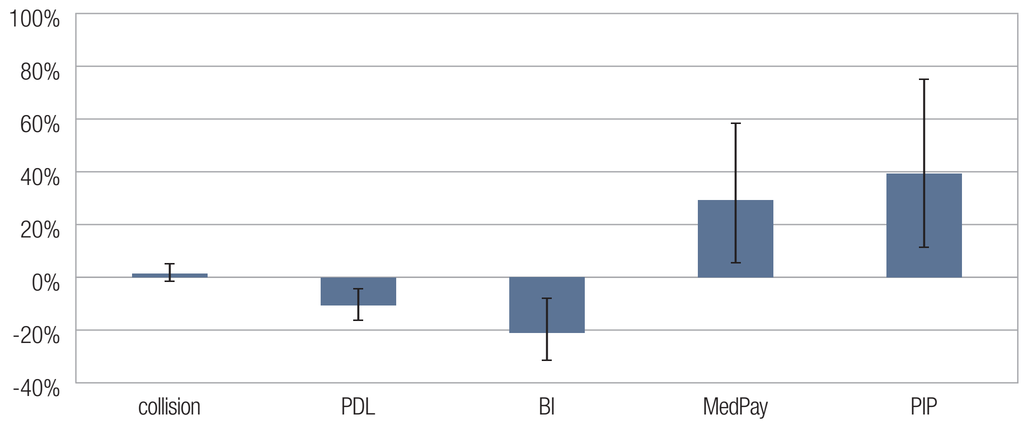
HLDI
Highway Loss Data Institute

Bulletin | Vol. 34, No. 30 : September 2017

Tesla Model S driver assistance technologies

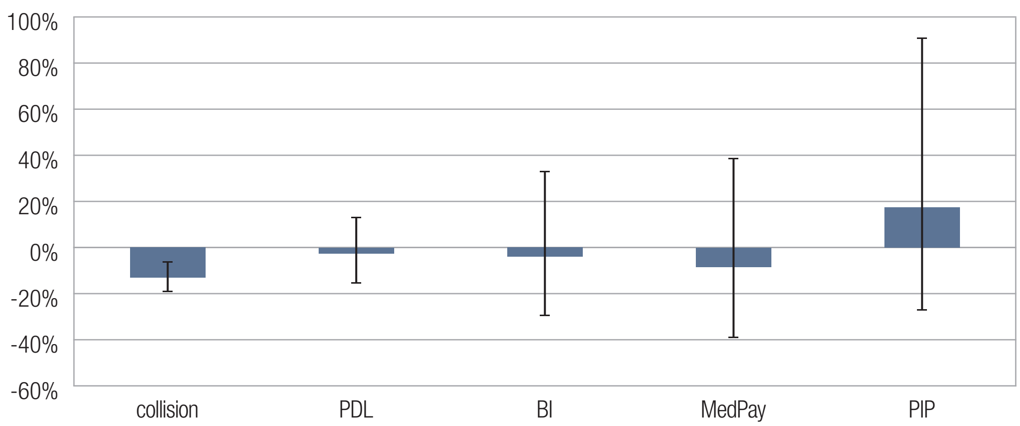
In late 2014, Tesla began producing vehicles equipped with the hardware necessary to provide several advanced driver assistance systems. These systems were later enabled via over-the-air software updates and included features such as forward collision warning (FCW), automatic emergency braking (AEB), blind spot warning, and Tesla's Autopilot system. The figure below shows the estimated effect on claim frequency for all these technologies combined for the Tesla Model S. The systems were associated with significant reductions in claim frequency of 11 percent under property damage liability coverage and 21 percent under bodily injury liability coverage. These results are consistent with prior HLDI research of front crash prevention systems. However, Tesla's driver assistance systems were associated with significant increases in both medical payment and personal injury protection claim frequencies. There was no significant effect on collision claim frequency.

Estimated effect of Tesla Model S driver assistance technology enabled by Hardware Version 1, including Autopilot, on claim frequency



An analysis isolating the incremental effect of the Autopilot system found generally little difference in claim frequencies after Autopilot was enabled, as seen in the figure below. Property damage and bodily injury liability claim frequency remained unchanged with the addition of Autopilot. Thus, the benefits noted above are likely driven by the front crash prevention and blind spot monitoring systems. Previous research has established similar benefits for those features. Medical payment and personal injury protection results were inconclusive for Autopilot, with no significant results and large confidence bounds. Collision claim frequency, however, did show a significant reduction of 13 percent.

Estimated incremental effect of Tesla Model S Autopilot on claim frequency over early driver assistance technology without Autopilot



Introduction

In 2015, Tesla added several key safety features via software updates to the Model S. Beginning with software update 6.1, Tesla enabled traffic aware cruise control (i.e. adaptive cruise control), forward collision warning and automatic high beams. In March of 2015, automatic emergency braking and blind spot monitoring were added. These safety systems were considered standard features and were available for all vehicles built after September 19, 2014, with Hardware Version 1, which included a windshield-mounted camera, a radar sensor mounted in the lower front grill, and ultrasonic sensors in the front and rear bumpers.

In October of 2015, with the 7.0 software update, Tesla added Autopilot, a Level 2 driver assistance system. Autopilot combines an autosteering function with traffic aware cruise control to assist the driver with speed control and lane maintenance simultaneously in certain driving conditions; assists the driver in transitioning to an adjacent lane when it is safe to do so and the turn signal is engaged (Auto lane change); and maneuvers the vehicle into a parking space by controlling the vehicle speed, gear changes, and steering (Autopark). Although all vehicles equipped with Hardware Version 1 had the capability of using Autopilot, it was considered an optional feature and cost approximately $5,000 to enable the system. Further enhancements were made to the Autopilot and Autopark systems with update 7.1.

In October 2016, Tesla began producing vehicles with Hardware Version 2, an updated hardware suite that Tesla says has the hardware needed for full self-driving capabilities. This included eight surround cameras, 12 ultrasonic sensors, a forward-facing radar, and an onboard computer to process the incoming sensor data. (Tesla).

Tesla's Autopilot system has been the subject of some controversy, making headlines in May 2016 when a Tesla owner was killed after crashing into the side of a tractor-trailer with Autopilot engaged. Critics argued that the term Autopilot was misleading and could "encourage drivers to put too much reliance on Autopilot to protect them from crashing and not pay proper attention behind the wheel." Both Germany's Transport Ministry and the Dutch Road Traffic Service requested Tesla use a different name for the system. (Woodyard, 2016).

