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Self-Insurance: The Case of Motorcycle Helmets

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ABSTRACT

This article develops the economic implications of a head-neck injury tradeoff that underlies the technological limitations of motorcycle helmets as a form of self-insurance. Conditional on this tradeoff, an analysis of the optimal self-insurance decision establishes that mandatory helmet use legislation results in expected welfare losses for a subset of the motorcycling population. These losses are not compensated by other forms of self-insurance expenditures because such expenditures are suboptimal. In the case of increased risk aversion, the model generates standard results for loss reduction activities with known productivities.

INTRODUCTION

This article examines the economic implications of a head-neck injury tradeoff encountered in the use of motorcycle helmets. This tradeoff establishes the technological limitations of motorcycle helmets as a form of self-insurance. In this context, a variant of Ehrlich and Becker's (1972) model of the interaction between market insurance, self-insurance, and self-protection and extensions of this framework that consider the role of increased risk aversion (Dionne and Eeckhoudt, 1985, and Hiebert, 1989) are used to establish an optimal decision rule for helmet use; evaluate mandatory helmet legislation, and assess changes in risk aversion on optimal self-insurance levels.

Using an econometric specification that considers the limits on the energy-dissipating capacity of motorcycle helmets, I have shown that, although helmets reduce head injuries at almost all realistic crash speeds, past a critical impact velocity (13.5 mph) to the helmet, helmets exacerbate the severity of neck injuries (Goldstein, 1986, 1988).[1] Beyond this critical speed, the energy-absorbing ability

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[1] The results of a number of empirical studies have weakened or reversed earlier findings on motorcycle helmet effectiveness. In particular, Sass and Leigh (1991), after correcting for selectivity bias, find that fatality rates in helmet law states are within one percent of rates in non–helmet law states. Goldstein (1986, 1988) finds a head-neck injury tradeoff. Bowman and Schneider (1980) find that helmets can induce neck injuries at higher impact velocities. Finally, Adams (1983) and Graham

of the helmet is surpassed and inertial and post-impact responses of the neck are intensified due to the added mass of the helmet. Thus, the loss-reduction productivity of helmet expenditures declines when helmet impact speeds exceed 13.5 mph and an individual's optimal self-insurance decision will be affected.

Optimal Self-Insurance Decisions Under the Head-Neck Injury Tradeoff

In contrast to Ehrlich and Becker (1972), who focus on the interaction between market insurance and self-insurance, I assume an exogenous level of partial market insurance (M) and, instead, consider the interaction between two forms of self-insurance: helmet expenditure (H) and expenditure on other forms of self-insurance such as protective clothing and/or driver safety courses (C).

The optimal self-insurance decision consists of choosing the values of H and C so as to maximize expected utility in a two-state world. The joint event of an accident and personal injury that occurs with probability p represents one state, and an injury-free period of riding constitutes the other state. Thus, the individual's self-insurance decision can be specified as

$$\text{maximize } V = (1-p(e;R))\, U(Y-H-C-M) + p(e;R)\, U(Y-\alpha L(H,C;S)-H-C-M) \quad (1)$$

where e = the endowed probability of personal injury,

R = the ridership—the amount of motorcycle use in a specified time period,
U = the utility function,
Y = endowed income,
L = expected losses (measured in units of income) in the hazardous state,
α = the percentage of losses not covered by market insurance, and
S = the operator's average driving speed.
R and S are assumed to be exogenous.

The exogenous treatment of R and S (driving time) distinguishes this analysis from Peltzman's (1975) model. Given that motorcycling is primarily a recreational activity, expenditure of time is the use of leisure time which has been derived from an optimal labor supply decision. A portion of leisure time is allocated to a particular type (s) of motorcycling activity—dirt riding, street riding, touring, etc.—each of which has associated with it an average driving speed. Thus, R and S become parameters of the model, and we focus on the conditional demand for C and H.[2]

In contrast to Peltzman's treatment of injury probability p as a function of driving speed S, here it is assumed that p is unrelated to S. Instead, injury prob-

and Lee (1986) find evidence to support the risk compensation hypothesis, which implies that regulation may intensify the head-neck injury tradeoff by inducing higher driving speeds.

