This article evaluates the effectiveness of motorcycle helmets in accident situations. A latent variable model is developed and estimated. It is concluded that (1) motorcycle helmets have no statistically significant effect on the probability of fatality; (2) helmets reduce the severity of head injuries; and (3) past a critical impact speed, helmets increase the severity of neck injuries. Further analysis establishes the qualitative and quantitative nature of the head-neck injury trade-off.

THE EFFECT OF MOTORCYCLE HELMET USE ON THE PROBABILITY OF FATALITY AND THE SEVERITY OF HEAD AND NECK INJURIES

A Latent Variable Framework

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The repeal or weakening of motorcycle helmet use laws in 31 states between 1976 and 1983 has generated a vigorous debate over the effectiveness of helmets in the prevention of fatalities and the reduction of injury severities. Statistical studies that have explored these issues have suffered from the lack of an accurate and detailed data set and, more important, have neglected to integrate causal models into their analysis. Although the former problem has been alleviated by the extensive data collection techniques employed by Hurt et al. (1981), the

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latter problem has not been addressed. The statistical techniques employed fail to control for the multifaceted and interrelated factors involved in motorcycle fatalities and injuries and thus conflate the effects of such factors and erroneously assign them to helmet use.

The purpose of this article is to develop, estimate, and statistically test three causal models for (1) the probability of a fatality; (2) the severity of head injuries; and (3) the severity of neck injuries, where each dependent variable is conditional on the occurrence of a motorcycle accident. A latent variable framework is employed in each case and particular attention is paid to the effectiveness of helmets in each instance.

In contrast to previous findings, it is concluded that (1) motorcycle helmets have no statistically significant effect on the probability of fatality, and that (2) past a critical impact speed helmets increase the severity of neck injuries. It is also shown that helmets reduce the severity of head injuries. Thus, a trade-off between head and neck injuries exists in deciding whether or not to mandate helmet use. Further analysis reveals that all possible combinations of the intensity of the trade-off, defined in terms of the severity of head injuries forgone and the severity of neck injuries incurred from helmet usage, are equally likely.

The arguments in this article are presented in four sections. Section I presents an overview of existing statistical studies. The next section develops the basic model and its variants. Section III discusses the data; section IV presents our results. Finally, section V contains our conclusions and their policy implications.

I: OVERVIEW

Existing statistical research on helmet effectiveness employs two alternative methodologies to analyze accident data. These techniques test the difference between death rates, injury rates, location rates of injuries, and severity rates of particular types of injuries. These rates are compared either for a similar period of time before and after helmet law repeal (Dare et al., 1979; McSwain and Lummis, 1980) or for helmeted riders and nonhelmeted riders during a single time period subsequent to helmet law repeal (Chang, 1981; Dare et al., 1979; Heilman et al., 1982; Hurt et al., 1981; Kraus et al., 1975; Luna et al., 1981; Scott, 1983). In each case statistically significant differences are attributed to helmet use or nonuse. Typical results associated with this literature are death and injury rates two to three times greater for nonhelmeted riders and increases in occurrence rates in repeal years that range from 19% to 63%.

The major limitation of previous studies is the lack of an effective control for other factors that concurrently determine death and injury rates. On one hand, helmet-nonhelmet comparisons fail to consider differences in these two categories of riders. The most plausible hypothesis is that helmeted riders are more risk averse and thus (1) have lower pre-crash and thus crash speeds; (2) are less likely to be involved in accidents; and (3) are less likely to combine alcohol consumption and driving.[1] Such behavior rather than helmet use per se may dramatically reduce the probability of a fatality or the severity of an injury.

On the other hand, before-and-after designs fail to control for dramatic trends in the data. In particular, trends toward (1) lower median age of motorcycle owners: (2) higher average annual miles traveled; (3) lower average experience level of riders; and (4) higher displacement machines (Motorcycle Industry Council, 1985) are not considered. Given the relationships between engine displacement and potential speed; age and risk aversion; and risk aversion, crash speeds, and alcohol ingestion, simple before-after comparisons cannot be expected to isolate the effectiveness of helmet use.

In the next section we develop an econometric model that considers the determinants of the probability of death, and the severity of head and neck injuries. This approach allows us to isolate the individual effect of helmet use on the variables in question.