Tesla officials responded to the criticism, emphasizing that they are clear with their customers that "Autopilot is a driver assistance system that requires the driver to pay attention at all times," and that they employ safeguards to prevent Autopilot from being misused (Lambert, 2016). Eight months after the fatal crash, federal auto-safety regulators said their investigation found no defects in the Autopilot system (Boudette, 2017). Furthermore, using mileage and airbag deployment data supplied by Tesla, the Office of Defects Investigation found that the Tesla vehicle crash rate dropped by almost 40 percent after Autosteer installation (NHTSA, 2017).

The purpose of this HLDI bulletin is to estimate the effect of adding driver assistance technologies, including Autopilot, on Tesla Model S insurance losses.

Method

Insurance data

Automobile insurance covers damages to vehicles and property, as well as injuries to people involved in crashes. Different insurance coverages pay for vehicle damage versus injuries, and different coverages may apply depending on who is at fault. The current study is based on property damage liability, collision, bodily injury liability, personal injury protection, and medical payment coverages. Exposure is measured in insured vehicle years. An insured vehicle year is one vehicle insured for one year, two vehicles for six months, etc.

Because different crash avoidance features may affect different types of insurance coverage, it is important to understand how coverages vary among the states and how this affects inclusion in the analyses. Collision coverage insures against vehicle damage to an at-fault driver's vehicle sustained in a crash with an object or another vehicle; this coverage is common to all 50 states. Property damage liability (PDL) coverage insures against vehicle damage that at-fault drivers cause to other people's vehicles and property in crashes. This coverage exists in all states except Michigan, where vehicle damage is covered on a no-fault basis (each insured vehicle pays for its own damage in a crash, regardless of who is at fault). Coverage of injuries is more complex. Bodily injury (BI) liability coverage insures against medical, hospital, and other expenses for injuries that at-fault drivers inflict on occupants of other vehicles or others on the road. Although motorists in most states may have BI coverage, this information is analyzed only in states where the at-fault driver has first obligation to pay for injuries (33 states with traditional tort insurance systems). Medical payment coverage (MedPay), also sold in the 33 states with traditional tort insurance systems, covers injuries to insured drivers and the passengers in their vehicles but not injuries to people in other vehicles involved in the crash. Seventeen other states employ no-fault injury systems (PIP coverage) that pay up to a specified amount for injuries to occupants of involved-insured vehicles, regardless of who is at fault in a collision. The District of Columbia has a hybrid insurance system for injuries and is excluded from the injury analysis.

Mileage data

The linking of mileage data and HLDI insurance data was made possible through a cooperative agreement with CARFAX, a unit of IHS Markit. Vehicle identification numbers (VINs) from the HLDI database were matched to odometer readings from CARFAX. Odometer readings came from multiple sources including title transfers, yearly inspections, and routine maintenance service. The frequency of odometer readings varied widely. Some vehicles had just one or two odometer readings, while others had numerous records (e.g., scheduled maintenance and state inspection). Miles per day was computed for each day of exposure by taking the ratio of the increase in miles from two consecutive odometer readings to the number of days between the two readings. When more than one mileage reading was available, miles per day was calculated for each pair. For example, the days between mileage readings 1 and 2 could be assigned different miles per day than the days between mileage readings 2 and 3. The different daily averages were assigned to the corresponding periods of matching collision coverage.

Vehicles

This study evaluates insurance losses for the 2012–16 Tesla Model S. Conventional large luxury vehicles of the same model years were used as a comparison group to account for trends in insurance losses over time. The combined collision exposure for these vehicles was 3,271,318 insured vehicle years.

Tesla vehicles produced after September 19, 2014, were equipped with Hardware Version 1. For the purposes of this analysis, HLDI assumes that any 2014 model year Tesla S vehicle whose first insurance or CARFAX mileage record occurs after September 19, 2014, was produced with Hardware Version 1. Likewise, a similar assumption is made for the 2016 model Tesla S produced after October 19, 2016, with Hardware Version 2.

A vehicle's age was calculated as the difference between the calendar year and model year. Many manufacturers release new models in the calendar year prior to the vehicle's model year. For example, a vehicle's 2014 model year may be released during the 2013 calendar year. For the purposes of this analysis, such a vehicle is considered to have an age of -1 in calendar year 2013, 0 in calendar year 2014, 1 in calendar year 2015, etc.

Analysis methods

Several different analyses were conducted in this study. For all regression analyses, claim frequency was modeled using a Poisson distribution, while claim severity (average loss payment per claim) was modeled using a Gamma distribution. Both models used a logarithmic link function. Estimates for overall losses were derived from the claim frequency and claim severity models. Estimates for frequency, severity, and overall losses are presented for collision and property damage liability. For PIP, BI, and MedPay, only frequency estimates are presented.

Covariates included in all analyses were calendar year, garaging state, vehicle density (number of registered vehicles per square mile), rated driver age group, rated driver gender, rated driver marital status, deductible range (collision coverage only), drive type (2WD vs. 4WD), and risk. Miles per day was included in the analysis for claim frequencies and thus overall losses. A Tesla indicator variable was included to identify whether the vehicle was a Tesla or a conventional large luxury.

The first analysis compared the insurance losses by model year of the Tesla Model S with the conventional large luxury vehicles. This analysis included model year and the interaction between model year and the Tesla indicator as covariates. The estimate was obtained by combining the Tesla indicator estimate with the corresponding model year interaction estimate.

The second analysis estimated the effect of the driver assistance technologies (including Autopilot) enabled by Hardware Version 1 on insurance losses for the Tesla Model S. Driver assistance technologies were first activated for Tesla vehicles with Hardware Version 1 beginning with ACC, FCW and automatic high beams in January 2015. AEB and blind spot were added in March 2015, and Autopilot and its associated systems were added in October 2015. This analysis did not separate out the individual effects of each system but looked at the combined effect of all these systems together.

