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THE OPTIMUM SPEED LIMIT

James Jondrow
Marianne Bowes
Robert Levy

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THE OPTIMAL SPEED LIMIT

JAMES JONDROW, MARIANNE BOWES, and ROBERT LEVY*

INTRODUCTION

The optimal speed for a driver and the optimal speed limit imposed by a government are two distinct concepts. A driver's optimum is determined by equating the marginal benefit of increased speed — reduced travel time — to the private marginal cost — increased fuel usage and increased probability of an accident. If the social marginal cost of speed exceeds the private, the private optimum speed will be higher than the welfare-maximizing speed, and society can benefit by imposing a speed limit.

In this paper, we describe an improved method of measuring the private and social benefits and costs associated with speed and give some simplified numerical examples. The examples illustrate that, without arbitrarily judging the value of human life, it is possible to: (1) estimate the optimum speed limit; (2) estimate the cost, per life saved, of a speed limit below the optimum, which can be compared with the cost of saving lives in other ways; and (3) specify the types of information needed to improve estimates of the optimum.

We have considered only the simplest case, in which all drivers are rational and informed. Further, drivers have the same parameters and, hence, would choose to go the same speed if there were no speed limit. Thus, we are abstracting from any variation in speed and the externalities that fast and slow drivers impose on each other.

Our method involves using the speed individuals would go if unencumbered by a speed limit. For this, we need to observe how fast drivers go in places where a limit is absent. The optimum speed limit is then obtained by adjusting this private speed so that the marginal benefits of extra speed equal the social marginal costs rather than the private. We conclude on the basis of our analysis that even if everyone would go the same speed without a speed limit, there are externalities present that justify a speed limit; and that the range of uncertainty about the optimal speed limit can be reduced drastically by paying close attention to driver behavior when there is no speed limit.

RELATED WORK

The present study is based on a number of valuable contributions. Several studies have evaluated the 55-mph speed limit in the United States [Castle (1976); Clotfelter and Hahn (1978); Lave (1979); U.S. National Highway Traffic Safety Administration (1977, 1979, 1980)]. Lave (1979), Castle (1976) and Clotfelter and Hahn (1978) (which we abbreviate as CH) estimated the benefits and costs of reducing the speed limit to 55. Lave and Castle concluded that the costs outweighed the benefits, while CH, using a different approach, reached the opposite conclusion. None of these studies tried to estimate the optimal speed limit. CH did, however, recognize two types of externality: the fact that drivers ignore the effect of their speed on the probability of an accident for other drivers and the divergence between the private and

social cost of gasoline when gas prices are controlled. Other relevant papers include a study of English Motorways [Ghosh, Lees, and Seal (1975)], which estimated the optimum speed limit, but did not include any discussion of externalities. Papers by Blomquist (1979, 1981) and Blomquist and Peltzman (1981) recognize the crucial importance of externalities in public policy having to do with auto safety. Finally, Thaler (1976) provides a good discussion of the role of externalities in the optimum speed limit, but he does not focus on how to estimate the optimum.

THE THEORY OF THE OPTIMUM SPEED LIMIT

Assume that the amount of driving the representative driver wishes to do is fixed at D miles per year. The driver's utility (U) is a function of three variables: a consumption good (X), the probability of being killed in an accident (ρ), and travel time (T). The dependence of U on T is meant to illustrate the fact that time is valuable, since other uses of time, including leisure or income production, decrease when one travels in an automobile.

The driver chooses X and S (speed) to maximize utility subject to his income constraint, $P_XX + P_GG = Y$, where

P_X = price of the consumption good;

P_G = price of gasoline;

G = quantity of gasoline;

Y = income.

The Lagrangian is

$$L = U(T, \rho, X) + \lambda(Y - P_XX - P_GG).$$

Utility is maximized with respect to speed when

(1) $$U_1 \frac{\partial T}{\partial S} + U_2 \frac{\partial \rho}{\partial S} - \lambda P_G \frac{\partial G}{\partial S} = 0,$$

where U_1 and U_2 are partial derivatives of U with respect to the first two arguments, T and ρ.

We will approximate U_1 and U_2 by constants. Relating U_1 and U_2 to the values of life and time eases the interpretation:

(2) $$U_1 = -V_T\lambda;$$

(2a) $$U_2 = -V_L\lambda,$$

where:

V_T is the dollar value of time (more precisely, the dollar value of the disutility of time spent driving);

V_L is the value of a life (dollars per person) as revealed by responses to the probability of being killed.[1]

λ is the marginal utility of income.

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1. More precisely, V_L is defined as $-(\partial U/\partial \rho)/(\partial U/\partial Y)$. In other words, V_L is the amount of income necessary to compensate a driver for a very small change in the chance of being killed, divided by the amount the chance is increased.