II: THE ECONOMETRIC MODEL

Models that explain the variation in the total number of automobile or motorcycle fatalities across states and/or across time have been presented by Forester et al. (1984), Koshal (1976), Peltzman (1975), and Prinzinger (1982). The model developed below extends these approaches to the case of accident (micro) data and to a consideration of both fatalities and injury severities. The classification of explanatory variables into three broad groups facilitates the development of the model. This typology consists of (1) factors governed by physics; (2) physiological factors; and (3) human factors and operator characteristics. We consider each of these categories in order. Variations of one basic model are employed for each of the three dependent variables considered.

An informative method for understanding motorcycle trauma is to consider it as the result of uncontrolled mechanical energy transfer

(Snively, 1983). Motorcycle accidents result in serious injuries because of the speeds involved and the associated energy that must be dissipated in the crash. In this light, the input energy and circumstances surrounding the dissipation of that energy are the crucial physical factors associated with injury severity.

Besides a measure of the energy transferred to the motorcycle operator—the potential for bodily damage—such factors as employment of a helmet as an energy handling device and the engineering and design limitations of such devices must be considered. Helmets control or mediate the transfer of impact energy to the head. The current engineering design, safety standards, and production techniques applicable to motorcycle helmets place limits on the energy-dissipating capacity of these protective devices. This implies that the effectiveness of the helmet is mediated by the force applied to the helmet.

As a measure of input energy, we employ two variants of the kinetic energy of the motorcycle operator that results from a collison. The formula for kinetic energy can be expressed as $K = 1/2mv^2$, where m is the mass of the operator and v is the velocity assumed by that mass. Two variants of the velocity variable are used. In the first measure, (K1), V is simply the crash speed of the motorcycle. In the alternative specification, (K2), v is assigned either the relative impact velocity of the motorcycle and other crash-involved vehicle, or the motorcycle crash speed.[2] The former is assigned when the injury mechanism associated with the rider's most severe injury is the other vehicle, whereas the latter is employed in all other circumstances.[3]

The effect of helmets is modeled through two variables: a qualitative variable, H, that distinguishes between helmet use and nonuse; and an interaction term, HI, constructed from the product of H and the normal component of impact velocity to the helmet. This specification implies that the overall effectiveness of the helmet decreases with helmet impact speed.

The physiological factors considered are the effect of age and alcohol consumption. Individuals can be considered to have an "injury threshold" that is based on physiological parameters. Those parameters in turn depend on an individual's age in such a manner that older people have a reduced resistance to injury.[4] Alcohol ingestion affects the severity of injuries in two ways. First, the presence of alcohol hinders not only the clinical diagnosis of injuries (Baker and Fisher, 1977; Champion et al., 1975) but the self-detection of injuries. More important, the cardiovascular effects of alcohol significantly inhibit the process of homeostasis, especially the dynamic management of circulatory stability (Champion et al., 1975). These two physiological variables are denoted by A and BA.

Although many human factors and operator characteristics were analyzed, the final equations include only two: the amount of rider on-road experience (EX) and a binary variable (EA) that establishes whether or not the rider had taken the correct evasive action for the particular accident situation. A special case of a linear spline, one where the slope of the linear segment beyond a critical experience level is constrained to be zero, is used to model the experience variable. This implies that $EX = EX$ for $0 \leq EX < EX^*$ and $EX = EX^*$ otherwise, where EX^* is the critical experience level. This specification is justified by marginal returns from additional experience that approach zero past some critical experience level, but is also necessitated by the nature of the data (discussed below).[5]

FATALITY MODEL

In order to model the probability of a fatality, we define a dichotomous variable, D_i, where $D_i = 1$ if the operator died given that an accident occurred and $D_i = 0$ otherwise. We also specify a latent variable D_i^*, an individual's propensity to die conditional on the occurrence of an accident. For notational simplicity and ease of exposition, we drop all references in the remainder of the text to the conditional nature of the three dependent and latent variables. We assume that

$$D_i^* = X_i'\beta + \epsilon_i$$

where X_i is a vector of independent variables, β is a vector of unknown parameters, and ϵ is a random error term. It is assumed that ϵ_i are i.i.d. drawings from $N(0,\sigma^2)$. In this model X_i includes K in one of its two forms, H, HI, A, BA, EA, EX, and a constant term. D_i can now be defined in terms of D_i^* in the following manner:

$$\begin{aligned} D_i &= 1 \text{ if } D_i^* \geq Z^* \\ &= 0 \text{ if } D_i^* < Z^* \end{aligned}$$

where Z^* is a threshold beyond which an individual expires. Given this specification the probability that $D_i = 1$ can be expressed as

$$P(D_i = 1 | X_i) = F(X_i'\beta/\sigma)$$

where F is the standard normal distribution function. The maximum likelihood (ML) probit estimates for the parameters of this model are reported below.