This analysis compared older model year Tesla vehicles without Hardware Version 1 to newer Tesla vehicles with Hardware Version 1. Consequently, vehicle age instead of model year was used as a covariate. In addition, trends in insurance losses change over time and these differences must be accounted for to allow an appropriate comparison of insurance losses between vehicles of the same age in different time periods, e.g., a 1-year-old vehicle in 2016 compared with a 1-year-old vehicle in 2014. Therefore, to estimate the effect of the driver assistance technologies enabled by Hardware Version 1, a difference-in-difference (Dimick, 2014) approach was used. Although this was not a traditional pre-post analysis often used with a difference-in-difference approach, a similar methodology was employed:

- 2012–2016 model year large luxury vehicles were included as the control population to account for changes in insurance trends.
- **Tesla/Conventional** — was used as an indicator variable to identify Tesla vehicles versus conventional large luxury vehicles.
- **With Tech/Without Tech** — was used as an indicator variable to identify loss experience for Teslas with driver assistance technology enabled by Hardware Version 1 versus those without. Model year 2015–16 conventional large luxury vehicles were included as the control population for the **With Tech** group. Model year 2012–14 conventional large luxury vehicles were included as the control population for the **Without Tech** group.

Generally, Tesla vehicles with Hardware Version 1 were treated as **With Tech**, whereas Teslas without Hardware Version 1 were treated as **Without Tech**. One slight complication however is that the driver assistance technology wasn't activated until January 2015. Consequently, a small amount of loss experience for Tesla vehicles equipped with Hardware Version 1 did not have driver assistance technology available at the time. To account for this, all loss experience for Teslas with Hardware Version 1 up to and including January 2015 was treated as **Without Tech**. Loss experience after January 2015 for these vehicles was treated as **With Tech**. Additionally, vehicles identified as having Hardware Version 2 were excluded from the analysis because reports indicate that these vehicles initially had AEB functionality disabled and only recently enabled (Olsen 2017).

The difference in insurance losses between Teslas with the driver assistance technology and the 2015–16 conventional large luxury vehicles was compared with the difference in insurances losses between the Teslas without the driver assistance technology and the 2012–14 conventional large luxury vehicles. This difference-in-difference effectively measures the effect on insurance losses of Tesla's driver assistance technology (including Autopilot) that was enabled by Hardware Version 1. Statistically, this estimate was derived from the regression model using the interaction between the **Tesla** and **With Tech** indicator variables.

To illustrate this analysis, Appendix A contains full model results for collision claim frequencies. To further simplify the presentation here, the exponent of the parameter estimate was calculated, 1 was subtracted, and the resultant multiplied by 100. The resulting number corresponds to the effect of that covariate on that loss measure. For example, the estimate of the effect of Tesla's driver assistance technology (including Autopilot), as measured by the interaction of **Tesla** and **With Tech**, on collision claim frequency was 0.0145; thus, Tesla vehicles with driver assistance technology had 1.5 percent more collision claims than those without the driver assistance technology ((exp(-0.0145)-1)*100=1.5).

Finally, the third analysis used a similar approach to isolate the incremental effect of the Autopilot system and its associated features, above any benefits provided by the earlier driver assistance systems (FCW, AEB, etc.). In this analysis, only the loss experience for Teslas with the driver assistance technology enabled and the 2015–16 conventional large luxury vehicles was included. Here the loss experience was divided based on when Autopilot was enabled in October 2015. Loss experience from February 2015 through October 2015 was considered pre-Autopilot, while loss experience after October 2015 was considered post-Autopilot. Again a difference-in-difference approach was used to compare insurance losses for Tesla versus conventional large luxury vehicles over the pre-and post-Autopilot time periods to isolate the effect of the Autopilot system.

Results

Figures 1–5 show the results of the first analysis comparing the insurance losses by model year of the Tesla Model S with conventional large luxury vehicles. The vertical I-bars represent the 95 percent confidence limits of the estimates. **Figure 1** compares collision claim frequencies for the Tesla Model S with conventional large luxury vehicles by model year. The 2012 Tesla Model S had a 32 percent higher collision claim frequency than conventional large luxury vehicles from the same model year. This difference increased with subsequent model years, peaking at 40 percent with the 2014 Tesla but declined slightly with the 2015 and 2016 model years.

Figure 1: Collision claim frequency of Tesla Model S versus large luxury vehicles, by model year

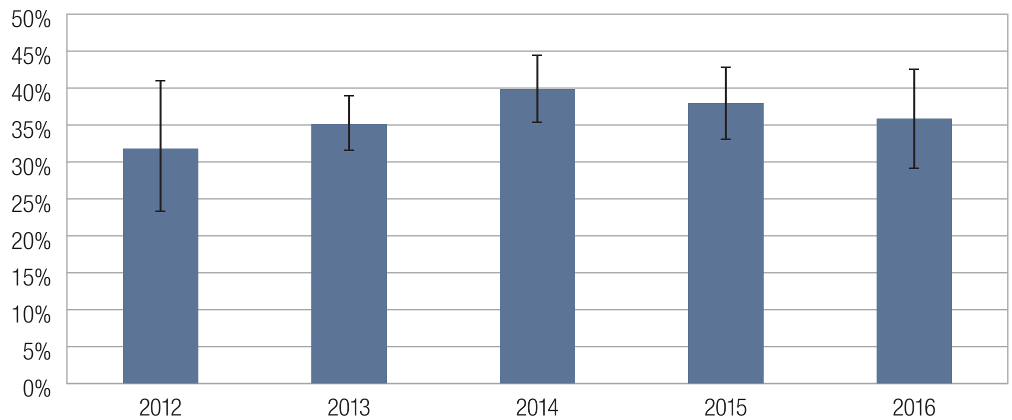
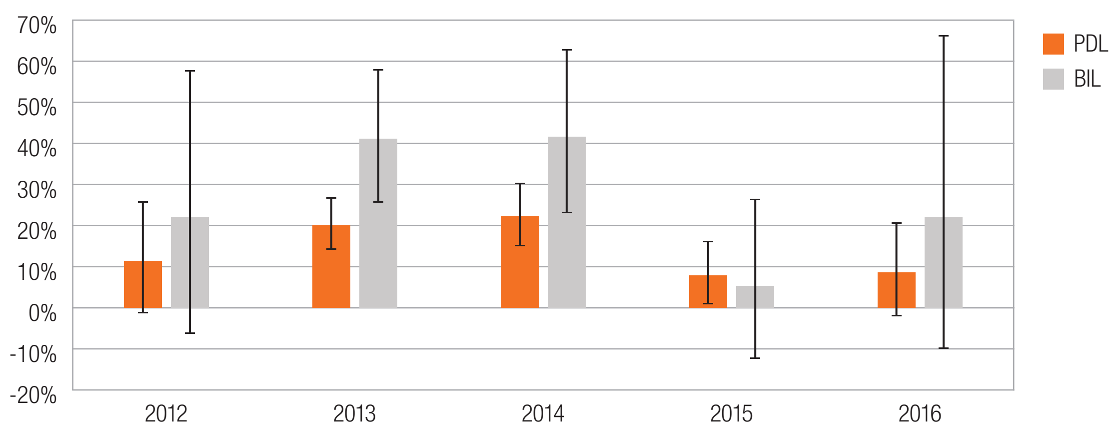


Figure 2 shows the results for PDL and BI claim frequency. PDL claim frequency peaked with model year 2014 at 22 percent higher than that of conventional large luxury vehicles. However, this difference dropped substantially down to only 8 percent higher for the 2015 model year. BI frequencies followed a similar pattern, peaking at 42 percent higher for the 2014 model year, then dropping to only 5 percent higher and not statistically significant for the 2015 model year. It should be noted that the 2015 model year was the first full model year of Teslas equipped with Hardware Version 1.