The values of $\partial T/\partial S$, $\partial \rho/\partial S$, and $\partial G/\partial S$ depend on the length of the trip, D (in miles). Since $T = D/S$,

$$\frac{\partial T}{\partial S} = \frac{-D}{S^2} .$$

which expresses the dependence on D. Define $\alpha(S)$ as the probability of being killed per mile, and assume[2]

$$\frac{\partial \alpha}{\partial S} = \frac{\partial \rho}{\partial S} \frac{1}{D} .$$

Finally, let $G = gD$, where g is the amount of gas used per mile so that

$$\frac{\partial G}{\partial S} = D \frac{\partial g}{\partial S} .$$

The Private Optimum

We assume that, when deciding how fast to drive, a driver only worries about his own personal costs and benefits. The individual therefore equates the marginal benefit from added speed, given by $\lambda V_T D/S^2$, with the private marginal cost, given by $\lambda V_L D(\partial \alpha/\partial S) + \lambda P_G D(\partial g/\partial S)$. The first term in marginal cost represents the costs of the increased chance of getting killed, the second the costs of increased gas consumption.

Figure 1 presents the graphic representation leading to the private optimal speed, S_p, which is given by

$$(3) \qquad S_p = V_T^5 \left[V_L \frac{\partial \alpha}{\partial S} + P_G \frac{\partial g}{\partial S} \right]^{-.5} .$$

Equation (3) shows that for an individual, the optimal speed depends positively on his value of time and negatively on his valuation of his own life, the increase in his probability of being killed at higher speeds, and on the extra amount spent on gasoline at higher speeds.
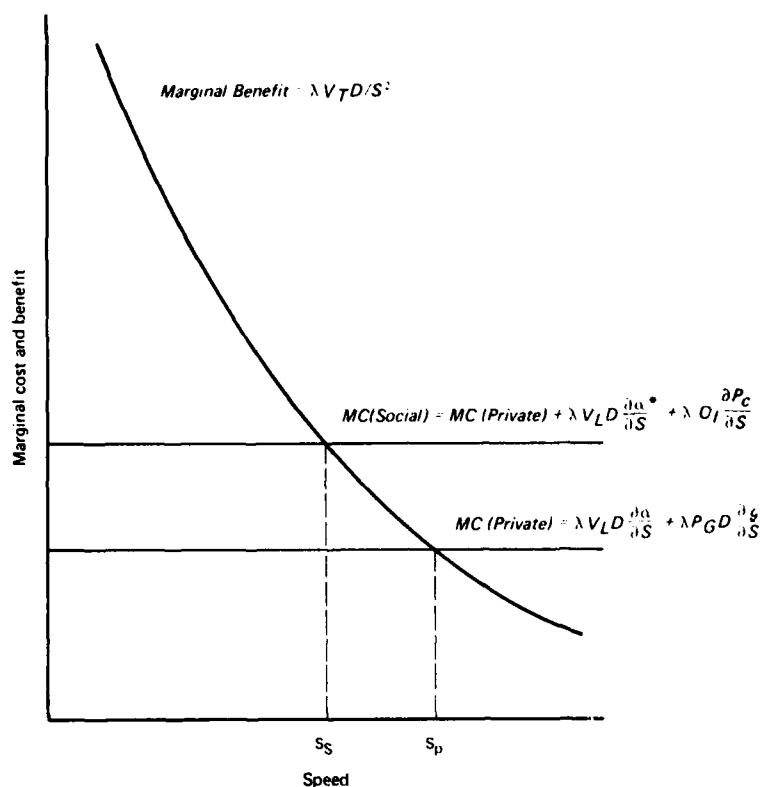
Information and Rationality

We have assumed that the individual is fully capable of determining his optimal speed. Two conditions are necessary for this to be true. First, we assume that the driver has the information necessary to determine his optimal speed or, at least, that he has as good knowledge as the government. This assumption is appealing because part of the information needed to determine the personal optimum consists of the value of the driver's life and his time, which the driver himself is in the best position to know. Even on more technical matters, such as the probability of an accident, the driver has unique sources of information; for example, he knows what characteristics of his driving behavior lead to "close calls."

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2. That D and ρ are roughly proportional may be derived as follows: the probability of having an accident in D miles is $1 - (1 - \alpha(S))^D$, or 1 minus the probability of not having an accident for D miles. We want to show that $1 - (1 - \alpha)^D = \alpha D$ or equivalently $(1 - \alpha)^D = 1 - \alpha D$. This is simply an approximation to the binomial theorem for α small.

FIGURE 1

Private vs. Social Optimum

Second, we assume that drivers are rational; that is, given the necessary information, they would drive at their optimum speed. While it may be that some drivers are irrational (teenagers are often mentioned),[3] the hypothesis of irrationality is untested. Indeed, it is hard to see how the concept could be made precise enough to be tested. Irrationality implies that drivers do not act in their own best interests, but we have no independent assessment of a driver's "best interest."

Together, the assumptions of complete information and rationality imply that the speed in the absence of a speed limit is the private optimum. These assumptions do not imply that a speed limit is therefore unnecessary. The next section outlines the reasons why society might find it necessary to impose a speed limit, even when drivers are assumed to be informed and rational.

