INSURANCE INSTITUTE
FOR HIGHWAY SAFETY

April 30, 2010

The Honorable David Strickland, Administrator
National Highway Traffic Safety Administration
1200 New Jersey Avenue, SE
Washington DC 20590

Plan Availability; Final Vehicle Safety Rulemaking and Research Priority Plan 2009-2011; 49 CFR Part 571.122 Federal Motor Vehicle Safety Standards, Motorcycle Brake Systems; Docket No. NHTSA 2009-0108

Dear Administrator Strickland:

In *Final Vehicle Safety Rulemaking and Research Priority Plan 2009-2011*, the National Highway Traffic Safety Administration (NHTSA) announced plans to amend Federal Motor Vehicle Safety Standard 122, Motorcycle Brake Systems, to require antilock braking systems (ABS) on motorcycles. The agency noted:

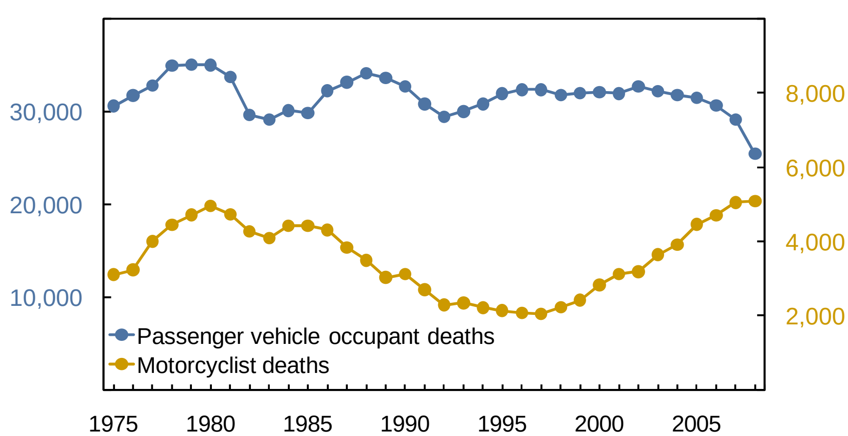
> When using a single exposure measure (registered vehicle years), a recent analysis of motorcycle fatalities by the Insurance Institute for Highway Safety showed that a select group of ABS-equipped motorcycles had 20 to 30 percent fewer fatalities per registered vehicle year compared to identical models not equipped with ABS. NHTSA believes an additional year of data and additional analyses are needed to determine the statistical significance of the results.

Recent research by the Insurance Institute for Highway Safety (IIHS) and affiliated Highway Loss Data Institute (HLDI) shows the statistically significant benefits of motorcycle ABS, which NHTSA needs as the necessary basis to move forward on the proposed amendment.

Risk of Motorcycling

About 80 percent of motorcycle crashes, compared with 20 percent of passenger vehicle crashes, result in injury or death (NHTSA, 2005). During 1998-2008, motorcyclists deaths more than doubled (Figure 1). Although deaths declined in 2009, the upward trend in recent years came at a time of record lows in passenger vehicle occupant deaths. One way to stem rider deaths is to equip more motorcycles with ABS. Two recent studies by IIHS and HLDI (enclosed) underscore the real-world benefits of this feature.

Figure 1
Passenger Vehicle Occupant versus Motorcyclist Deaths, 1975-2008



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Benefits of Motorcycle ABS

As NHTSA noted in its Priority Plan, IIHS first reported on the effectiveness of motorcycle ABS in 2008 by examining fatal motorcycle crashes of models with and without ABS during 2005-06. The rate of fatal crashes was 38 percent lower for motorcycles equipped with optional ABS (4.1 crashes per 10,000 registered vehicle years) than for the same models without this feature (6.6 crashes) (Teoh, 2008). A companion HLDI study compared insurance losses under collision coverage for 12 motorcycle models with and without optional ABS, finding that claim frequencies were 19 percent lower for motorcycles with optional ABS. This was a statistically significant finding (HLDI, 2008).

IIHS and HLDI have updated these studies with additional years of data, providing further evidence that motorcycle ABS reduces fatal crash risk and lowers insurance losses (Figures 2-3). The rate of fatal crashes per 10,000 registered vehicle years during 2003-08 was 37 percent lower for ABS models compared with the same models without this feature, a statistically significant finding (Teoh, 2010). Insurance claims filed for vehicle damage were 22 percent lower for ABS motorcycles, also a statistically significant finding (HLDI, 2009). These collision loss findings are based on a dataset of 2003-08 models with nearly 149,000 insured vehicle years of exposure.

Figure 2
Fatal Crashes per 10,000 Registered Vehicle Years for Motorcycles with and without ABS, 2003-08 Calendar Years

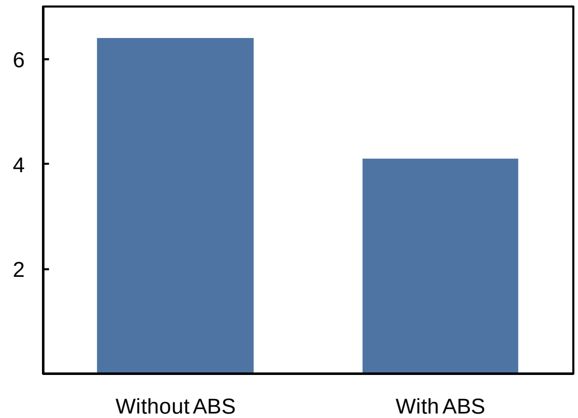
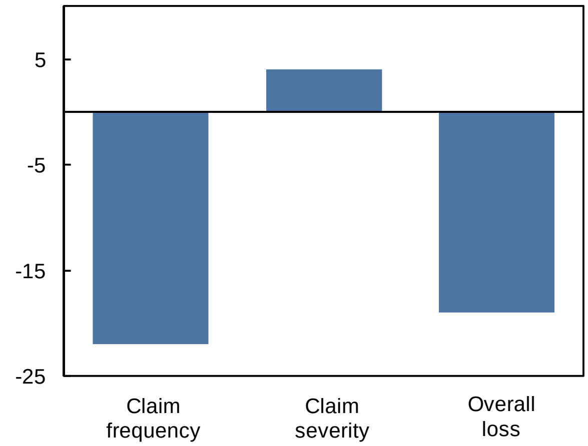


Figure 3
Percent Changes in Collision Losses for Motorcycles with ABS compared to those without ABS, 2003-08 Model Years



Drivers younger than 25 have the highest estimated motorcycle collision claim frequencies. The areas where motorcyclists ride also affect claims. Claim frequencies for motorcycle crash damage were 9 percent higher in urban areas with heavy traffic, compared with areas with moderate congestion, and 13 percent lower in the least-populated areas compared with medium-density areas. The effect of ABS on collision claims was estimated only after controlling for these and other factors.

An examination of injury claims found that claim frequencies under medical payment coverage were 30 percent lower for motorcycles with ABS compared with models without this feature. Claim frequencies under bodily injury liability coverage were 33 percent lower for ABS models.

Both motorcyclists and motorcycle manufacturers are showing increasing support for ABS. IIHS recently conducted telephone interviews of 1,818 riders to determine nationwide trends in motorcycling. More than half of the motorcyclists said safety is enhanced by ABS compared with conventional brakes, and 54 percent said they would get ABS on their next motorcycles.

Conclusion

Research by IIHS and HLDI shows that equipping motorcycles with ABS reduces the rates of fatal and nonfatal crashes. The recent IIHS survey indicates that motorcyclists believe this feature improves safety and would want it on their next motorcycles. NHTSA should mandate ABS on all motorcycles.

Sincerely,

Adrian K. Lund, Ph.D.
President

Attachments

Highway Loss Data Institute. 2009. Insurance special report (A-81): Motorcycle antilock braking system (ABS). Arlington, VA.

Teoh, Eric R. 2010. Effectiveness of antilock braking systems in reducing motorcycle fatal crash rates. Arlington, VA: Insurance Institute for Highway Safety.

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Teoh, Eric R. 2010. Effectiveness of antilock braking systems in reducing motorcycle fatal crash rates. Arlington, VA: Insurance Institute for Highway Safety.

Effectiveness of Antilock Braking Systems in Reducing Motorcycle Fatal Crash Rates

Eric R. Teoh

January 2010

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Abstract

The effect of antilock braking systems (ABS) on motorcyclist fatal crash risk during 2003-08 was studied by comparing fatal crash rates per registrations of motorcycles with and without ABS. Study motorcycles included those for which ABS was optional equipment and could be identified as present by the vehicle identification number. Fatal motorcycle crashes per 10,000 registered vehicle years were 37 percent lower for ABS models than for their non-ABS versions.

Keywords: Motorcycles; Crashes; Antilock braking system; Combined braking systems; Wheel lock; Insurance claims

1. Introduction

Annual motorcyclist deaths in the United States have more than doubled, from 2,077 in 1997 to 5,091 in 2008 (Insurance Institute for Highway Safety, 2009), and motorcycle registrations have increased by about two-thirds, from 5,174,326 in 2000 (earliest year for which data are available) to 9,850,301 in 2008, according to data obtained from R.L. Polk and Company. Many factors contribute to motorcycle crashes, but improper braking was identified as a major pre-impact factor in a study of motorcycle crash causation (Hurt et al., 1981) and again, 20 years later, in the Motorcycle Accident In-Depth Study (MAIDS) (Association of European Motorcycle Manufacturers, 2004).