[2] More formally, this approach can be justified by assuming that the utility function for the optimal labor supply decision is separable, that the resulting utility function for the optimal choice of protective goods and all other goods is separable, and that the choice of different motorcycling activities have different endowed average driving speeds associated with them.

ability is determined by the riskiness of the type of motorcycling activity undertaken and not by the driving speed associated with that activity.[3]

Alternatively, the effect of driving speed (S) on expected losses is two-fold. Expected losses (L) depend directly on the crash speed (v) and indirectly on the impact speed to the helmet (I) which mediates the loss-reduction productivity of the helmet. In assessing the expected loss, it is assumed that $\frac{E(I|S)}{S} > 0$ and $\frac{E(v|S)}{\alpha S} > 0$. Thus, the dual effect of S on L can be summarized by the following partial derivatives: $L_{HS} > 0$ and $L_S > 0$.

In addition, the effect of increased risk aversion on the optimal levels of C and H can be analyzed, as in Dionne and Eeckhoudt (1985) and Hiebert (1989), through the use of a concave transformation of U.

For purposes of exposition, let $y_0 = Y - H - C - M$, net income in state 0; and let $y_1 = Y - \alpha L(H,C;S) - H - C - M$, net income in state 1. It is assumed that

$$U_{y0} > 0,\ U_{y1} > 0,\ U_{y0y0} < 0,\ U_{y1y1} < 0,\ p_R > 0,\ L_C < 0,\ L_{CC} > 0,\ L_H \lesseqgtr 0,\ L_{HH} > 0.$$

The ambiguous sign on L_H—the loss-reduction productivity of H—is the result of the head-neck injury tradeoff. A critical average driving speed, S*, is defined as the speed above which $L_H > 0$. S* is such that $E(I|S^*) > I^*$ defined as the critical helmet impact speed beyond which the increase in neck injuries outweighs the reduction in head injuries.[4] In the theoretical arguments that follow, frequent references are made to numerous specific values of S, such as S*. These values are defined as follows:

S^* is defined as $L_H(S^*) = 0$.

$S^{**} < S^*$ is defined as $\alpha L_H(S^{**}) + 1 = 0$.

$S^{***} < S^{**}$ is defined as upper S limit for $H > 0$ when $H^* = 0$.

$S^{****} > S^{**}$ is defined as $\frac{dC}{dH^*}(S^{****}) = 0$.

The values of H and C that maximize expected utility must satisfy the first-order optimality conditions:

$$V_H = -(1 - p(e,R))\, U_{y0} - p(e,R)\, U_{y1}\, (\alpha L_H + 1) = 0 \qquad (2)$$

$$V_C = -(1 - p(e,R))\, U_{y0} - p(e,R)\, U_{y1}\, (\alpha L_C + 1) = 0. \qquad (3)$$

The necessary conditions for equations (2) and (3) to hold are $(\alpha L_H+1) < 0$ and $(\alpha L_C+1) < 0$—both expenditures on self-insurance must increase net income in the hazardous state. Although this condition holds in the case of C, the ambiguous sign on L_H implies that it does not hold under all circumstances for H. Thus, an optimal decision rule for helmet use ($V_H = 0, H > 0$) or nonuse ($V_H < 0, H = 0$) can be derived.

[3] For example, dirt bike riding in comparison to long distance touring will have a higher injury probability and a lower driving speed because of the inherent differences in the nature of the two activities.

[4] This impact (normal component of) velocity is estimated by Goldstein (1986) to be 20.8 mph.

