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Vehicle registration year, age, and weight – Untangling the effects on crash risk

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The aim of the present study was to investigate the effects of passenger cars' first year of registration, weight, and age on the number of killed or seriously injured (KSI) car drivers, pedestrians, and cyclists. Poisson regression models were developed of injury crashes involving passenger cars in Norway in 2000-2016, with the following predictor variables: The cars' first year of registration and weight, either crash year or car age, the drivers age and gender, and in models for car-car collisions the crash partner cars' weight and either registration year or age. The results show that there are fewer KSI car drivers in more recent, newer, and heavier cars. It is estimated that the number of KSI car drivers in all types of crashes on average decreases by 6.7% for each consecutive registration year (-7.2% in car-car collisions and -6.0% in single vehicle crashes), increases by 3.7% for each consecutive year of age (+2.1% in car-car collisions and +5.3% in single vehicle crashes), and decreases by 4.9% on average for each 100 kg weight increase (-11.1% in car-car collisions and -2.3% in single vehicle crashes). In car-car collisions there are fewer KSI car drivers when the crash partner car is more recent (-4.4% for each consecutive registration year), and more KSI car drivers when the crash partner car is older (+4.1% for each consecutive year of age), or heavier (+6.8% per 100 kg weight increase). In collisions with pedestrians or cyclists, there are fewer KSI pedestrians/cyclists when the car is more recent (-3.3% per consecutive registration year) and more KSI pedestrians/cyclists when the car is heavier (+4.6% per 100 kg weight increase). Due to the large effects of safety improvements in more recent cars, an increased renewal rate in the passenger car fleet can be expected to contribute to large safety improvements. The increasing weight of more recent cars may contribute to improved safety for those who drive heavier cars, but overall the effect of increasing weight is probably small or even negative because heavier vehicles impose greater risk on other car drivers, pedestrians, and cyclists.

Keywords: Registration year; car age; vehicle weight; fatality, serious injury

1. Introduction

Passenger cars have become considerably safer over the past decades, partly because of improvements of crashworthiness (Anderson & Searson, 2015), partly because of active safety systems (Glassbrenner, 2012), and partly because of increasing weight (Broughton, 2008). Additionally, road safety in general has improved over time, which is partly due to safer cars, but also to other factors such as improved infrastructure, reduced drunk driving (Elvik et al., 2012), improved medical services (Schoell, 2014), increased seat belt use (Høye, 2016), and reduced speed (Sagberg & Bjørnskau, 2016).

There are relatively few other studies that have investigated the relationships between passenger cars' registration year, car age, weight and crash or injury risk that have controlled for relevant confounding variables, and still fewer studies of the effects of the properties of crash partner vehicles on the driver of the own car or of the effects of the own cars' registration year, age and weight on injury or crash risk among pedestrians and cyclists.

A general problem when investigating the effects of registration year, car age, and weight on crash or injury risk is that there are strong relationships between these variables and that all variables are strongly correlated to crash year. In later crash years, there are more cars from later registration years, and cars from later registration years are on average both newer and heavier. When the effects of registration year or car age are investigated without statistical control for crash year and either car age or registration year, the results for registration year or car age may be partly due to general safety improvement over time and the relationship between registration year and car age (e.g. Broughton, 2012; Martin & Lenguerrand, 2008; Newstead et al., 2013). When the effects of vehicle weight on crash or injury risk are investigated without control for registration year (e.g. Anderson & Auffhammer, 2014; Adolph et al., 2015) the results may be affected by the relationship between weight and model year (heavier cars are on average from later years). There are also relationships between properties of the cars and the drivers' age, gender and behavior. For example, older cars are more often driven by young males, and by drivers who are drunk, speeding, and/or not wearing seat belts (Høye, 2017A; White, 2003).

Another general problem when investigating effects of registration year, car age, and weight is that the only available exposure date often is crash involvement. Only very few studies of have used vehicle kilometers as exposure variable. Broughton (2008, 2012) and Farmer (2005) have used numbers of registered vehicles as exposure variable. Since older cars on average drive less than newer cars, such studies will overestimate the exposure of older cars and consequently underestimate the crash or injury risk of older cars. Wenzel (2013) and Pucket & Kindelberger (2016) have used an induced exposure methodology as an approximation for vehicle kilometers. Most other studies of the effects of registration year, age or weight have therefore investigated effects on the number of fatally or seriously injured drivers per crash.

The aim of the present paper is to investigate the effect of passenger cars' year of first registration, age, and weight on the number of KSI car drivers and pedestrians/cyclists in different types of crashes, based on Norwegian crash data from 2000-2016, with statistical control for millions of vehicle kilometers, crash year and the drivers' age and gender. Crash types included in the study are all crashes, single vehicle crashes, car-car collisions, and collisions with pedestrians or cyclists. In car-car collisions, the effects of the other cars' registration year or age, and weight were investigated as well. Dependent variables are the number of killed or seriously injured (KSI) car drivers (all crashes, single vehicle crashes and car-car collisions), and the number of KSI pedestrians or cyclists (collisions with pedestrians/cyclists). Since the effects of registration year, car age, and crash year cannot be investigated simultaneously, models were developed with registration year and either crash year or car age among the predictor variables, and relationships between these variables were taken into account.

2. Method

Poisson regression models were developed for all crashes, single vehicle crashes, car-car collisions, and collisions with pedestrians or cyclists. In Poisson regression the logarithm of the expected values of a dependent variable (numbers of KSI in the present study) is modeled as a linear combination of predictor variables according to the following formula:

$$\log(E(Y|x)) = \alpha + \sum_i \beta_i * x_i$$

$E(Y|x)$ is the expected number of KSI, α is an intercept, x_i are the predictor variables, and β_i the coefficients for the predictor variables. In the present study, all predictor variables are defined as sets of dummy variables. The estimated coefficient for a dummy predictor variable can be interpreted as the natural logarithm of the relative number of the dependent variable when the predictor is one (present), compared to zero (absent). For example, a coefficient of 0.5 means that the expected value of the dependent variable is 65% higher when the predictor variable is present than when it is absent ($Ln(1.65) = 0.5$ or $e^{0.5} = 1.65$).

The dependent variable in the models for the first three crash types is the number of KSI car drivers. The study focuses on passenger car drivers because each car normally has one driver, which makes it possible to apply exposure data for cars to car drivers. Exposure data is available at the required level of detail for cars, but not for passengers. In the models for collisions with pedestrians/cyclists the number of KSI pedestrians/cyclists is the dependent variable.

Predictor variables in all models are the cars' year of first registration year, the cars' weight, the drivers' age and gender, and exposure (millions of vehicle kilometers). Additionally, either crash year or the cars' age are predictor variables. Both crash year and car age cannot be predictor variables because among the three variables registration year, car age, and crash year, one is always a function of the other two. In car-car collisions, the crash partners' (the other cars') registration year (car age in the models with the own cars' age among the predictor variables) and weight are additional predictor variables. Million vehicle kilometers is included as an exposure variable, i.e. the coefficient for the natural logarithm of million vehicle kilometers is fixed at one such that the assumed relationship between the total number of vehicle kilometers and KSI is linear. All models were calculated in Stata (version 14.2).