Figure 2: PDL and BI claim frequencies for Tesla Model S versus large luxury vehicles, by model year



MedPay and PIP claim frequency results are shown in **Figure 3**. The Tesla Model S was associated with significantly lower first-party injury claim frequencies than conventional large luxury vehicles for every model year except 2016. This benefit was largest with the 2012 model year, with 63 and 48 percent lower frequencies for MedPay and PIP, respectively. However, the benefit generally decreased with each subsequent model year down to 31 and 6 percent lower for MedPay and PIP, respectively, for model year 2016.

Figure 3: MedPay and PIP claim frequencies for Tesla Model S versus large luxury vehicles, by model year

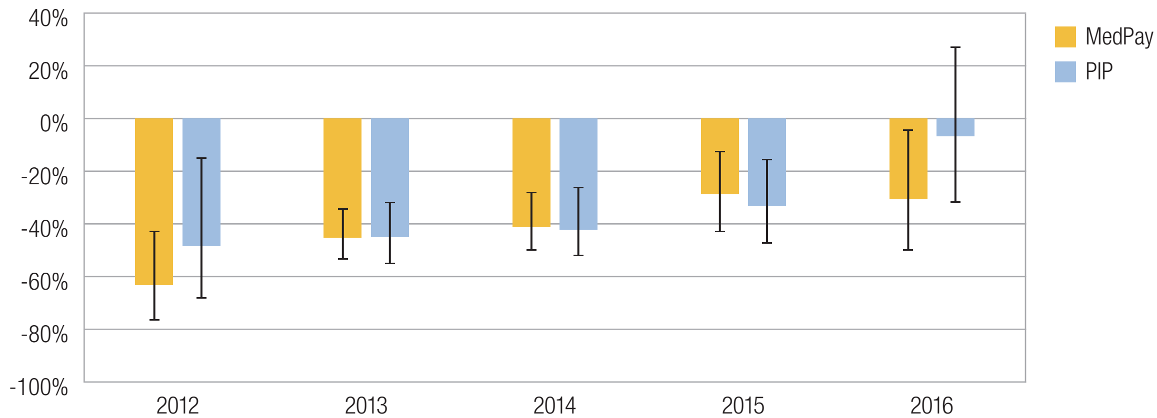


Figure 4 shows the collision and PDL claim severity results by model year. Collision claim severity was significantly higher for the Tesla Model S compared with large luxury vehicles. However, this difference decreased slightly with each model year from 62 percent higher for model year 2012 down to 28 percent higher for model year 2016. PDL severity was also higher for the Tesla Model S but increased from 13 percent higher for model year 2012 to 25 percent higher for model year 2015. It then decreased to 5 percent higher for model year 2016.

Figure 4: Collision and PDL claim severity for Tesla Model S versus large luxury vehicles, by model year

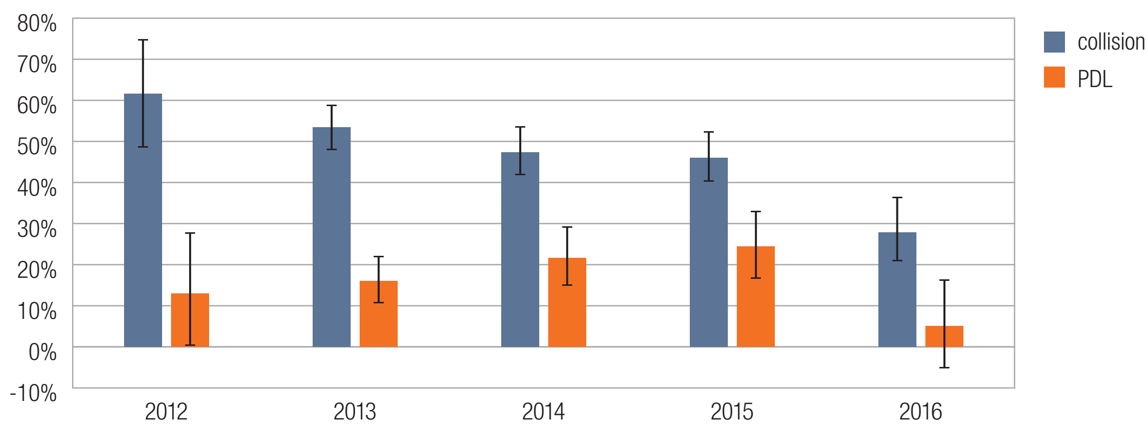
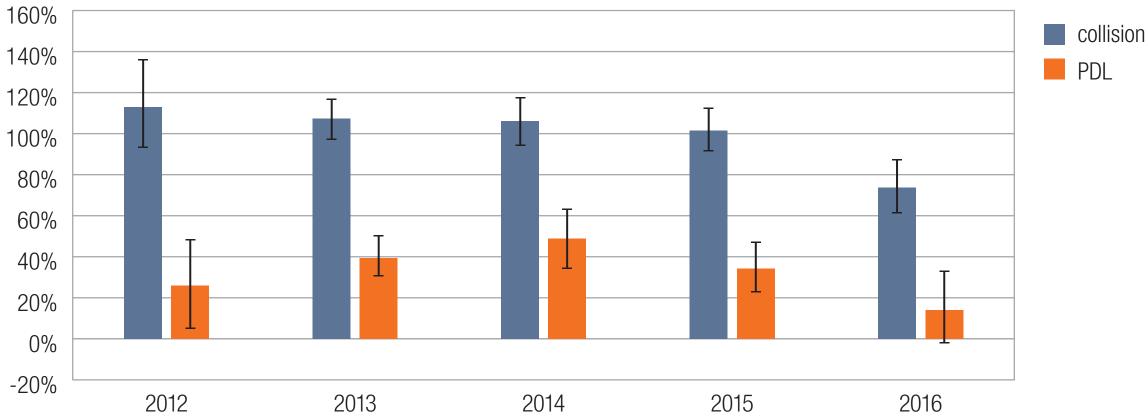


Figure 5 shows the overall losses for collision and PDL by model year. Collision overall losses were between 113 percent and 74 percent higher than those of conventional large luxury vehicles. PDL overall losses were between 14 percent and 49 percent higher for the Tesla Model S. All results except the 2016 model year PDL result were statistically significant.