A boundary solution ($H = 0$) exists if $-(1-p(e;R))U_{y0} < p(e;R)U_{y1}(\alpha L_H+1)$— the net expected utility gains from an additional unit of H is negative for all positive values of H. Holding all other rider characteristics constant, the decision to wear or not to wear a helmet depends on S. As $S \rightarrow S^{**}$, the speed (below S^*) that ensures $(\alpha L_H+1) > 0$ and $V_H < 0$, then $H \rightarrow 0$. Thus, a strong condition for $H = 0$ is that $S \geq S^{**}$. At $S \geq S^{**}$, helmet use lowers income in both states; thus, the decision not to wear a helmet is equivalent to income loss minimization or expected utility maximization. In contrast, $H > 0$ if $-(1-p(e;R))\ U_{y0} > p(e;R)U_{y1}(\alpha L_H+1)$ at $H = 0$. Given that $L_{HS} > 0$, there must exist an average driving speed $S^{***} < S^{**}$ that insures V_H approaches a positive value from below when $H = 0$. *Ceteris paribus,* if $S^{***} > 0$, then a helmet will be used in the range $0 < S \leq S^{***}$.

Comparative Statics and Constrained Optimization

The effect of mandatory helmet legislation can be analyzed by subjecting the individual's maximization problem in equation (1) to the inequality constraint: $H \geq H^*$, where H^* is the minimum acceptable expenditure on helmets. Comparative static results, derived in the Appendix, show that, in the case where $H > H^*$—the helmet expenditure constraint is not binding—$\frac{dH}{dH^*}=\frac{dC}{dH^*}=0$. In the case where $H = H^*$, $\frac{dH}{dH^*}=1$ and $\frac{dC}{dH^*} \lessgtr 0$. The sign of $\frac{dC}{dH^*}$ depends on the value of S. Given an optimal $H = H^*$, a strong condition for $\frac{dC}{dH^*} < 0$ is $S < S^{**}$ or $(\alpha L_H+1) < 0$.[5]

The weak condition for $\frac{dC}{dH^*} < 0$ requires that

$$(1-p)|U_{y0y0}| > p(\alpha L_H+1)(\alpha L_C+1)U_{y1y1} \tag{4}$$

at the new level of H^*. It can be shown that this condition holds at values of $S > S^{**}$.[6] Furthermore, as $p \rightarrow 0$, $\frac{dC}{dH^*} < 0$ at higher values of S. Given that the

[5] In this situation, an increase in H, in response to a unit increase in H^*, increases net income and thus expected utility in state 1 and decreases net income and expected utility in state 0. Prior to the increase in H^*, C was chosen to satisfy equation (3). The respective changes in income in both states, unambiguously cause $V_C < 0$ as U_{y1} decreases and U_{y0} increases, and thus induces a reduction in C. With a reduction in U_{y1}, a marginal increase in C, when the marginal productivity of $C(L_C)$ is held constant, will have less impact on utility in state 1 and is incapable of offsetting the losses in utility in state 0 which would be incurred if C was increased.

[6] If the right-hand side of equation (4) is a continuous function of S, F(S) (as is assumed and demonstrated empirically in Goldstein, 1986), $F(S^{**}) = 0$ (by definition of S^{**}), and the left-hand side of equation (4) is not a function of S, then the definition of continuity implies that, for an $\varepsilon > 0$, the left-hand side of equation (4) is greater than $F(S^{**}+\varepsilon)$: $\frac{dC}{dH^*} < 0$ for $S > S^{**}$. Given $\delta > 0$, there is an $\varepsilon > 0$ such that

probability of a motorcycle accident in a one-year period is small,[7] it is plausible that the speed interval over which the weak condition holds includes values of $S > S^*$; speeds at which increased helmet expenditures also increase losses ($L_H > 0$).[8] Thus, for $S > S^*$, the joint occurrence of $\frac{dC}{dH^*} < 0$ and $L_H > 0$ will have important implications for regulation-induced welfare losses. In the remainder of this article, it is assumed that $\frac{dC}{dH^*} < 0$ for $S^* < S < S^{****}$, where S^{****} is the S value at which $\frac{dC}{dH^*} = 0$.

In contrast, $\frac{dC}{dH^*} > 0$ if both $(\alpha L_H+1) > 0$ and $p(\alpha L_H+1)(\alpha L_C+1)U_{y1y1} > |(1-p)U_{y0y0}|$. This latter condition is met as $S \rightarrow \infty$ from above S^{**}. In this case, large expected losses induced by mandatory increases in H increase the expected utility gains from expenditures on C (due to increases in U_{y1}) such that $V_C > 0$.

