Review of Helmet and Helmet Law Effectiveness Studies

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I. Helmet Effectiveness Studies based on Variants of Correlation Analysis Which Support Motorcycle Helmet Effectiveness

Introduction

There are two types of studies in this category: (1) before-after helmet law repeal studies, and (2) accident victim studies. The former tests the difference between death rates, injury rates' location rates of injuries, and severity rates of particular types of injuries (for all accidents occurring in a particular geographic region) for a similar period of time before and after helmet law repeal (Dare et al., 1979; McSwain and Lummis, 1980). The latter test the difference between these same rates for helmeted and non-helmeted accident victims (for a sample of all accidents during a single time period) in a geographic locale that does not have a mandatory helmet use law (Chang, 1981: Dare et al., 1979; Heilman et al., 1982; Hurt et al. F 1981; Kraus et al., 1975; Luna et al., 1981; Scott 1983). In each case statistically significant differences are attributed to helmet use or non-use. Typical results associated with this literature are death and injury rates two to three times greater for non- helmeted accident victims and increases in occurrence rates (death and injury) in repeal years that range from 19% to 63%. Typical conclusions are that the non-use of a helmet are responsible for these differences: helmet use is effective in the reduction of death and injury.

The major limitation of these studies is the use of some variant of correlation analysis as a statistical methodology. In general' correlation analysis cannot be used to establish a causal mechanism between any two variables (i.e. helmets and injury). **This limitation of correlation analysis is universally recognized and is not disputed.** The fatal flaw in correlation analysis is its inability to control for **all relevant factors** that could be responsible for movements or changes in a targeted (dependent variable) variable such as death or injury. Failure to control for all such factors implies that a third (uncontrolled for) factor could be responsible for the movements in one or both of the correlated variables. Thus' the effects of a third factor could erroneously be assigned to one of the two correlated variables implying that the "causal" effect of that variable is either over or understated.

In accident studies, the uncontrolled factor is the difference in risk aversion between helmeted and non- helmeted riders. non-helmeted riders are inherently more risky implying that on average they are more likely to have higher speeds, crash speeds and alcohol consumption (see Goldstein 1985) for statistical evidence). Given that speed and alcohol are major determinants of death and injury in motorcycle accidents, the failure of correlation analysis to control for these differences implies that the death and injury inducing effect of higher speed and alcohol levels will be inappropriately assigned to the non- use of a helmet. **Thus, helmet effectiveness is systematically overstated by these types of studies.**

The before-after designs fail to control for time as a third factor. Dramatic time trends towards (1) lower median age and experience of motorcycle owners , (2) higher average annual miles traveled, (3) higher displacement machines, and (4) less strict enforcement of federally mandated speed limits are not controlled for. Given that most before-after studies are done during a period when these injury and death inducing trends are dramatically increasing, these studies erroneously assign these time related increases in death and injury to the repeal of helmet laws which occur concurrently with these other trends. **Thus, before-after studies systematically overstate the effectiveness of mandatory helmet use laws.**

The most commonly used statistical methodology that can potentially avoid the methodological flaws inherent in correlation analysis is regression analysis. Unfortunately regression analysis is not a panacea for the problems of correlation analysis. Regression equations must be carefully specified in order to avoid specification bias which could lead to the systematic over or understatement of helmet effectiveness. Regression studies are analyzed below in **Section III**.

In the reviews that follow references will be made to the concepts developed in this introduction.

1. Hurt, H. H., Jr., Ouellet, J. V., and Thom, D. R. (1981, January) Motorcycle Accident Cause Factors and Identification of Countermeasures, Volume I: Technical Report, Volume II: Appendix/ Supplemental Data, Contract DOT HS-5-01160. NHTSA, Washington, DC.

The "Hurt Study", a two-volume' 829 page report for the National Highway Traffic Safety Administration (NHTSA) based on a $501,814 grant, is the most widely referenced study on motorcycle accidents and motorcycle safety issues. This accident victim study is based on data from the on-scene, in-depth investigation of 900 motorcycle accidents in the Los Angeles area for which 1,045 pieces of information (variables) where collected for each accident. The most important contribution of this study is its data collection. **This study provides the best and most comprehensive set of data on motorcycle accidents available in the world.** The quality and detail of the data, compared to typical accident reports, was enhanced through the use of an on-scene multi-disciplinary research team that collected more complete and accurate accident reconstruction, engineering, medical, environmental, protection system, and operator and passenger information.

The main weakness of the study is its statistical methodology. Comparisons of statistical frequencies for helmeted and non helmeted riders and cross tabulations, both forms of correlation analysis (criticized in above introduction), are the statistical techniques used to establish "causal" relations. The Hurt study's findings on protective equipment are that "the only significant protective equipment is the qualified safety helmet, and it is capable of a spectacular reduction of head injury frequency and severity." In particular, helmeted riders (1) show significantly lower injury frequency in all types of lesions -- helmeted riders comprised 39.4% of the sample and experienced 22.8% of all head and neck injuries; (2) show significantly lower injury frequency at all levels of injury severity; (3) are more likely to have no head or neck injuries; and (4) are less likely to experience severe F critical and clearly fatal head and neck injuries. While the Hurt study recognizes the theoretical possibility for helmets to cause neck injuries (p. 292), the findings indicate that "there is no world- shaking advantage or disadvantage of motorcycle helmet use in relation to neck injury."