HEAD INJURY SEVERITY (HIS) MODEL

In this model the dependent variable, HS, is the sum of squared severities for all head injuries sustained by the driver, where the severity of each injury is measured by the Abbreviated Injury Scale (AIS).[6] Although the dependent variable is continuous, the large number of limit (zero valued) observations—396 out of 644 cases—suggest a Tobit specification. We define a latent variable, HS_i^*, the sum of squared severities for all head injuries, and assume that

$$HS_i^* = X_i'\beta + \epsilon_i$$

where β, X_i, and ϵ_i are as defined in the fatality model. HS_i can now be defined in terms of HS_i^* in the following fashion

$$\begin{aligned} HS_i &= HS_i^* \text{ if } HS_i^* > 0 \\ &= 0 \text{ if } HS_i^* \leq 0 \end{aligned}$$

Given this specification the regression function can be written as

$$E(HS_i | X_i) = \beta[F(X_i'\beta/\sigma)X_i] + \sigma f(X_i'\beta/\sigma)$$

where f is the density function of the standard normal variable. The ML Tobit estimates for the parameters of this model are reported below.

NECK INJURY SEVERITY (NIS) MODEL

The dependent variable in this case is NS, the sum of squared severities for all neck injuries.[7] Given the large number of limit observations, 576 out of 644 cases, a Tobit specification is utilized. A latent variable framework analogous to the HIS model is employed.

Thus, the regression function can be written as follows:

$$E(NS_i | X_i) = \beta[F(X_i'\beta/\sigma)X_i] + \sigma f(X_i'\beta/\sigma)$$

Where β, F, f, and σ are defined as in the previous model. One additional explanatory variable (HW) is included in X_i. This variable is an interaction variable and is formed as the product of H and the weight of the helmet.

The inclusion of both the HI and HW interaction variables in the neck equation are justified by the laws of physics. Impacts to the helmet are capable of causing a flexure or extension displacement (cervical stretch) of the neck and the prospect of a related neck injury. Although a helmet may attenuate head impact and thus the extension-flexsion response of the neck, this result can only be expected to occur until some critical impact speed beyond which the energy absorbing capabilities of the helmet are surpassed. Beyond that speed, the added mass of the helmet increases the inertial and post-impact response of the neck and is theoretically related to the severity of neck injuries.[8]

The ML Tobit estimates for the parameters of the model when HW_i is both included and excluded from X_i are reported below.

III: THE DATA

The data used was collected from the on-scene, in-depth investigations of 900 motorcycle accidents in the Los Angeles area, supervised by Hurt et al. (1981). Each accident was completely reconstructed and 1045 data elements were recorded covering accident characteristics; environmental factors; vehicle factors; motorcycle rider, passenger, and other vehicle driver characteristics; and human factors including both injuries and protection system effectiveness. The data was collected by a multidisciplinary research team that ensured more accurate and detailed information than is typically available from police and hospital records (Hurt et al., 1981: 1-35).

A subsample of 644 cases was selected based on our twofold treatment of missing data. In general, cases with missing data on the independent variables were dropped from the sample (H, EA, A, BA, and K variables). In the case where such a deletion would result in possible selection bias or the significant loss of data, missing values were assigned the mean value of the variable in question (EX and HI variables).

As argued above, one limitation of the data directly affects the specification of our model. Although the use of a linear spline to model the effects of EX is theoretically justified, it is also necessitated by the truncated range used to record that variable: values of EX greater than 96 months were assigned a value of 97. Although different critical values of EX less than or equal to 96 were used, the best fit occurred when EX* equals 96. Although it was not possible to test critical points above 96 to determine if a better fit existed, the EX variable was insignificant in all but the HIS model. And deletion of this variable in other models had negligible influence on all results.