Operating the brakes on most motorcycles is much more complicated than on four-wheel vehicles. Most motorcycles have separate controls for the front and rear brakes, with the front brake usually controlled by a lever on the right handlebar and the rear brake controlled by a pedal operated by the rider's right foot. During braking, a rider must decide how much force to apply to each control. As with other types of vehicles, much more deceleration can be obtained from braking the front wheel than from braking the rear wheel.

Motorcycles are inherently less stable than four-wheel vehicles and rely on riders' skills to remain upright during demanding maneuvers such as hard braking. Braking too hard and locking a wheel creates an unstable situation. Locking the front wheel is particularly dangerous, with falling down being almost certain. A locked rear wheel is more controllable but still can lead to loss of control if the rider simultaneously tries to steer the motorcycle, as in an emergency avoidance maneuver. In such situations, riders concerned about wheel lock may be reluctant to apply full force to the brakes, particularly to the front brake, resulting in braking that is not adequate to avoid or mitigate impact. Hurt et al. (1981) and MAIDS (Association of European Motorcycle Manufacturers, 2004) had examples of both loss of control due to wheel lock and failure to adequately brake.

Although proper braking practices can be taught, rider training courses have not been shown to be effective in reducing motorcycle crash rates or have provided mixed results at best (Billheimer, 1998; Mayhew and Simpson, 1996). To address the issue of underbraking (especially the front wheel), manufacturers have developed braking systems that essentially link the actions of the front and rear brake controls. These systems, referred to collectively here as combined braking systems (CBS), apply braking force to both wheels when either control is engaged. The degree to which braking force is applied to the front wheel, for example, when the pedal for the rear brake is depressed varies by design, but the concept is the same. CBS has been shown to reduce stopping distances of experienced riders on closed test tracks (Green, 2006) and would be expected to be beneficial in situations in which a rider underbrakes (or does not brake) the front wheel to avoid locking it or causing the motorcycle to pitch forward. With CBS, however, it still is possible to lock a wheel during hard braking.

ABS has been adapted and tuned for motorcycles to help riders solve this dilemma. Antilock braking systems monitor wheel speed and reduce brake pressure when impending wheel lock is detected. Brake pressure is increased when traction is restored, and the system evaluates and adjusts brake pressure many times per second. These systems allow riders to apply brakes fully in an emergency without fear of wheel lock. ABS was first developed for commercial aircraft in 1929 (Maslen, 2008) and was first implemented in production automobiles with the 1971 Chrysler Imperial (Douglas and Schafer, 1971). BMW was the first manufacturer to implement ABS on a motorcycle with its K100RS Special model in 1988 (Tuttle, 2001). ABS and CBS are not necessarily related; either or both can be implemented on a motorcycle.

ABS has not significantly reduced crash risk for passenger vehicles (Farmer, 2001; Farmer et al., 1997), but there is reason to expect ABS will be more helpful to motorcycles because of the instability that occurs when either wheel locks. Studies conducted on closed test tracks have demonstrated that ABS can reduce motorcycle stopping distances (Green, 2006; Vavryn and Winkelbauer, 2004). It is clear that reducing wheel lock is crucial in maintaining stability during hard braking. These results suggest that ABS has the potential to reduce motorcycle crash rates in real-world situations. Serious motorcycle crashes identified from insurance liability claims were analyzed in a small study to determine, by crash reconstruction, how certain crashes could have been affected by ABS (Gwehenberger et al., 2006). About half of the 200 crashes studied were deemed to be relevant to ABS, and the majority of those involved another vehicle violating a motorcyclist's right-of-way. Crash reconstruction analyses showed that between 17 and 38 percent of the crashes deemed to have been ABS relevant could have been avoided had the motorcycles been equipped with ABS. No results were presented on how increased stability or stopping power provided by ABS might have reduced the severities of the crashes that were deemed inevitable.

A study by the Highway Loss Data Institute (HLDI), conducted in conjunction with the present study, found that motorcycles equipped with optional ABS had 22 percent fewer insurance claims for collision damage per insured vehicle year than the same motorcycle models without ABS (HLDI, 2009). The goal of the present study was to evaluate the effectiveness of ABS in reducing the rate of fatal motorcycle crashes on public roads. Specifically, rates of fatal crash involvement per registered vehicle were compared for motorcycles with and without ABS installed as optional equipment.

2. Methods

Data on fatal motorcycle crashes were extracted from the Fatality Analysis Reporting System (FARS), a national census of fatal crashes occurring on public roads that is maintained by the National Highway Traffic Safety Administration. Exposure data consisted of national motorcycle registration records obtained from R.L. Polk and Company. Each vehicle record in both databases was indexed by its vehicle identification number (VIN), which encodes vehicle information, and the first 10 digits of the VINs were used to determine make, model name, and model year according to records in a motorcycle features database created and maintained by HLDI. Vehicles with missing or invalid VINs were excluded.

To be included in the study, a motorcycle model was required to have ABS as an option, and the presence of that option must have been discernable by the presence of a VIN ABS indicator or equivalently from the model name (e.g., Honda Gold Wing vs. Honda Gold Wing ABS). This eliminated bias due to the comparison of different makes or, especially, styles of motorcycles, the driver death rates of which have been shown to vary widely (Insurance Institute for Highway Safety, 2007). Although ABS has been an option on BMW models for much longer than the study period, BMW does not use a VIN indicator for ABS. All BMW models were excluded. The final study population (Table 1) included 13 make/model motorcycles, each with both ABS and non-ABS versions. Some vehicles were excluded due to zero registrations of the ABS model during the study years in the Polk records or zero riders involved in fatal crashes for both ABS and non-ABS versions. For each motorcycle model, model years were held identical for both ABS and non-ABS versions. Among the motorcycles included, all of the Hondas (both ABS and non-ABS) were equipped with standard CBS; CBS was not available on any of the other motorcycles.

At the time this study was conducted, registration data were available only for 2000 and 2003-08, and FARS data were available through 2008. There were no registrations of the ABS versions of these motorcycles in 2000. Therefore, data were analyzed for years 2003-08. Fatal crash rates per 10,000 registered vehicle years for each motorcycle model, both ABS and non-ABS versions, were calculated by dividing 10,000 times the number of motorcycle driver fatal crash involvements during 2003-08 by the number of motorcycles registered during these years. Because registration counts spanned 6 years, the denominator was interpreted as registered vehicle years instead of as the number of registered vehicles.

If ABS does not affect the risk of fatal motorcycle crashes, then fatal crash rates per registration for each motorcycle model should not vary by whether or not it has ABS. Under this assumption, an expected count of fatal crash involvements was computed for each ABS motorcycle model as the product of the rate of fatal crash involvements per registered vehicle year for the non-ABS version and the number of registered vehicle years of the ABS version. A rate-ratio estimating the effect of ABS was calculated as the sum of the observed fatal crash involvements for ABS motorcycles (O) divided by the sum of their expected fatal crash involvements (E). Using formulas derived by Silcocks (1994), a 95 percent confidence interval for the rate-ratio was computed as (L, U), where:

$$L = \beta_{0.025}(O, E+1) / [1 - \beta_{0.025}(O, E+1)]$$

$$U = \beta_{0.975}(O+1, E) / [1 - \beta_{0.075}(O+1, E)]$$

where $\beta_p(a, b)$ is the $100 \times p^{th}$ percentile from the beta distribution with parameters a and b.

In addition to the main analysis, information was extracted from FARS describing driver age, speeding behavior, blood alcohol concentration (BAC), number of involved vehicles, helmet use, and crash location (rural vs. urban) for ABS and non-ABS groups. Missing values of BACs were accounted for using multiple imputation results available in FARS. Speeding was coded if the motorcycle driver was cited for speeding, or if contributing factors indicated the motorcycle was exceeding the posted limit or was traveling too fast for conditions. Helmet law type — universal coverage, partial coverage in which only some riders (usually those below a certain age) must wear helmets, and no law — was coded for the state in which a crash occurred, and varied by year with changes in laws.

3. Results

Table 2 presents fatal crash involvements, registered vehicle years, and the rate of fatal crash involvements per 10,000 registered vehicle years for the study motorcycles during 2003-08. Motorcycles manufactured by Honda, particularly the Gold Wing model, dominated the sample, but the pattern for all but two of the motorcycles was a lower fatal crash rate for ABS motorcycles. Across all ABS motorcycles, the rate of fatal crash involvements per 10,000 registered vehicle years was 4.1, compared with 6.4 for the same motorcycles not equipped with ABS.