The study also recognizes (p. 281) that extreme accident conditions present a formidable problem for head protection by helmets. Thus, practical limitations exist. Other main findings of the study are that the main causes of accidents and injury are: (1) lack of caution and awareness of involved automobile drivers; (2) lack of motorcycle conspicuity; (3) lack of operator skill; and (4) crash speed. The best countermeasures proposed are: (1) motorcycle training; (2) better licensing procedures; (3) use of safety helmets; (4) use of eye protection; (5) use of headlamps during daytime; and (5) use of bright upper torso garments.

The statistical methodology employed in this study systematically overstates the effectiveness of helmets (see introduction). Thus, this study does not provide any scientifically valid evidence in favor of motorcycle helmet effectiveness. **An alternative study (Goldstein 1986, 1988) that uses the Hurt data and controls for the uncontrolled factors in the Hurt study finds dramatically different results concerning helmet effectiveness.**

2. McSwain, N.E., and Lummis, M. (1980) "Impact of Repeal of Motorcycle Helmet Law." Surgery, Gynecology, and Obstetrics 151: 215-24. This study was supported by the Federal Department of Transportation: Contract No. DOT-HS- 7-01563.

This paper conducts both a before-after study for the State of Kansas using data from 1975 and 1976 and an accident victim study Limited to three primary population centers in the state. The study finds: (1) a 19.4% increase in the crude accident rate (accidents/ 1,000 registrations) from 12.8 to 15.3; (2) a 63.3% increase in the crude fatality rate (fatalities per 1,000 accidents) from 15.0 to 24.5; (3) a 95% increase in fatalities per 100,000 registrations from 19.2 to 37.5; (4) a 333% greater fatality per 1,000 occupants for non helmeted riders; and (5) a 51% increase in head injuries per 1,000 accidents after helmet law repeal. The accident victim study found: (1) a 25% greater injuries per 1,000 accident victims; (2) a 35% higher general body injury rate; (3) a 106% greater head injury rate; and (4) a 67% increase in head injury severity for non helmeted riders. The study also finds that fewer neck injuries are associated with helmet use. The study concludes that significant differences in death and injury rates based on helmet use imply that mandatory helmet legislation significantly reduces death and disability.

The statistical methodology is based on the comparison of before-after and helmeted-non helmeted rates, a form of correlation analysis. The accident victim study is subject to the above discussed criticism. In addition, the inability to explain why non helmeted riders have 35% more general body injuries highlights that the more risky behavior of this group of riders has not been controlled for by the simple correlation analysis. The before-after comparisons fail to control for the time trends discussed above and the dramatic change in economic conditions from the 1975 recession to the 1976 recovery which affect riding patterns. In particular, the inability to explain a 19.5% increase in the accident rate highlights these limitations.

3. Dare, C. E., Owens, J.C., and Krane, S. (1979) "Effect of Motorcycle Safety Helmet Use on Injury Location and Severity: Before-and-After Helmet Law Repeal in Colorado".

This paper conducts both a before-after helmet law repeal study (1976-1977) and an accident victim study to determine the effect of helmet usage on the location, number , and severity of motorcycle injuries. The before- after study finds: (1) a 48% increase in total accidents; and (2) a 140% increase in the number of fatalities. The accident victim study finds: (1) an increase in the number of injuries at all levels of injury severities except the most minor types of injury; (2) a fatality rate 2.2 times greater; (3) a critical injury rate 3.3 times greater; and (4) a head injury rate that is 2.6 times greater for non helmeted riders. In addition the study shows that the rate of the **most severe neck injury decreased slightly for non helmeted riders but, non helmeted riders had a neck injury rate (for all neck injuries) 1.3 times greater than helmeted riders.** It is also found that non helmeted riders are over represented in accidents.

The statistical methodology employed is the same as other studies in this category. Failure to explain the 48% increase in total accidents suggests that all relevant trends in the post-repeal period have not been controlled for and failure to explain the over representation of non helmeted riders in accidents implies that the inherently more risky behavior of this group of riders has not been considered. Thus overstated estimates of helmet effectiveness result.

4. Kraus, J. F., Riggins, R. S., and Franti, C. E. (1975). "Some Epidemiologic Features of Motorcycle Collision Injuries." American Journal of Epidemiology, 102:99-109.

This accident victim study (Sacramento County, California) establishes the major factors associated with motorcycle injuries and the severity of such injuries. Findings include: (1) the severity of injury is positively related to age; (2) the frequency of serious head injuries was highest for non helmeted drivers -- 14.1% of helmeted riders compared to 22.8% of non helmeted riders had serious head injuries; and (3) the severity of injury is positively related to crash speed -- serious injuries increased when crash speeds exceeded 48/km/hr. This study is good for isolating potential factors (age, speed, helmet use) which should be included in an (regression) analysis that controls for all factors associated with motorcycle injuries. The study, because of its correlation methodology , is not capable of isolating the individual effect of helmets in reducing injuries. Thus, the author's conclusion that mandatory helmet laws are effective for reducing fatalities and injuries is not scientifically supported.