The definition, construction, units of measurement, and sample means for all variables in our final equations are contained in Appendix A.

IV: RESULTS

The results of the fatality model and the HIS and NIS models are respectively reported in Tables 1, 3, and 4. Estimates are based on the 644 cases remaining after the treatment of the missing values. For each model two equations corresponding to the two variants of K are reported. In the NIS model an additional two equations associated with the inclusion-exclusion of the HW variable are reported.

FATALITY MODEL

The results in Table 1 reveal that the coefficients of all variables take on their expected signs. Both the H and HI variables are insignificant, indicating that helmet use has no statistically significant effect on the probability of death. The major determinants of the probability of a fatality are the kinetic energy imparted to the rider—the potential for bodily damage—and the operator's blood alcohol level (BA). The results also reveal that the proper execution of evasive action, an individual's age, and experience level have no statistically significant impact on the probability of a fatality. Deletion of all insignificant variables with the exception of H and HI from the equation produces negligible changes in the remaining coefficients and their standard errors. Finally, on the basis of comparisons between the log of the likelihood function, l, equation 1 better fits the data.

TABLE 1

Probit Estimates of Fatality Model

Equation	*Constant*	*H*	*HI*	*K1*	*K2*	*BA*	*A*	*EA*	*EX*	*l*	χ^2
1	−2.33*	−1.22	0.065	0.00010*		0.067*	0.017	−0.23	−0.0033	−90.32	67.93
	(−7.50)	(−1.45)	(0.80)	(4.86)		(3.49)	(1.59)	(−0.96)	(−1.02)		
2	−2.09*	−1.23	0.065		0.000050*	0.077*	0.015	−0.28	−0.0018	−95.53	57.52
	(−7.36)	(−1.43)	(0.78)		(3.85)	(4.31)	(1.46)	(−1.22)	(−0.61)		

NOTE: t statistics are in parenthesis.

*Significant at .01 level.

The quantitative importance of the statistically significant variables is best understood through the total effects of relevant changes in those variables on the probability of death, holding all other variables at their sample means. Such results are reported in Table 2. Alternatively, partial derivatives ($\partial P/\partial X_K$) evaluated at sample means are reported in Appendix B. Referring to Table 2, the probability of dying in the average motorcycle accident is .0228 or .0262. These estimates are consistent with actual fatality rates reported in Dare et al. (1979), McSwain and Lummis (1980), and Scott (1983). A change in BA from 0 to 10 (sober to legally intoxicated in most states) increases the probability of a fatality dramatically from .0207 to .0853 or from .0233 to .1131, depending on which equation is employed. In the same vein, an increase in the relevant crash speed from 40 to 60 mph increases the probability from .0708 to .3632, or from .0446 to .1230.

These results clearly establish that crash speed and the blood alcohol level of the rider are the most important determinants of fatalities, whereas helmets are shown to have no statistically significant effect on the probability of survival.

TABLE 2
Total Effects on P (D = 1 | X)

		Equation 1		*Equation 2*	
Variable	*Condition*	$F(X'\hat{\beta})$	$\Delta F(X'\hat{\beta})$	$F(X'\hat{\beta})$	$\Delta F(X'\hat{\beta})$
All	$X' = \bar{X}'$	.0228		.0262	
BA	BA = 0	.0207		.0233	
			.0646		.0898
	BA = 10	.0853		.1131	
K	M = 5.01[a] V = 0 mph	.0091		.0166	
			.0071		.0051
	M = 5.01 V = 20 mph	.0162		.0217	
			.0546		.0229
	M = 5.01 V = 40 mph	.0708		.0446	
			.2924		.0784
	M = 5.01 V = 60 mph	.3632		.1230	

a. The average weight and mass are, respectively, 161.19 and 5.01.

HEAD INJURY SEVERITY MODEL

Parameter estimates associated with the HIS model are reported in Table 3. As in the previous model, the statistically most significant determinants of the severity of head injuries are the rider's kinetic energy and blood alcohol level. In sharp contrast to the previous model, methods for the reduction of the gravity of head injuries exist. The most effective one is the energy-absorbing capability of the helmet. The statistical significance of the H variable and insignificance of the interaction term (HI) imply that not only do helmets reduce head injuries, but they do so at almost all realistic impact speeds to the helmet. For example, in equation 3 at the average impact speed of 10.13 mph to riders experiencing an impact to the helmet, HS is reduced by 12.68. Other deterrents to head injuries include execution of the proper evasive action and rider experience. Finally, as in the fatality model, equation 3 better fits the data.