The effect of ABS on fatal crash involvement is given by the rate-ratio estimate for ABS motorcycles against non-ABS motorcycles of 0.625 with associated 95 percent confidence interval (0.425, 0.912). The rate-ratio estimate corresponds to a statistically significant 37 percent reduction (computed as (RR-1)×100%) in the rate of fatal crash involvements per 10,000 registered vehicle years for the ABS models compared to the non-ABS models.

Influences on the observed rate-ratio of known risk factors for fatal motorcycle crashes were investigated by comparing their distributions among ABS motorcycles and non-ABS motorcycles included in the study, as summarized in Table 3. The average driver age for non-ABS motorcycles was 53, compared with 51 for ABS motorcycles. Drivers of non-ABS motorcycles were slightly more likely than drivers of ABS motorcycles to have been cited for speeding or to have been impaired by alcohol at the time of their fatal crashes. However, they also were somewhat more likely to have been helmeted, a difference not clearly explained by helmet laws in the states in which they were travelling. In other words, there was little difference in the distribution of helmet laws between ABS and non-ABS motorcycle drivers (Table 3) and the effect of helmet laws on helmet use did not substantially differ between the two groups (data not shown). No substantial difference between the two groups was observed in the likelihood of single-vehicle crashes or of rural vs. urban crash locations. None of these differences in risk factors between ABS and non-ABS motorcycles in Table 3 were statistically significant at the 0.05 level.

4. Discussion

Results of this analysis provide evidence that ABS is effective in reducing fatal motorcycle crash rates. Study motorcycles with ABS had a fatal crash involvement rate 37 percent lower than that for their non-ABS versions during the study years. This difference was statistically significant from zero at the customary 0.05 level. Thus, there is considerable confidence that ABS is preventing fatal crashes among motorcyclists. This confidence is bolstered by the fact that a separate analysis of insurance collision coverage losses among crashes of all severities also shows a statistically significant reduction in crashes of about 22 percent for motorcycles equipped with ABS (HLDI, 2009). These results provide confirmatory evidence of the expected benefit of ABS from engineering principles, test-track trials, and a crash reconstruction analysis.

The substantial effectiveness estimate observed in this study is not, however, without limitations. ABS was studied as optional equipment, so the cohort of motorcyclists who choose to purchase ABS may differ from those who decline to purchase it. In particular, motorcyclists who choose ABS may be more concerned about safety than those who decline, thus leading to lower fatal crash rates due to safer riding practices. Investigation of known risk factors did not reveal evidence of such a selection bias. However, levels of these factors were not known for riders who were not involved in fatal crashes. Therefore, it was not possible to accurately quantify how such factors influenced the observed reduction in fatal crash rate for ABS motorcycles. It is also possible, however, that riders who choose ABS ride more miles than those who decline, which would result in an upward bias in the fatal crash rate for the ABS cohort relative to the non-ABS cohort. As purported to occur in passenger vehicles (Grant and Smiley, 1993; Winston et al., 2006), motorcyclists may tend to drive ABS motorcycles more aggressively than non-ABS motorcycles, also resulting in a higher than expected crash rate for the ABS group and thus underestimating the effectiveness of ABS. Without more extensive data, it was not possible to estimate the magnitude or direction of any bias of the estimated rate-ratio comparing crash rates for ABS and non-ABS motorcycles.

With or without ABS, CBS also may reduce the likelihood of certain types of crashes. However, due to the small sample of non-CBS motorcycles in this study, the effect of CBS could not be evaluated. Still, CBS is not expected to bias the results because the braking systems of the ABS and non-ABS motorcycles differed only by whether or not they were equipped with ABS. In other words, each ABS/non-ABS pair either did or did not have CBS, making the effect of CBS independent of that of ABS in the present study. ABS showed a benefit in both the CBS and non-CBS groups, suggesting the presence of CBS on some of the motorcycles did not confound the observed effect of ABS.

ABS cannot be expected to prevent or mitigate all types of crashes, as demonstrated by Gwehenberger et al. (2006). For example, ABS would not affect the likelihood or outcome of a crash involving a motorcycle struck from behind by another vehicle. The small sample of ABS motorcycles and the lack of detailed information on pre-crash events in FARS precluded examination of the effects of ABS on crashes that would or would not likely have been influenced by its presence.

Acknowledgments

Motorcycle VINs were decoded by Marvin Campbell of the Highway Loss Data Institute, which created and currently maintains the database used to decode these VINs. Anne T. McCartt, Charles M. Farmer, and Adrian K. Lund of the Insurance Institute for Highway Safety contributed comments and suggestions that improved this study. This work was supported by the Insurance Institute for Highway Safety.

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Table 1
Study motorcycles, each with ABS and non-ABS versions in these model years

Make/model	Model years
Harley-Davidson V-Rod	2008
Honda Gold Wing	2001-08
Honda Interceptor 800	2002-08
Honda Reflex	2001-07
Honda ST1300	2003-08
Honda Silver Wing	2003-08
Kawasaki Concours 14	2008-09
Suzuki Bandit 1250	2007-08
Suzuki Burgman 650	2006-08
Suzuki SV650	2007-08
Suzuki V-Strom 650	2007-08
Triumph Sprint ST	2006-08
Yamaha FJR1300	2004-05

Table 2
Motorcycle fatal crash involvements and registered vehicle years, 2003-08

	Non-ABS models			ABS models			
	Fatal crash involvements	Registered vehicle years	Rate (x10,000)	Observed fatal crash involvements	Registered vehicle years	Rate (x10,000)	Expected fatal crash involvements
Harley-Davidson V-Rod	1	2,901	3.4	0	963	0.0	0.3
Honda Gold Wing	165	271,875	6.1	23	65,694	3.5	39.9
Honda Interceptor 800	18	25,818	7.0	7	7,086	9.9	4.9
Honda Reflex	15	43,900	3.4	2	7,734	2.6	2.6
Honda ST1300	9	21,888	4.1	6	10,418	5.8	4.3
Honda Silver Wing	19	23,430	8.1	3	3,951	7.6	3.2
Kawasaki Concours 14	3	1,686	17.8	1	1,426	7.0	2.5
Suzuki Bandit 1250	3	1,995	15.0	0	445	0.0	0.7
Suzuki Burgman 650	7	9,031	7.8	1	2,825	3.5	2.2
Suzuki SV650	15	7,022	21.4	0	246	0.0	0.5
Suzuki V-Strom 650	3	5,064	5.9	0	827	0.0	0.5
Triumph Sprint ST	4	3,035	13.2	1	1,240	8.1	4.6
Yamaha FJR1300	12	12,458	9.6	3	12,301	2.4	11.8
Total	274	430,103	6.4	47	115,156	4.1	75.2

Table 3
Driver and crash factors of study motorcycle drivers

	Non-ABS models		ABS models	
	N	%	N	%
Drivers				
Age <30	18	7	2	4
Age 30-39	23	8	5	11
Age 40-49	48	18	13	28
Age 50+	185	68	27	57
Who were speeding	59	22	8	17
With BAC $\geq$ 0.08 g/dL	44	16	6	12
Who were helmeted	204	74	33	70
Crashes				
Single-vehicle crash	115	42	19	40
Rural crash location	182	66	33	66
Universal helmet law	109	40	20	43
Partial helmet law	149	54	24	51
No helmet law	16	6	3	6
Total	274		47	

INSURANCE SPECIAL REPORT

Motorcycle Antilock Braking System (ABS)

December 2009
A-81

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Contents

Introduction

According to the National Highway Traffic Safety Administration (NHTSA, 2008) motorcycle registrations increased by 75 percent during 1997-2006. Analysis by the Insurance Institute for Highway Safety of data from the Fatality Analysis Reporting System shows that, during the same time period, fatalities in motorcycle crashes increased by 128 percent. Unlike automobiles, motorcycles offer little if any occupant protection. Only 20 percent of automobile crashes result in injury or death, whereas 80 percent of motorcycle crashes have this outcome (NHTSA, 2005). Therefore any countermeasure aimed at reducing the likelihood of motorcycle crashes should significantly reduce the risk of injury or death.

One technology designed to reduce the likelihood of motorcycle crashes is antilock braking systems (ABS). While in motion, motorcycles are kept stable by the gyroscopic effect of the wheels and lateral grip of the tires. If a wheel is braked too hard, so that it locks, both lateral grip and gyroscopic effect are lost. When this occurs, the motorcycle is immediately destabilized, and any remaining tire grip is engaged in uncontrolled skidding, leaving no grip for maneuvering. ABS has independent braking sensors for each wheel. If the system detects a difference in the rotation speeds of the wheels, it partially releases brake pressure to allow the locked wheel to spin and the tire to retain grip before reapplying the brake. ABS then modulates braking pressure to achieve optimum braking.

The Highway Loss Data Institute (HLDI) initially reported on motorcycle ABS in April 2008, in which the model years of the motorcycles studied ranged from 2003 to 2007. Significant reductions in collision claim frequencies and overall losses were found for motorcycles equipped with ABS. No significant reductions were found for claim severities. This report updates and expands the initial analysis by adding the 2008 model year, increasing the number of make/series from 12 to 18, and doubling the collision exposure. This study also includes an analysis of medical payment coverage, which typically pays for operator injuries, and bodily injury liability coverage, which typically pays for passenger injuries.