Figure 5: Collision and PDL overall losses for Tesla Model S versus large luxury vehicles, by model year



Figures 6–9 show the results from the analysis estimating the effect of the driver assistance technologies (including Autopilot) enabled by Hardware Version 1 on insurance losses for the Tesla Model S. **Figure 6** compares claim frequencies for Teslas with and without driver assistance technologies (including Autopilot) with their conventional large luxury control groups.

Figure 6: Tesla Model S claim frequencies with and without driver assistance technology, including Autopilot, versus large luxury vehicles

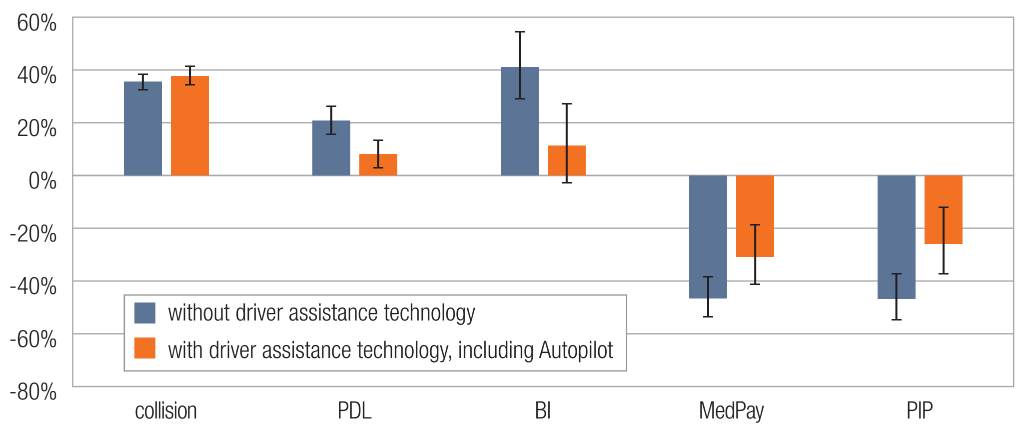


Figure 7 shows the results for the estimated effect of the driver assistance technologies on claim frequency. The technologies were associated with no significant change in collision claim frequency but significant reductions to PDL and BI claim frequencies of 11 and 21 percent, respectively. MedPay and PIP both showed significant increases in claim frequency of 29 and 39 percent, respectively. Note that due to the nonlinearity of the Poisson based regression, the results for **Figure 7** are not simply the difference in percentages between the results in **Figure 6**. They are equal to the difference in modeled results prior to taking the exponent and calculating the resulting percentage. For example, the BI with and without technology estimates were 0.1077 (11 percent) and 0.3441 (41 percent), respectively. The estimated effect of the driver assistance technology on BI claim frequency is then 0.1077-0.3441 = -.2363 (-21 percent).

Figure 7: Estimated effect of Tesla Model S driver assistance technology enabled by Hardware Version 1, including Autopilot, on claim frequency

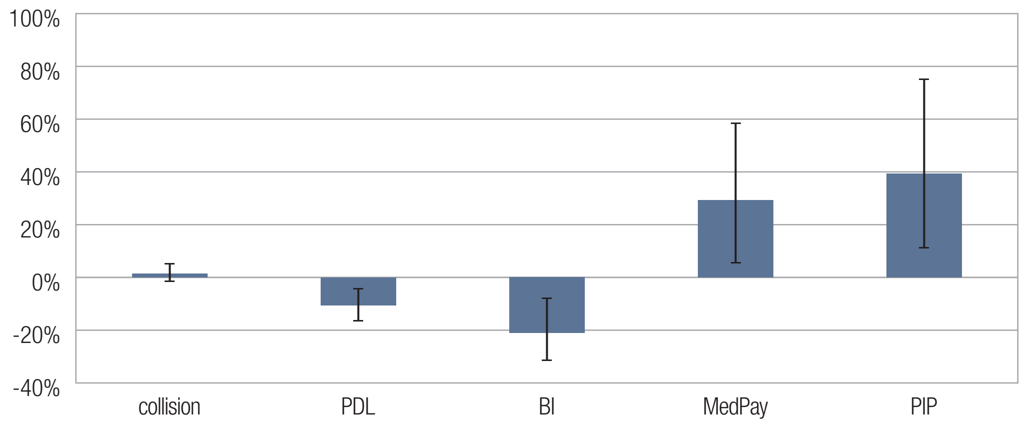
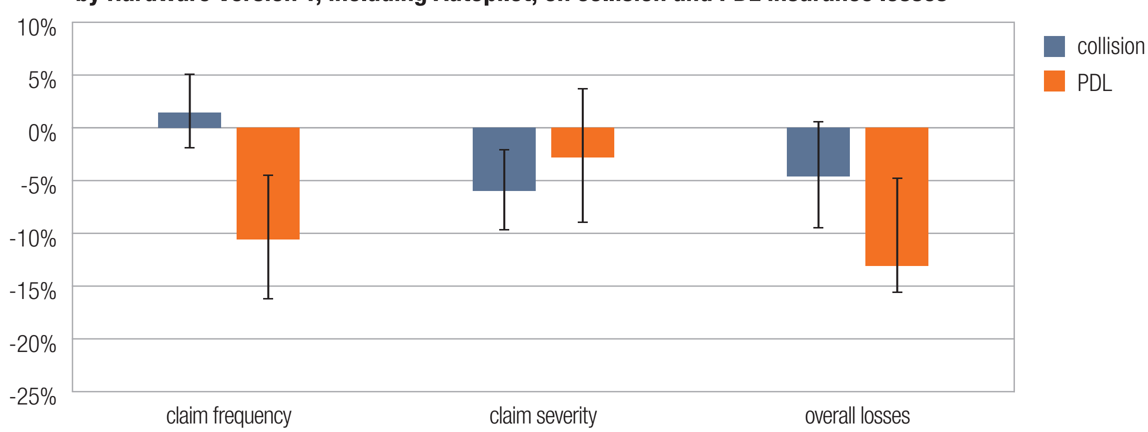


