EVALUATION OF MOTORCYCLE ANTILOCK BRAKING SYSTEMS

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ABSTRACT

Objective: Previous studies have found lower crash rates for motorcycles equipped with antilock braking systems (ABS). Although prior studies controlled for a variety of personal factors related to motorcycle crashes, they did not control for the possibility that riders with similar demographics still can differ in the likelihood that they buy optional safety equipment and that this difference might be related to their crash likelihood. Specifically, motorcyclists who purchase ABS might be more likely to behave in a manner that makes them less likely to crash. The purpose of the current analysis was to examine the influence of individual crash risk on the frequency of insurance claims under collision coverage for ABS-equipped motorcycles. Auto collision claim histories were used as a proxy for the crash risk of individual riders, independent of the motorcycles they ride.

Methods: Coverage and loss data on nearly 2 million motorcycles by their unique vehicle identification numbers (VIN) were supplied by 13 insurers for model years 2003-14. The VINs were used to determine the ABS status of each motorcycle. Demographic characteristics including gender, marital status, date of birth, zip code, and insurance company were used to match the riders of these motorcycles to their auto insurance histories. Riders without any auto insurance history were excluded. Regression analysis was used to quantify the effect of ABS while controlling for auto claim frequency and other covariates including rider age and gender, garaging state, and collision deductible.

Results: Motorcycle riders with higher auto collision claim frequencies were associated with higher motorcycle collision claim frequencies. Riders with high auto claim frequencies (an average of more than two auto claims per 5 years insured) were associated with motorcycle claim frequencies that were 64 percent higher than those for riders with a history of zero auto claims. The percentage of motorcycles with ABS optionally equipped increased with the riders' auto claim frequencies. After controlling for auto claim frequency, motorcycles equipped with optional ABS were associated with a 21 percent reduction in claim frequency compared with similar motorcycles without ABS. Further analysis indicated that the reduction in motorcycle claim frequency associated with motorcycles equipped with ABS did not vary significantly depending on the auto claim frequency of the rider.

Discussion: Among motorcyclists with both auto and motorcycle collision insurance coverage, there was a strong relationship between motorcycle and auto claims experience. However, there was no evidence that safer riders, as measured by auto claim frequency, were more likely to purchase motorcycles with optional ABS. Rather, riders with higher auto claim frequencies were more likely to ride motorcycles with ABS. Most important, controlling for a rider's auto claim frequency did not substantively change the observed ABS effect, and the 21 percent estimated reduction in motorcycle collision claim frequency was consistent with prior research.

Conclusion: This analysis evaluated the real-world safety benefits of motorcycle ABS while also addressing the potential influence of self-selection by safer riders. Results indicate that all riders may be expected to benefit from ABS technology on their motorcycles. This study also confirms that auto crash risk is a reasonable proxy for a safety profile that may be applied to future research on other optional safety technologies.

INTRODUCTION

According to the National Highway Traffic Safety Administration (NHTSA), motorcycle registrations more than doubled between 1997 and 2010 (NHTSA, 2012). 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 110 percent. Motorcyclist deaths began to increase in 1998 and continued to increase and peaked in 2008. Motorcyclist deaths decreased by 16 percent in 2009 compared with 2008 and increased only slightly from 2010 through 2012. Motorcyclist deaths decreased again slightly in 2013. It is not known to what extent the overall decrease from 2008 is related to improvements in highway safety or due to the significant drop in new motorcycle sales from more than 1.1 million in 2008 to only 560,000 in 2010 (Motorcycle Industry Council, 2011). Compared with automobiles, motorcycles offer much less occupant protection in the event of a crash. Only 20 percent of automobile crashes result in injury or death, whereas 80 percent of motorcycle crashes do (NHTSA, 2005). Therefore, any countermeasure aimed at reducing the likelihood of motorcycle crashes should significantly reduce the risk of injury or death.

Improper braking was identified as a significant factor in causes of motorcycle crashes (Association of European Motorcycle Manufacturers, 2004; Hurt et al., 1981). Braking too hard and locking a wheel on a motorcycle can lead to loss of control resulting in a crash. Riders concerned with wheel lock may avoid applying full force to the brakes resulting in insufficient braking power to avoid or mitigate an impact. Antilock braking systems (ABS) were developed to help riders solve this dilemma by automatically adjusting braking pressure to avoid wheel lock. These systems allow a rider to brake with full force without fear of the wheels locking.

Evaluations of ABS have shown strong benefits for motorcyclists. Closed test track studies have shown that ABS improves the braking performance for both novice and experienced riders (Green, 2006; Vavryn and Winkelbauer, 2004). Other studies reconstructed real-world crashes to determine if ABS may have prevented the crash. Gwehenberger et al. (2006) estimated that approximately half of the crashes studied were relevant to ABS and, of those, between 17 and 38 percent could have been avoided if the motorcycle was equipped with ABS. Rizzi et al. (2009) and Roll et al. (2009) estimated that ABS had the potential to prevent 38 to 50 percent of motorcycle crashes. Teoh (2011, 2013) examined the motorcycle fatal crash rate per registrations for motorcycles with ABS compared with the rate for the same models without ABS. The author's most recent study estimated a statistically significant 31 percent reduction in the fatal crash rate for ABS-equipped motorcycles.