5. Heilman, D. R., Weisbuch, J. B., Blair, R. W., and Graf, L. L. (19821. "Motorcycle-Related Trauma and Helmet Usage in North Dakota." Annuals of Emergency Medicine, 11:659-664.

This accident victim study (North Dakota) uses comparative frequencies and cross tabulations to find that helmetless riders: (1) suffer head, neck and face injuries at a rate 2.3 greater; (2) sustain 3.19 times more fatalities and 2.83 more life threatening injuries; and (3) have more injuries and more severe injuries than helmeted riders. Quoting other studies from Maryland and Colorado, the study addresses the costs to society: the average medical costs without doctor's fees of a motorcycle accident is estimated to be $11,038 and 53.7% of those costs are paid by the taxpayer. **The study also recognizes that non helmeted riders are over represented in accidents and that 50% of crash victims didn't have a valid license to operate a motorcycle. The Hurt study has similar findings on over representation and the unlicensed driver Problem.** Policy recommendations include mandatory helmet use and stricter licensing requirements and enforcement. On the basis of its flawed statistical methodology, this study inappropriately concludes that helmets are effective and inappropriately infers that the costs to society could be reduced by the imposition of a helmet law.

6. Luna, G. K., Copass, M. K., Oreskovich, M. R., and Carrico, C. J. (1981). "The Role of Helmets in Reducing Head Injuries from Motorcycle Accidents: A Political or Medical Issue?" The Western Journal of Medicine, 135:89-92.

This accident victim study (Seattle) finds: (1) **the death rate for helmeted and non helmeted was not significantly different**; (2) helmeted and unhelmeted fatal accident victims had statistically identical total severity scores; (3) the chance of sustaining a severe head injury was significantly higher for non helmeted riders -- 82% of such injuries were sustained by unhelmeted riders; and (4) the incidence of long-term neurological damage from severe head injury was three times greater for non helmeted riders. While this study supports typical findings on head injury severity for non helmeted riders, it does contradict the findings of earlier studies on a three times -greater incidence of sustaining a fatal injury for non helmeted riders. The statistical methodology of this study -- frequency comparisons -is subject to the same criticisms discussed above.

II. Helmet Effectiveness Studies Based on Variants of Correlation Analysis Which Partially or Fully Contradict the Effectiveness of Helmets

1. Luna, G. K., Copass, M. K., Oreskovich, M. R., and Carrico, C. J. (1981). "The Role of Helmets in Reducing Head Injuries from Motorcycle Accidents: A Political or Medical Issue?" The Western Journal of Medicine, 135:89-92.

This study, discussed above, finds no statistically significant difference in the death rate and total severity of all injuries sustained by helmeted and non helmeted fatal accident victims. Once again , the statistical methodology used to derive these results is subject to the same criticisms discussed above. This result is substantiated (for accident victims and state fatality rates in Goldstein (1985 , 1986 , 1988). The statistical methodology employed in these latter studies is regression analysis and given the careful specification of the regression equation does not suffer from any type of statistical bias.

2. Hart, D. N. J., Cotter, P. W., and MacBeth, W. A. A. G. (1975). "Christchurch Traffic Trauma Survey: Part 2, Victims and Statistics," The New Zealand Medical Journal, 81:542, June.

This accident victim study (New Zealand) finds that: (1) non helmeted riders are over represented in motorcycle accidents; and (2) the use of crash helmets did not significantly reduce the severity and the number of head injuries -- the slight reduction in the number of head injuries for helmeted riders was not statistically significant. The methodology of this study is subject to the same criticisms discussed above. In addition, the result concerning no significant reduction in the severity of head injuries was not formally reported and thus is suspect. No other study tends to support the result that helmets do not prevent head injuries. The over representation result lends further support to the lack of controls for the more risky behavior of non helmeted found in all studies that rely on correlation analysis.

3. New York State, Department of Motor Vehicles. (1969). An Evaluation of Motor Vehicle Accidents Involving Motorcycles - Severity, Characteristics, Effects of Safety Regulation, Research Report No. 1969-12.

This before-after study finds: (1) a 39% decrease in the total number of motorcycle accidents; (2) a 40% reduction in the number of fatalities; and (3) a reduction in the number of fatal head injuries from 75.4% to 45.9% of all fatalities; and (4) **an increase in the number of fatal neck injuries from 5.8% to 37.8% of all fatalities as a result of the helmet law enacted in 1967.** Results (3) and (4) support the head-neck injury tradeoff result found in the regression analysis used by Goldstein (1986, 1988). While the results of the NYS Study are subject to the same criticisms of correlation studies advanced above, the neck injury result in Goldstein is based on a sound statistical specification that avoids potential sources of statistical bias.

4. Mackenzie , A. R. "Accident and Fatality Rate Data" unpublished.

Dr. MacKenzie uses standard fatality, accident, and registration data and shows that **the average accident and fatality rates per million registrations is higher in helmet states** than in repeal (non helmet) states for 1985 and for the nine years ending in 1985. He concludes that states without helmet laws are safer. These simple rate comparisons are subject to the criticisms of correlation analysis advanced above.