Methods

Coverages

Motorcycle insurance covers damage to vehicles and property as well as injuries to people involved in crashes. Different insurance coverages pay for physical damage versus injuries. Also, different coverages may apply depending on who is at fault. In the present study, three different insurance coverage types were examined: collision, bodily injury liability, and medical payment. Collision insures against physical damage to a motorcycle sustained in a crash when the driver is at fault. Medical payment covers injuries sustained by motorcycle operators, whereas bodily injury liability typically insures against injuries to motorcycle passengers.

Rated Drivers (Riders)

For insurance purposes, a rated driver is assigned to each motorcycle on a policy. The rated driver is the one who typically is considered to represent the greatest loss potential for the insured vehicle. In a multiple-vehicle/driver household, the driver assigned to a vehicle can vary by insurance company and state. Information on the actual driver at the time of a loss is not available in the HLDI database. HLDI collects a limited number of factors about rated drivers. For the present study, data were stratified by rated driver age group (<25, 25-39, 40-64, 65+, or unknown) and gender (male, female, or unknown).

Subject Motorcycles

For motorcycles to be included in the present study, their vehicle identification numbers (VINs) had to have an ABS indicator. This allowed for very tight control over the study population. Twenty motorcycles met this criterion, but two of them did not have claims and therefore were excluded. There were motorcycles available with ABS that were not included because their VINs did not have an ABS indicator.

All of the Honda motorcycles (both ABS and non-ABS) were equipped with combined braking systems (CBS). CBS applies braking force to both wheels when either the rear or front brake control is engaged. Even with CBS, wheel lock still is possible. With or without ABS, CBS may affect collision losses. Due to the small sample of non-CBS motorcycles in the study, the effect of CBS could not be evaluated. This is not expected to bias the results because the motorcycles in the study differed only by whether or not they were equipped with ABS. Each ABS/non-ABS pair either did or did not have CBS. ABS showed a benefit in both the CBS and non-CBS groups, suggesting the presence of CBS on some of the motorcycles did not confound the observed effect of ABS.

Analysis Methods

Data were collected by vehicle make and series, rated driver age and gender, and vehicle age and density. Vehicle density was defined as the number of registered vehicles (<100, 100-499, and 500+) per square mile. Vehicle age was defined as the difference between the calendar year and model year, measured in years.

As previously mentioned, rated driver age group and gender were included in the analysis. The dataset also was stratified by make/series and vehicle density (<100, 100-499, and 500+ vehicles per square mile). For example, a 1-year-old Honda Gold Wing, equipped with ABS, with a 40-64 year-old male as the rated driver, and garaged in an area with a vehicle density of 100-499 vehicles per square mile constituted one unit of observation. The distributions of motorcycle exposure by coverage type for the six independent variables are listed in the Appendices. Rated driver factors and vehicle density were included to control for their potential impact on losses and not to produce estimates for these variables. The estimated parameters for these variables may not generalize from this subset to the much larger motorcycle population.

Regression analysis was used to quantify the effect of ABS on motorcycle losses while controlling for other covariates. Claim frequency was modeled using a Poisson distribution, whereas claim severity 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. Reference categories for the categorical independent variables were assigned to the values with the highest exposure. The reference categories were as follows: make/series = Honda Gold Wing, ABS = without ABS, rated driver age range = 40-64, vehicle density = 100-499 vehicles per square mile, and rated driver gender = male. Losses for each unit of observation were weighted by the exposure in the linear regression. The key independent variable in the model, ABS, was treated as categorical. Models were constructed that examined the interaction of the rated driver factors and vehicle density with the presence or absence of ABS. None of these interactions were found to be significant.

Results

Collision Coverage

Summary results of the regression analysis of motorcycle collision claim frequencies using the Poisson distribution are listed in Table 1. Results for all independent variables in the model, including ABS, had p-values less than 0.05, indicating their effects on claim frequencies were statistically significant. Detailed results of the regression analysis using claim frequency as the dependent variable are listed in Table 2. The table shows estimates and significance levels for the individual values of the categorical variables. To make results more illustrative, a column was added that contains the exponents of the estimates. The exponent of the intercept equals 0.0000687 claims per day, or 2.5 claims per 100 insured vehicle years. The intercept outlines losses for the reference (baseline) categories: the estimate corresponds to the claim frequency for a Honda Gold Wing without ABS, with vehicle age 0, garaged in a medium vehicle density area, and driven by a male age 40-64. The remaining estimates are in the form of multiples, or ratios relative to the reference categories. For example, the estimate corresponding to female gender equals 0.87, so female rated drivers had estimated claim frequencies 13 percent lower than those for male rated drivers.

The estimate corresponding to motorcycle ABS (-0.25) was highly significant ($p<0.0001$). The estimate corresponded to a 22 percent reduction in claim frequencies for motorcycles equipped with ABS. Individual make/series motorcycles were included in the model, and estimates of their effect on collision claim frequencies were reported in Table 2. As previously mentioned, the reference category for the make/series variable was the Honda Gold Wing. Significant predictions for make/series ranged from 1.37 for the Triumph Tiger to 5.4 for the Honda CBR1000RR. All make/series estimates were significant at the $p=0.05$ level except for the Aprilia Caponord and Suzuki V-Strom 650. Vehicle age significantly affected collision claim frequency. Claim frequencies were estimated to decrease 19 percent ($p<0.0001$) for each 1-year increase in vehicle age.

Driver age was highly significant in predicting motorcycle collision claim frequency. Compared with losses for rated drivers ages 40-64 (reference category), estimated claim frequencies were 145 percent higher ($p<0.0001$) for rated drivers 24 and younger, 23 percent higher ($p<0.0001$) for rated drivers ages 25-39 and 18 percent higher ($p=0.003$) for rated drivers 65 and older. Rated driver gender also significantly predicted collision claim frequencies. Compared with losses for male rated riders (reference category), estimated claim frequencies were 8 percent lower ($p=0.02$) for drivers with unknown gender and 13 percent lower, nearly significant ($p=0.06$), for female rated drivers.

Motorcycle collision claim frequencies increased with vehicle density. Compared with losses in medium vehicle density areas (reference category), estimated claim frequencies were 9 percent higher ($p=0.04$) in high vehicle density areas and 13 percent lower ($p=0.002$) in low vehicle density areas.

Table 1 Summary Results of Linear Regression Analysis of Collision Claim Frequencies

	Degrees of Freedom	Chi-Square	p-value
ABS	1	31.920	<0.0001
Vehicle Make/Series	17	432.810	<0.0001
Vehicle Age	1	289.610	<0.0001
Rated Driver Age	4	87.180	<0.0001
Rated Driver Gender	2	7.350	0.025
Vehicle Density	2	23.230	<0.0001

Table 2 Detailed Results of Linear Regression Analysis of Collision Claim Frequencies

Parameter	Estimate	Exponent Estimate	Standard Error	Chi-Square	p-value
Intercept	-9.586	6.87E-05	0.046	44,115.80	<0.0001
ABS					
ABS Model	-0.246	0.782	0.044	30.8	<0.0001
Non-ABS Model	0	1.000	0		
Vehicle Make/Series					
Aprilia Caponord	0.100	1.105	1.001	0.01	0.920
Aprilia Scarabeo 500	0.871	2.390	0.270	10.44	0.001
Harley Davidson V-Rod	0.662	1.938	0.097	46.78	<0.0001
Honda CBR1000RR	1.686	5.400	0.502	11.27	0.001
Honda Gold Wing	0	1.000	0		
Honda Interceptor 800	0.882	2.417	0.078	128.03	<0.0001
Honda Reflex	0.570	1.767	0.081	49.27	<0.0001
Honda Silver Wing	0.716	2.047	0.076	89.71	<0.0001
Honda ST1300	0.241	1.273	0.080	9.16	0.003
Kawasaki Concours 14	0.941	2.561	0.098	91.47	<0.0001
Suzuki Bandit 1250	0.941	2.563	0.136	48.13	<0.0001
Suzuki B-King	1.432	4.187	0.222	41.55	<0.0001
Suzuki Burgman 650	0.660	1.935	0.067	98.1	<0.0001
Suzuki SV650	1.093	2.983	0.084	169.3	<0.0001
Suzuki V-Strom 650	0.104	1.110	0.127	0.68	0.411
Triumph Sprint ST	1.065	2.901	0.104	104.47	<0.0001
Triumph Tiger	0.314	1.368	0.152	4.23	0.040
Yamaha FJR1300	0.449	1.567	0.062	53	<0.0001
Vehicle Age	-0.214	0.807	0.013	276.61	<0.0001
Rated Driver Age					
Unknown	0.362	1.436	0.068	28.04	<0.0001
14-24	0.897	2.452	0.108	69.66	<0.0001
25-39	0.209	1.232	0.050	17.24	<0.0001
40-64	0	1.000	0		
65+	0.167	1.181	0.057	8.66	0.003
Rated Driver Gender					
Female	-0.137	0.872	0.074	3.46	0.063
Male	0	1.000	0		
Unknown	-0.087	0.917	0.038	5.16	0.023
Vehicle Density					
0-99	-0.136	0.873	0.043	9.95	0.002
100-499	0	1.000	0		
500+	0.081	1.085	0.040	4.18	0.041

Summary results of the regression analysis of motorcycle collision claim severities using the Gamma distribution are listed in Table 3. Of the six variables included in the analysis, only vehicle make/series and vehicle age had p-values less than 0.05. Neither the rated driver nor the driving environment significantly affected the claim size.