The unit of analysis is a group of cars, with each group containing all Norwegian cars from registration year A (10 groups), in weight class B (four weight classes), with a driver in group C (eight groups according to age and gender), in crash year D (years 2000-2016), with a crash partner from registration year E in weight class F (crash partner registration year and weight only in the model for car-car collisions). In the models with car age among the predictor variables, crash year is replaced by car age, calculated as the difference between crash year and the average registration year in each group of registration year.

For each unit of analysis and each type of crash, the numbers of KSI car drivers (pedestrians/cyclists in collisions with pedestrians/cyclists) have been retrieved from official injury crash statistics published by Statistics Norway (www.ssb.no). The total number of vehicle kilometers has been estimated based on a cohort model of the national car fleet (Fridstrøm et al., 2016). The model describes the annual mileages for cars of different ages, weight classes, and engine types, based on odometer readings from the registry of periodic vehicle inspection. Based on these data relative annual mileages were calculated for cars in each group of car age (yearly) and weight, and relative annual mileages in each group of registration year and weight were calculated for each year in the study period. The distribution of annual mileages on car age and weight categories is assumed to remain unchanged over time.

Relative annual driving lengths for drivers in each group of age and gender were retrieved from Bjørnskau (2015) who has analyzed data from national travel surveys among representative samples of the Norwegian population. Data are available every fourth year. The distribution of relative annual driving lengths on the groups by age and gender are relatively unchanged over time and are in the present study assumed to be the same in all years.

Total annual driving lengths with passenger cars in Norway for each year during the study period were retrieved from Farstad (2016). The total annual driving lengths were then distributed over all combinations of the cars registration year and age and the drivers age and gender, assuming no interaction effect between car and driver characteristics. The latter assumption is not likely to be true. For example, young drivers are on average driving older cars than older drivers. However, no information was available to link relative driving lengths between driver of different ages and gender and cars of different registration year and weight.

3. Results

Table 1 shows the numbers of KSI car drivers in all crashes, single vehicle crashes, and car-car collisions and the numbers of KSI pedestrians and cyclists in collisions between a car and a pedestrian or cyclist for all predictor variables. An overview of the developed models is shown in Table 2. As a measure of model fit McFadden's log-likelihood ratio index Pseudo R-squared has been calculated in Stata. Pseudo R-squared approaches one as the fit of the model becomes better and zero as the fit becomes weaker. Table 3 and Table 4 show the results from Poisson regression models for all crash types, in Table 3 with crash year (and not the age of the own car) among the predictor variables, and in Table 4 with the own cars' age (and not crash year) among the predictor variables. The models for each of the dependent variables contain all variables in the tables as predictor variables, i.e. the results for each predictor variable describe the relationship between predictor and dependent variable when all other variables in the model are held constant (i.e. statistically controlled for). The coefficients for the own and the other cars' weight and for the drivers' age and gender are very similar between the two types of models.

Table 1: Descriptive statistics; millions of vehicle kilometers, KSI car drivers (own car) in all crashes, single vehicle crashes, and car-car collisions, and KSI pedestrians/cyclists in collisions with cars (KSI/million vehicle kilometers above median in bold).

		All crashes		SV crashes		Car-car collisions		Ped./cyc. collisions	
	Mill. veh. km	KSI car drivers	KSI/mill. veh. km	KSI car drivers	KSI/mill. veh. km	KSI car drivers	KSI/mill. veh. km	KSI ped./cyc.	KSI/mill. veh. km
Registration year (own car)									
X-1979	3,264	52	**0.0159**	21	**0.0064**	14	**0.0043**	10	0.0031
1980-1990	45,941	1,730	**0.0377**	729	**0.0159**	463	**0.0101**	363	**0.0079**
1991-1995	56,627	1,252	**0.0221**	509	**0.0090**	300	**0.0053**	301	**0.0053**
1996-2000	137,216	1,545	**0.0113**	601	0.0044	369	0.0027	516	**0.0038**
2001-2003	77,818	532	0.0068	208	0.0027	119	0.0015	233	0.0030
2004-2006	78,716	385	0.0049	133	0.0017	83	0.0011	162	0.0021
2007-2009	59,507	209	0.0035	75	0.0013	50	0.0008	111	0.0019
2010-2011	31,770	103	0.0032	32	0.0010	27	0.0008	74	0.0023
2012-2013	22,860	68	0.0030	22	0.0010	19	0.0008	64	0.0028
2014-2016	13,511	31	0.0023	13	0.0010	9	0.0007	42	0.0031
Weight (own car)									
0-1199 kg	151,070	2,510	**0.0166**	939	**0.0062**	704	**0.0047**	590	**0.0039**
1200-1399 kg	159,732	1,936	**0.0121**	781	**0.0049**	459	**0.0029**	578	0.0036
1400-1599 kg	128,357	970	0.0076	410	0.0032	204	0.0016	391	0.0030
1600+ kg	88,072	491	0.0056	213	0.0024	86	0.0010	317	0.0036
Registration year (other car)									
X-1979						10	**0.0031**		
1980-1990						273	**0.0059**		
1991-1995						271	**0.0048**		
1996-2000						428	**0.0031**		
2001-2003						150	0.0019		
2004-2006						154	0.0020		
2007-2009						88	0.0015		
2010-2011						34	0.0011		
2012-2013						32	0.0014		
2014-2016						13	0.0010		
Weight (other car)									
0-1199 kg						376	0.0025		
1200-1399 kg						465	0.0029		
1400-1599 kg						340	0.0026		
1600+ kg						272	0.0031		
Driver									
Female, 18-24 years	16,425	381	**0.0232**	156	**0.0095**	105	**0.0064**	78	**0.0047**
Female, 25-44 years	84,020	623	0.0074	181	0.0022	172	0.0020	217	0.0026
Female, 45-64 years	63,618	504	0.0079	137	0.0022	135	0.0021	154	0.0024
Female, 65+ years	14,780	247	**0.0167**	83	**0.0056**	73	**0.0049**	90	**0.0061**
Male, 18-24 years	26,960	1,243	**0.0461**	727	**0.0270**	233	**0.0086**	285	**0.0106**
Male, 25-44 years	147,877	1,460	0.0099	615	0.0042	340	0.0023	473	0.0032
Male, 45-64 years	133,956	786	0.0059	250	0.0019	214	0.0016	321	0.0024
Male, 65+ years	39,594	663	**0.0167**	194	**0.0049**	181	**0.0046**	258	**0.0065**
Crash year									
2000	26,136	550	**0.0210**	212	**0.0081**	154	**0.0059**	151	**0.0058**
2001	26,772	437	**0.0163**	178	**0.0066**	111	**0.0041**	135	**0.0050**
2002	27,539	497	**0.0180**	194	**0.0070**	126	**0.0046**	136	**0.0049**
2003	28,022	437	**0.0156**	179	**0.0064**	107	**0.0038**	134	**0.0048**
2004	28,570	408	**0.0143**	145	**0.0051**	107	**0.0037**	120	**0.0042**
2005	29,300	385	**0.0131**	153	**0.0052**	91	**0.0031**	113	**0.0039**
2006	29,799	374	**0.0126**	155	**0.0052**	83	0.0028	126	**0.0042**
2007	30,936	346	0.0112	138	**0.0045**	85	0.0027	92	0.0030
2008	31,296	358	**0.0114**	154	**0.0049**	86	0.0027	108	0.0035
2009	31,727	316	0.0100	116	0.0037	83	0.0026	80	0.0025
2010	32,120	326	0.0101	127	0.0040	68	0.0021	64	0.0020
2011	32,725	276	0.0084	108	0.0033	64	0.0020	86	0.0026
2012	33,115	266	0.0080	109	0.0033	61	0.0018	85	0.0026
2013	33,604	267	0.0079	94	0.0028	73	0.0022	109	0.0032
2014	34,434	230	0.0067	88	0.0026	58	0.0017	118	0.0034
2015	35,409	225	0.0064	103	0.0029	54	0.0015	111	0.0031
2016	35,727	209	0.0058	90	0.0025	42	0.0012	108	0.0030
Car age									
0-5 years	197,993	885	0.0045	302	0.0015	222	0.0011	484	0.0024
6-10 years	155,659	1263	0.0081	479	0.0031	279	0.0018	488	0.0031
11-15 years	94,212	1284	**0.0136**	497	**0.0053**	313	**0.0033**	380	**0.0040**
16-20 years	59,266	1810	**0.0305**	777	**0.0131**	477	**0.0080**	404	**0.0068**
21-25 years	12,833	520	**0.0405**	224	**0.0175**	127	**0.0099**	95	**0.0074**
26-30 years	3,300	81	**0.0245**	38	**0.0115**	18	**0.0055**	12	0.0036
31-35 years	2,804	55	**0.0196**	22	**0.0078**	15	**0.0053**	12	**0.0043**
36+ years	1,163	9	0.0077	4	0.0034	2	0.0017	1	0.0009
Total	**527,213**	**5,907**	**0.0112**	**2,343**	**0.0044**	**1,453**	**0.0028**	**1,876**	**0.0036**