NECK INJURY SEVERITY MODEL

The results associated with the NIS model are reported in Table 4. The inclusion of the HW variable in the equations results in four variants of the model. As in the previous models K and BA are important determinants of injury severity, but in addition we find that past a critical impact velocity to the helmet, measured by the normal component of velocity, helmet use has a statistically significant effect that exacerbates the severity of neck injuries. Using the point estimates in equations 5-8 and the average weight of the helmet (2.70), estimates of this critical impact speed are around 13 mph. Beyond this critical speed the energy-absorbing ability of the helmet is surpassed and the inertial and post-impact responses of the neck are intensified due to the added mass of the helmet. An impact to the head whose normal component of velocity is 20 mph will increase the severity of neck injuries by around 10. Equations 7 and 8 also reveal that marginal increases in helmet weight do not have a statistically significant effect on the severity of neck injuries. This finding, along with the acceptance of the zero constraints in equations 5 and 6, implies that it is the added mass of a helmet and not its specific weight that is responsible for exacerbating neck injuries. Finally, on the basis of likelihood comparisons, equation 5 better fits the data.

TABLE 3

Tobit Estimates of Head Injury Severity Model

Equation	*Constant*	*H*	*HI*	*K1*	*K2*	*BA*	*A*	*EA*	*EX*	*σ*	*l*
3	−9.97*	−17.24*	0.45	0.0016*		1.23*	0.13	−5.31**	−0.068**	20.58	−1275.6
	(−3.03)	(−3.58)	(0.95)	(5.98)		(4.48)	(1.07)	(−2.34)	(−2.09)		
4	−8.23**	−17.34*	0.42		0.0010*	1.41*	0.12	−5.85*	−0.057	20.83	−1279.5
	(−2.54)	(−3.58)	(0.86)		(5.123)	(5.149)	(1.02)	(−2.56)	(−1.76)		

NOTE: t statistics are in parenthesis.
*Significant at .01 level; **significant at .05 level.

TABLE 4
Tobit Estimates of Neck Injury Severity Model

Equation	*Constant*	*H*	*HI*	*K1*	*K2*	*BA*	*A*	*EA*	*EX*	*HW*	*σ*	*l*
5	–28.42*	–21.34*	1.58**	0.00081*		0.55**	0.21	–4.59	0.021		16.96	–409.98
	(–6.08)	(–2.58)	(2.02)	(2.83)		(2.02)	(1.71)	(–1.68)	(0.58)			
6	–27.60*	–22.59*	1.68**		0.00041**	0.70*	0.20	5.24	0.032		17.33	411.87
	(–5.94)	(–2.61)	(2.05)		(2.02)	(2.59)	(1.64)	(–1.88)	(0.87)			
7	–28.85*	- 30.12**	1.61**	0.00080*		0.54**	0.23	–4.56	0.021	3.10	17.02	- 409.90
	(–6.09)	(2.09)	(2.02)	(2.82)		(1.99)	(1.81)	(–1.67)	(0.57)	(0.72)		
8	–28.00*	- 26.18	1.63**		0.00040**	0.69**	0.22	–5.25	0.033	1.48	17.40	411.84
	(–5.95)	(- 1.76)	(2.01)		(1.96)	(2.54)	(1.70)	(–1.87)	(0.89)	(0.32)		

NOTE: t statistics are in parenthesis.
*Significant at .01 level; **significant at .05 level.

The most important finding generated by the HIS and NIS models is that a trade-off between head and neck injuries confronts a potential helmet user. Past a critical impact speed to the helmet, which is likely to occur in real-life accident situations, helmet use reduces the severity of head injuries at the expense of increasing the severity of neck injuries. We now consider the qualitative and quantitative nature of this trade-off.