5. Dare, C. E., Owens, J. C., and Krane, S. (1979). "Effect of Motorcycle Safety Helmet Use on Injury Location and Severity: Before-and-After Helmet Law Repeal in Colorado."

As discussed above, this study finds that **the rate of the most severe neck injuries increased slightly for helmeted riders.** The statistical methodology employed is subject to the same criticisms advanced above.

III. Helmet Effectiveness Studies Using Regression Analysis Introduction

These studies use regression analysis -- a statistical technique that isolates the individual effect of each systematic determinant (independent variables) of a particular subject (dependent variable) -- to analyze motorcycle fatalities and fatality rates. With the exception of Goldstein (1986) who analyses accident victim data (Hurt data), regression studies have been confined to an analysis of the determinants of total motorcycle fatalities for the 50 states (Prinzinger (1982), deWolfe (1986), Watson et al. (1980) and Graham and Lee (1986). These studies focus on the effect of mandatory helmet use laws and typically find a 10%-38% increase in the fatality rate resulting from the repeal of a helmet law.

While regression analysis is a potentially superior statistical technique, it is not a panacea for the statistical deficiencies of correlation analysis. Unlike simpler techniques, regression analysis must be carefully implemented in order to derive more reliable (unbiased) statistical estimates. Failure to correctly specify (include all relevant (determinants) independent variables) in the regression equation can result in statistical estimates that are biased and thus unreliable. Thus, it is essential that all relevant factors are controlled for in the regression equation specification.

The studies reviewed all suffer from serious misspecification problems that lead to estimates of motorcycle helmet law effectiveness that are systematically overstated (biased upward). Goldstein (1985) proves theoretically that the Hatson et al. (1980) methodology

produces upwardly biased estimates of helmet effectiveness and proves empirically that Prinzinger's (1982) estimates are also upwardly biased. The criticism of the Prinzinger study also apply to the deWolf (1986) and Graham and Lee (1986) studies.

1. Prinzinger, J. M. (1982). "The Effect of the Repeal of Helmet Use Laws on Motorcycle Fatalities." Atlantic Economic Journal, 10:36-39.

This regression study explains the variation in the motorcycle fatality rate per capita (fatalities/population) across the 50 states by variations in: (1) helmet law status (law/no law); (2) alcohol consumption per capita; (3) personal income per capita; (4) the ratio of the number of males age 15-34 to the number of males age 35-65; (5) the average speed; and (6) a congestion index for each state. A separate equation is estimated for each year between 1975 and 1978. The study concludes that (1) a positive and statistically significant relation exists between alcohol consumption and fatalities; and (2) a negative relation exists between helmet use laws and fatalities -mandatory use laws reduce fatalities per capita by 25%.

In Goldstein (1985) it is shown that Prinzinger's use of fatalities/population rather than the more typical fatalities/ registrations results in a misspecification of the regression model and in estimates of helmet law effectiveness that are biased upward. Correcting for this misspecification, Goldstein (1985) shows that mandatory helmet use laws have no statistically significant effect on the number of fatalities and/or the fatalities per registration.

2. deWolfe, V. A (1986). "The Effect of Helmet Law Repeal on Motorcycle Fatalities." Contract DOT HS-807-065. NHTSA, Washington, DC.

This regression study cites problems in the consistency of the measured data across states to justify an alternative regression equation specification.

In this study both the specification of the equation (independent variables) and the dependent variable are different -- fatalities/ accident is used. deWolf explains variations in this fatality rate across the 50 states for the years 1975-1984 by variations in: (1) helmet law status (law/no law); (2) the number of motorcycle registrations; (3) 49 state "dummy" variables; and (4) 9 year "dummy" variables. Here the registration variable is used as a "proxy for economic conditions" and the state and time "dummy" variables are used to capture all other factors (i.e. the variables that affect fatalities but are not consistently measured across states). The state dummies "control" for how these factors vary across states in a given time period and the year dummies "control" for how these factors vary across time for all states. The study concludes that: (1) a negative and statistically significant relation exists between registrations (economic conditions) and fatalities/accident; and (2) a negative and statistically significant relation exists between helmet use laws and fatalities/accident. In particular, it is estimated that **the repeal of mandatory helmet use laws results in a 10.4%-33.3% increase in fatalities/accident and a 3.6%-9.5% increase in fatalities.**

The fundamental weakness of the de Wolf study is that the regression equation is misspecified on two levels: (1) the dependent variable -- fatalities/accidents -- is misspecified; and (2) the independent variables are misspecified. As a result of these misspecifications de Wolf's estimates of the effectiveness of helmet use laws are biased.

First, the choice of fatalities per accident implies that de Wolf's regression does not test the hypothesis that helmet laws decrease fatalities. Given that helmets potentially limit peripheral vision, increase noise distraction and result in driver fatigue, it is possible that they decrease the chance of accident avoidance and may even cause additional accidents. Thus helmet laws may increase accidents, particularly the type of accidents (low speed where accident avoidance techniques are most fruitful) that are less likely to result in fatalities. Given this scenario, a regression equation that shows that helmet laws reduce fatalities per accident is not capable of concluding that helmet laws save lives. The negative effect of helmet laws on fatalities per accident could result from an increase in accidents at the same time that fatalities remain constant (fatalities per accident decline). Thus' the statistically significant negative effect of helmet laws on fatalities per accident does not provide conclusive evidence that helmet laws save lives.