Table 2: Model characteristics.

	Among the predictors	N*	Pseudo R-squared
All crashes	**Crash year**	3,680	0.4073
	Car age	3,680	0.4064
Single vehicle crashes	**Crash year**	3,680	0.3923
	Car age	3,680	0.3910
Car-car collisions	**Crash year**	104,320	0.1337
	Car age	104,320	0.1328
Collisions with ped./cycl.	**Crash year**	3,680	0.1365
	Car age	3,680	0.1312

*The number of rows in the data file, depending on the grouping of the data according to the predictor variables.

Table 3: Model results, coefficients from Poisson regression models with crash year (and not car age) among the predictor variables for all crashes, single vehicle crashes, and car-car collisions (statistically significant coefficients in bold).

	All crashes		Single vehicle crashes		Car-car collisions		Ped./cyc. collisions	
	Coeff.	**p**	**Coeff.**	**p**	**Coeff.**	**p**	**Coeff.**	**p**
Registration year (own car)								
X-1979	**2.285**	.000	**2.560**	0.000	**1.919**	0.000	0.365	0.315
1980-1990	**3.122**	.000	**3.439**	0.000	**2.749**	0.000	**1.312**	0.000
1991-1995	**2.551**	.000	**2.796**	0.000	**2.106**	0.000	**0.906**	0.000
1996-2000	**1.823**	.000	**1.992**	0.000	**1.404**	0.000	**0.520**	0.004
2001-2003	**1.269**	.000	**1.391**	0.000	**0.843**	0.019	0.242	0.183
2004-2006	**0.888**	.000	**0.836**	0.005	0.473	0.192	-0.181	0.326
2007-2009	**0.509**	.010	0.470	0.124	0.222	0.549	-0.313	0.099
2010-2011	0.393	.059	0.188	0.573	0.200	0.611	-0.182	0.363
2012-2013	0.280	.200	0.093	0.793	0.143	0.727	-0.099	0.624
2014-2016	(ref.)		(ref.)		(ref.)			
Weight (own car)								
0-1199 kg	**0.418**	.000	**0.206**	0.008	**0.899**	0.000	**-0.349**	0.000
1200-1399 kg	**0.499**	.000	**0.401**	0.000	**0.817**	0.000	**-0.160**	0.024
1400-1599 kg	**0.421**	.000	**0.418**	0.000	**0.604**	0.000	-0.100	0.188
1600+ kg	(ref.)		(ref.)		(ref.)		(ref.)	
Registration year (other car)								
X-1979					0.703	0.108		
1980-1990					**1.365**	0.000		
1991-1995					**1.213**	0.000		
1996-2000					**0.814**	0.007		
2001-2003					0.403	0.189		
2004-2006					0.479	0.115		
2007-2009					0.230	0.458		
2010-2011					-0.050	0.883		
2012-2013					0.236	0.482		
2014-2016					(ref.)			
Weight (other car)								
0-1199 kg					**-0.510**	0.000		
1200-1399 kg					**-0.201**	0.009		
1400-1599 kg					-0.126	0.123		
1600+ kg					(ref.)			
Driver								
Female, 18-24 years	**0.220**	.001	**0.567**	0.000	0.214	0.081	**-0.373**	0.004
Female, 25-44 years	**-0.902**	.000	**-0.902**	0.000	**-0.901**	0.000	**-0.978**	0.000
Female, 45-64 years	**-0.769**	.000	**-0.842**	0.000	**-0.787**	0.000	**-1.001**	0.000
Female, 65+ years	0.113	.131	0.239	0.069	0.207	0.137	-0.020	0.872
Male, 18-24 years	**0.926**	.000	**1.626**	0.000	**0.538**	0.000	**0.429**	0.000
Male, 25-44 years	**-0.628**	.000	**-0.255**	0.002	**-0.799**	0.000	**-0.766**	0.000
Male, 45-64 years	**-1.099**	.000	**-1.012**	0.000	**-1.106**	0.000	**-1.020**	0.000
Male, 65+ years	(ref.)		(ref.)		(ref.)		(ref.)	
Crash year								
2000	**-0.476**	.000	**-0.807**	0.000	**-0.797**	0.000	-0.129	0.366
2001	**-0.569**	.000	**-0.825**	0.000	**-0.902**	0.000	-0.161	0.265
2002	**-0.429**	.000	**-0.728**	0.000	**-0.763**	0.000	-0.174	0.226
2003	**-0.468**	.000	**-0.708**	0.000	**-0.787**	0.000	-0.148	0.301
2004	**-0.435**	.000	**-0.804**	0.000	**-0.639**	0.002	-0.207	0.154
2005	**-0.387**	.000	**-0.628**	0.000	**-0.651**	0.002	-0.211	0.150
2006	**-0.302**	.001	**-0.484**	0.000	**-0.587**	0.005	-0.040	0.779
2007	**-0.320**	.000	**-0.541**	0.000	**-0.473**	0.023	**-0.355**	0.020
2008	-0.155	.087	**-0.278**	0.043	-0.261	0.206	-0.109	0.453
2009	**-0.192**	.038	**-0.463**	0.001	-0.167	0.417	**-0.369**	0.018
2010	-0.090	.324	**-0.290**	0.041	-0.256	0.226	**-0.560**	0.001
2011	-0.167	.075	**-0.345**	0.018	-0.174	0.412	-0.244	0.107
2012	-0.110	.242	-0.223	0.125	-0.088	0.679	-0.234	0.120
2013	-0.012	.902	-0.257	0.086	0.214	0.293	0.029	0.835
2014	-0.079	.414	-0.225	0.137	0.093	0.656	0.104	0.444
2015	-0.023	.808	0.023	0.872	0.128	0.535	0.027	0.843
2016	(ref.)		(ref.)		(ref.)		(ref.)	
Mill. vehicle km	1.000		1.000		1.000		1.000	
Constant	**-5.959**	.000	**-7.051**	.000	**-7.585**	.000	**-5.090**	.000

Table 4: Model results, coefficients from Poisson regression models with car age (and not crash year) among the predictor variables for all crashes, single vehicle crashes, and car-car collisions (statistically significant coefficients in bold).