THE NATURE OF THE TRADE-OFF

To gain insight into the qualitative nature of the head-neck injury trade-off associated with helmet use, we specify and estimate two probit equations. The first considers the determinants of the probability that a rider's most severe head injury is either critical or fatal ($AIS \geq 5$), whereas the second considers a rider's most severe neck injury. In each case the vector of independent variables is the same as in the HIS and NIS models. We thus define $HD = 1$ if $AIS_{MH} \geq 5$ and $HD = 0$ if $0 \leq AIS_{MH} < 5$, where the subscript MH refers to the rider's most severe head injury. Analogously, $ND = 1$ if $AIS_{MN} \geq 5$ and $ND = 0$ if $0 \leq AIS_{MN} < 5$.[9] Given that HD and ND are conditional on the occurrence of an accident, the sample size is the same as in the previous models. These estimates are reported in Table 5.

These results indicate that the only statistically significant determinants of the probability that an individual's most severe head or neck injury will be severe (critical or fatal) is the rider's blood alcohol level and kinetic energy, which is dominated by the crash speed. With respect to helmets, this finding implies that both helmeted and nonhelmeted riders are equally likely to have their most severe head and neck injuries classified as severe or minor. This further suggests that, ceteris paribus, an individual who decides to wear a helmet and who experiences an impact velocity to the head greater than the critical level may forego either severe or minor head injuries and incur either a severe or minor neck injury; all forms of the trade-off are equally likely to occur.

The quantitative nature of the trade-off, measured in terms of the net change in the expected sum of squared severities for both neck and head injuries resulting from helmet use, can be derived from simulations based on the point estimates in equations 3 and 5. Figure 1 depicts the two components of this net change (evaluated at sample means)—$[E(HS|X, H = 1) - E(HS|X,H = 0)]$ and $[E(NS|X,H = 1) - E(NS|X,H = 0)]$—as functions of I, the impact speed to the helmet. For notational

TABLE 5

Trade-off Results

Equation/ Variable	*Constant*	*H*	*HI*	*K1*	*BA*	*A*	*EA*	*EX*	*1*	χ^2
9/HD	−1.89*	−1.04	0.069	0.000074*	0.052*	0.0050	−0.21	−0.0049	−93.03	38.07
	(−6.54)	(−1.31)	(0.90)	(3.54)	(2.75)	(0.48)	(−0.93)	(−1.49)		
10/ND	−2.58*	−1.30	0.072	0.000093*	0.044	−0.0072	−3.73	0.0022	−23.46	30.32
	(−4.88)	(−0.40)	(0.22)	(3.22)	(1.62)	(−0.36)	(−0.13)	(0.35)		

NOTE: t statistics are in parenthesis.

*Significant at .01 level; **significant at .05 level.

simplicity, these two components are respectively referred to as Δ E(HS|X) and Δ E(NS|X). Under the assumption that units of HS and NS are equivalent measures of injury severity, Figure 1 reveals that below the critical helmet impact speed I*—around 21 mph—the net benefits associated with helmet use are positive. Beyond I* the increase in neck severities outweighs the reductions in head injuries and helmet use is undesirable.

V: CONCLUSIONS AND POLICY IMPLICATIONS

From our empirical results we conclude that helmet use has no statistically significant effect on the probability of a motorcycle fatality and that helmet users face a trade-off between reductions in the severity of head injuries and increases in the severity of neck injuries. It is also shown that all possible combinations of the intensity of this trade-off are equally likely to occur. In addition, it is found that the major determinants of injury and death are speed and blood alcohol level.

If a major concern of policymakers is the prevention of fatalities, our results imply that helmet legislation may not be effective in achieving that objective. Alternatively, if the overall costs to society in the form of