NHTSA (2010) conducted a study of motorcycle ABS effectiveness by defining a group of crashes likely to be affected by ABS. A comparison group comprised of crash types deemed not relevant to ABS was used as an alternative measure of exposure. The agency found that ABS had no statistically significant effect on motorcycle crash risk. However, the agency acknowledged the difficulty in identifying types of crashes for which ABS would not be relevant. Behavioral differences between the ABS and non-ABS groups of riders could also result in differing distributions of crash types causing selection bias.

The Highway Loss Data Institute (HLDI, 2009, 2013) examined the effects of ABS on insurance claim frequency. Its most recent results showed that ABS-equipped motorcycles were associated with a statistically significant 20 percent reduction in collision claims per insured vehicle year compared with the same model motorcycles without ABS. Another HLDI (2012) study found that ABS was more effective during the first 3 months of collision insurance policies. A new policy could represent a first time rider, an experienced rider on a new motorcycle, or a rider who changed their insurance company. Motorcycles with ABS were associated with a 30 percent reduction in collision claim frequency versus the non-ABS versions of the same motorcycle during the first 90 days of the policy. For policies in effect 91-720 days, ABS motorcycles were associated with a 19 percent reduction in collision claim frequency compared with the non-ABS versions.

Although the HLDI studies controlled for rated rider characteristics such as age, gender, marital status, and insurance risk group, one criticism is that there may still be a self-selection bias. People who place a greater value on safety may be more likely to purchase an optional safety feature and to ride in a manner that makes them less likely to crash. If primarily safer riders are the ones purchasing ABS-equipped motorcycles, then it is possible that a portion of the ABS benefit observed in prior research was attributable to safer crash risk.

The purpose of this study was to examine the relationship between ABS and insurance losses under collision coverage while controlling for self-selection. This study controls for the safer rider effect by using a motorcycle rider's available auto claim history as a measure of their crash risk. Doing so separates the effect on motorcycle collision claim frequency due to the ABS technology from that attributable to crash risk.

METHODS

Insurance Data

Automobile insurance covers damage 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 collision coverage. Collision coverage insures against vehicle damage to an at-fault driver's vehicle sustained in a crash with an object or other vehicle; this coverage is common to all 50 states. HLDI has data on the vehicles insured by its member companies including the length of time those vehicles were insured as well as any claims filed for that vehicle under collision coverage. Using this information, HLDI calculates collision claim frequency as the number of collision claims divided by exposure, where exposure is defined as the number of insured vehicle years. One insured vehicle year can represent one motorcycle insured for 1 year, two motorcycles insured for 6 months, etc. HLDI also receives the vehicle identification numbers (VINs) of the vehicles on the insurance policy. The VIN for a motorcycle contains information about the manufacturer, model year, and model type. In some instances, the ABS status of a motorcycle may also be determined from the VIN.

Information about the garaging zip code of the vehicle, deductible amount, and rated rider are also provided. Rated rider characteristics include age, gender, marital status, and insurance risk group. Insurance risk group is a binary variable indicating whether the rated rider is considered to have standard or non-standard insurance risk. The rated rider is the one who typically is considered to represent the greatest loss potential for the insured vehicle. In a household with multiple vehicles and/or riders, the assignment of riders to vehicles can vary by insurance company and by state. The actual rider operating the motorcycle at the time of the claim is unknown.

Motorcycle and Auto Loss Data

The HLDI database does not include a direct link between a given person's auto and motorcycle insurance policies. Therefore, it was necessary to match motorcycle and auto loss data using rated driver characteristics. The following multi-step process was used:

1. Rated rider/driver demographic data was used to create a mapping of a rated motorcycle rider's policy with their corresponding auto policy. An individual rated rider/driver was identified by their insurance company, gender, marital status, year of birth, date of birth, zip code, and state. Full date of birth data for some companies first became available to HLDI beginning in 2011.

2. In total, 505,864 unique combinations of insurance company, gender, marital status, year of birth, date of birth, zip code, and state existed in both auto and motorcycle databases concurrently. Approximately 13 percent of these combinations were associated with multiple auto or multiple motorcycle policies or both and were therefore excluded from the analysis. The remaining 87 percent had a one-to-one mapping of motorcycle and auto policies.

3. Once the mapping of policies was established, the motorcycle and auto loss data associated with the rated rider/driver were linked. Although a rider/driver's full date of birth was initially used to create the policy mappings, full date of birth data were only available beginning in 2011. Therefore, after motorcycle and auto policies were matched, year of birth was used as a substitute to track a rated rider/driver's motorcycle and auto loss data through years preceding 2011.

This procedure resulted in 949,551 years of motorcycle collision exposure and 16,605 motorcycle claims for model years 2003 to 2014, and calendar years 2006 to 2013. This was matched to 1,204,271 years of auto collision exposure and 62,742 auto claims.

Analysis Methods

The observed auto claim frequency for each rider, based on their total available matched auto history, was calculated as the total number of auto claims divided by the total years insured times 100. For example, a rider with one auto claim over 5 years with auto insurance would have an observed auto claim frequency of 1/5 * 100 = 20. The total years insured is the number of years the rider/driver had auto insurance. The observed auto claim frequencies were then categorized, as shown in Table 1.

Table 1.
Categorization of auto claim frequencies.

Category	Auto claim frequency	Description
Zero	0	No auto claims
Low	0-20	An average of between 0 and 1 claims per 5 years insured
Medium	20-40	An average of between 1 and 2 claims per 5 years insured
High	40+	An average of more than 2 claims per 5 years insured

Regression analysis was used to quantify the effect of ABS and/or auto claim frequency on motorcycle collision claim frequency while controlling for other covariates. Covariates included calendar year, vehicle age, garaging state, vehicle density (number of registered vehicles per square mile), rated driver age group, rated driver gender, rated driver marital status, deductible range, and insurance risk group. For analysis including only optional ABS vehicles, make and model was included as a covariate. For analysis including vehicles where ABS is standard or not available, motorcycle class and engine displacement were included as covariates. Claim frequency was modeled using a Poisson distribution using a logarithmic link function.

