injury than other drivers.

Table 4: Incompatibility and risk of death or serious injury

Drive	Impact with	Mass ratio	Odds Ratio	95% Interval
Pickup	Pickup	Smaller	**2.10**	**(1.82-2.42)**
Car	Pickup	Smaller	**1.94**	**(1.80-2.10)**
SUV	Pickup	Smaller	**1.81**	**(1.56-2.10)**
Minivan	Pickup	Smaller	**1.71**	**(1.52-1.93)**
Car	SUV	Smaller	**1.70**	**(1.52-1.89)**
Car	Minivan	Smaller	**1.62**	**(1.50-1.76)**
SUV	SUV	Smaller	**1.58**	**(1.34-1.87)**
Pickup	Pickup	=	**1.57**	**(1.38-1.79)**
SUV	Minivan	Smaller	**1.51**	**(1.30-1.76)**
Minivan	SUV	Smaller	**1.49**	**(1.30-1.72)**
Car	Pickup	=	**1.45**	**(1.35-1.56)**
Minivan	Minivan	Smaller	**1.43**	**(1.27-1.61)**
Pickup	SUV	Smaller	**1.39**	**(1.20-1.60)**
SUV	Pickup	=	**1.35**	**(1.18-1.56)**
Car	Car	Smaller	**1.34**	**(1.27-1.42)**
Pickup	Minivan	Smaller	**1.33**	**(1.17-1.50)**
Minivan	Pickup	=	**1.28**	**(1.15-1.42)**
Car	SUV	=	**1.27**	**(1.14-1.41)**
SUV	Car	Smaller	**1.25**	**(1.08-1.44)**
Car	Minivan	=	**1.21**	**(1.13-1.31)**
Minivan	Car	Smaller	**1.18**	**(1.05-1.32)**
SUV	SUV	=	**1.18**	**(1.01-1.39)**
SUV	Minivan	=	1.13	(0.98-1.30)
Minivan	SUV	=	1.12	(0.98-1.27)
Pickup	Car	Smaller	1.09	(0.98-1.23)
Pickup	Pickup	Bigger	1.07	(0.92-1.24)
Minivan	Minivan	=	1.07	(0.96-1.19)
Pickup	SUV	=	1.04	(0.90-1.19)
Car	Car	=	1.00	Ref.
Car	Pickup	Bigger	0.99	(0.89-1.10)
Pickup	Minivan	=	0.99	(0.88-1.11)
SUV	Car	=	0.93	(0.82-1.06)
SUV	Pickup	Bigger	0.92	(0.79-1.08)
Minivan	Car	=	**0.88**	**(0.81-0.96)**
Minivan	Pickup	Bigger	**0.87**	**(0.77-0.99)**
Car	SUV	Bigger	**0.87**	**(0.76-0.99)**
Car	Minivan	Bigger	**0.83**	**(0.74-0.92)**
Pickup	Car	=	**0.82**	**(0.74-0.90)**
SUV	SUV	Bigger	**0.81**	**(0.68-0.96)**
SUV	Minivan	Bigger	**0.77**	**(0.66-0.90)**
Minivan	SUV	Bigger	**0.76**	**(0.66-0.88)**
Minivan	Minivan	Bigger	**0.73**	**(0.64-0.83)**
Pickup	SUV	Bigger	**0.71**	**(0.61-0.82)**
Car	Car	Bigger	**0.68**	**(0.64-0.73)**
Pickup	Minivan	Bigger	**0.68**	**(0.59-0.77)**
SUV	Car	Bigger	**0.64**	**(0.56-0.73)**
Minivan	Car	Bigger	**0.60**	**(0.54-0.66)**
Pickup	Car	Bigger	**0.56**	**(0.50-0.62)**

5. Conclusion

Logistic regression was used to model the risk of death or serious injury to drivers involved in two-vehicle collisions. The effects of the aggressivity and self-protection of pickup trucks, minivans and SUVs compared to passenger cars are statistically significant. Pickups emerged as more aggressive than SUVs and minivans, while minivans stood out from SUVs and pickups for self-protection. Controlling for mass ratio, the effects of LTV aggressivity remained statistically significant. However, adding this variable reduced the estimated effects of LTVs in terms of both aggressivity and self-protection.