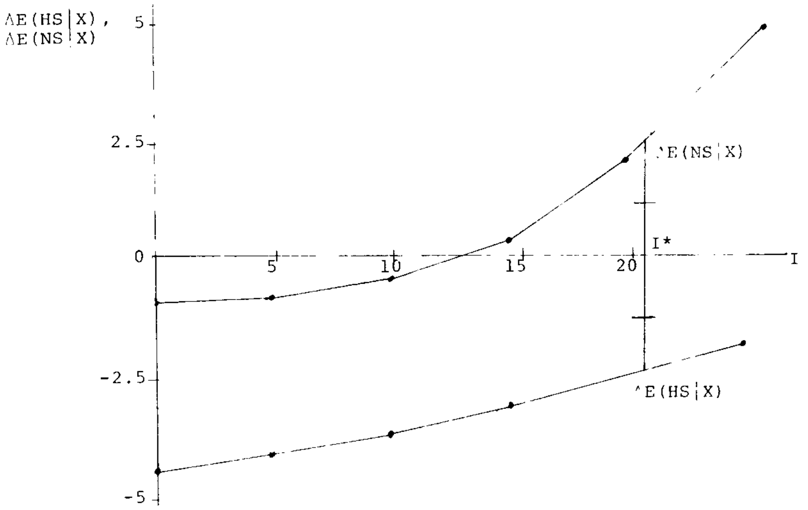

Figure 1: The Head-Neck Injury Trade-Off

health-care costs and lost productive output are at issue, our results imply that existing cost-benefit analyses that fail to consider the injury trade-off (Hartunian et al., 1983; Mueller, 1980; Scott, 1983) are inappropriate for policy guidance. Until studies are adequately designed and completed, the passage of helmet-use laws that may seriously jeopardize the health and earning capacities of an individual is not a viable policy option. Even in the event that cost-benefit studies show a net benefit to society from helmet legislation, the existence of externalities and high marginal disutilities associated with helmet use for all or a subset of motorcyclists may imply a net cost to the individual and thus raise questions about the redistribution of income resulting from helmet legislation.[10] Furthermore, alterations in driving behavior in response to mandatory helmet-use laws, predicted by the theories of risk compensation and risk homeostasis, may dissipate the net benefits to society from regulation (Adams, 1983; Peltzman, 1975; Wilde, 1982).

Under these circumstances mandatory helmet-use laws cannot be considered as an effective method to eradicate the slaughter and maiming of individuals involved in motorcycle accidents. A more viable policy approach would be two-pronged. On one hand, policy must address the causes of motorcycle accidents. On the other hand, as all accidents are not preventable, policy must consider the major determinants of death and injury and effective methods for their reduction.

Although our empirical results do not shed light on the causes of accidents, other evidence leads us to suggest the following policies: (1) the education of the general driving public about the coexistence of heterogeneous road users; (2) the education of a younger and more inexperienced population of motorcyclists on the issues of accident avoidance and the proper use of all-too-often overpowered machines; and (3) stricter enforcement of drunk driving laws, an increase in the legal drinking age, and alcohol awareness programs in order to reduce the accident rate.

With respect to the second type of policy, our results show that the major determinants of death and injury are speed and alcohol consumption. Policies aimed at the former problem range from stricter enforcement of speed limits to horsepower restrictions on the vehicle population (Russo, 1978). In the latter case, policy options are the same as those mentioned above. Finally, a viable alternative to helmets as a means for reducing the severity of head injuries exists. Mandatory driver training and education programs that emphasize the proper execution of evasive action in accident situations can effectively serve this purpose.

APPENDIX A

D = qualitative variable; D = 1 if operator died as a result of injuries sustained in accident; D = 0 otherwise; $\overline{D}$ = 0 .048.

HS = $\sum_{h=1}^{N} (AIS_h)^2$ where N is the number of head injuries incurred. $\overline{HS}$ = 3.56.

NS = $\sum_{i=1}^{K} (AIS_i)^2$ where K is the number of neck injuries sustained. $\overline{NS}$ = 0.638.

K1 = $.5MV^2$, measured in foot pounds, where M (measured in slugs) = $\frac{WT}{g}$, where WT is the weight of the operator measured in pounds and g is the gravitational constant measured in ft/sec^2. V is the crash speed of the motorcycle measured in ft/sec. $\overline{K1}$ = 3506.33.

K2 = $.5\ MV^2$, measured in foot-pounds, where V is the relative velocity of the motorcycle and other vehicle. $\overline{K2}$ = 3793.39.

H = qualitative variable; H = 1 if operator wore a helmet; H = 0 otherwise; $\overline{H}$ = 0.43.

HI = interaction variable equal to product of H and I where I is the normal component of impact velocity to the helmet measured in miles per hour; $\overline{HI}$ = 3.64.

A = age of operator measured in number of years; $\overline{A}$ = 26.25.

BA = blood alcohol level corrected to time of accident, measured in number (interger) of hundredths of 1% of blood alcohol; $0 \leqslant BA \leqslant 31$; $\overline{BA}$ = 0.62.

EA = qualitative variable; EA = 1 if evaise action was attempted by the operator and if the action was considered appropriate for the situation; $\overline{EA}$ = 0.33.