	All crashes		Single vehicle crashes		Car-car collisions		Ped./cyc. collisions	
	Coeff.	**p**	**Coeff.**	**p**	**Coeff.**	**p**	**Coeff.**	**p**
Registration year (own car)								
X-1979	**0.702**	0.005	0.189	0.631	**1.103**	0.024	-0.044	0.913
1980-1990	**2.078**	0.000	**1.842**	0.000	**2.235**	0.000	**1.006**	0.000
1991-1995	**1.795**	0.000	**1.611**	0.000	**1.752**	0.000	**0.623**	0.001
1996-2000	**1.249**	0.000	**1.068**	0.000	**1.158**	0.001	0.274	0.106
2001-2003	**0.837**	0.000	**0.670**	0.020	0.674	0.054	0.018	0.919
2004-2006	**0.569**	0.002	0.281	0.335	0.374	0.289	**-0.386**	0.028
2007-2009	0.301	0.119	0.068	0.821	0.197	0.588	**-0.499**	0.006
2010-2011	0.275	0.179	-0.067	0.839	0.223	0.563	-0.277	0.152
2012-2013	0.227	0.295	-0.054	0.877	0.214	0.596	-0.099	0.618
2014-2016	(ref.)		(ref.)		(ref.)		(ref.)	
Weight (own car)								
0-1199 kg	**0.418**	0.000	**0.206**	0.008	**0.899**	0.000	**-0.345**	0.000
1200-1399 kg	**0.500**	0.000	**0.401**	0.000	**0.817**	0.000	**-0.161**	0.023
1400-1599 kg	**0.420**	0.000	**0.418**	0.000	**0.603**	0.000	-0.101	0.182
1600+ kg	(ref.)		(ref.)		(ref.)		(ref.)	
Weight (other car)								
0-1199 kg					**-0.512**	0.000		
1200-1399 kg					**-0.203**	0.008		
1400-1599 kg					-0.126	0.122		
1600+ kg					(ref.)			
Driver								
Female, 18-24 years	**0.222**	0.001	**0.567**	0.000	0.218	0.077	**-0.380**	0.003
Female, 25-44 years	**-0.902**	0.000	**-0.902**	0.000	**-0.902**	0.000	**-0.979**	0.000
Female, 45-64 years	**-0.769**	0.000	**-0.842**	0.000	**-0.790**	0.000	**-1.002**	0.000
Female, 65+ years	0.110	0.142	0.239	0.069	0.204	0.142	-0.006	0.964
Male, 18-24 years	**0.926**	0.000	**1.626**	0.000	**0.538**	0.000	**0.429**	0.000
Male, 25-44 years	**-0.627**	0.000	**-0.256**	0.002	**-0.799**	0.000	**-0.772**	0.000
Male, 45-64 years	**-1.098**	0.000	**-1.012**	0.000	**-1.106**	0.000	**-1.028**	0.000
Male, 65+ years	(ref.)		(ref.)		(ref.)		(ref.)	
Car age (own car)	**0.036**	0.000	**0.052**	0.000	**0.020**	0.003	0.006	0.289
Car age (other car)					**0.040**	0.000		
Mill. vehicle km	1.000		1.000		1.000		1.000	
Constant	**-5.991**	0.000	**-7.089**	0.000	**-7.530**	0.000	**-5.070**	0.000

3.1 Registration year

The results in Table 1 and the model results (Table 3 and Table 4) show consistently for all crash types that there are fewer KSI car drivers in cars from later registration years than in cars from earlier years, and fewer KSI pedestrians/cyclists in collisions with cars from later registration years. However, in cars registered before 1980 there are fewer KSI drivers than in cars from 1980-1990 which may be a veteran car effect. Many drivers of very old cars are careful with their cars, drive only at low speed under low-risk conditions, and possibly less than assumed in the models.

Figure 1 shows the relationships between registration year and relative numbers of KSI, both unadjusted (per million vehicle kilometers as shown in Table 1) and adjusted (based on model results with statistical control for all other variables in the models; Table 3 and Table 4). The estimated changes of numbers of KSI from registration year 1980-1990 to 2014-2016 and from registration year X to X+1 for all types of crashes, are shown in Table 5, based on the unadjusted results (Table 1) and the adjusted results with crash year (Table 3) or car age (Table 4) among the predictor variables.