Detailed results of the regression analysis using motorcycle collision claim severity as the dependent variable are listed in Table 4. The structure of the table, as well as the variables and reference categories, are the same as those used for claim frequency in Table 2. The variables and reference categories that were used for claim frequency were used for claim severity. The exponent of the intercept equals $8,829. The intercept outlines losses for the reference (baseline) categories: the estimate corresponds to the claim severity for a Honda Gold Wing without ABS, with vehicle age of 0, garaged in a medium vehicle density area, and driven by a male age 40-64.

The estimate corresponding to the ABS effect was a 4 percent increase in claim severity. However, the estimate was not significant (p=0.3), indicating ABS does not affect claim severity. As previously mentioned, vehicle make/series and vehicle age were significant predictors of claim severity. Significant estimates of claim severities for the 18 make/series motorcycles, compared with those for the Honda Gold Wing (reference category), ranged from 23 percent lower for the Honda ST1300 to 74 percent lower for the Honda Reflex. As motorcycles age, their claim severities decrease. The model estimated a 4 percent decrease (p<0.0001) in claim severity per 1-year increase in vehicle age.

Table 3 Summary Results of Linear Regression Analysis of Collision Claim Severities

	Degrees of Freedom	Chi-Square	p-value
ABS	1	1.020	0.312
Vehicle Make/Series	17	643.930	<0.0001
Vehicle Age	1	16.070	<0.0001
Rated Driver Age	4	4.600	0.331
Rated Driver Gender	2	2.910	0.233
Vehicle Density	2	5.340	0.069

Table 4 Detailed Results of Linear Regression Analysis of Collision Claim Severities

Parameter	Estimate	Exponent Estimate	Standard Error	Chi-Square	p-value
Intercept	9.086	8,829.03	0.040	52,266.80	<0.0001
ABS					
ABS Model	0.037	1.038	0.0371	1.02	0.313
Non-ABS Model	0	1.000	0		
Vehicle Make/Series					
Aprilia Caponord	-0.497	0.608	0.825	0.36	0.547
Aprilia Scarabeo 500	-1.139	0.320	0.223	26.16	<0.0001
Harley Davidson V-Rod	-0.503	0.605	0.083	36.59	<0.0001
Honda CBR1000RR	-0.199	0.819	0.479	0.17	0.677
Honda Gold Wing	0	1.000	0		
Honda Interceptor 800	-0.587	0.556	0.0654	80.56	<0.0001
Honda Reflex	-1.355	0.258	0.0673	404.93	<0.0001
Honda Silver Wing	-1.054	0.349	0.0635	275.2	<0.0001
Honda ST1300	-0.260	0.771	0.067	15.04	0.0001
Kawasaki Concours 14	-0.406	0.667	0.0833	23.7	<0.0001
Suzuki Bandit 1250	-0.826	0.438	0.113	53.43	<0.0001
Suzuki B-King	-0.609	0.544	0.1883	10.46	0.001
Suzuki Burgman 650	-0.845	0.429	0.0562	226.35	<0.0001
Suzuki SV650	-0.793	0.453	0.0714	123.27	<0.0001
Suzuki V-Strom 650	-0.850	0.427	0.1066	63.67	<0.0001
Triumph Sprint ST	-0.454	0.635	0.0876	26.83	<0.0001
Triumph Tiger	-0.491	0.612	0.1261	15.18	<0.0001
Yamaha FJR1300	-0.477	0.621	0.0513	86.47	<0.0001
Vehicle Age	-0.042	0.959	0.010	16.25	<0.0001
Rated Driver Age					
Unknown	0.089	1.094	0.060	2.2	0.139
14-24	0.122	1.130	0.088	1.95	0.163
25-39	0.011	1.011	0.043	0.07	0.794
40-64	0	1.000	0		
65+	0.047	1.048	0.047	1	0.317
Rated Driver Gender					
Female	0.091	1.095	0.062	2.17	0.140
Male	0	1.000	0		
Unknown	-0.014	0.986	0.032	0.2	0.656
Vehicle Density					
0-99	0.038	1.039	0.036	1.1	0.295
100-499	0	1.000	0		
500+	0.080	1.083	0.034	5.57	0.018

Table 5 summarizes the effects of the independent variables on motorcycle collision overall losses, derived from the claim frequency and claim severity models. Overall losses can be calculated by simple multiplication because the estimates for the effect of ABS on claim frequency and claim severity were in the form of ratios relative to the reference (baseline) categories. The standard error for overall losses can be calculated by taking the square root of the sum of the squared standard errors for claim frequency and severity. Based on the value of the estimate and the associated standard error, the corresponding two-sided p-value was derived from a standard normal distribution approximation.

The estimated effect of ABS was a significant (p=0.0003) 19 percent decrease in collision overall losses. This is a strong indication that ABS is effective in reducing collision overall losses for motorcycles. Estimated overall losses for the 18 make/series motorcycles, compared with those for the Honda Gold Wing (reference category), ranged from 54 percent lower for the Honda Reflex to 342 percent higher for the Honda CBR1000RR. Ten of the make/series estimates were significantly different from the reference category, and the other seven estimates were not significant. Vehicle age also had significant effects in reducing collision overall losses. Collision overall losses were estimated to decrease 23 percent (p<0.0001) for each 1-year increase in vehicle age. Driver age was a significant predictor of motorcycle collision overall losses. Compared with losses for rated drivers ages 40-64 (reference category), estimated overall losses were 177 percent higher (p<0.0001) for rated drivers 24 and younger, 25 percent higher (p=0.0011) for rated drivers ages 25-39, and 24 percent higher (p=0.004) for rated drivers 65 or older. Estimated overall losses for drivers with unknown gender were 10 percent lower (p=0.04) than those for male rated drivers (reference category). Estimated overall losses for rated female drivers were not significant.

Motorcycle collision overall losses were predicted to increase with vehicle density. Compared with losses in medium vehicle density in areas (reference category), estimated overall losses were 17 percent higher (p=0.002) in high vehicle density areas and 9 percent lower, nearly significant (p=0.08), in low vehicle density areas.

Table 5 Results for Collision Overall Losses Derived from Claim Frequency and Severity Models								
	Frequency		Severity		Overall Losses			
Parameter	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error	Exponent Estimate	p-value
Intercept	-9.586	0.046	9.086	0.040	-0.500	0.060	0.606	<0.0001
ABS								
ABS Model	-0.246	0.044	0.037	0.037	-0.209	0.058	0.812	0.0003
Non-ABS Model	0	0	0	0	0	0	1	
Vehicle Make/Series								
Aprilia Caponord	0.100	1.001	-0.497	0.825	-0.397	1.297	0.673	0.760
Aprilia Scarabeo 500	0.871	0.270	-1.139	0.223	-0.267	0.350	0.765	0.444
Harley Davidson V-Rod	0.662	0.097	-0.503	0.083	0.159	0.128	1.173	0.212
Honda CBR1000RR	1.686	0.502	-0.199	0.479	1.487	0.694	4.424	0.032
Honda Gold Wing	0	0	0	0	0	0	1	
Honda Interceptor 800	0.882	0.078	-0.587	0.065	0.295	0.102	1.343	0.004
Honda Reflex	0.570	0.081	-1.355	0.067	-0.785	0.105	0.456	<0.0001
Honda Silver Wing	0.716	0.076	-1.054	0.064	-0.337	0.099	0.714	0.0006
Honda ST1300	0.241	0.080	-0.260	0.067	-0.019	0.104	0.981	0.856
Kawasaki Concours 14	0.941	0.098	-0.406	0.083	0.535	0.129	1.707	<0.0001
Suzuki Bandit 1250	0.941	0.136	-0.826	0.113	0.115	0.177	1.122	0.513
Suzuki B-King	1.432	0.222	-0.609	0.188	0.823	0.291	2.277	0.005
Suzuki Burgman 650	0.660	0.067	-0.845	0.056	-0.185	0.087	0.831	0.033
Suzuki SV650	1.093	0.084	-0.793	0.071	0.300	0.110	1.350	0.006
Suzuki V-Strom 650	0.104	0.127	-0.850	0.107	-0.746	0.165	0.474	<0.0001
Triumph Sprint ST	1.065	0.104	-0.454	0.088	0.611	0.136	1.842	<0.0001
Triumph Tiger	0.314	0.152	-0.491	0.126	-0.178	0.198	0.837	0.370
Yamaha FJR1300	0.449	0.062	-0.477	0.051	-0.028	0.080	0.973	0.731
Vehicle Age	-0.214	0.013	-0.042	0.010	-0.256	0.017	0.774	<0.0001
Rated Driver Age								
Unknown	0.362	0.068	0.089	0.060	0.451	0.091	1.570	<0.0001
14-24	0.897	0.108	0.122	0.088	1.019	0.1387	2.771	<0.0001
25-39	0.209	0.050	0.011	0.043	0.220	0.0661	1.246	0.001
40-64	0	0	0	0	0	0	1	
65+	0.167	0.057	0.047	0.047	0.214	0.074	1.238	0.004
Rated Driver Gender								
Female	-0.137	0.074	0.091	0.062	-0.046	0.096	0.955	0.634
Male	0	0	0	0	0	0	1	
Unknown	-0.087	0.038	-0.014	0.032	-0.101	0.050	0.904	0.043
Vehicle Density								
0-99	-0.136	0.043	0.038	0.036	-0.098	0.056	0.907	0.082
100-499	0	0	0	0	0	0	1	
500+	0.081	0.040	0.080	0.034	0.161	0.052	1.174	0.002