Regarding the control variables, the effects obtained were appreciably the same as those in the literature. However, we note that the risk incurred by males compared to females depends on the dependent variable being modelled. Our results showed that men are more likely to die than women but run less risk of serious or fatal injury. The differences noted between men and women assume a combination of behavioural and physiological factors that significantly affect driver injury severity (Ulfarsson and Mannering, 2004). This study re-iterates that safety belt use are highly effective in reducing injuries and deaths.

Also, the risks are very large when colliding vehicles have a large mass ratio difference; if the relative proportions of heavy vehicles and light vehicles in the fleet are altered, negative effects on road safety might results.

We must point out that this study is limited in some respects. For one thing, using data from police reports is imprecise because reports tend to overstate the injury severity. The study was limited in its analysis of available information that does not necessarily give an accurate picture of factors contributing to collisions. For example, the information in the database does not tell us which vehicle impacted or was impacted.

Bibliography

- Acierno S., Rivara, F. P., Grossman, D. C. and Mock, C. (2004). “Vehicle mismatch: injury patterns and severity," in Accident Analysis and Prevention, 36: 761-772.
- Bedard, M., Guyatt, G.H., Stones, M.J. and Hirdes, J.P. (2002). “The independent contribution of driver, crash, and vehicle characteristics to driver fatalities,” in Accident Analysis and Prevention 34: 717-727.
- Broyles, R.W., Narine, L., Clarke, S.R. and Baker, D.R. (2003). “Factors associated with the likelihood of injury resulting from collisions between four-wheel drive vehicles and passenger cars,” in Accident Analysis and Prevention 35: 677-681.
- Dissanayake, S. and Lu, J.J. (2002). “Factors influential in making an injury severity difference to older drivers involved in fixed object-passenger car crashes,” in Accident Analysis and Prevention 34: 609-618.
- Farmer, C.M., Braver, E.R. and Mitter, L. (1997). “Two-Vehicle side impact crashes: the relationship of vehicle and crash characteristics to injury severity,” in Accident Analysis and Prevention 29(3): 399-406.
- Gabler, H.C. and Hollowel, W.T. (1996). “NHTSA’s vehicle aggressivity and compatibility research program,” in Proceedings of the 15th International Technical Conference on the Enhanced Safety of Vehicles. 576-592.
- Joksch, H.C. (2000). “Vehicle design versus aggressivity.” US Department of Transport Report. DOTHS 809:194.
- Mayrose, J. and Jehle, D.V.K. (2002). “Vehicle Weight and Fatality Risk for Sport Utility Vehicle-versus-Passenger Car Crashes,” in Journal of TRAUMA 53(4): 751-753.
- Mercier, C.R., Shelley II, M.C., Rimkus, J.B. and Mercier, J.M. (1997). “Age and Gender as Predictors of Injury Severity in Head-on Highway Vehicular Collisions,” in Transportation Research Record 1581: 37-46.
- O’Neill, B. and Kyrychenko, S.Y. (2004). “Crash Incompatibilities Between Cars and Light Trucks: Issues and Potential Countermeasures.” Society of Automotive Engineers: 39-47.
- Toy, E.L. and Hammitt., J.K. (2003). “Safety Impacts of SUVs, Minivans, and Pickup Trucks in Two-Vehicle Crashes,” in Risk Analysis 23(4): 641-650.
- Ulfarsson, G.F. and Mannering, F.L. (2004). “Differences in male and female injury severities in sport-utility vehicle, minivan, pickup and passenger car accidents,” in Accident Analysis and Prevention 36: 135-147.

Appendix

Tables 5 to 7 show the conditional distributions that reflect the different categories of independent variables.