These results can be used to assess the effects of mandatory helmet laws on an individual's expected losses and expected utility. Under the joint condition that $\frac{dC}{dH^*} < 0$ and $S > S^*$ or equivalently that $S^* < S^{****}$, our model predicts that riders with $S^* < S \leq S^{****} + \varepsilon$ will experience regulation-induced increases in expected losses, and riders with $S^{****} - \varepsilon \leq S \leq S^{****} + \varepsilon$ will suffer regulation-induced expected welfare losses, where ε is an arbitrarily small value. Depending on the degree of illiquidity of C expenditures, the speed interval over which welfare losses occur may include the entire interval over which increased expected losses are experienced.[9] Here, increases in regulation result in expected income losses because the high probability associated with the initial state implies that compensating expenditures on C lower the expected utility in the initial state more than they are capable of increasing expected utility in the alternative state. Welfare

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$$|S - S^{**}| < \varepsilon \rightarrow |F(S) - F(S^{**})| < \delta < |(1-p)U_{y0y0}|.$$

Given that $F(S^{**}) = 0$, this implies that $|(1-p)U_{y0y0}| > F(S)$ for $S^{**} + \varepsilon$.

[7] Given that the conditional probability of injury given the occurrence of an accident has been shown to be approximately 1 (0.98 in Hurt, Ouellet, and Thom, 1981, p. 169), p reduces to the probability of an accident which the Motorcycle Safety Foundation estimates to be 0.021 in 1993 for all 50 states.

[8] The gap between S and S^{**} and S^* also depends on α. As α increases, the gap declines.

[9] The existence of these regulation-induced losses requires that $S^* < S^{****}$ or equivalently that $dC/dH^* < 0$ and $S > S^*$—a sufficient condition for increased expected losses and welfare losses when C is sufficiently illiquid; and that S^* and S^{****} take on feasible values. To establish that these conditions hold, we evaluate the weak condition for $dC/dH^* < 0$, equation (4), at values of $S > S^*$. Estimates of L_H and L_C are derived from the results in Goldstein (1986), Hurt, Ouellet, and Thom (1981), Lloyd, Lauderdale, and Betz (1987), and Rivara et al. (1988), while estimates of relative risk aversion are taken from Friend and Blume (1975) and Hubbard and Judd (1986). This evaluation shows for realistic parameter values that $S^* < S^{****}$ or equivalently that the strong condition for regulation-induced expected losses and for expected welfare losses when C is significantly illiquid is satisfied at a realistic driving speed of 59.4 mph. An appendix containing a detailed derivation of this result is available upon request from the author.

losses result in the neighborhood of $\frac{dC}{dH^*} = 0$ because regulation lowers income in both states and thus reduces expected utility. These results are formally derived in the Appendix.

The effect of increased risk aversion can be analyzed through a concave transformation of U in equation (1). It is formally shown in the Appendix that, in the unconstrained case, increased risk aversion leads to *ceteris paribus* increases in each of the forms of self-insurance as long as each loss reduction activity increases income in the hazardous state. In the case where $(\alpha L_H+1) > 0$, increased risk aversion implies less usage of H but since H = 0, the optimal solution is unaffected. In the constrained case, the results are the same except when desired H < H*. In this case, H remains the same at H*. These results are standard for loss reduction activities with known productivities.[10]

Conclusion

This analysis of the optimal self-insurance decision, conditional on the existence of a head-neck injury tradeoff, establishes that mandatory helmet use legislation results in expected welfare losses for a subset of the motorcycling population. For this segment of the population, the increase in net injuries, and thus expected losses as a result of regulation, are not compensated by other forms of self-insurance expenditures because such expenditures are suboptimal.