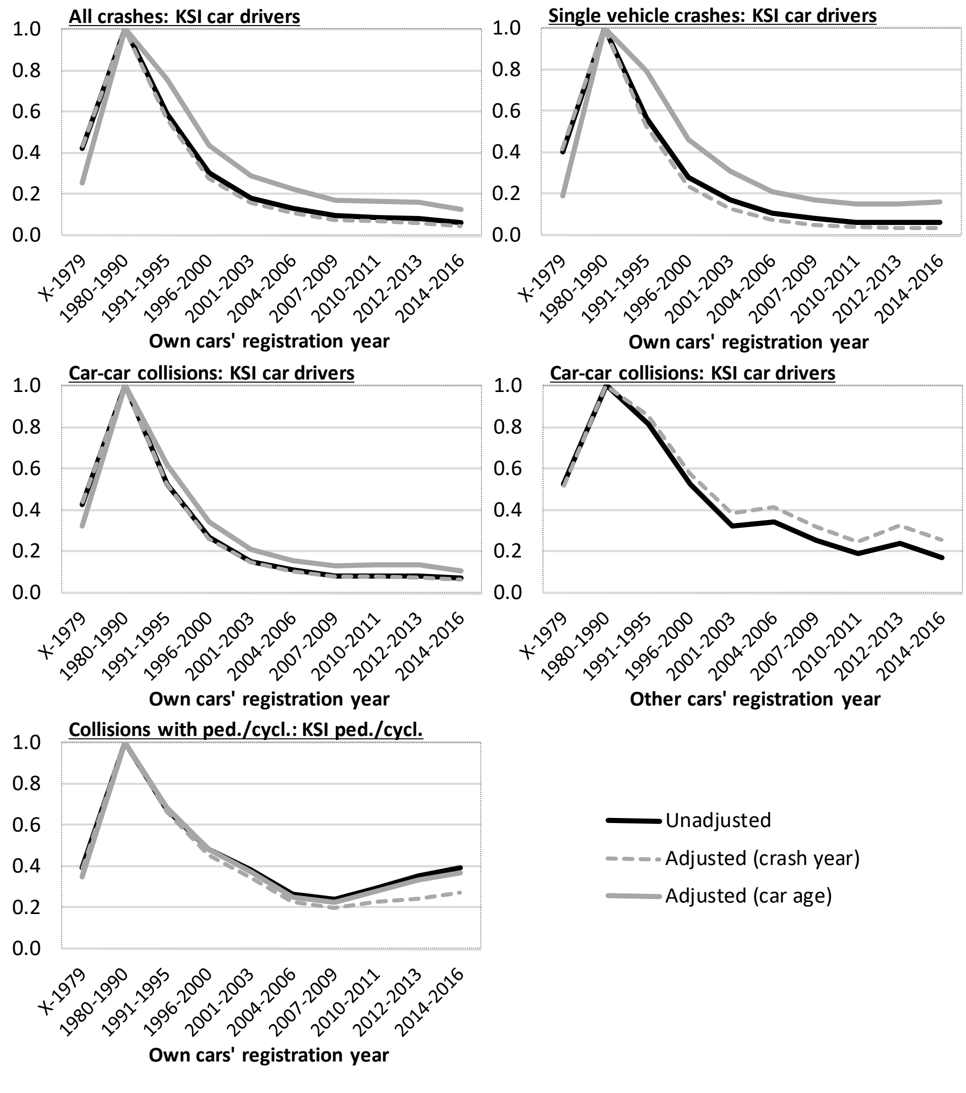

Figure 1: Relationships between the own and other cars' registration year and relative numbers of KSI car drivers (own car) or pedestrians/cyclists; unadjusted and adjusted results (rel. number of KSI is in each diagram set equal to one for cars from 1980-1990).

Table 5: Estimated changes of numbers of KSI from registration year 1980-1990 to 2014-2016 and from registration year X to X+1 for all types of crashes, unadjusted and adjusted.

Crash type: Effect of reg. year: Effect on KSI:	All crashes Own car Drivers (own car)	Single vehicle crashes Own car Drivers (own car)	Car-car collisions Own car Drivers (own car)	Car-car collisions Other car Drivers (own car)	Collisions with pedestrians/cyclists Own car Pedestrians/ cyclists
From registration year 1980-1990 to 2014-2016					
Unadjusted	-94 %	-94 %	-93 %	-83 %	-61 %
Adjusted (crash year pred.)	-96 %	-97 %	-94 %	-74 %	-73 %
Adjusted (car age pred.)	-87 %	-84 %	-89 %		-63 %
From registration year X to X+1					
Unadjusted	-8.9 %	-8.8 %	-8.5 %	-5.7 %	-3.1 %
Adjusted (crash year pred.)	-9.9 %	-10.8 %	-8.8 %	-4.4 %	-4.3 %
Adjusted (car age pred.)	-6.7 %	-6.0 %	-7.2 %		-3.3 %

According to the unadjusted results and the adjusted results with crash year among the predictor variables, Figure 1 and Table 5 show that the numbers of KSI car drivers per million vehicle kilometers have decreased by over 90% in cars from 2014-2016 compared to cars from 1980-1990 in all crashes, single vehicle crashes and car-car collisions. The slope of the decrease has changed less than it may appear in Figure 1 because more years are grouped together during earlier years than during later years. However, even when taking into account the different sizes of the age groups, the decrease seems to have leveled off during the later years.

The adjusted effects of the own cars' registration year with crash year among the predictor variables are slightly larger than the unadjusted effects. This is contrary to expectation because both weight and crash year are statistically controlled for. The average weight of new cars has increased from about 1100 kg in 1970-1990 to about 1460 in 2015 and 2016. Increasing weight was found to be related to decreasing injury risk for the driver, both in the present and in other studies (section 3.3). Crash year is also related to crash and injury risk, the number of KSI per million vehicle kilometers has decreased by 72% from 2000 to 2016 (Table 1). Possible explanations for the large adjusted effects of registration year with crash year among the predictor variables are discussed in section 4.1.

The adjusted effects of the own cars' registration year with car age (and not crash year) among the predictor variables in Figure 1 are still large, but consistently smaller than the unadjusted effects and the adjusted effects with crash year among the predictor variables, except in collisions with pedestrians/cyclists. In all crashes they indicate that the number of KSI car drivers in the own car decreases on average by 6.7% for each consecutive registration year.

In car-car collisions, more recent own and other cars are related to fewer KSI car drivers (in the own car), with the effect of the own cars' registration year being larger than the other cars' registration year. Whether the effect of the own cars' registration year on KSI car drivers is larger or smaller in car-car collisions or in single vehicle crashes, differs between the models with crash year and car age among the predictor variables.

In collisions with pedestrians/cyclists, the number of KSI pedestrians/cyclists was found to increase for cars of the latest registration years, compared to cars from 2004-2009 in the models with car age among the predictor variables, while the differences between the latest registration years in the models with crash year among the predictor variables is not statistically significant.

3.2 Car age

The relationships between car age and relative numbers of KSI car drivers and pedestrians/cyclists are shown in Figure 2, both unadjusted (as in Table 1) and adjusted (as in Table 4), disaggregated by year. The relative number of KSI is in each diagram set equal to one for one-year-old cars.

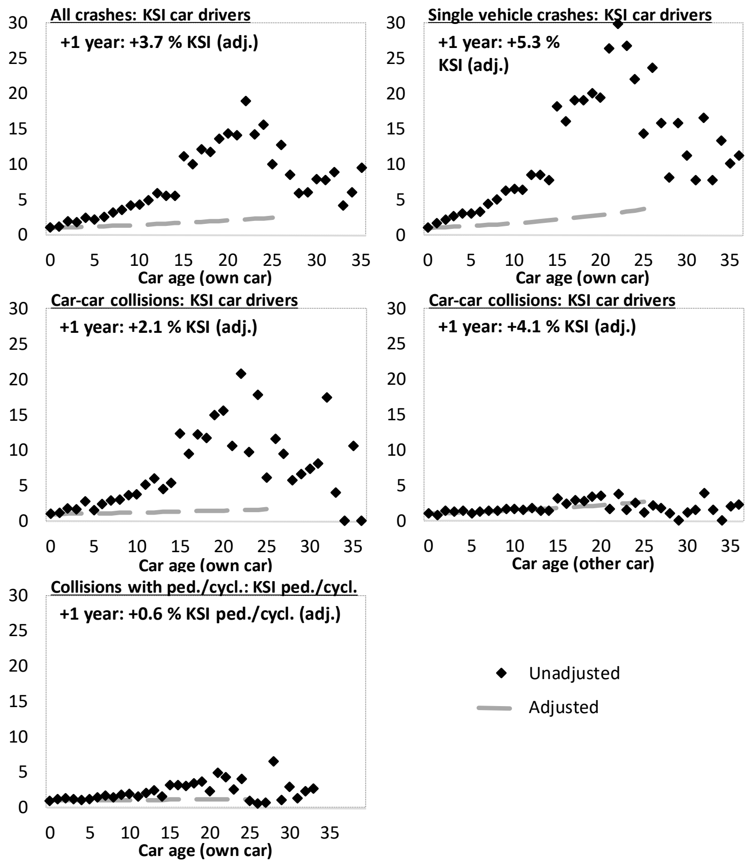

Figure 2: Relationships between the own and other cars' age and relative numbers of KSI car drivers (own car) or pedestrians/cyclists; unadjusted and adjusted results (rel. number of KSI is in each diagram set equal to one for one-year-old cars).