EX = amount of street motorcycle-riding experience in months; EX = EX for $0 \leqslant EX \leqslant EX^*$; EX = EX* otherwise; EX* = 96 and $\overline{EX}$ = 44.44.

HW = interaction variable equal to product of H and W where W is the weight of the helmet in pounds; $\overline{HW}$ = 1.16.

APPENDIX B

Variable	*Equation 1* $\frac{\partial P}{\partial X_K}$	*Equation 2* $\frac{\partial P}{\partial X_K}$
Constant	−0.13	−0.13
H	−0.066	−0.075
HI	0.0035	0.0040
K1	0.0000056	---
K2	---	0.0000031
BA	0.0036	0.0047
A	0.00092	0.00090
EA	−0.013	−0.017
EX	−0.00017	−0.00011

NOTES

1. The systematic overrepresentation of nonhelmeted riders in accident samples is a manifestation of the relation between helmet use and risk-averse driving behavior. Dare et al. (1979: 14), Hart et al. (1975: 544), Heilman et al. (1982: 663), Hurt (1981: 6), Mueller (1980: 590), and U.S. Department of Transportation, (1980: IV-21) document this occurence and/or discuss this relation. Scott (1983: 33) establishes the relation between alcohol use and helmet use.

2. Relative velocity is defined as $\sqrt{(v \cos \Theta + V)^2 + (v \sin \Theta)^2}$ where v is the crash speed of the motorcycle, V is the crash speed of the other vehicle, and Θ is the angle of impact, where $0 \leq \Theta \leq 180$.

3. Qualitatively and quantitatively similar results to those that will be reported are obtained for a third variant of kinetic energy—one that uses the relative velocity in all instances.

4. A continuous relation exists between age and reduced pulmonary functions, reduced cardiovascular reserves, brittle bones (osteoporosis), rigid ligaments, and coexisting diseases that may complicate the process of homeostasis.

5. Other variables considered but not included in our final equations include: rider drug involvement, rider permanent physiological impairment, driver training, the operator's past accident and violation history, operator height and weight, voluntary separation of rider from motorcycle before impact, coefficient of braking friction, and traffic density. In all cases and in all equations the coefficients of these variables were statistically insignificant and their deletion had negligible effects on the remaining coefficients and standard errors.

Finally, in order to control for any influences of risk aversion not captured by K1, K2, BA, or H and thus to avoid specification bias, proxy variables such as income, number of children, marital status, and education were included in our equations. These variables were singularly and in all possible combinations statistically insignificant and were eliminated with the same results as other such variables.

6. The AIS developed by the American Association for Automotive Medicine (1976) classifies injuries using the following scores: zero, no injuries; 1, minor injuries; 2, moderate injuries; 3, severe injuries—no threat to life; 4, serious injury—life-threatening, survival probable; 5, critical injury—survival uncertain; and 6, fatal injury. Under this classification system, the cumulative effect of multiple injuries is measured by the sum of squared AIS.

Head injuries are defined as those occurring in the following regions: Basal, Frontal, Face, Mandible, Maxilla, Nasal, Occipital, Orbit, Parietal, Brain, Sphenoid, Temporal, and Zygoma. Alternative specifications of the HS variable that exclude different combinations of regions considered to constitute the face were tested, and the results did not deviate qualitatively from those reported below.

7. Neck injuries are defined as those occurring in the following regions: the general cervical area, cervical vertebrae 1-7, and the foramen magnum. Alternative specifications of NS including different combinations of the above regions and in some cases the throat region produce the same qualitative results.

8. The average weight of the human head is 8-12 pounds; the average weight of the helmet used in our sample is 2.7 pounds. Thus, the weight of the helmeted head increases by 23%-34%. The helmet literature has paid little attention to the relationship between helmet use and neck injury. For example, an analysis of this relation has never been an objective of National Highway Traffic Safety Administration research (see U.S. Department of Transportation, 1980: II-5).

9. Different variants of HD and ND, where these variables are assigned a value of 1 if either AIS ≥ 3 or AIS ≥ 4, are tested. The results are qualitatively the same as those reported in the following text.

10. Deviations between individual costs and societal costs may result from the structure of insurance rates that tend to redistribute the high costs associated with high-risk policy holders to all policy holders.

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