Second, de Wolf's use of state and year dummies to replace the "inconsistently measured" factors implies that the level of alcohol consumption, traffic density, etc. remain constant within each state over a ten year period. Thus, her specification fails to recognize within state changes in the non-measured variables (i.e. changes in alcohol consumption or average highway speed or age composition in a single state over a 10 year period (1975-1984)) and thus does not consider the effects of such changes on fatalities per accident. If the influence of these changes on the fatality rate is not assigned to changes in the non-measured variables through the dummy variables it will be inappropriately assigned to other explanatory variables such as the helmet law variable. For example, if a state repeals a helmet law in 1976 at the same time that state backs off from the strict enforcement of the 55 MPH speed limit (instituted in 1973) the effect of higher speeds on the fatality rate (because they are not controlled for in de Wolf's equation) will incorrectly be assigned to the repeal of the helmet law and will incorrectly overstate the effectiveness of helmet laws. Thus de Wolf's results suffer from biased estimates of helmet law effectiveness. In contrast, this specification bias problem can be avoided by measuring the relevant variables (alcohol, speed, congestion, etc.) and incorporating them in the equation as in Goldstein (1985).

3. Graham, J. D., and Lee, Y. (1986). "Behavioral Response to Safety Regulation: The Case of Motorcycle Helmet-Wearing Legislation." Policy Sciences, 19:253-273.

This regression study employs the same methodology as the de Wolf study with the exception that the dependent variable is measured as fatalities/registrations and a different mix of independent variables is used. This study explains variations in fatalities/registrations across the 50 states for the years 1975 to 1984 by variations in: (1) helmet law status (law/no law); (2) a linear time trend beginning in the year after the repeal of a law in a particular state; (3) a linear time trend beginning in the year after adoption of the law in a particular state; (4) 49 state dummy variables; and (5) 9 year dummy variables. (4) and (5) are justified on the same grounds as in the de Wolf study. The inclusion of (2) and (3) , not found in the de Wolf equation, are used to test the risk compensation hypothesis (outlined below, Section VI) -- gradual compensating responses in behavior that offset the intent of the law. In addition no proxy for economic conditions is used, it is assumed that this determinant is captured in the dummy variables.

The study concludes that mandatory helmet use laws have: (1) a negative and statistically significant effect on fatalities and the fatality rate; and (2) **a statistically significant gradual risk compensating effect that erodes the benefits of helmet laws in (1). In particular, repeal of helmet laws induces a 12% increase in the fatality rate but, this detrimental effect is eroded at a rate of roughly 2.5% per year**, as motorcyclists adjust (compensate) their risky behavior downward.

The statistical estimates of this study suffer from the same specification problem as the de Wolf study: the dummy variable specification does not control for dynamic trends within states for the non-measured factors (speed, alcohol, etc.) between 1975-1984. Thus the effect of these dynamic trends are inappropriately assigned to helmet law repeal causing estimates of helmet effectiveness to be upwardly biased (see discussion in de Wolf review).

Finally the **risk compensation estimates are also biased.** These estimates are modeled as within state time trends after a law change. These within state time trends not only capture any risk compensation effects, but also partially (because they are only used for years after a law has changed) capture the within state dynamic trends in the non-measured variables. Thus these estimates are biased because they do not separate out the risk compensation effects from other dynamic effects.

Once again the problems inherent in this study could be resolved by measuring all relevant factors and including them in the equation.

4. Watson, G. S., Zador, P. L., and Wilks, A. (1980). "The Repeal of Helmet Use Laws and Increased Motorcyclist Mortality in the United States F 1975-1978." American Journal of Public Health, 70:6.

Based on the same premise that data on the multiple factors that influence motorcycle fatalities are either not available or not reliable, this study develops an alternative regression model that explains the number of fatalities in one state by the number of fatalities in a state in the same geographic region. The authors argue that this design overcomes data irregularities by assuming that "most factors affecting... motorcyclists fatalities... are likely to be similar... in states in the same geographic region." In other words, the determining factors in both states are hypothesized to be so similar that variations in the number of fatalities in one state can explain variations in the number of fatalities in another geographical similar state. Based on this premise an equation explaining monthly fatalities for each state that eventually repeals a helmet law by the monthly fatalities of a geographically similar state which does not repeal its helmet law is estimated for all 26 states that eventually repealed helmet use laws for a 48 month period prior to repeal. This equation is then used to forecast the number of fatalities that a repeal state should expect to experience if it had not repealed its law. **This forecast is compared to the actual number of fatalities and it is concluded that in 23 of 26 states a - greater number of deaths than expected occurred. The typical percent increase in fatalities is estimated to be 38%.**

Based on the underlying theoretical assumption used to justify the design of the regression equation -- that the factors influencing the number of fatalities are the same in the matched states -- it is theoretically proven in Goldstein (1985) that the predicted number of deaths in this study are biased. In the most relevant case the biased is signed and it is concluded that predicted fatalities from the regression equation are biased downward. Thus, comparisons of actual and predicted fatalities in post repeal years systematically overestimate the effectiveness of mandatory helmet use laws. The methodology employed to avoid "inconsistently measured" data , results in biased estimates and is thus not reliable.