The results in Table 1 and Figure 2 show that there are more KSI car drivers in older cars up to an age of about 25 years. In cars above 25 years, the number of KSI decreases with increasing age. This may be the same veteran car effect as for cars from the earliest registration years.

The adjusted results show far weaker increases of the number of KSI with increasing car age than the unadjusted effects. A large part of the unadjusted effects of age on KSI is likely to be due to the effect of registration year which is strongly related to both KSI and car age. Cars from 2014-2016 are on average 1.4 years old, while cars from 1980-1990 on average are 19.6 years old.

The strongest increase of KSI with increasing car age was found in single vehicle crashes. The adjusted effects may be somewhat underestimated because of the decrease of KSI in the oldest cars. However, only 2.5% of all KSI drivers had driven cars above 25 years of age, while 39.4% had a car that was 16-25 years old. The adjusted effects are therefore not likely to be strongly affected by the decreasing numbers of KSI in the oldest cars.

The age of the crash partner in car-car collisions has a far weaker effect on KSI car drivers than the age of the own car according to the unadjusted results. However, the adjusted effect of the other cars' age is about twice as large as the adjusted effect of the own cars' age (+4.1% vs. +2.1% KSI per additional year).

In collisions with pedestrians/cyclists the effect of the own cars' age on KSI pedestrians/cyclists is far smaller than the effects on KSI drivers in other crashes and not statistically significant.

3.3 Weight

The relationships between the cars' weight and relative numbers of KSI car drivers and pedestrians/cyclists are shown in Figure 3, both unadjusted (based on the results in Table 1) and adjusted (based on the results in Table 3). The coefficients for weight are almost identical to the third decimal in the models with crash year and car age among the predictors. The relative number of KSI is in all diagrams set equal to one for the lightest cars. Additionally, exponential trend functions of the adjusted effects are shown in each diagram as well as the average effects of a weight increase by 100 kg, based on the trend functions.

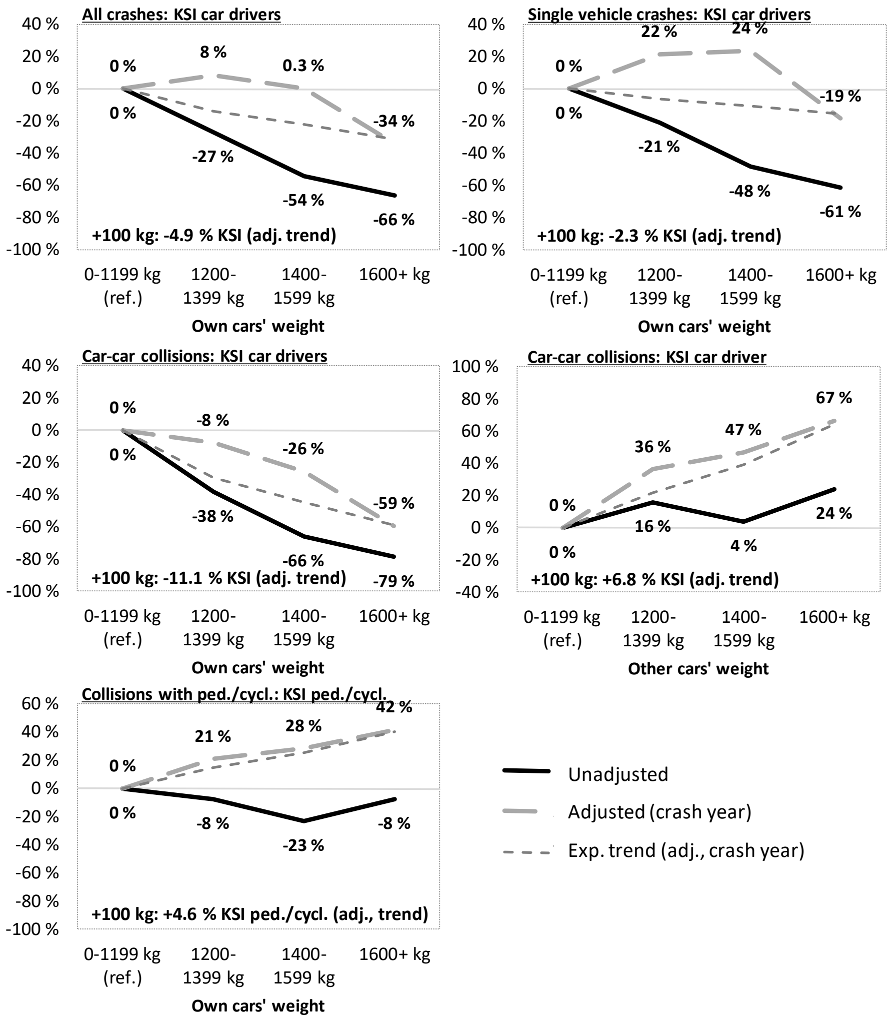

Figure 3: Relationships between the own and other cars' weight and relative numbers of KSI car drivers (own car) or pedestrians/cyclists; unadjusted and adjusted results (rel. number of KSI is in each diagram set equal to one for the lightest cars).

The adjusted effects of the own cars' weight on KSI car drivers are consistently smaller than the corresponding unadjusted effects. This is probably mainly due to the statistical control for registration year because more recent cars are on average both heavier and safer than cars from earlier years.

In all crashes and in and single vehicle crashes non-linear relationships were found between weight and KSI car drivers. The trend functions and the estimated average changes of the number of KSI per 100 kg weight increase are therefore somewhat misleading for these crashes. Regardless of this, the adjusted results indicate that the effect of the own cars' weight on the number of KSI drivers of the own car is far larger in car-car collisions than in single vehicle crashes.

Increasing weight among crash partner vehicle is related to increasing numbers of KSI in the own car. The average absolute effect of a weight increase by 100 kg is somewhat smaller (+6.8%) than the corresponding effect of the own cars weight (-11.1%). In collisions with pedestrians and cyclists, heavier cars impose higher risk on pedestrians and cyclists than lighter cars according to the adjusted effects.

3.4 Driver

The results in Table 1, Table 3, and Table 4 show consistently that young drivers, especially young men, are more often KSI than other drivers, especially in single vehicle crashes. Older drivers are also more often KSI than drivers in the middle age groups, but less often than the youngest. While young men are more often KSI than young women, there are no large or statistically significant differences between men and women in the age groups above 25 years. Young men impose also considerably larger risk to pedestrians and cyclists than other drivers. The results from the present study are in accordance with results from other studies (e.g. Bjørnskau, 2015; Kockelman & Kweon, 2002; Martin & Lenguerrand, 2008).