If a major concern of policy-makers is the overall costs to society in the form of health care costs and lost productive output from motorcycle accidents, our empirical and theoretical results imply that existing cost-benefit analyses that fail to consider the injury tradeoff are inappropriate for policy guidance. Until studies are adequately designed and completed, the passage of helmet use laws, which 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 individual losses that are not compensated by other forms of self-insurance, externalities, and high marginal disutilities associated with helmet use for all or a subset of motorcyclists imply a net cost to the individual and thus raise questions about the redistribution of income resulting from helmet legislation. Furthermore, alterations in driving behavior in response to mandatory helmet use laws, predicted by the theories of risk compensation and risk homeostasis, may dissipate net benefits to society from regulation.

[10] Hiebert (1989) shows that, when the effectiveness of loss reduction measures are uncertain, this intuitive result may not hold. In particular, the uncertainty increases the variance of the loss, thus making it possible for the risk-averse individual to choose less self-insurance.

APPENDIX

In this Appendix, comparative static results are derived for changes in both regulation and risk aversion, and the existence of regulation-induced welfare losses are derived. Consider a constrained variant of the self-insurance problem in equation (1).

$$\text{maximize } V = (1-p(e;R))\,U(Y-H-C-M) + p(e;R)\,U(Y-\alpha L(H,C,S)-H-C-M) \quad \text{(A1)}$$

subject to

$$H \geq H^*. \quad \text{(A2)}$$

The Kuhn-Tucker conditions associated with an interior solution are

$$-(1-p(e;R))U_{y0} - p(e;R)U_{y1}(\alpha L_H+1) + \lambda = 0 \quad \text{(A3)}$$

$$-(1-p(e;R))U_{y0} - p(e;R)U_{y1}(\alpha L_C+1) = 0 \quad \text{(A4)}$$

$$\lambda(H-H^*) = 0. \quad \text{(A5)}$$

Total differentiation of equations (A3), (A4), and (A5) under the assumption that $dR = dS = 0$ (exogeniety of S and R) yields the following equations:

$$A\,dH + B\,dC + d\lambda = 0$$

$$B\,dH + G\,dC = 0$$

$$K\,dH + L\,d\lambda = M\,dH^*,$$

where, under the assumption that $L_{HC} = L_{CS} = 0$,

$$A = (1-p)U_{y0y0} + p(\alpha L_H+1)^2 U_{y1y1} - U_{y1}p\alpha L_{HH}$$

$$B = (1-p)U_{y0y0} + p(\alpha L_H+1)(\alpha L_C+1)\,U_{y1y1}$$

$$F = B$$

$$G = (1-p)U_{y0y0} + p(\alpha L_C+1)^2 U_{y1y1} - U_{y1}p\alpha L_{CC}$$

and $K = M = \lambda$ and $L = H-H^*$.

Effect of Regulation

Given this model,

$$\frac{dC}{dH^*} = \frac{-M}{BL+\frac{KG}{B}-\frac{AGL}{B}}, \text{ and } \frac{dH}{dH^*} = \frac{M}{K-LA+\frac{LB^2}{G}}.$$

In the case where $H > H^*$, $\lambda = 0$, implying that $\frac{dC}{dH^*} = \frac{dH}{dH^*} = 0$. In the case where $H = H^*$ and $S < S^{**}$, $(\alpha L_H+1) < 0$ and $L = 0$, implying that $\frac{dC}{dH^*} < 0$ and $\frac{dH}{dH^*} = 1$, but if $S > S^{**}$, $(\alpha L_H+1) > 0$ and the sign of B and thus $\frac{dC}{dH^*}$ depends on the size of $p(\alpha L_H+1)(\alpha L_C+1)U_{y1y1}$ in relation to $|(1-p)U_{y0y0}|$.

To assess the effects of regulation on expected losses and expected utility, consider three groups of riders distinguished by the value of S: (1) low S such that $H > H^*$ and thus $\frac{dC}{dH^*}=0$; (2) medium S such that $\frac{dC}{dH^*}<0$; and (3) high S such that $\frac{dC}{dH^*}>0$. Total expected losses, E(L), associated with regulation can be expressed as

$$\frac{dE(L)}{dH^*}=p\alpha L_C\frac{dC}{dH^*}+p\alpha L_H\frac{dH}{dH^*}.$$

For group 1, $\frac{dC}{dH^*}=\frac{dH}{dH^*}=0$, implying that E(L) and V are unaffected by helmet legislation. If $S^* < S^{****}$ (the joint condition for regulation-induced increases in expected losses holds), for group 2 $\frac{dC}{dH^*}<0$, $\frac{dH}{dH^*}=1$, and $L_H \leq 0$ for $S \leq S^*$, whereas $L_H > 0$ otherwise. Thus, a subset of this group may experience a decline in E(L), while the remaining individuals ($\frac{dC}{dH^*}<0$ and $S > S^*$) will sustain an increase.