In addition, Adams (1983) (reviewed below) argues that a downward bias in predicted deaths (upward bias in helmet law effectiveness) is induced by the smoothing technique employed by Waston et al. The critique offered in Goldstein (1985) is more general in that it focuses on the structure of the model rather than the transformation made to the data.

IV. Other Methodologies Used to Estimate Helmet

Effectiveness
Introduction

Two other methodologies have been employed to analyze helmet effectiveness. Evans and Frick (1986) use a "double pair comparison method" where one of the occupants of a motorcycle is used as a control for the other occupant in motorcycle accidents. Bowman and Schneider (1980) use a computer simulation model of impact responses of motorcycle victims that is extrapolated from the impact responses of primates and dummies. Both of these methodologies suffer from critical flaws and tend to produce unreliable estimates of helmet effectiveness.

1. Evans, L. and M. C. Frick (1986). "Helmet Effectiveness in Preventing Driver and Passenger Fatalities." General Motors Research Publication No. GMR- 5602.

Using the "double pair comparison method (DPCM) where one of the occupants of a motorcycle, either the driver or the passenger, is used as a control for the other occupant in motorcycle accidents involving both a male driver and a male or female passenger in which there is at least one fatality, this study concludes that: (1) **helmeted riders are 27% less likely to die compared to non helmeted riders**; and (2) the fatality in the driver's seat exceeds that in the passenger's seat by 31%.

While the methodology employed in this paper is superior to previous studies using correlation analysis, the DPCM still fails to control for **all** of the factors that influence motorcycle fatalities and thus results in bias (unreliable) estimates of helmet effectiveness. In particular, under a realistic set of assumptions, it can be shown that the DPCM produces estimates of helmet effectiveness that are systematically biased upward (overstated).

The authors incorrectly argue that the DPCM controls for all relevant factors by using one occupant as a control for the other occupant. While it is true that many aspects of a crash are the same for both driver and passenger (i.e. crash speed, object struck, road conditions, etc.), other important factors that dramatically influence the probability of death are not controlled for. In particular, the blood alcohol content (BAC) of the passenger and driver -- a major determinant of fatalities (see Goldstein (1986)) -- cannot be assumed to be the same in both occupants nor can the dynamic response to impact of the driver and passenger be assumed to be the same. In this latter situation, the kinetic energy -- potential for bodily damage -imparted to the two occupants can be used up very differently, thus creating dramatic differences in the injuries sustained and the probability of fatality for driver and passenger.

Given that these two very important factors that influence death and injury have not been controlled for, it can be shown that the DPCM approach will erroneously assign the adverse effects of these two factors to the non- use of a helmet. Thus overstating the effectiveness of helmets (a technical appendix that outlines this argument is available).

2. Bowman, B. M. and Schneider, L. W. (1980). "Simulation Analysis of Head/Neck Impact Response for Helmeted and Unhelmeted Motorcyclists." Highway Safety Research Institute, Ann Arbor.

This study estimates the effectiveness of motorcycle helmets through the use of computer simulations of the dynamic response of the head and neck. The study concludes that: (1) **helmet use invariably lessens the exposure levels of dynamic responses which have a role in Producing head injury; and (2) helmet use almost always reduces the severity of neck response** and for no simulation configuration or condition to greatly increase the likelihood of neck injury. It is further predicted that helmet use significantly reduces the likelihood and severity of both head and neck injuries.

Some interesting findings of this study are the result that helmets can induce neck injuries and the results on the limitations of helmet design (pp. 170-203). In particular, it is found that: (1) a high probability of serious brain injury for a 20 mph head impact with a vertical rigid "truck" surface is equally likely for helmeted and non helmeted riders; (2) little differences between shear forces at the upper neck exist but greater shear forces at the lower neck exist for head impacted helmeted cyclist; (3) at 20 mph head impacts, peak extension torques are double the injury tolerance level for helmeted riders (and even higher for unhelmeted riders); (4) peak flexion torques at the upper neck are significantly greater for head impacted helmeted cyclists; and (5) for chest impacts, neck elongation forces are 30% greater and shear forces are also greater for helmeted riders. **Thus helmets are most effective at lower impact velocities (10 mph or less) and helmets can induce neck injuries.**

The methodology employed by simulation studies are also subject to criticism. These computer models are based on extrapolations of the dynamic similarities of the post-impact responses between primates and human beings based on impact speeds from 0-7 mph. As is commonly accepted, at least by statisticians, predictions from such models that are made beyond the range of experience (0-7 mph) on which the models are based are highly unreliable. As Goldstein (1986) shows, neck injuries do not occur until 13 mph impacts -- speeds well beyond the range of experience of the simulation models -- implying that such extrapolations are subject to bias and/or have such a large variance around their point estimates that they are of little use for the evaluation of helmet effectiveness.