This study consisted of two main analyses to examine the effect of ABS on motorcycle crashes. The first compared the collision claim frequency of motorcycles with optional ABS to the same year\make\models without. For comparative purposes, the same study vehicles from the HLDI (2013) ABS-only study were chosen for this portion of the analysis. For a motorcycle to be included, its VIN had to have an ABS indicator. Only motorcycles with optional ABS and with loss data for both ABS and non-ABS versions were included. It should be noted that some motorcycles in this study population were also equipped with combined control braking systems (CCBS). However, both the ABS and non-ABS motorcycles had CCBS. Since CCBS was present in both the control and study group for those motorcycles, the estimated effect was for ABS only. Table 2 shows the exposure and percentage of exposure with and without ABS for the 17 models included in this portion of the analysis. In total there were 38,838 years of motorcycle exposure and 622 motorcycle claims, matched with 56,707 years of auto insurance with 2,638 auto claims. The effect of ABS with and without controlling for auto claim frequency was estimated and the results compared.

The second analysis examined a much broader range of motorcycles and included models where ABS was standard or not available, as well as motorcycles where ABS was optional and the presence of ABS was indicated by the VIN. The motorcycles were divided into two groups: with ABS and without ABS. Motorcycles where the ABS status

Table 2.
Distribution of exposure of antilock braking systems for April 2013 study vehicles.

Make/Series	Exposure	Percent ABS	Percent no ABS
Aprilia Scarabeo 500	174	32%	68%
Honda Gold Wing	25,581	23%	77%
Honda Interceptor 800	1,005	29%	71%
Honda Reflex	856	16%	84%
Honda Silver Wing	1,221	20%	80%
Honda ST1300	2,448	31%	69%
Kawasaki Ninja 650	90	36%	64%
Kawasaki Ninja ZX-10R	119	40%	60%
Suzuki Bandit 1250	503	27%	73%
Suzuki Burgman 400	181	42%	58%
Suzuki Burgman 650	1,447	20%	80%
Suzuki V-Strom 650	1,672	30%	70%
Triumph Sprint ST	587	41%	59%
Triumph Thunderbird	477	58%	42%
Triumph Tiger	672	34%	66%
Triumph Tiger 800	310	89%	11%
Yamaha FJR1300	1,496	48%	52%
Total	38,838	26%	74%

was unknown were excluded. Unlike the first analysis, the motorcycle models in the with-ABS and without-ABS groups were not the same. Therefore, in order to control for differences between models, motorcycle class and engine displacement were included as covariates. In addition, while only motorcycles with known ABS status are included in this analysis, the CCBS status is not always known. In the HLDI (2013) study of ABS with CCBS, an extensive review of publically available documentation was conducted on all motorcycles included in the analysis. However, information about the presence of CCBS for some motorcycles is not always available from public sources. This analysis includes more than 630 different motorcycle series over 12 model years. As a result, the effect of ABS in this study may be confounded with CCBS since some of the study motorcycles have ABS only while others may have both ABS and CCBS. Therefore the effect being measured may be attributable to "ABS and ABS/CCBS" as opposed to solely ABS. In addition, some of the motorcycles without ABS may have CCBS. However, this analysis assumes that CCBS in non-ABS motorcycles is a small part of the overall exposure.

Therefore, the second analysis is a less focused examination of the ABS effects but has the advantage of involving much more exposure. The addition of motorcycles with standard and not available ABS resulted in 842,487 years of motorcycle exposure and 14,311 motorcycle claims matched with 1,093,225 years of auto exposure and 57,193 auto claims. This was an increase of more than 21 times the motorcycle exposure of the optional ABS analysis. The effect of ABS and ABS/CCBS is estimated with and without controlling for auto claim frequency and the results compared. Finally, the interaction effect of ABS and ABS/CCBS with auto claim frequency category is also estimated.

RESULTS

Full regression results for the second analysis are shown in the Appendix. To further simplify the presentation here, the exponent of the parameter estimate was calculated, 1 was subtracted, and the result multiplied by 100. The resulting number corresponds to the effect of the feature on that loss measure. For example, the estimate of the effect for ABS and ABS/CCBS on motorcycle collision claim frequency was (-0.3268); thus, collision claim frequency for motorcycles with ABS and ABS/CCBS is expected to be 28 percent lower than for motorcycles without ABS ((exp(-0.3268) -1)*100 = -28).

Figure 1 shows the relationship between auto claim frequency category and motorcycle claim frequency. Riders with higher auto claim frequencies were associated with higher motorcycle claim frequency. The black bars correspond to the 95 percent confidence intervals. Riders in the high auto claim frequency category were associated with a statistically significant 64 percent increase in motorcycle collision claim frequency compared with riders with no history of auto claims. Riders in the medium auto claim frequency category were associated with a statistically significant 18 percent increase, while those categorized as having low auto claim frequency were associated with a 4 percent increase.