Medical Payment Coverage

Summary results of the regression analysis of motorcycle medical payment claim frequencies using the Poisson distribution are listed in Table 6. Results for the following independent variables: ABS, vehicle make/series, vehicle age and rated driver gender had p-values less than 0.05, indicating their effects on claim frequencies were statistically significant. Rated driver age was marginally significant while vehicle density was not significant.

Detailed results of the regression analysis using claim frequency as the dependent variable are listed in Table 6. The exponent of the intercept equals 0.000046 claims per day, or 16.8 claims per 1,000 insured vehicle years. The estimate corresponding to motorcycle ABS (-0.36) was highly significant (p=0.003). The estimate corresponded to a 30 percent reduction in medical payment claim frequencies for motorcycles equipped with ABS.

The estimate corresponding to the ABS effect on medical payment claim severity was a nonsignificant (p=0.32) 13 percent increase in claim severity, indicating ABS does not affect claim severity. Rated driver age and make/series were the strongest predictors of claim severity. The predictive value of make/series is perhaps a proxy for policy limits. More expensive motorcycles are more likely to have higher policy limits than less expensive motorcycles. Higher policy limits allow higher claim severities to occur in the event of a crash. The Honda Gold Wing is the most expensive motorcycle in the study. The make/series estimates for the other motorcycles studied are less than that for the Gold Wing except for the Honda CBR1000RR, which typically is among the motorcycles with the highest collision losses primarily due to its very high claim frequency.

Overall losses for medical payment coverage were calculated in the same fashion as collision coverage. ABS was estimated to reduce overall medical payment losses by 21 percent, although the estimate was not statistically significant (p=0.16).

Table 6 Summary Results of Linear Regression Analysis of Medical Payment Claim Frequencies

	Degrees of Freedom	Chi-Square	p-value
ABS	1	9.640	0.002
Vehicle Make/Series	17	92.390	<0.0001
Vehicle Age	1	57.850	<0.0001
Rated Driver Age	4	9.140	0.058
Rated Driver Gender	2	7.840	0.020
Vehicle Density	2	1.820	0.403

Table 7 Detailed Results of Linear Regression Analysis of Medical Payment Claim Frequencies

Parameter	Estimate	Exponent Estimate	Standard Error	Chi-Square	p-value
Intercept	-9.985	4.61E-05	0.109	8,387.580	<0.0001
ABS					
ABS Model	-0.358	0.699	0.119	9.050	0.003
Non-ABS Model	0	1	0		
Vehicle Make/Series					
Aprilia Scarabeo 500	0.041	1.042	1.004	0.000	0.968
Harley Davidson V-Rod	0.206	1.229	0.261	0.620	0.431
Honda CBR1000RR	0.759	2.135	0.309	6.010	0.014
Honda CBR600RR	1.445	4.241	0.177	66.640	<0.0001
Honda Gold Wing	0	1	0		
Honda Interceptor 800	0.367	1.444	0.252	2.120	0.146
Honda Reflex	0.744	2.104	0.168	19.620	<0.0001
Honda Silver Wing	0.559	1.750	0.182	9.480	0.002
Honda ST1300	0.582	1.789	0.170	11.640	0.001
Kawasaki Concours 14	0.502	1.651	0.292	2.950	0.086
Suzuki Bandit 1250	0.343	1.410	0.416	0.680	0.409
Suzuki B-King	0.617	1.854	0.714	0.750	0.387
Suzuki Burgman 650	0.347	1.415	0.191	3.300	0.069
Suzuki SV650	1.137	3.119	0.187	37.010	<0.0001
Suzuki V-Strom 650	0.406	1.501	0.257	2.500	0.114
Triumph Sprint ST	1.029	2.797	0.257	16.020	<0.0001
Triumph Tiger	0.677	1.968	0.310	4.760	0.029
Yamaha FJR1300	0.028	1.028	0.190	0.020	0.884
Vehicle Age	-0.234	0.792	0.031	55.330	<0.0001
Rated Driver Age					
Unknown	0.064	1.066	0.141	0.210	0.649
14-24	0.529	1.698	0.191	7.680	0.006
25-39	0.077	1.080	0.125	0.380	0.537
40-64	0	1	0		
65+	-0.165	0.848	0.150	1.210	0.271
Rated Driver Gender					
Female	-0.072	0.931	0.188	0.150	0.703
Male	0	1	0		
Unknown	0.253	1.288	0.093	7.340	0.007
Vehicle Density					
0-99	-0.028	0.972	0.096	0.080	0.772
100-499	0	1	0		
500+	0.104	1.109	0.096	1.180	0.277

Table 8 Summary Results of Linear Regression Analysis of Medical payment Claim Severities

	Degrees of Freedom	Chi-Square	p-value
ABS	1	1.010	0.314
Vehicle Make/Series	17	53.340	<0.0001
Vehicle Age	1	0.000	0.981
Rated Driver Age	4	34.650	<0.0001
Rated Driver Gender	2	15.970	0.0003
Vehicle Density	2	0.060	0.970

Table 9 Detailed Results of Linear Regression Analysis of Medical Payment Claim Severities

Parameter	Estimate	Exponent Estimate	Standard Error	Chi-Square	p-value
Intercept	8.018	3,034.798	0.113	5,032.420	<0.0001
ABS					
ABS Model	0.120	1.127	0.120	1.000	0.318
Non-ABS Model	0	1	0		
Vehicle Make/Series					
Aprilia Scarabeo 500	-1.129	0.324	0.897	1.580	0.208
Harley Davidson V-Rod	-0.791	0.453	0.304	6.790	0.009
Honda CBR1000RR	0.076	1.079	0.323	0.060	0.814
Honda CBR600RR	-0.206	0.814	0.195	1.120	0.291
Honda Gold Wing	0	1	0		
Honda Interceptor 800	-0.440	0.644	0.262	2.820	0.093
Honda Reflex	-0.410	0.664	0.1716	5.720	0.017
Honda Silver Wing	-0.570	0.566	0.1949	8.540	0.004
Honda ST1300	-0.441	0.643	0.1672	6.970	0.008
Kawasaki Concours 14	-0.172	0.842	0.3156	0.300	0.586
Suzuki Bandit 1250	-0.471	0.624	0.4172	1.280	0.259
Suzuki B-King	-0.049	0.952	0.905	0	0.957
Suzuki Burgman 650	-0.957	0.384	0.1965	23.740	<0.0001
Suzuki SV650	-0.566	0.568	0.1977	8.190	0.004
Suzuki V-Strom 650	-0.746	0.474	0.2535	8.660	0.003
Triumph Sprint ST	-0.973	0.378	0.2758	12.460	0.0004
Triumph Tiger	-0.323	0.724	0.3219	1.010	0.316
Yamaha FJR1300	-0.549	0.578	0.1772	9.590	0.002
Vehicle Age	-0.001	0.999	0.033	0.000	0.981
Rated Driver Age					
Unknown	0.756	2.130	0.152	24.760	<0.0001
14-24	-0.422	0.656	0.206	4.200	0.040
25-39	0.073	1.076	0.147	0.250	0.617
40-64	0	1	0		
65+	0.093	1.097	0.154	0.360	0.547
Rated Driver Gender					
Female	0.399	1.490	0.191	4.380	0.036
Male	0	1	0		
Unknown	-0.319	0.727	0.105	9.270	0.002
Vehicle Density					
0-99	0.023	1.023	0.098	0.050	0.818
100-499	0	1	0		
500+	0.018	1.019	0.103	0.030	0.858

Table 10 Results for Medical Payment Overall Losses Derived from Claim Frequency and Severity Models