3.5 Crash year

In later crash years there are fewer KSI car drivers per million vehicle kilometers (Table 1), but the model results indicate that there are more KSI car drivers in later years (Table 3). A likely explanation is the statistical control for registration year. The model results show there are more KSI car drivers in later years *if all else is equal*, where *all else* includes the cars' registration year. Cars from the same registration year are older in later crash years, and older cars can be assumed to have more KSI than newer cars, both according to the results from the present study, according to other studies (Farmer & Lund, 2015; Wenzel, 2013), and because of the relationship between car age and driver related risk factors (see section 4.2). Consequently, if *all else*, including the cars' registration year, is equal, the higher car age in later years can expected to contribute to more KSI in later years. An example of the same type of effect is described by Kennedy (2005). In the example, an additional family room in residential houses contributes to decreasing house prices with statistical control for total square meters: Adding a family room while holding total square meters constant entails a reduction of either total square meters or number of rooms elsewhere in the house, which negatively affects the price. Thus, the addition of the family room as such cannot be held responsible for the negative effect on house prices.

4. Discussion

The present study has investigated effects of passenger cars' first year of registration, weight, and age on the number of KSI drivers of passenger cars and pedestrians/cyclists. A general problem in estimating the effects of registration year and car age is that both variables are highly correlated both to each other and to crash year. Moreover, two of these variables are always a function of the third and it is therefore not possible to develop models with all three variables as predictors. In the present study, controlling for crash year contributed to unrealistically large effects of registration year, at the same time as the adjusted effects of crash year have the «wrong» sign. The most likely explanations are the large correlation between registration year and crash year (se section 4.1) and the fact that cars from the same registration year are older in later crash years and that older cars have higher risk than newer cars (see section 3.5).

4.1 Registration year

Cars from later registration years were in the present study found to have far fewer KSI drivers than cars from earlier registration years (back to around 1980). The estimated reduction of the number of KSI drivers in all crashes per year, i.e. from one registration year to the next, according to the model with crash year (and not car age) among the predictor variables (-9.9%) is likely to be overestimated because it is larger than the unadjusted effect (-8.9%), although both crash year and weight of the cars are statistically controlled for. With car age (and not crash year) among the predictor variables, the estimated reduction is smaller (-6.7%). Moreover, the decrease seems to have levelled off during later years.

A possible explanation for the large effect of registration year with statistical control for crash year is that the registration year predictor variable may «explain» a part of the effect of crash year. This is possible because registration year and crash year are highly correlated; cars from 2014-2016 crashed on average in 2015, while cars from 1980-1990 on average crashed in 2004. Such an effect may also be a part of the explanation for the finding that the adjusted effects of crash year have the «wrong» sign (see section 3.5).

Directly comparable other studies were not found, i.e. studies that also have controlled for crash year or car age and that have used vehicle kilometers as exposure variable. The study that is most comparable to the present study (Broughton, 2012) found an average decrease of the number of fatally injured car drivers by 9.3% and an average decrease of seriously injured car drivers by 6.3% per registration year in car-car collisions from registration years 1988-1991 to 2004-2007 which is similar to the results from the present study (-8.8% or -7.2% KSI car drivers in car-car collisions, depending to the model). Broughton (2012) have investigated the effects on the number of fatally and seriously injured car drivers per registration year. Crash year (2001-2005) is not statistically controlled for.

Whether the effect of registration year is larger in single vehicle crashes or in car-car collisions is not quite clear in the results from the present study. The unadjusted effects of registration year are similar in single vehicle crashes and in car-car collisions, and the results from models with crash year and car age among the predictor variables yield contradicting results. Another study that has investigated effects of registration year in both types of crashes (Méndez et al., 2010) found no statistically significant effects in single vehicle crashes and an average decrease of the number of KSI car drivers per injured car driver by 2.9% per registration year (registration years from pre 1985 to 2005 are included in the study) in car-car collisions. The effect is estimated based on an exponential trend function fitted to the results reported in the original study. These results refer injury risk, not crash risk. Crash year (2000-2005) is statistically controlled for.

Factors that may have contributed to the decrease of KSI car drivers in more recent cars (besides methodological factors as discussed above), are improved active safety and crashworthiness (see section 1). Both have improved considerably in cars from later years. Since the cars' weight is statistically controlled for, the effects of registration year can be assumed to be independent of the effect of increasing weight over time. The decrease of KSI drivers can be assumed to be due to decreases of both crash and injury risk, although it is not possible, based on the results that are presented in the present paper, to keep apart the effects on crash and injury risk. However, it is reasonable that the effects that were found in the present study and that refer to both crash and injury risk, are larger than effects that are found in studies that have investigated effects on injury risk alone (studies with crash involvement as exposure variable).

Crash partner cars from later registration years were in the present study found to be related to fewer KSI car drivers in car-car collisions. On average, the number of KSI car drivers in car-car collisions is reduced by 5.7% (unadjusted effect) or by 4.4% (adjusted effect with car age among the predictor variables) per year, i.e. from one registration year to the next. Broughton (2012) found an average increase of the number of fatally injured car drivers by 1.3% (not statistically significant) and an average decrease of seriously injured car drivers by 1.9% per registration year in car-car collisions from registration years 1988-1991 to 2004-2007. Méndez et al. (2010) found an average increase of the number of KSI crash partner drivers per injured crash partner driver in car-car collisions by 3.1% per registration year. These results refer only to injury risk, not crash risk. Taken together, the results indicate that the effects of the crash partners' registration year that were found in the present study, mainly are due to the reduced crash risk of more recent crash partners, and less or not at all to reduced aggressivity of more recent crash partners. Had more recent crash partner cars been less aggressive than crash partner cars from earlier years, one would have expected the effects of the crash partners' registration year to be more similar to the own cars' registration year (and not smaller as in the present study). One would also have expected results from studies that have investigated effects on injury risk to be more similar to the results from the present study. Factors that may have contributed to the decrease of KSI in car-car collisions in crashes with more recent crash partners are the same as those that are assumed to have contributed to the crash risk part of the decrease of KSI in more recent cars.

4.2 Car age

The results from the present study indicate that there are more KSI drivers in older cars than in newer cars. Without adjusting for registration year, there are about 15 times as many KSI in 20-year-old cars than in new cars. A large part of the effect of car age is probably due to effects of registration year which is strongly related to car age. However, even with control for registration year, the number of KSI drivers was found to increase by 3.7% per year in all crashes. The effect is considerably larger in single vehicle crashes (+5.3% per year) than in car-car collisions (+2.1% per year).

Increasing numbers of passenger car driver fatalities in older cars were also found in other studies that have controlled for registration year (Farmer & Lund, 2006, 2015; Wenzel, 2013). Factors that may contribute to the increasing risk of older cars (up to 25 years) are increasing occurrence of technical defects (Christensen & Elvik, 2006; Lécuyer & Chouinard, 2006) and more high-risk behavior among drivers. Amongst other things, drivers of older cars are more often drunk, speeding, and/or unbelted (White, 2003; Høye, 2017B), and more often involved in hit-and-run crashes (MacLeod et al., 2012). Moreover, older cars have shorter annual mileages than newer cars and drivers who drive little have on average higher crash risk than drivers who drive more (Langford et al., 2006). The finding that drivers of older cars show more high-risk behavior is consistent with the larger effect of car age that was found in single vehicle crashes compared to car-car collisions. The high-risk behaviors that are overrepresented in older cars have also been found to be overrepresented in single vehicle crashes (Ferguson, 2012; Mørland et al., 2011; Høye, 2017B).