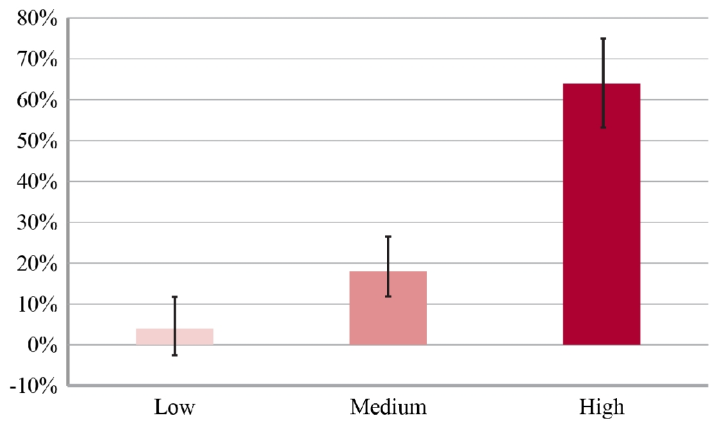

Figure 1. Motorcycle collision claim frequency by auto claim frequency category relative to rider/drivers with no auto claims.

Figures 2 and 3 show the results of the first analysis examining collision claim frequencies for motorcycles equipped with optional ABS relative to the same models without ABS. Figure 2 compares the estimated ABS effect in the present dataset, without controlling for auto claim frequency, with results from the full dataset used in the 2013 HLDI study. The ABS effect is essentially the same in both datasets — a 20 percent reduction in collision claim frequency compared with motorcycles not equipped with ABS.

Given that the ABS effect is present in the matched data set, the effect of additionally controlling for auto claim frequency was then analyzed. Table 3 shows the breakdown of motorcycle exposure with and without ABS by auto claim frequency category. Although the amount of the exposure is small, the percentage of exposure with ABS increases with auto claim frequency; 26 percent of the motorcycle exposure with zero auto claim frequency was for motorcycles with ABS compared with 32 percent of the exposure with high auto claim frequency.

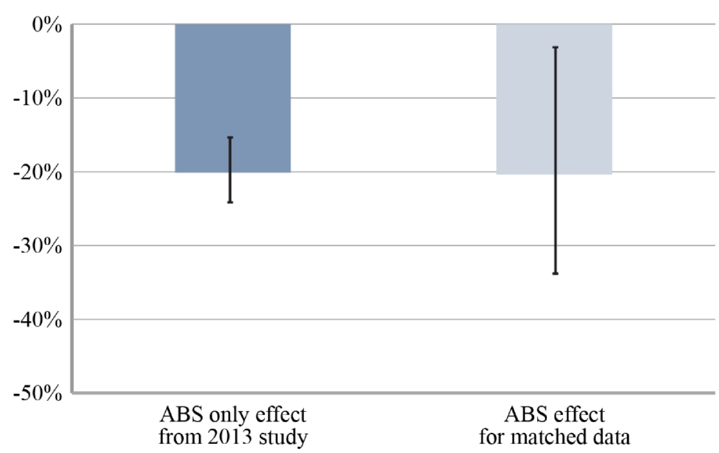

Figure 2. Effect of optional ABS on motorcycle collision claim frequency without regard to auto claim frequency, HLDI (2013) study vehicles

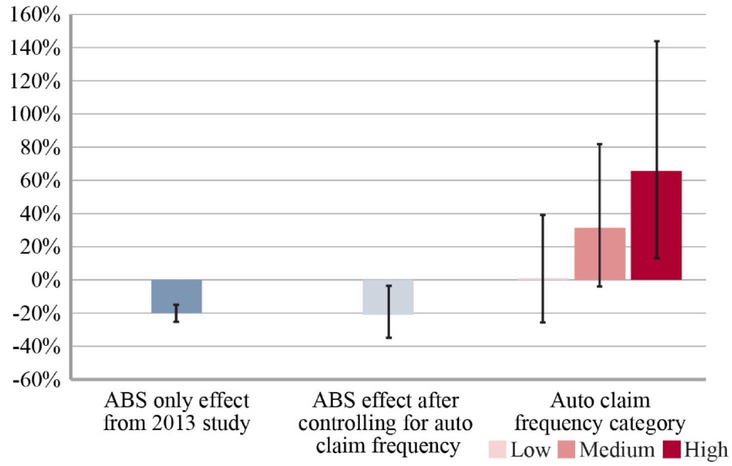

Figure 3. Effect of optional ABS and auto collision claim frequency on motorcycle collision claim frequency, HLDI (2013) study vehicles

Table 3.
Distribution of exposure by auto claim frequency category for April 2013 study vehicles.

Auto claim frequency category	Exposure	Percent ABS	Percent no ABS
Zero	33,279	26%	74%
Low	2,590	28%	72%
Medium	1,949	29%	71%
High	1,021	32%	68%

Figure 3 shows the results when both ABS status and the auto claim frequency categories are added as variables in the regression model. After controlling for auto claim frequency, the reduction in motorcycle collision claim frequency for ABS-equipped motorcycles increases slightly from 20 to 21 percent. Also shown in Figure 3 is the relationship between auto claim frequency category and motorcycle claim frequency using this subset of data. The results are consistent with Figure 1, although the confidence bounds are larger due to the reduced size of the dataset.

Figures 4 and 5 show the results of the second analysis that examines the effect of ABS and ABS/CCBS on motorcycles where ABS is standard or equipped with optional ABS versus motorcycles without ABS. Figure 4 compares the estimated ABS and ABS/CCBS effect in the present dataset, without controlling for auto claim frequency, with results from the 2013 HLDI study. The observed effect of 28 percent for ABS and ABS/CCBS falls between the 2013 study results of 20 percent for ABS only and 31 percent for ABS/CCBS.