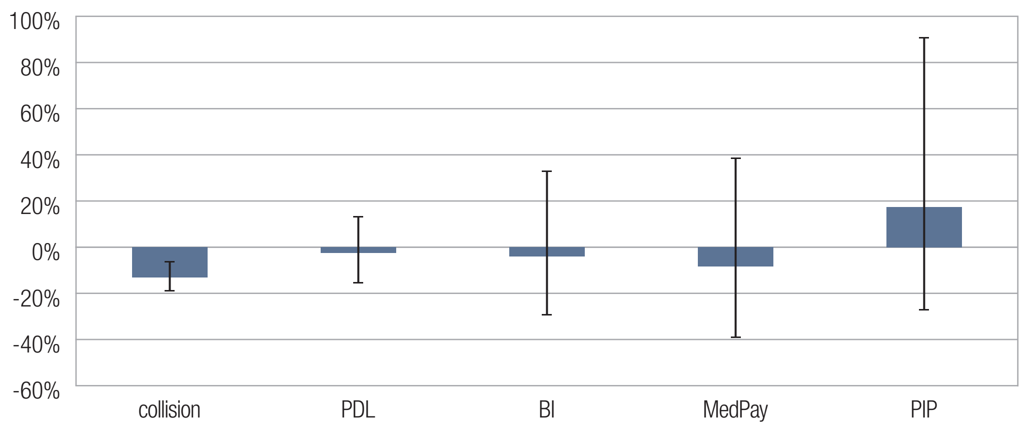
Figure 8 shows the estimated effect of the driver assistance technologies on collision and PDL insurance losses. The driver assistance technologies were also associated with reductions to both collision and PDL claim severity and overall losses.

Figure 8: Estimated effect of Tesla Model S driver assistance technology enabled by Hardware Version 1, including Autopilot, on collision and PDL insurance losses



Finally, Figure 9 shows the estimated incremental effect on claim frequency of Tesla's Autopilot system and its associated features over the effect provided by the earlier driver assistance technologies such as ACC, FCW, AEB, and blind spot. Only collision claim frequency showed a significant change, with a reduction of 13 percent. Estimates for the other coverages were not significant and had large confidence bounds.

Figure 9: Estimated incremental effect of Tesla Model S Autopilot on claim frequency over early driver assistance technology without Autopilot



Discussion

Compared to their conventional large luxury counterparts, the 2012-16 Tesla Model S had higher collision and PDL claim frequencies, severities and overall losses. Bodily injury liability claim frequency was also higher for the Tesla Model S. However, first party injury claim frequencies for MedPay and PIP were significantly lower for the Tesla Model S compared to conventional large luxury vehicles. The introduction of driver assistance technologies on the Tesla Model S appears to have diminished some of those differences. Driver assistance technologies on the Tesla Model S are associated with significant reductions to both third-party physical damage and injury liability claims. The estimated reductions of 11 percent for PDL and 21 percent for BI claim frequencies are consistent, both in direction and magnitude, with prior HLDI research for front crash prevention systems (HLDI, 2017). Changes in collision claim frequency were not significant, which is also consistent with prior HLDI research. On the other hand, the driver assistance technologies were associated with increases to both MedPay and PIP claim frequencies, although both first-party injury claim frequencies were still lower than for the conventional large luxury control population. It is unclear why these technologies might cause an increase in first-party injury claims.

This study does not account for increases in the prevalence of driver assistance technologies on the conventional large luxury vehicles. However, except for Autopilot and its associated features, once enabled, these systems were standard features on the Teslas with Hardware Version 1, while on conventional large luxury vehicles, they were typically optional.

A separate analysis of the incremental effect of Autopilot and its associated features proved inconclusive. Although Autopilot was associated with an increase in PIP claim frequency of nearly 20 percent, MedPay was down 8 percent. However, neither result was statistically significant, and both had large confidence bounds. This suggests that the increase in first party injury frequencies may be attributable to ACC, FCW, AEB, blind spot warning or some other unaccounted factor, rather than Autopilot.

PDL and BI results for Autopilot also showed no significant changes in claim frequency, compared with the early driver assistance technologies available prior to Autopilot (i.e., FCW, AEB, blind spot monitoring, etc.). Prior HLDI research has found significant PDL and BI benefits for FCW, AEB, and blind spot systems. Therefore, it stands to reason that the PDL and BI benefits observed in Figure 7 are likely attributable to these systems and not to Autopilot. The data are still sparse, however, particularly the loss experience of vehicles with the early driver assistance technology but without Autopilot. In addition, as Autopilot is an optional feature, HLDI is also unable to discern which vehicles had Autopilot, and whether Autopilot was on at the time of a crash.

Nevertheless, Autopilot was associated with a significant reduction in collision claim frequency. Although of a smaller magnitude, this is consistent with the Office of Defects Investigation's finding that airbag deployment rates dropped by almost 40 percent after Autopilot installation. The difference could be attributable to the difference in metrics. Airbags typically deploy in only moderate to severe crashes, so many collision claims would not be associated with an airbag deployment. Additional data are needed to determine if these results continue to persist or if Autopilot translates into benefits or disbenefits for other coverage types. Collision severities have also been declining for the Tesla Model S. This may be attributable to economies of scale, driving down the cost of replacement parts. According to *Autoblog,* a Tesla Motors representative said "Tesla is committed to making the production and service of our cars increasingly cost effective for our customers and our company. As we continue to produce more vehicles, economies of scale naturally decrease the price of individual parts" (Blanco, 2015). More recently, Tesla is claiming a 35 percent reduction in battery costs due to its Gigafactory 1 (Lambert, 2017) that could further reduce repair costs.

Limitations

There are limitations to the data used in this analysis. Although the hardware necessary to use Autopilot was equipped on all Tesla vehicles produced after September 19, 2014, Autopilot was an optional feature. HLDI is unable to discern which vehicles had Autopilot enabled or whether Autopilot was being used at the time of crash. In addition, several other technologies in this study can be deactivated by the driver, and there is no way to know how many of the drivers in these vehicles turned off a system prior to the crash. However, surveys conducted by the Insurance Institute for Highway Safety (Reagan et al., 2017) indicate that large majorities of drivers with these types of systems leave them on, with the notable exception of lane assist systems (also see Flannagan et al., 2016). If a significant number of drivers do turn off these features, any reported reductions may actually be underestimates of the true effectiveness of these systems.