Furthermore, a portion of group 2 riders will experience an absolute decline in V. Recalling that $\frac{dC}{dH^*}(S^{****})=0$ and recognizing that $S^* < S^{****}$, at $S = S^{****}$ as $H \rightarrow H^*$ from 0 the average expenditure on a helmet and the increase in expected losses ($L_H > 0$) lower y_0 and y_1 and thus reduce V.

The magnitude of welfare losses is expressed by an ex ante compensating variation (CV) for $S^* < S < S^{****}$:

$$CV=\frac{(1-p)(dH^*+dC)U_{y0}+p[(L_C+1)dC+(L_H+1)dH^*]U_{y1}}{(1-p)U_{y0}+pU_{y1}},$$

where dH^* is the average price of a helmet, and $dC = \frac{dC}{dH^*}\cdot dH^*$. In the case where $\frac{dE(L)}{dH^*}>0$, a strong condition for $CV > 0$ is that $dH^* > -dC$, while the weak condition requires that the numerator is positive.

Given the illiquid nature of C expenditures—boots, gloves, leather clothing, training courses, etc.—it is likely that effective regulation-induced C reductions are less than notional reductions, effectively implying that $0<\left|\frac{dC}{dH^*}\right|<1$ is likely to hold at speeds well below S^{****}. Thus, it is quite plausible that all riders with

$\frac{dC}{dH^*} < 0$ and $S^* < S < S^{****}$ experience welfare losses—the strong condition for expected losses is the same as for expected utility losses.

Finally, for group 3, $\frac{dC}{dH^*} > 0$, $\frac{dH}{dH^*} = 1$, and $L_H > 0$. Although the change in total expected losses cannot be easily signed, it can be shown that there exists a range of $S > S^{****}$ $\left(\frac{dC}{dH^*} > 0\right)$ for which CV > 0. Given the continuous CV function, G(S), and that $G(S^{****}) > 0$, then the definition of continuity implies that $G(S^{****} + \varepsilon) > 0$. Thus, some riders in this group will meet the weak condition for CV > 0.

Effect of Risk Aversion

To assess the effects of increased risk aversion, consider a concave transformation (K) of U for the problem in equation (A1) such that

$$Z = K(U) \text{ with } K_U > 0,\ K_{UU} < 0.$$

The first-order conditions for the constrained problem evaluated at the optimal C and H levels, $\overline{C}$ and $\overline{H}$ are

$$V_H' = -(1-p)K_U U_{y0}(\overline{C},\overline{H}) - pK_U U_{y1}(\overline{C},\overline{H})(\alpha L_H + 1) + \lambda = 0$$

$$V_C' = -(1-p)K_U U_{y0}(\overline{C},\overline{H}) - pK_U U_{y1}(\overline{C},\overline{H})(\alpha L_C + 1) = 0$$

$$V_\lambda' = \lambda(H - H^*) = 0,$$

where V′ is the transformation of V.

In the unconstrained case ($\lambda = 0$) when an interior solution exists, given that $K_U U_{y1} > K_U U_{y0}$ evaluated at $\overline{C}$ and $\overline{H}$, then $V_H' > 0$ and $V_C' > 0$, implying that C and H will both increase. For an H boundary solution ($(\alpha L_H + 1) > 0$), H remains the same at H = 0 while C increases. In the constrained case ($\lambda \neq 0$) with functions evaluated at $\overline{C}$ and $\overline{H}$ for $\overline{H} \geq H^* \rightleftarrows \lambda = 0$, both C and H increase. For $\overline{H} \leq H^*$, H remains at H* and C increases.

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