Figure 5 shows that after controlling for auto claim frequency, the effect of ABS and ABS/CCBS was also a statistically significant 28 percent. The relationship between auto claim frequency category and motorcycle claim frequency using this subset of data is also shown. Again, the results for auto claim frequency are consistent with Figure 1. Full regression results for this model are shown in the Appendix.

Figure 6 shows the effect of ABS and ABS/CCBS by auto claim frequency category. The effect by auto claim frequency category is fairly consistent. Motorcycles with ABS and ABS/CCBS are associated with a 29 percent reduction in motorcycle claim frequency compared with motorcycles without ABS for riders with no history of auto claims. ABS and ABS/CCBS for riders categorized with a low auto claim frequency was associated with a 24 percent reduction. ABS and ABS/CCBS for riders categorized with medium or high auto claim frequencies was associated with 26 and 25 percent reductions, respectively. The differences between the effects of ABS and ABS/CCBS by rider auto claim frequency was not statistically significant.

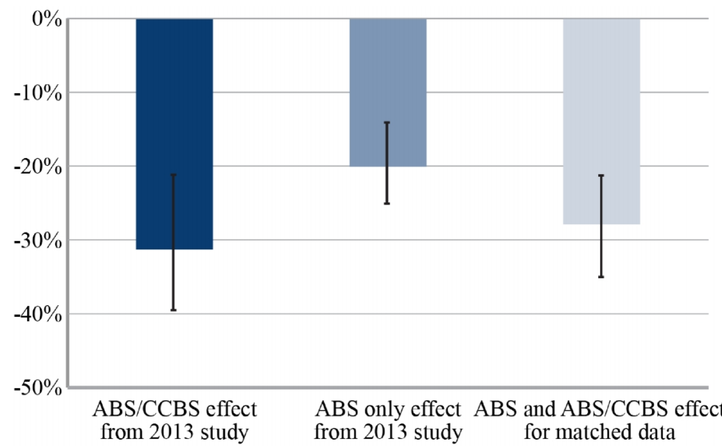

Figure 4. Effect of ABS and ABS/CCBS on motorcycle collision claim frequency, no auto claim frequency

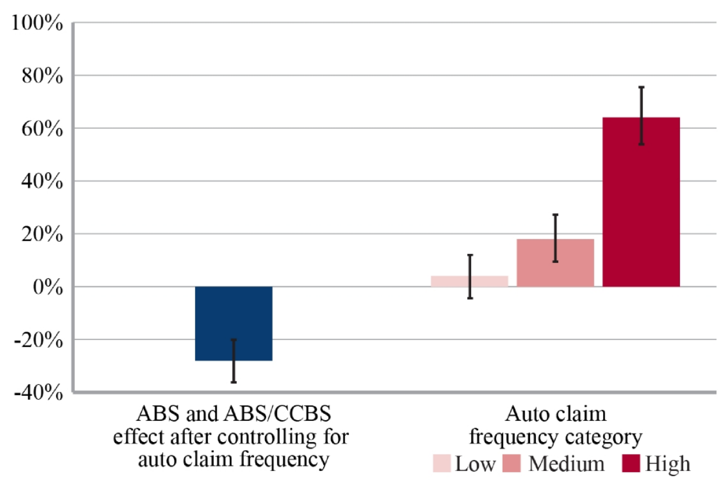

Figure 5. Effect of ABS and ABS/CCBS and auto collision claim frequency on motorcycle collision claim frequency

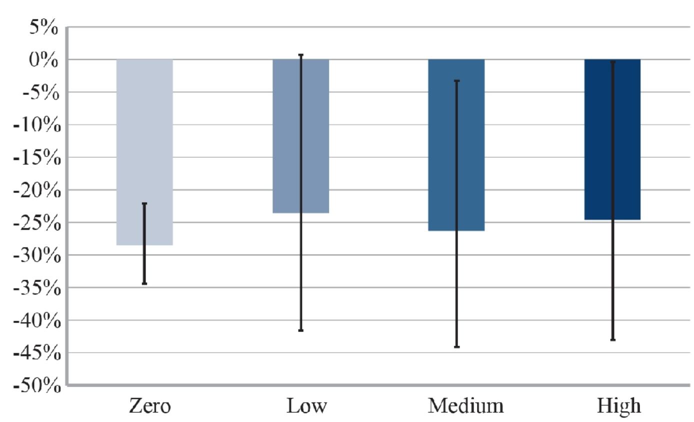

Figure 6. Effect of ABS and ABS/CCBS by auto claim frequency category

DISCUSSION

Prior HLDI studies have shown that ABS on motorcycles is effective in reducing collision losses by 20 percent, and others have shown motorcycle ABS reduces fatal crashes by 31 percent (HLDI, 2013; Teoh, 2013). These studies were criticized because they did not control for the possibility that the crash reductions attributed to ABS were not instead the result of safer riders choosing ABS. The present study addresses this concern by using a rider's auto claim frequency as an independent measure of their crash risk. Regression analysis showed that riders with higher auto claim frequencies were associated with higher motorcycle collision claim frequencies and, after taking this into account, the ABS benefit persists.

European regulators have acted on the strong evidence of the benefits of ABS for motorcycles, Beginning in 2016 in the European Union, ABS will be mandatory for motorcycles that have an engine displacement greater than 125 cc. In contrast, motorcycle ABS is not required in the United States. Despite the lack of a requirement, manufacturers have taken the initiative to increase the availability of ABS on new motorcycles in the United States during the past few years.