V. Cost-Benefit Studies of Helmets and Helmet Laws

Introduction

Cost-benefit studies attempt to estimate the dollar value of the costs and benefits associated with either (1) the repeal of a helmet law; (2) the non-use of helmets, or (3) the cost of motorcycle accidents. Typically direct (hospital care costs, rehabilative costs and professional fees) and indirect costs (lost earnings/productivity) are estimated. Most studies have concentrated on the costs associated with fatal injuries (Watson et al. (1981), Hartunian (1983)), while others consider both fatal and non-fatal accident costs (Mueller (1980) and Rivara (1988)). These latter studies also estimate the percentage of direct costs paid for by public funds. Typical findings are that mandatory helmet use laws could save between 500- 600 lives , and between $60-$180 million annually. In addition it is estimated that between 50%-63% of direct costs are paid for by public funds.

There are two fundamental problems with these studies. First , they rely on the overstated (biased) statistical estimates of helmet effectiveness from correlation and regression analyses , reviewed above, to establish the "benefit" of wearing a helmet. Clearly, this approach substantial overstates the costs associated with the non-use of a helmet because it inappropriately assigns the effects of speed and alcohol to the non-use of a helmet. Second , these studies do not consider all of the costs associated with the use of helmets or with mandatory helmet laws. Typically the only cost considered is the purchase price of the helmet. The costs associated with the neck injury inducing aspects of helmet use (established in Goldstein (1986)) and the costs generated by risk compensating behavior (discussed in next section) are never considered. Thus, the benefits associated with helmet use are overstated and the costs are understated. It is conceivable that the costs of helmet use could offset or outweigh the benefits, but this never surfaces in the literature.

1. Watson, G. S., Zador, P. L., and Wilkes, A. W. (1981). "Helmet Use , Helmet Use Laws, and Motorcycle Fatalities." American Journal of Public Health, 71:3.

This article is a response to criticisms of Watson et al. (1980) reviewed above. In this paper, the authors rely on alternative data sets to corroborate their original finding that on average helmet law repeal increases fatalities by 38%. In addition they estimate the cost of helmet law repeal or enactment in terms of additional lives lost or saved. Using before-after correlations and comparisons of helmeted-non helmeted accident victims (the type of studies criticized in Section I) Watson et al. find "support" for their original finding. They conclude that: (1) helmet use in accident situations could reduce unhelmeted rider fatalities by 52%; and (2) that repeal of mandatory helmet use laws increase fatalities by 40% while enactment of such laws decrease fatalities by 30%. Using the latter result, they estimate **the cost of repealing all existing helmet laws as an additional 1,100 fatalities and the benefits of all states enacting laws as a reduction of 600 fatalities.**

As argued above , this cost-benefit analysis is based on estimates of helmet effectiveness that are overstated and fails to consider the neck injury inducing effects of helmets and the risk compensating behavioral responses as costs of helmet legislation.

2. Mueller, A. (1980). "Evaluation of the Costs and Benefits of Motorcycle Helmet Laws." American Journal of Public Health, 70:6.

Relying on the estimates of helmet effectiveness generated from correlation analyzes of accident victim data from Colorado, Oklahoma and South Dakota (some of which are reviewed above), the author compares the costs of motorcycle helmets with the medical costs averted due to helmet use. The author concludes that $61 million could be saved annually if all motorcyclists were to use helmets. The author limits his analysis to a comparison of the cost of helmets and the cost of medical care expenses averted. Lost lives and lost productivity are not considered. The medical care benefit of helmet use is based on estimates of (1) the probability of an accident; (2) the effectiveness of helmets; (3) medical care expenses for injuries of different severity class; and (4) the percentage increase in helmet use resulting from mandatory helmet use.

This cost-benefit analysis is subject to the two main criticisms advanced above. In addition the author recognizes these problems: "the cost-benefit analysis . . . assumes that differences in injury severity between helmeted and unhelmeted riders is due entirely to the effectiveness of helmets. It is conceivable, however, that part or all of the difference is due to confounding factors. For instance, if helmeted motorcyclists travel at lower speeds... then they would be less likely to sustain injuries..."

3. Hartunian, N. S., Smart, C. N., Willemain, T. R., and Zador, P. L. (1983). "The Economics of Safety Deregulation: Lives and Dollars Lost Due to Repeal of Motorcycle Helmet Laws." Journal of Health Politics, Policy and Law, 8:1, Spring.

Following the approach of Watson et al. (1980) (reviewed above), the authors estimate the number of excess deaths attributable to helmet law repeal and the associated costs to society. No attempt was made to estimate excess non-fatal injuries and costs. The authors findings indicate that 516 excess deaths (24% of all fatalities) occurred in 1980 in the 28 states with no helmet laws. The associated economic costs were estimated to be at least $180 million. Economic cost estimates include direct costs -- hospital, doctor, legal, and funeral costs -- and indirect costs -- cost of foregone earnings.

The estimates in this study are subject to the above criticisms advanced of the statistical methods employed by Watson et al. (1980). In addition these estimates fail to consider any of the cost inducing effects (increased neck injuries) of helmet use. Finally, the portions of the statistical analysis that differ from Watson et al. (1980) are subject to the same criticisms of the other regression studies analyzed in Section III above. Thus, this study produces cost estimates of helmet law repeal that are systematically overstated. It is conceivable that correctly generated estimates could show no costs or net benefits associated with helmet law repeal.