Parameter	Frequency Estimate	Frequency Standard Error	Severity Estimate	Severity Standard Error	Overall Losses Estimate	Overall Losses Standard Error	Overall Losses Exponent Estimate	Overall Losses p-value
Intercept	-9.985	0.109	8.018	0.113	-1.967	0.157	0.140	<0.0001
ABS								
ABS Model	-0.358	0.119	0.120	0.120	-0.239	0.169	0.788	0.157
Non-ABS Model	0	0	0	0	0	0	1	
Vehicle Make/Series								
Aprilia Scarabeo 500	0.041	1.004	-1.129	0.897	-1.088	1.346	0.337	0.419
Harley Davidson V-Rod	0.206	0.261	-0.791	0.304	-0.585	0.401	0.557	0.144
Honda CBR1000RR	0.759	0.309	0.076	0.323	0.834	0.447	2.303	0.062
Honda CBR600RR	1.445	0.177	-0.206	0.195	1.239	0.263	3.452	<0.0001
Honda Gold Wing	0	0	0	0	0	0	1	
Honda Interceptor 800	0.367	0.252	-0.440	0.262	-0.073	0.364	0.930	0.841
Honda Reflex	0.744	0.168	-0.410	0.172	0.334	0.240	1.396	0.165
Honda Silver Wing	0.559	0.182	-0.570	0.195	-0.010	0.266	0.990	0.969
Honda ST1300	0.582	0.170	-0.441	0.167	0.140	0.239	1.151	0.557
Kawasaki Concours 14	0.502	0.292	-0.172	0.316	0.330	0.430	1.390	0.443
Suzuki Bandit 1250	0.343	0.416	-0.471	0.417	-0.128	0.589	0.880	0.828
Suzuki B-King	0.617	0.714	-0.049	0.905	0.568	1.153	1.765	0.622
Suzuki Burgman 650	0.347	0.191	-0.957	0.197	-0.610	0.274	0.543	0.026
Suzuki SV650	1.137	0.187	-0.566	0.198	0.5716	0.272	1.771	0.036
Suzuki V-Strom 650	0.406	0.257	-0.746	0.254	-0.3400	0.361	0.712	0.346
Triumph Sprint ST	1.029	0.257	-0.973	0.276	0.055	0.377	1.057	0.884
Triumph Tiger	0.677	0.310	-0.323	0.322	0.354	0.447	1.425	0.428
Yamaha FJR1300	0.028	0.190	-0.549	0.177	-0.521	0.260	0.594	0.045
Vehicle Age	-0.234	0.031	-0.001	0.033	-0.235	0.046	0.791	<0.0001
Rated Driver Age								
Unknown	0.064	0.141	0.756	0.152	0.820	0.208	2.271	<0.0001
14-24	0.529	0.191	-0.422	0.206	0.108	0.281	1.113	0.702
25-39	0.077	0.125	0.073	0.147	0.150	0.192	1.162	0.435
40-64	0	0	0	0	0	0	1	
65+	-0.165	0.150	0.093	0.154	-0.072	0.215	0.930	0.737
Rated Driver Gender								
Female	-0.072	0.188	0.399	0.191	0.327	0.268	1.387	0.222
Male	0	0	0	0	0	0	1	
Unknown	0.253	0.093	-0.319	0.105	-0.066	0.140	0.936	0.639
Vehicle Density								
0-99	-0.028	0.096	0.023	0.098	-0.005	0.137	0.995	0.969
100-499	0	0	0	0	0	0	1	
500+	0.104	0.096	0.018	0.103	0.122	0.140	1.130	0.384

Bodily Injury Liability Liability Coverage

Due to limited exposure, only 12 of the 18 motorcycles used in collision coverage analysis were used in analysis of bodily injury liability coverage. Summary results of the regression analysis of motorcycle bodily injury liability claim frequencies using the Poisson distribution are listed in Table 11. Results for all of the independent variables except rated driver gender had p-values less than 0.05, indicating their effects on claim frequencies were statistically significant.

Detailed results of the regression analysis using claim frequency as the dependent variable are listed in Table 12. The exponent of the intercept equals 0.0000085 claims per day, or 3.1 claims per 1,000 insured vehicle years. The estimate corresponding to motorcycle ABS (-0.394) was significant ($p = 0.03$). The estimate corresponded to a 33 percent reduction in bodily injury liability claim frequencies for motorcycles equipped with ABS. The estimated claim frequency for rated drivers 24 and younger was more than 4 times that for rated drivers ages 40-64 (reference category).

Of the 12 estimates for make/series, only two were statistically different from the reference make/series. Claim frequencies were estimated to be 0.474 for the Yamaha FJR1300 and 2.614 for the Honda CBR1000RR. Claim frequencies were estimated to decrease 16 percent ($p = 0.0002$) for each 1-year increase in vehicle age.

None of the variables in the analysis were shown to have a statistically significant impact on bodily injury liability claim severity. Although ABS was estimated to reduce overall bodily injury liability losses by more than 43 percent, the estimate was not statistically significant ($p = 0.185$).

REFERENCES

National Highway Traffic Safety Administration. 2008. Traffic Safety Facts, 2007. Report no. DOT HS-810-990. Washington, DC: US Department of Transportation.

National Highway Traffic Safety Administration. 2005. Without Motorcycle Helmets We All Pay the Price. Washington, DC: US Department of Transportation.

Table 11 Summary Results of Linear Regression Analysis of Bodily Injury Liability Claim Frequencies

	Degrees of Freedom	Chi-Square	p-value
ABS	1	5.050	0.025
Vehicle Make/Series	11	22.610	0.020
Vehicle Age	1	14.540	0.0001
Rated Driver Age	4	17.980	0.001
Rated Driver Gender	2	4.010	0.135
Vehicle Density	2	6.420	0.040

Table 12 Detailed Results of Linear Regression Analysis of Bodily Injury Liability Claim Frequencies

Parameter	Estimate	Exponent Estimate	Standard Error	Chi-Square	p-value
Intercept	-11.679	8.47E-06	0.159	5,429.750	<0.0001
ABS					
ABS Model	-0.394	0.674	0.182	4.690	0.030
Non-ABS Model	0	1	0		
Vehicle Make/Series					
Harley Davidson V-Rod	-0.033	0.968	0.409	0.010	0.936
Honda CBR1000RR	0.961	2.614	0.342	7.900	0.005
Honda Gold Wing	0.000	1.000	0.000		
Honda Interceptor 800	-0.243	0.784	0.360	0.460	0.500
Honda Reflex	-0.689	0.502	0.3926	3.080	0.079
Honda Silver Wing	0.035	1.036	0.284	0.020	0.901
Honda ST1300	0.015	1.015	0.260	0.000	0.955
Kawasaki Concours 14	-0.225	0.799	0.517	0.190	0.664
Suzuki Bandit 1250	-1.088	0.337	1.006	1.170	0.280
Suzuki Burgman 650	-0.390	0.677	0.330	1.390	0.238
Suzuki SV650	-0.066	0.936	0.363	0.030	0.855
Yamaha FJR1300	-0.747	0.474	0.316	5.600	0.018
Vehicle Age	-0.176	0.839	0.047	14.110	0.0002
Rated Driver Age					
Unknown	0.159	1.172	0.288	0.300	0.582
14-24	1.415	4.116	0.353	16.110	<0.0001
25-39	-0.007	0.993	0.233	-	0.976
40-64	0	1	0		
65+	0.354	1.424	0.185	3.660	0.056
Rated Driver Gender					
Female	-0.153	0.858	0.331	0.210	0.643
Male	0	1	0		
Unknown	-0.289	0.749	0.147	3.860	0.049
Vehicle Density					
0-99	-0.163	0.850	0.163	1.000	0.316
100-499	0	1	0		
500+	0.257	1.293	0.150	2.930	0.087

Table 13 Summary Results of Linear Regression Analysis of Bodily Injury Liability Claim Severities

	Degrees of Freedom	Chi-Square	p-value
ABS	1	0.200	0.652
Vehicle Make/Series	11	6.490	0.839
Vehicle Age	1	0.230	0.628
Rated Driver Age	4	4.520	0.341
Rated Driver Gender	2	0.150	0.928
Vehicle Density	2	0.200	0.906

Table 14 Detailed Results of Linear Regression Analysis of Bodily Injury Liability Claim Severities

Parameter	Estimate	Exponent Estimate	Standard Error	Chi-Square	p-value
Intercept	10.150	25,578.310	0.293	1,201.140	<0.0001
ABS					
ABS Model	-0.179	0.836	0.393	0.210	0.648
Non-ABS Model	0	1	0		
Vehicle Make/Series					
Harley Davidson V-Rod	-0.289	0.749	0.994	0.080	0.771
Honda CBR1000RR	0.108	1.114	0.768	0.020	0.888
Honda Gold Wing	0	1	0		
Honda Interceptor 800	0.622	1.863	0.748	0.690	0.405
Honda Reflex	-1.273	0	0.906	1.980	0.160
Honda Silver Wing	-0.856	0.425	0.872	0.960	0.326
Honda ST1300	-0.512	0.599	0.531	0.930	0.334
Kawasaki Concours 14	-0.572	0.564	0.832	0.470	0.491
Suzuki Bandit 1250	-0.014	0.986	1.535	0.000	0.993
Suzuki Burgman 650	-0.862	0.422	0.696	1.530	0.216
Suzuki SV650	-0.144	0.866	0.913	0.020	0.875
Yamaha FJR1300	-0.003	0.997	0.609	0	0.996
Vehicle Age	-0.043	0.958	0.088	0.240	0.626
Rated Driver Age					
Unknown	-1.347	0.260	0.699	3.710	0.054
14-24	-0.665	0.514	0.806	0.680	0.409
25-39	-0.097	0.908	0.681	0.020	0.887
40-64	0	1	0		
65+	0.238	1.269	0.390	0.370	0.541
Rated Driver Gender					
Female	0.226	1.254	0.671	0.110	0.736
Male	0	1	0		
Unknown	0.079	1.082	0.320	0.060	0.806
Vehicle Density					
0-99	0.052	1.054	0.336	0.020	0.876
100-499	0	1	0		
500+	0.162	1.176	0.367	0.190	0.659