Older crash partner cars were in the present study also found to be related to more KSI drivers in the own car. Although the unadjusted effect of crash partner age is far smaller than the unadjusted effect of the own cars age, the adjusted effect of crash partner age is almost twice as large as the effect of the own cars age (+4.1% vs. +2.1). Factors that may contribute to the effect of the crash partners age are the same as for the own cars age.

4.3 Weight

The results from the present study indicate that the relationship between car weight and KSI drivers is different between single vehicle crashes and car-car collisions. In single vehicle crashes, there are least KSI drivers in the heaviest cars, followed by the lightest cars, and most KSI drivers in cars between 1200 and 1600 kg. In car-car collisions, increasing weight of the own car is related to monotonically decreasing numbers of KSI drivers, while increasing weight of the crash partner car is related to monotonically increasing numbers of KSI drivers. Larger effects of the own cars weight in car-car collisions than in single vehicle crashes were also found by Chen & Kockelman (2012). The results refer to injury severity (not crash risk). Model year is statistically controlled for, and so are the vehicles' footprint and height. Martin & Lenguerrand (2008) did not find any statistically significant effects of vehicle weight on the drivers' risk of being fatally injured in single vehicle crashes, but a large and statistically significant effect in car-car collisions. Drivers of cars above 1150 kg had 52% reduced fatality risk in car-car collisions, compared to drivers of cars below 850 kg. Studies that have investigated the effects of vehicle weight in all crashes have also found relationships between increasing weight and fewer fatalities for serious injuries among drivers of the own car (e.g. Adolph et al., 2015; Wenzel & Ross, 2005).

The difference that was found between single vehicle crashes and car-car collisions in the present and other studies is consistent with differences between factors that can be assumed to contribute to the effects of vehicle weight. Heavier cars have on average smaller changes in velocity in collisions with other cars and are more likely to knock down (instead of being stopped by) objects such as small trees or poles (Wenzel, 2013). This gives heavier cars an advantage in collisions with other motor vehicles and in some single vehicle crashes. On the other hand, in rollover crashes and in some collisions with solid stationary objects (mostly single vehicle crashes), lower weight can be an advantage because less energy will have to be absorbed by the car structure (Friedman et al., 2013; Wenzel, 2013). Additionally, heavier cars are on average larger and can therefore have larger deformation zones which may be an advantage for the car occupants in all types of crashes.

The results from the present study indicate that the advantage of heavier cars for the drivers of the heavier cars more than outweigh the disadvantage of heavier cars for drivers of crash partners. In car-car collisions, an increase of the own cars weight by 100 kg is on average related to a decrease of KSI drivers by 11.1% while the same weight increase among crash partners is related to an increase of KSI drivers in the own car by 6.8%. In collisions between two cars, the total number of KSI drivers can therefore be expected to decrease by 5.1% if both cars increase their weight by 100 kg (the product of the effects of the own and the other cars' weight). More fatalities among car drivers in collisions with heavier crash partners were also found in other studies. However, in the studies by Martin & Lenguerrand (2008) and Anderson & Auffhammer (2014) the increases of fatality risk for the driver of the own car that follows from a weight increase of the other vehicle in car-car collisions, is larger than the decrease of the drivers' fatality risk than follows from a weight increase of the own car. Thus, in contrast to the present study, the advantage of heavier cars for the drivers of the heavier cars do not outweigh the disadvantage of heavier cars for the drivers of crash partner vehicles.

4.4 Pedestrians and cyclists

Cars from later registration years were found to impose lower risk on pedestrians and cyclists than cars from earlier years. Only the latest registration years (compared to cars from 2004-2009) were found to be related to more KSI pedestrians and cyclists. However, the effect is statistically significant only in the model with car age among the predictor variables, not in the model with crash year. Improvements of vehicle design with an increased focus on the protection of vulnerable road users may explain the decrease of KSI pedestrians/cyclists in collisions with more recent cars (Li et al., 2017; Otte & Haasper, 2007). If one assumes the increase of KSI pedestrians in collisions with more recent cars to be real, the large increase of the proportion of electric vehicles in the Norwegian car fleet in recent years may have contributed. Several studies found electric vehicles to be overrepresented in collisions with pedestrians (Morgan et al., 2011; Wu et al., 2011) and electric vehicles are driving far more in urban areas (with many pedestrians and cyclists) than other vehicles.

Heavier cars were found to impose higher risk on pedestrians and cyclists than lighter cars according to the adjusted effects (not according to the unadjusted effects). The effect may be underestimated because exposure is not controlled for at a detailed geographical level. Exposure of pedestrians and cyclists is indirectly controlled for (crash year is related to the change of the total number of pedestrians and cyclists over time). However, heavier cars can be assumed to drive more in areas with few or no pedestrians and cyclists, while lighter cars drive more in urban areas with many pedestrians and cyclist. Consequently, exposure (in terms of potential encounters between a car and a pedestrian/cyclist) is likely to be overestimated for heavier cars and underestimated for lighter cars, and when exposure is overestimated, risk will be underestimated.

The most important factor that can be assumed to contribute to the relationship between weight and KSI pedestrians/cyclists is the type of car and the design of the cars' front. Several other studies show that pedestrians and cyclists have far higher injury and fatality risk in collisions with SUVs that are both heavier and have higher and more rigid fronts, than in collisions with passenger cars (Kim et al., 2010; Lefler & Gabler, 2004; Simms & Wood, 2006). Weight as such has in other studies not been found to have any large effect on injury or fatality risk among pedestrians when the type of car is statistically controlled for (Roudsari et al., 2004).

5. Conclusions

The results show that there are fewer KSI car drivers in cars from later registration years and in newer cars. Due to the large effects of safety improvements in more recent cars, an increased renewal rate in the passenger car fleet can be expected to contribute to large safety improvements. The effect of car age is probably mainly due to the relationship between car age and driver behavior, in addition to a possible effect of increased technical defects in older cars. Drivers of older cars show on average far more high-risk behavior such as drunk driving, speeding and non-use of seat belts, than drivers of newer cars. Consequently, decreasing the average age in the car fleet in itself is not likely to contribute to safety improvements.

Heavier cars were found to reduce injury risk for the drivers of the heavier cars, but at the cost of increased injury risk for crash partners. The results from the present study indicate that the advantages of heavier cars for the drivers of the heavier cars more than outweigh the increased risk for crash partners. This would imply that overall safety for car drivers would improve if all cars were heavier. On the other hand, heavier cars have only relatively small benefits in single vehicle crashes and impose greater risk to pedestrians and cyclists. Moreover, results from other studies indicate that the disadvantages of heavier cars for crash partner cars more than outweigh the advantages for the driver of the own car. Therefore, it cannot be concluded that increasing average car weight would be beneficial for overall safety.

6. Acknowledgement

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