4. Rivara, F. P., Dicker, B. G., Bergman, A. B., Dacey, R., and Herman, C. (1988). Journal of the American Medical Association. 260: 221-223.

This study estimates the direct and indirect costs and the percentage of direct costs paid by public funds associated with 105 motorcycle accidents at a level I trauma center in Seattle. The study finds that average direct costs per patient was $25,764 and that 63% of these costs were paid by public funds. While the study does not compare the costs incurred by helmeted riders to those incurred by non-helmeted riders, it concludes on the basis of previous helmet effectiveness studies that mandatory helmet use could dramatically reduce the direct and indirect costs and thus the costs to society.

While the study calculates direct, indirect and societal costs in a fairly standard manner, the results are unrepresentative of the costs associated with the average motorcycle accident and the

conclusion that mandatory helmet use could dramatically reduce these costs is unfounded.

The study analyzes atypical motorcycle accidents. The types of accidents sent to a level I trauma center involve the most seriously injured patients and thus dramatically biases estimates of average direct, indirect, and societal costs in an upward direction. In addition, the percentage of direct costs paid for by public funds is also overestimated. If the average (less severe) accident is considered, excessive bills that go beyond the economic means of accident victims are less likely to occur and thus accident victims are less likely to rely on public assistance.

Finally, the inference that mandatory motorcycle helmet use could dramatically reduce such costs is unfounded. This inference is based on the results of helmet effectiveness studies that systematically overstate the effectiveness of helmet use and that totally ignore the negative impacts (costs) of helmets which occurs through an increase in neck injuries, potential increase in the probability of a motorcycle accident and risk compensating behavior.

VI. Studies Supporting the Risk Compensation Hypothesis for Motorcycle Helmet Laws Introduction

In its crude form (Wilde (1982)), the risk compensation hypothesis states that individuals have a target (equilibrium) level of risk that they try to maintain. Thus, the implementation of helmet laws will lower the actual level of risk for a group of individuals (non helmeted riders). It is hypothesized that these riders will respond behaviorally by increasing their risk level to its target through other types of risky activity (i.e. higher driving speeds, alcohol consumption, more risky driving patterns, etc.). It is argued that this behavioral response can offset the positive affects of helmet laws on motorcycle safety.

The more sophisticated variant (Peltzman (1975) recognizes that the equilibrium level of risk is variable. In particular, regulatory legislation that lowers risk typically has two competing effects -- an income and substitution effect -- on an individual's response. Thus, total risk can increase or decrease in response to a regulatory act. In the case of motorcycle helmet laws, the law reduces the probability of a bad state -- injury and lost productivity -- and thus increases the expected income of individuals. The law also reduces the cost or price associated with driving intensity (i.e. high speeds) because of expected reductions in injury. In response, the individual uses the extra expected income (income effect) to buy more of all goods including more safety and more driving intensity but, because the price of driving intensity declines the individual will "buy" an additional amount of driving intensity because it is cheaper (substitution effect). The overall effect on safety depends on the size of the competing safety and driving intensity "purchases".

Thus the risk compensation effect of helmet laws becomes an empirical question. The measurement of such effects is a difficult empirical problem. Graham and Lee (1986) and Adams (1983) attempt to measure this effect. Both studies suggest that a risk compensation effect exists. The former study shows that a 2.5% increase per year in the fatality rate follows the initial 12% decline in the fatality rate from enactment of a helmet law. Thus within 5 years the fatality reducing benefits of helmet laws are eradicated. Adams (1983) casually argues that risk compensation responses could explain some of the stylized facts about motorcycle accidents and he cites other studies on automobile safety equipment and driver response as supporting evidence.

The risk compensation hypothesis is different but not inconsistent with the more risky behavior hypothesis (of non helmeted riders) discussed in Section I. The former argues that individuals have target levels of risk, the latter argues that different groups of riders (helmeted and non helmeted) have different target levels of and thus behave differently. While risk compensation is an interesting subject, good estimates of this effect are hard to come by.

1. Graham, J. D., and Lee, Y. (1986). "Behavioral Response to Safety Regulation: the Case of Motorcycle Helmet-Wearing Legislation." Policy Sciences, 19: 253-273.

As argued above the finding that the initial decline in the fatality rate of 12% after passage of a helmet law is eroded at a of 2. 5% per year is generated from a misspecified regression equation and thus is potentially biased. In this case the bias could be upward or downward. Thus, a reliable estimate of the risk compensation effect has not be generated.

2. Adams, J. G. U. (1983). "Public Safety Legislation and Risk Compensation Hypothesis: The Example of Motorcycle Helmet Legislation," Environment and Planning C, 1: 193-203.

Adams' paper has two parts. First he critiques the NHTSA and the Watson et al. (1980) studies reviewed above. Second he advances the risk compensation hypothesis, but offers only the we of empirical support for it.

The criticism of existing studies is noteworthy. The critic analysis focuses on the treatment of the data used by these studies rather than on the statistical techniques employed to analyze the data. NHTSA studies are criticized for the level of aggregation data and Watson et al. are criticized for the smoothing technique they apply. In both cases , Adams claims that the manner of data manipulation leads to overstated estimates of helmet effectiveness.

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Other references cited in this review are either given in the text or appear in the references of the three above papers.