Table 5: Vehicle characteristics and injury severity

	Injury severity (%)				
	None	Minor	Major	Fatal	**% of Total** (n=3,153,813)
Driver's vehicle					
Car	91.61%	7.64%	0.62%	0.13%	**54.41%**
Pickup truck	94.08%	5.16%	0.61%	0.14%	**10.07%**
Minivan	93.77%	5.74%	0.42%	0.07%	**8.79%**
SUV	93.92%	5.56%	0.45%	0.07%	**4.51%**
Other	94.27%	4.87%	0.70%	0.17%	**10.62%**
Not stated	92.73%	6.53%	0.59%	0.15%	**11.67%**
Other vehicle					
Car	92.52%	6.90%	0.52%	0.06%	**54.32%**
Pickup truck	91.31%	7.58%	0.91%	0.21%	**10.00%**
Minivan	92.46%	6.82%	0.59%	0.12%	**8.78%**
SUV	92.71%	6.60%	0.57%	0.12%	**4.50%**
Other	92.37%	6.35%	0.88%	0.41%	**10.64%**
Not stated	94.01%	5.40%	0.47%	0.12%	**11.77%**
Mass ratio					
(0.00; 0.50]	84.29%	12.57%	2.33%	0.81%	**0.93%**
(0.50; 0.80]	90.82%	8.33%	0.71%	0.14%	**10.46%**
(0.80; 1.20]	91.79%	7.56%	0.58%	0.07%	**17.75%**
(1.20; 2.00]	93.72%	5.85%	0.39%	0.03%	**10.46%**
(2.00; +∞)	95.94%	3.77%	0.27%	0.02%	**0.93%**
Not stated	92.97%	6.28%	0.60%	0.15%	**59.48%**

Table 6: Driver characteristics and injury severity

	Injury severity (%)				
	None	Minor	Major	Fatal	**% of Total** (n=3,153,813)
Sex					
Female	89.70%	9.52%	0.68%	0.10%	**32.26%**
Male	93.66%	5.60%	0.59%	0.15%	**64.85%**
Not stated	99.82%	0.16%	0.01%	0.01%	**2.90%**
Age					
24 or less	91.41%	7.75%	0.71%	0.13%	**21.09%**
25-44	92.41%	6.92%	0.57%	0.10%	**43.89%**
45-64	92.72%	6.56%	0.59%	0.13%	**23.16%**
65 or +	92.33%	6.50%	0.84%	0.33%	**7.58%**
Not stated	99.30%	0.63%	0.05%	0.01%	**4.29%**
Safety device					
Belt not worn	41.89%	44.93%	9.80%	3.38%	**0.94%**
Safety belt	93.45%	6.03%	0.44%	0.08%	**97.2%**
Not stated	71.66%	22.98%	4.26%	1.10%	**1.86%**

Table 7: Collision characteristics and injury severity

	Injury severity (%)				
	None	Minor	Major	Fatal	**% of Total** (n=3,153,813)
Maximum authorized speed					
Less than 50 kph	91.61%	7.95%	0.40%	0.04%	**1.91%**
50-70 kph	85.77%	13.30%	0.83%	0.10%	**25.11%**
80-90 kph	73.03%	20.77%	4.58%	1.63%	**3.63%**
100 kph and +	85.41%	11.80%	1.95%	0.84%	**1.57%**
Not stated	96.31%	3.36%	0.28%	0.05%	**67.79%**
Configuration of collision					
Head-on	77.55%	15.22%	5.17%	2.06%	**2.76%**
Rear-end	88.81%	9.99%	1.05%	0.15%	**15.51%**
Broadside	93.30%	6.44%	0.23%	0.03%	**31.92%**
Same direction	97.06%	2.65%	0.23%	0.05%	**15.07%**
Other directions	91.89%	7.42%	0.59%	0.10%	**26.38%**
Not stated	95.64%	3.92%	0.37%	0.07%	**8.37%**