Additionally, the data supplied to HLDI do not include detailed crash information. Information on point of impact and the vehicle's transmission status is not available. The technologies in this report target certain crash types. For example, a forward collision warning system is designed to prevent front into rear collisions. All collisions, regardless of the ability of a feature to mitigate or prevent the crash, are included in the analysis.

Although classified as a large luxury vehicle, the Tesla Model S is only available as an electric vehicle. The type of person who chooses to drive a Tesla may differ from one who chooses a conventional large luxury vehicle. For example, the exposure-weighted average rated driver age was close to 3 years younger for the Tesla Model S, compared with the conventional large luxury vehicles (45 versus 48). While the analysis controls for several driver characteristics, including rated driver age, there may be other uncontrolled attributes among people who select this type of vehicle.

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Appendix A

Appendix A: Illustrative regression results — collision claim frequency

Parameter		Degrees of freedom	Estimate	Effect	Standard error	Wald 95% confidence limits		Chi-square	P-value
Intercept		1	-8.3249		0.0119	-8.3482	-8.3015	488022.00	<0.0001
Vehicle age	-1	1	-0.1073	-10.2%	0.0170	-0.1405	-0.0740	40.02	<0.0001
	0	1	0.0207	2.1%	0.0062	0.0085	0.0329	11.01	0.0009
	2	1	-0.0461	-4.5%	0.0063	-0.0585	-0.0338	53.63	<0.0001
	3	1	-0.0581	-5.6%	0.0082	-0.0741	-0.0420	50.28	<0.0001
	4	1	-0.0687	-6.6%	0.0105	-0.0892	-0.0482	43.00	<0.0001
	5	1	-0.0601	-5.8%	0.0182	-0.0957	-0.0245	10.94	0.0009
	1	0	0	0	0	0	0		
Calendar year	2011	1	-0.2867	-24.9%	0.0410	-0.3670	-0.2065	49.01	<0.0001
	2012	1	-0.2902	-25.2%	0.0142	-0.3180	-0.2625	420.71	<0.0001
	2013	1	-0.2026	-18.3%	0.0105	-0.2232	-0.1820	371.70	<0.0001
	2014	1	-0.1262	-11.9%	0.0086	-0.1431	-0.1094	215.33	<0.0001
	2015	1	-0.0917	-8.8%	0.0064	-0.1042	-0.0792	206.12	<0.0001
	2017	1	0.0216	2.2%	0.0081	0.0058	0.0374	7.20	0.0073
	2016	0	0	0	0	0	0		
Rated driver age group	< 25	1	0.0678	7.0%	0.0109	0.0465	0.0891	39.05	<0.0001
	66+	1	0.0705	7.3%	0.0051	0.0606	0.0804	194.92	<0.0001
	Unknown	1	-0.0279	-2.8%	0.0118	-0.0510	-0.0048	5.62	0.0177
	25–65	0	0	0	0	0	0		
Rated driver gender	Male	1	-0.0182	-1.8%	0.0044	-0.0268	-0.0097	17.43	<0.0001
	Unknown	1	-0.0902	-8.6%	0.0155	-0.1205	-0.0598	33.91	<0.0001
	Female	0	0	0	0	0	0		
Rated driver marital status	Single	1	0.2673	30.6%	0.0047	0.258	0.2766	3176.11	<0.0001
	Unknown	1	0.0500	5.1%	0.0146	0.0214	0.0786	11.72	0.0006
	Married	0	0	0	0	0	0		
Risk	Nonstandard	1	0.3210	37.9%	0.0097	0.3019	0.3401	1086.60	<0.0001
	Standard	0	0	0	0	0	0		
State	Alabama	1	0.1005	10.6%	0.0215	0.0584	0.1426	21.93	<0.0001
	Alaska	1	0.4353	54.5%	0.0732	0.2918	0.5789	35.34	<0.0001
	Arizona	1	0.1097	11.6%	0.0180	0.0744	0.1449	37.25	<0.0001
	Arkansas	1	0.0938	9.8%	0.0391	0.0171	0.1704	5.75	0.0165
	California	1	0.3375	40.1%	0.0081	0.3217	0.3533	1747.81	<0.0001
	Colorado	1	0.1521	16.4%	0.0196	0.1138	0.1905	60.42	<0.0001
	Connecticut	1	-0.0213	-2.1%	0.0184	-0.0573	0.0147	1.34	0.2464