Figure 7 shows the increase in ABS availability by model year as indicated in motorcycle VINs process by HLDI, which represents a large sample of the registered fleet. More than 90 percent of 2002 model year bikes were not available with ABS. In contrast, more than two-thirds of new bikes in the 2013 model year have either standard (22 percent) or optional (46 percent) ABS. Moreover, manufacturers such as BMW, KTM, and Ducati have begun fitting stability controls systems that promise to prevent even more loss of control crashes among motorcycles (Bosch, 2014)

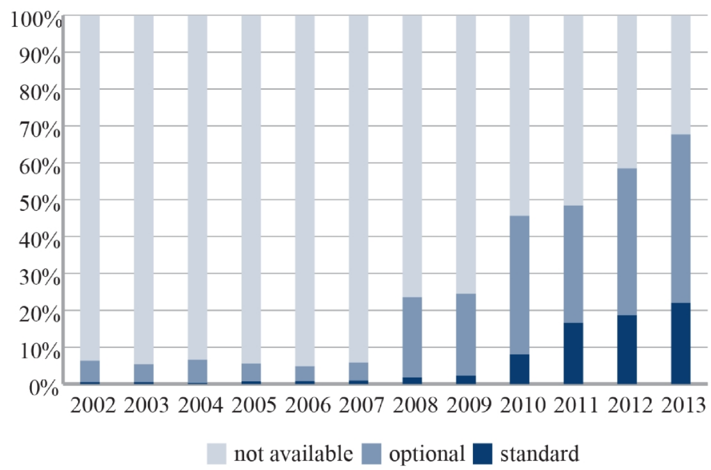

Figure 7. Motorcycle ABS availability by model year

Limitations

There are limitations on the data used in this analysis. Using auto claim frequency as a covariate in the regression required matching data from two separate databases using demographic data. Although there is no way to be absolutely certain that a matched rider/driver is the same person, using the full date of birth, zip code, gender, and marital status limit the likelihood of erroneous matches. It is also possible that a particular person would have their auto and motorcycle policies with different companies. These individuals would be excluded from the analysis. In addition, motorcycle riders who do not have an auto policy would also be excluded from this analysis. It is unknown whether there are significant differences between riders who also have an auto policy and those with just a motorcycle policy.

REFERENCES

Association of European Motorcycle Manufacturers. 2004. MAIDS In-depth investigations of accidents involving powered two wheelers. Final report 1.2. Brussels, Belgium.

Bosch. 2014. MSC motorcycle stability control for all classes of bike. Mobility Solutions, Press Release. EICMA International Motorcycle Show 2014. Stuttgart, Germany. Retrieved from http://www.bosch-presse.de/presseforum/details.htm?txtID=7020&tk_id=108

Green D. 2006. A comparison of stopping distance performance for motorcycles equipped with ABS, CBS, and conventional hydraulic brake systems. Paper presented at the 2006 International Motorcycle Safety Conference, March 28-38, Long Beach, CA.

Gwehenberger J, Schwaben I, Sporner A, Kubitzki J. 2006. Schwerstunfälle mit Motorrädern – Analyse der Unfallstruktur und der Wirksamkeit von ABS. VKU Verkehrsunfall und Fahrzeugtechnik, Issue 1. Springer Automotive Media/GWV Fachverlage GmbH.

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

Highway Loss Data Institute. 2012. Motorcycle ABS and time to claim. *HLDI Bulletin* 29(4). Arlington, VA.

Highway Loss Data Institute. 2013. Evaluation of motorcycle antilock braking systems, alone and in conjunction with combined control braking systems. *HLDI Bulletin* 30(10). Arlington, VA.

Hurt HH, Ouellet JV, Thom DR. 1981. Motorcycle accident cause factors and identification of countermeasures; Volume 1: Technical report, Final report. Washington, DC: U.S. Department of Transportation.

Motorcycle Industry Council. 2011. Statistical annual. Irvine, CA.

National Highway Traffic Safety Administration. 2005. Without motorcycle helmets we all pay the price. Washington, DC: U.S. Department of Transportation.

National Highway Traffic Safety Administration. 2010. Motorcycle antilock braking systems and crash risk estimated from case-control comparisons. Submitted to Docket No. NHTSA-2002-11950. Washington, DC: U.S. Department of Transportation.

National Highway Traffic Safety Administration. 2012. Traffic safety facts, 2010. Report no. DOT HS-811-659. Washington, DC: U.S. Department of Transportation.

Rizzi M, Strandroth J, Tingball C. 2009. The effectiveness of antilock brake systems on motorcycles in reducing real-life crashes and injuries. *Traffic Injury Prevention* 10:479-87

Roll G, Hoffman O, König J. 2009. Effectiveness of antilock brake systems (ABS) for motorcycles in real-world accident scenarios. *Proceedings of the 21st International Technical Conference on the Enhanced Safety of Vehicles* (CD-ROM). Washington, DC: National Highway Traffic Safety Administration.

Teoh ER. 2011. Effectiveness of antilock braking systems in reducing motorcycle fatal crash rates. *Traffic Injury Prevention*. 12:169-73

Teoh ER. 2013. Effects of antilock braking systems on motorcycle fatal crash rates: an update. Insurance Institute for Highway Safety, Arlington, VA.

Vavryn K, Winkelbauer M. 2006. Braking performance of experienced and novice motorcycle rides: results of a field study. Paper presented at the 2004 International Conference on Transport and Traffic Psychology, Nottingham, United Kingdom.