Table 15 Results for Bodily Injury Liability Overall Losses Derived from Claim Frequency and Severity Models

	Frequency		Severity		Overall Losses			
Parameter	Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error	Exponent Estimate	p-value
Intercept	-11.679	0.159	10.150	0.293	-1.529	0.333	0.217	<0.0001
ABS								
ABS Model	-0.394	0.182	-0.179	0.393	-0.574	0.433	0.563	0.185
Non-ABS Model	0	0	0	0	0	0	1	
Vehicle Make/Series								
Harley Davidson V-Rod	-0.033	0.409	-0.289	0.994	-0.322	1.075	0.725	0.765
Honda CBR1000RR	0.961	0.342	0.108	0.768	1.069	0.841	2.912	0.204
Honda Gold Wing	0	0	0	0	0	0	1	
Honda Interceptor 800	-0.243	0.360	0.622	0.748	0.379	0.830	1.461	0.648
Honda Reflex	-0.689	0.393	-1.273	0.906	-1.962	0.987	0.141	0.047
Honda Silver Wing	0.035	0.284	-0.856	0.872	-0.821	0.917	0.440	0.371
Honda ST1300	0.015	0.260	-0.512	0.531	-0.498	0.591	0.608	0.400
Kawasaki Concours 14	-0.225	0.517	-0.572	0.832	-0.797	0.979	0.451	0.416
Suzuki Bandit 1250	-1.088	1.006	-0.014	1.535	-1.102	1.836	0.332	0.548
Suzuki Burgman 650	-0.390	0.330	-0.862	0.696	-1.251	0.770	0.286	0.104
Suzuki SV650	-0.066	0.363	-0.144	0.913	-0.210	0.982	0.811	0.831
Yamaha FJR1300	-0.747	0.316	-0.003	0.609	-0.751	0.686	0.472	0.274
Vehicle Age	-0.176	0.047	-0.043	0.088	-0.219	0.100	0.803	0.028
Rated Driver Age								
Unknown	0.159	0.288	-1.347	0.699	-1.188	0.756	0.305	0.116
14-24	1.415	0.353	-0.665	0.806	0.750	0.879	2.116	0.394
25-39	-0.007	0.233	-0.097	0.681	-0.104	0.720	0.901	0.885
40-64	0	0	0	0	0	0	1	
65+	0.354	0.185	0.238	0.390	0.592	0.431	1.808	0.170
Rated Driver Gender								
Female	-0.153	0.331	0.226	0.671	0.073	0.748	1.076	0.922
Male	0	0	0	0	0	0	1	
Unknown	-0.289	0.147	0.079	0.320	-0.210	0.352	0.810	0.550
Vehicle Density								
0-99	-0.163	0.163	0.052	0.336	-0.111	0.373	0.895	0.767
100-499	0	0	0	0	0	0	1	
500+	0.257	0.150	0.162	0.367	0.419	0.397	1.520	0.291

Appendix A Distribution of Exposure for Independent Variables, Collision Coverage

Vehicle Make/Series	Exposure without ABS	Percent of Series	Exposure with ABS	Percent of Series
Aprilia Caponord	1	2%	64	98%
Aprilia Scarabeo 500	120	34%	234	66%
Harley Davidson V-Rod	2,052	79%	551	21%
Honda CBR1000RR	22	89%	3	11%
Honda Gold Wing	61,949	80%	15,712	20%
Honda Interceptor 800	4,335	76%	1,404	24%
Honda Reflex	6,001	87%	909	13%
Honda Silver Wing	5,961	84%	1,122	16%
Honda ST1300	6,781	68%	3,142	32%
Kawasaki Concours 14	1,120	53%	978	47%
Suzuki Bandit 1250	885	82%	198	18%
Suzuki B-King	202	99%	3	1%
Suzuki Burgman 650	7,447	86%	1,198	14%
Suzuki SV650	2,702	95%	131	5%
Suzuki V-Strom 650	2,339	85%	426	15%
Triumph Sprint ST	1,314	66%	680	34%
Triumph Tiger	1,470	84%	281	16%
Yamaha FJR1300	6,397	37%	10,765	63%
Total	**111,099**	**75%**	**37,801**	**25%**

	Exposure	Percent of Total
Vehicle Age		
-1	1,227	1%
0	22,160	15%
1	34,976	23%
2	31,451	21%
3	25,513	17%
4	18,997	13%
5	11,569	8%
6	3,008	2%
Rated Driver Age		
Unknown	9,034	6%
14-24	1,063	1%
25-39	16,550	11%
40-64	104,169	70%
65+	18,084	12%
Rated Driver Gender		
Female	9,684	7%
Male	83,269	56%
Unknown	55,947	38%
Vehicle Density		
0-99	45,234	30%
100-499	60,499	41%
500+	43,168	29%

Appendix B Distribution of Exposure for Independent Variable, Medical Payment Coverage

Vehicle Make/Series	Exposure without ABS	Percent of Series	Exposure with ABS	Percent of Series
Aprilia Scarabeo 500	31	35%	57	65%
Harley Davidson V-Rod	647	83%	129	17%
Honda CBR1000RR	273	99%	3	1%
Honda CBR600RR	784	100%	2	0%
Honda Gold Wing	17,351	81%	3,974	19%
Honda Interceptor 800	942	77%	283	23%
Honda Reflex	1,984	89%	252	11%
Honda Silver Wing	1,837	83%	368	17%
Honda ST1300	1,704	72%	673	28%
Kawasaki Concours 14	267	54%	230	46%
Suzuki Bandit 1250	226	78%	65	22%
Suzuki B-King	57	99%	1	1%
Suzuki Burgman 650	1,455	80%	362	20%
Suzuki SV650	755	96%	34	4%
Suzuki V-Strom 650	611	84%	117	16%
Triumph Sprint ST	323	64%	182	36%
Triumph Tiger	378	87%	55	13%
Yamaha FJR1300	1,045	28%	2,634	72%
Total	**30,671**	**77%**	**9,420**	**23%**

	Exposure	Percent of Total
Vehicle Age		
-1	306	1%
0	5,973	15%
1	9,330	23%
2	8,211	20%
3	6,799	17%
4	5,090	13%
5	3,323	8%
6	1,060	3%
Rated Driver Age	**Exposure (Yrs)**	**%**
Unknown	4,144	10%
14-24	582	1%
25-39	4,257	11%
40-64	25,977	65%
65+	5,130	13%
Rated Driver Gender	**Exposure (Yrs)**	**%**
Female	2,155	5%
Male	25,866	65%
Unknown	12,070	30%
Density	**Exposure (Yrs)**	**%**
0-99	13,389	33%
100-499	16,099	40%
500+	10,603	26%

Appendix C Distribution of Exposure for Independent Variable, Bodily Injury Liability Coverage

Vehicle Make/Series	Exposure without ABS	Percent of Series	Exposure with ABS	Percent of Series
Harley Davidson V-Rod	1,825	79%	471	21%
Honda CBR1000RR	1,424	100%	2	0%
Honda Gold Wing	55,249	80%	13,922	20%
Honda Interceptor 800	4,707	76%	1,472	24%
Honda Reflex	6,302	87%	920	13%
Honda Silver Wing	6,112	85%	1,110	15%
Honda ST1300	6,357	69%	2,893	31%
Kawasaki Concours 14	1,067	55%	870	45%
Suzuki Bandit 1250	962	82%	209	18%
Suzuki Burgman 650	5,109	82%	1,148	18%
Suzuki SV650	3,071	96%	137	4%
Yamaha FJR1300	4,420	30%	10,317	70%
Total	**96,605**	**74%**	**33,470**	**26%**

	Exposure	Percent of Total
Vehicle Age		
-1	1,206	1%
0	20,356	16%
1	29,044	22%
2	27,415	21%
3	23,034	18%
4	17,077	13%
5	10,458	8%
6	1,487	1%
Rated Driver Age	**Exposure (Yrs)**	**%**
Unknown	8,977	7%
14-24	1,304	1%
25-39	14,454	11%
40-64	88,583	68%
65+	16,758	13%
Rated Driver Gender	**Exposure (Yrs)**	**%**
Female	5,835	4%
Male	72,444	56%
Unknown	51,797	40%
Vehicle Density	**Exposure (Yrs)**	**%**
0-99	39,326	30%
100-499	52,750	41%
500+	38,000	29%

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