Appendix A: Illustrative regression results — collision claim frequency									
Parameter		Degrees of freedom	Estimate	Effect	Standard error	Wald 95% confidence limits		Chi-square	P-value
	Delaware	1	0.1703	18.6%	0.0364	0.0990	0.2416	21.89	<0.0001
	Dist of Columbia	1	0.3787	46.0%	0.0331	0.3138	0.4436	130.67	<0.0001
	Florida	1	-0.0320	-3.1%	0.0090	-0.0497	-0.0143	12.59	0.0004
	Georgia	1	-0.0385	-3.8%	0.0129	-0.0638	-0.0132	8.88	0.0029
	Hawaii	1	0.2852	33.0%	0.0331	0.2204	0.3500	74.45	<0.0001
	Idaho	1	-0.0349	-3.4%	0.0701	-0.1724	0.1025	0.25	0.6184
	Illinois	1	0.0116	1.2%	0.0128	-0.0135	0.0368	0.82	0.3645
	Indiana	1	-0.0338	-3.3%	0.0261	-0.0849	0.0173	1.68	0.1951
	Iowa	1	-0.0210	-2.1%	0.0460	-0.1112	0.0692	0.21	0.6485
	Kansas	1	-0.1844	-16.8%	0.0379	-0.2586	-0.1102	23.72	<0.0001
	Kentucky	1	-0.1738	-16.0%	0.0328	-0.2380	-0.1096	28.13	<0.0001
	Louisiana	1	0.1853	20.4%	0.0187	0.1486	0.2219	98.28	<0.0001
	Maine	1	0.1592	17.3%	0.0599	0.0419	0.2766	7.07	0.0078
	Maryland	1	0.0913	9.6%	0.0142	0.0634	0.1192	41.13	<0.0001
	Massachusetts	1	-0.1548	-14.3%	0.0181	-0.1902	-0.1194	73.39	<0.0001
	Michigan	1	0.3540	42.5%	0.0155	0.3236	0.3844	520.22	<0.0001
	Minnesota	1	-0.0981	-9.3%	0.0252	-0.1474	-0.0488	15.20	<0.0001
	Mississippi	1	0.0400	4.1%	0.0329	-0.0245	0.1045	1.48	0.2242
	Missouri	1	-0.1210	-11.4%	0.0245	-0.1689	-0.0731	24.47	<0.0001
	Montana	1	0.0224	2.3%	0.0917	-0.1573	0.2022	0.06	0.8067
	Nebraska	1	-0.2771	-24.2%	0.0549	-0.3847	-0.1694	25.45	<0.0001
	Nevada	1	0.2508	28.5%	0.0212	0.2093	0.2923	140.43	<0.0001
	New Hampshire	1	0.1133	12.0%	0.0355	0.0438	0.1828	10.21	0.0014
	New Jersey	1	0.0400	4.1%	0.0112	0.0180	0.0620	12.68	0.0004
	New Mexico	1	0.1251	13.3%	0.0410	0.0448	0.2054	9.32	0.0023
	New York	1	0.2219	24.8%	0.0099	0.2025	0.2414	501.27	<0.0001
	North Carolina	1	-0.2323	-20.7%	0.0167	-0.2651	-0.1994	192.46	<0.0001
	North Dakota	1	0.1167	12.4%	0.1098	-0.0985	0.3318	1.13	0.2878
	Ohio	1	-0.1473	-13.7%	0.0169	-0.1804	-0.1142	76.04	<0.0001
	Oklahoma	1	0.0487	5.0%	0.0282	-0.0065	0.1040	2.99	0.0838
	Oregon	1	0.0403	4.1%	0.0273	-0.0131	0.0937	2.19	0.1389
	Pennsylvania	1	0.1358	14.5%	0.0124	0.1115	0.1602	119.33	<0.0001
	Rhode Island	1	0.1317	14.1%	0.0376	0.0580	0.2053	12.28	0.0005
	South Carolina	1	-0.0965	-9.2%	0.0217	-0.1391	-0.0539	19.74	<0.0001
	South Dakota	1	-0.0435	-4.3%	0.0977	-0.2351	0.1481	0.20	0.6562
	Tennessee	1	-0.0229	-2.3%	0.0202	-0.0624	0.0167	1.28	0.2574
	Utah	1	-0.0645	-6.2%	0.0365	-0.1361	0.0071	3.12	0.0773
	Vermont	1	-0.2051	-18.5%	0.0822	-0.3663	-0.0439	6.22	0.0126
	Virginia	1	0.0514	5.3%	0.0138	0.0243	0.0785	13.85	0.0002
	Washington	1	0.1348	14.4%	0.0180	0.0994	0.1701	55.80	<0.0001
	West Virginia	1	-0.0936	-8.9%	0.0537	-0.1988	0.0116	3.04	0.0812
	Wisconsin	1	-0.0636	-6.2%	0.0289	-0.1203	-0.0069	4.83	0.0279
	Wyoming	1	0.0947	9.9%	0.1015	-0.1042	0.2936	0.87	0.3507
	Texas	0	0	0	0	0	0		

Appendix A: Illustrative regression results — collision claim frequency									
Parameter		Degrees of freedom	Estimate	Effect	Standard error	Wald 95% confidence limits		Chi-square	P-value
Drive type	4WD	1	0.0067	0.7%	0.0052	-0.0035	0.0169	1.65	0.1990
	2WD	0	0	0	0	0	0		
Deductible range	0	1	-0.1141	-10.8%	0.0903	-0.2910	0.0628	1.60	0.2062
	1–50	1	0.5159	67.5%	0.0351	0.4472	0.5846	216.43	<0.0001
	51–100	1	-0.1431	-13.3%	0.0085	-0.1597	-0.1264	284.45	<0.0001
	101–200	1	0.1837	20.2%	0.0156	0.1530	0.2143	137.90	<0.0001
	201–250	1	0.2459	27.9%	0.0069	0.2324	0.2595	1261.23	<0.0001
	501–1000	1	-0.2222	-19.9%	0.0049	-0.2318	-0.2126	2054.86	<0.0001
	1001+	1	-0.5635	-43.1%	0.0207	-0.6041	-0.5230	742.28	<0.0001
	251–500	0	0	0	0	0	0		
Registered vehicle density	< 50	1	-0.3584	-30.1%	0.0162	-0.3902	-0.3266	487.08	<0.0001
	50–99	1	-0.2941	-25.5%	0.0113	-0.3161	-0.272	683.18	<0.0001
	100–249	1	-0.2582	-22.8%	0.0078	-0.2735	-0.2429	1093.34	<0.0001
	250–499	1	-0.2220	-19.9%	0.0073	-0.2363	-0.2077	924.85	<0.0001
	500–999	1	-0.1234	-11.6%	0.0058	-0.1347	-0.1121	458.82	<0.0001
	1000+	0	0	0	0	0	0		
Miles driven per day	Unknown	1	-0.1996	-18.1%	0.0068	-0.2129	-0.1863	864.35	<0.0001
	<10	1	-0.3625	-30.4%	0.0127	-0.3874	-0.3376	814.49	<0.0001
	10–19.9	1	-0.0966	-9.2%	0.0078	-0.1118	-0.0814	154.86	<0.0001
	30–39.9	1	0.0734	7.6%	0.0071	0.0594	0.0874	105.88	<0.0001
	40–49.9	1	0.1471	15.8%	0.0084	0.1307	0.1635	309.39	<0.0001
	50–59.9	1	0.2095	23.3%	0.0107	0.1885	0.2306	381.39	<0.0001
	60–79.9	1	0.2705	31.1%	0.0122	0.2465	0.2944	490.83	<0.0001
	80–99.9	1	0.3753	45.5%	0.0223	0.3315	0.4191	282.42	<0.0001
	100+	1	0.5157	67.5%	0.0307	0.4555	0.5759	281.78	<0.0001
	20–29	0	0	0	0	0	0		
Tesla		1	0.3045	35.6%	0.0118	0.2813	0.3277	660.91	<0.0001
With Tech		1	0.0270	2.7%	0.0085	0.0103	0.0437	10.06	0.0015
Tesla * With Tech		1	0.0145	1.5%	0.0177	-0.0203	0.0492	0.66	0.4149

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