APPENDIX

Table A1
Illustrative regression results: Collision claim frequency
for motorcycles with and without ABS or ABS/CCBS.

Parameter	Degrees of freedom	Estimate	Effect	Standard error	Wald 95% confidence limits		Chi-square	p-value
Intercept	1	-9.2916		0.4588	-10.1908	-8.3925	410.22	<0.0001
Calendar Year								
2006	1	-0.3742	-31.2%	0.0961	-0.5626	-0.1857	15.15	<0.0001
2007	1	-0.4147	-33.9%	0.0571	-0.5266	-0.3029	52.83	<0.0001
2008	1	-0.4572	-36.7%	0.0428	-0.5412	-0.3732	113.87	<0.0001
2009	1	-0.5816	-44.1%	0.0389	-0.6578	-0.5053	223.49	<0.0001
2010	1	-0.5634	-43.1%	0.0332	-0.6285	-0.4982	287.54	<0.0001
2011	1	-0.3190	-27.3%	0.0249	-0.3679	-0.2701	163.45	<0.0001
2012	1	-0.2549	-22.5%	0.0230	-0.3001	-0.2098	122.37	<0.0001
2013	0	0	0	0	0	0		
Vehicle age	1	-0.1087	-10.3%	0.0038	-0.1161	-0.1013	825.01	<0.0001
Rated driver age								
14-24	1	0.9486	158.2%	0.0545	0.8417	1.0554	302.84	<0.0001
25-39	1	0.3173	37.3%	0.0383	0.2422	0.3923	68.65	<0.0001
40-64	1	0.0105	1.1%	0.0347	-0.0575	0.0784	0.09	0.7629
65+	0	0	0	0	0	0		
Gender								
Female	1	-0.1211	-11.4%	0.0266	-0.1732	-0.0691	20.79	<0.0001
Male	0	0	0	0	0	0		
Marital status								
Married	1	-0.1211	-11.4%	0.0978	-0.3128	0.0706	1.53	0.2158
Single	1	0.0231	2.3%	0.0988	-0.1706	0.2168	0.05	0.8152
Unknown	0	0	0	0	0	0		
State								
Alabama	1	0.3570	42.9%	0.1816	0.0011	0.7130	3.86	0.0493
Arizona	1	0.4653	59.2%	0.1771	0.1182	0.8125	6.90	0.0086
Arkansas	1	0.2089	23.2%	0.1995	-0.1820	0.5999	1.10	0.2949
California	1	0.4862	62.6%	0.1724	0.1484	0.8240	7.96	0.0048
Colorado	1	0.2029	22.5%	0.1782	-0.1463	0.5521	1.30	0.2548
Connecticut	1	0.2198	24.6%	0.1846	-0.1420	0.5817	1.42	0.2337
Delaware	1	0.8593	136.2%	0.3354	0.2018	1.5167	6.56	0.0104
District of Columbia	1	0.6508	91.7%	0.2285	0.2031	1.0986	8.12	0.0044
Florida	1	0.1984	21.9%	0.1726	-0.1398	0.5366	1.32	0.2502
Georgia	1	0.3296	39.0%	0.1762	-0.0157	0.6748	3.50	0.0614
Hawaii	1	0.2810	32.4%	0.2000	-0.1111	0.6730	1.97	0.1601
Idaho	1	0.1199	12.7%	0.2018	-0.2757	0.5155	0.35	0.5525
Illinois	1	0.0813	8.5%	0.1768	-0.2653	0.4279	0.21	0.6457
Indiana	1	0.2783	32.1%	0.1842	-0.0829	0.6394	2.28	0.1310
Iowa	1	-0.0066	-0.7%	0.1868	-0.3727	0.3594	0.00	0.9717
Kansas	1	0.1217	12.9%	0.1895	-0.2498	0.4931	0.41	0.5209
Kentucky	1	0.3797	46.2%	0.1978	-0.0080	0.7674	3.68	0.0549
Louisiana	1	0.4134	51.2%	0.1817	0.0573	0.7695	5.18	0.0229
Maine	1	0.3473	41.5%	0.2226	-0.0890	0.7836	2.43	0.1187

Parameter	Degrees of freedom	Estimate	Effect	Standard error	Wald 95% confidence limits		Chi-square	p-value
Maryland	1	0.3205	37.8%	0.1769	-0.0262	0.6673	3.28	0.0700
Michigan	1	0.3058	35.8%	0.1845	-0.0558	0.6674	2.75	0.0974
Minnesota	1	0.0431	4.4%	0.1875	-0.3243	0.4105	0.05	0.8181
Mississippi	1	0.2709	31.1%	0.2041	-0.1292	0.6710	1.76	0.1845
Missouri	1	0.2400	27.1%	0.1890	-0.1304	0.6105	1.61	0.2040
Montana	1	-0.1582	-14.6%	0.3089	-0.7637	0.4472	0.26	0.6085
Nebraska	1	0.0666	6.9%	0.1946	-0.3147	0.4479	0.12	0.7322
Nevada	1	0.6364	89.0%	0.1901	0.2639	1.0090	11.21	0.0008
New Hampshire	1	0.2025	22.4%	0.2255	-0.2395	0.6446	0.81	0.3691
New Jersey	1	0.1643	17.9%	0.1879	-0.2039	0.5325	0.76	0.3818
New Mexico	1	0.2884	33.4%	0.1846	-0.0735	0.6502	2.44	0.1183
New York	1	0.3641	43.9%	0.1733	0.0243	0.7038	4.41	0.0357
North Carolina	1	0.2203	24.6%	0.1785	-0.1295	0.5701	1.52	0.2171
North Dakota	1	0.1481	16.0%	0.3090	-0.4575	0.7536	0.23	0.6318
Ohio	1	0.0211	2.1%	0.1763	-0.3245	0.3667	0.01	0.9046
Oklahoma	1	0.2389	27.0%	0.1851	-0.1238	0.6016	1.67	0.1968
Oregon	1	0.3714	45.0%	0.1877	0.0035	0.7394	3.92	0.0478
Pennsylvania	1	0.2132	23.8%	0.1760	-0.1318	0.5582	1.47	0.2258
Rhode Island	1	0.1529	16.5%	0.2267	-0.2914	0.5973	0.46	0.4999
South Carolina	1	0.2064	22.9%	0.1838	-0.1538	0.5667	1.26	0.2614
South Dakota	1	0.0033	0.3%	0.2620	-0.5102	0.5169	0.00	0.9898
Tennessee	1	0.3529	42.3%	0.1738	0.0122	0.6935	4.12	0.0423
Texas	1	0.3324	39.4%	0.1729	-0.0064	0.6713	3.70	0.0545
Utah	1	-0.0321	-3.2%	0.1852	-0.3951	0.3309	0.03	0.8623
Vermont	1	-0.0052	-0.5%	0.2690	-0.5324	0.5220	0.00	0.9845
Virginia	1	0.2582	29.5%	0.1750	-0.0847	0.6012	2.18	0.1400
Washington	1	0.3058	35.8%	0.1786	-0.0443	0.6558	2.93	0.0869
West Virginia	1	-0.0597	-5.8%	0.2119	-0.4749	0.3556	0.08	0.7781
Wisconsin	1	0.0623	6.4%	0.1917	-0.3135	0.4380	0.11	0.7453
Wyoming	1	0.2364	26.7%	0.2433	-0.2404	0.7132	0.94	0.3313
Alaska	0	0	0	0	0	0		
Density								
<50	1	-0.4348	-35.3%	0.0380	-0.5092	-0.3603	130.95	<0.0001
50-99	1	-0.3254	-27.8%	0.0322	-0.3884	-0.2624	102.39	<0.0001
100-249	1	-0.2349	-20.9%	0.0277	-0.2892	-0.1806	71.87	<0.0001
250-499	1	-0.2269	-20.3%	0.0274	-0.2806	-0.1732	68.59	<0.0001
599-999	1	-0.1463	-13.6%	0.0277	-0.2006	-0.0920	27.86	<0.0001
>999	0	0	0	0	0	0		
Risk								
Nonstandard	1	0.0509	5.2%	0.0202	0.0112	0.0905	6.32	0.0119
Standard	0	0	0	0	0	0		
Deductible range								
0	1	-0.2403	-21.4%	0.4516	-1.1254	0.6447	0.28	0.5946
1-50	1	0.6109	84.2%	0.4142	-0.2009	1.4228	2.18	0.1402
51-100	1	-0.2555	-22.5%	0.4096	-1.0583	0.5472	0.39	0.5327
101-200	1	-0.1534	-14.2%	0.4106	-0.9581	0.6513	0.14	0.7087
201-250	1	-0.0151	-1.5%	0.4090	-0.8167	0.7865	0.00	0.9706

Parameter	Degrees of freedom	Estimate	Effect	Standard error	Wald 95% confidence limits		Chi-square	p-value
251-500	1	-0.1875	-17.1%	0.4087	-0.9884	0.6135	0.21	0.6464
501-1000	1	-0.5987	-45.0%	0.4102	-1.4028	0.2053	2.13	0.1444
>1000	0	0	0	0	0	0		
Motorcycle class								
Chopper	1	-0.8309	-56.4%	0.1007	-1.0283	-0.6335	68.07	<0.0001
Cruiser	1	-0.5776	-43.9%	0.0505	-0.6765	-0.4786	130.85	<0.0001
Dual purpose	1	-1.0269	-64.2%	0.0777	-1.1792	-0.8747	174.73	<0.0001
Scooter	1	-0.2698	-23.6%	0.0674	-0.4018	-0.1377	16.03	<0.0001
Sport	1	0.2885	33.4%	0.0584	0.1740	0.4030	24.39	<0.0001
Sport touring	1	-0.1931	-17.6%	0.0759	-0.3419	-0.0442	6.46	0.0110
Standard	1	-0.2881	-25.0%	0.0841	-0.4529	-0.1233	11.74	0.0006
Super sport	1	0.5819	78.9%	0.0535	0.4771	0.6868	118.31	<0.0001
Touring	1	-0.4736	-37.7%	0.0553	-0.5820	-0.3651	73.27	<0.0001
Unclad sport	0	0	0	0	0	0		
Engine displacement	1	0.0004	0.0%	0.0000	0.0004	0.0005	235.58	<0.0001
Auto claim frequency category								
Low	1	0.0358	3.6%	0.0377	-0.0381	0.1098	0.90	0.3422
Medium	1	0.1661	18.1%	0.0349	0.0976	0.2345	22.63	<0.0001
High	1	0.4975	64.5%	0.0358	0.4272	0.5677	192.65	<0.0001
Zero	0	0	0	0	0	0		
ABS and ABS/CCBS								
Equipped	1	-0.3268	-27.9%	0.0421	-0.4092	-0.2444	60.38	<0.0001
Not equipped	0	0	0	0	0	0		