3. Transportation engineers sometimes define the "optimal speed limit" as the 85th percentile in the distribution of unrestricted speeds. One possible explanation for this rule is that transportation engineers regard the 15 percent fastest drivers as irrational.

The Social Optimum

The private optimum is not the same as the social optimum because of external costs. We will consider two types of externality, one to do with the probability of an accident and the other with the cost of gasoline.

The Accident Externality

A speeding driver increases not only the probability of killing himself but also the probability of killing others. Let us represent the increased probability of killing oneself by $\partial\alpha/\partial S$ and the increased probability of killing others by $\partial\alpha^*/\partial S$.[4] For simplicity, we assume a linear relationship so that the accident component of social marginal cost is given by $\lambda V_L D(\partial\alpha/\partial S + \partial\alpha^*/\partial S)$. The ratio of total to internal (or social to private) cost is thus given by $(\partial\alpha/\partial S + \partial\alpha^*/\partial S)/(\partial\alpha/\partial S)$ or $1 + \beta$, where $\beta = (\partial\alpha^*/\partial S)/(\partial\alpha/\partial S)$ is the accident externality ratio.

The Gasoline Externality

The decontrol of crude oil and gasoline prices has removed much of the difference between the private and social cost of gasoline. Yet, there remains one externality associated with increased speed and the subsequent effect on the price of oil. The externality arises when, due to increased speed, there is a transfer of income from citizens of the U.S. to citizens of oil-producing nations and, in particular, OPEC.[5] We can expand the notion of external costs by including a term representing the external cost of crude oil consumption. This term is given by $Q_I(\partial P_c/\partial S)$, where Q_I = the amount of imported oil and P_c = the price of crude oil. It expresses the dollar value of the transfer to foreign producers that arises when average speed is increased by one mile per hour.

The calculation of the gasoline externality requires an estimate of $\partial P_c/\partial S$. Our estimate is based on the following assumptions:[6]

1. OPEC acts as a profit-maximizing monopolist, while oil producers in the rest of the world act as a competitive fringe.

2. The demand for OPEC oil, which equals world demand less supply from the rest of the world, is a linear function of P_c and S, average driving speed:

(4) $$Q = f(P_c, S) \text{ with } f_r < 0, \ f_s > 0, \ f_{rr} = f_{rs} = f_{ss} = 0.$$

3. Marginal cost of production is zero.

The first-order condition for profit maximization for OPEC is that marginal revenue equal marginal cost, or

(5) $$P_c + \frac{1}{f_r} Q = MC.$$

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4. In this analysis, we abstract from the fact that the probability of killing or being killed at a given speed is a function of the density of traffic on the road.

5. The transfer is similar to that involved in an optimum tariff [Johnson (1950-51)]. Of course, a speed limit does not generate tariff revenue, but it does shift the terms of trade in the same direction as a tariff.

6. Admittedly, some of the assumptions in this section are a bit strong. We are presenting the case where external costs are highest and therefore obtain an upper bound on the externality.

Totally differentiating, we obtain

$$(6) \qquad\qquad f_r dP_r + dQ = 0.$$

Totally differentiating the demand equation (4) gives:

$$(7) \qquad\qquad dQ = f_r dP_r + f_s dS.$$

Solving for dQ from (6) and substituting into (7) yields

$$(8) \qquad\qquad dP_r = -.5 \, \frac{f_s}{f_r} \, dS.$$

At the profit-maximizing price, the elasticity of demand is -1, i.e., $f_r = -Q/P_r$. Substituting into (8) gives the relationship between changes in speed and changes in the price of oil:

$$(9) \qquad\qquad \frac{dP_r}{dS} = \frac{1}{2} \, \frac{P_r}{Q} \, f_s.$$

The external cost of crude oil consumption due to increased speed is therefore

$$\frac{1}{2} \, P_r \, \frac{Q_t}{Q} \, f_s.$$

The Optimal Speed Limit

Assuming the costs of government intervention are outweighed by the benefits of reducing the accident and gasoline externalities, an optimal speed limit may be imposed with the proper information. The government should start from the personal optimum and adjust it only for externalities.

The socially optimal speed is determined by equating marginal benefit and social marginal cost:

$$(10) \qquad \lambda V_T D/S_s^2 = \lambda V_L D \left(\frac{\partial \alpha}{\partial S} + \frac{\partial \alpha^*}{\partial S} \right) + \lambda P_L D \, \frac{\partial g}{\partial S} + \lambda Q_t \, \frac{\partial P_r}{\partial S} \, .$$

Figure 1 may also be used to illustrate the graphical determination of the optimal speed limit. The difference between MC(Social) and MC(Private) is equal to $\lambda V_L D(\partial \alpha^*/\partial S) + \lambda Q_t (\partial P_r/\partial S)$. This is the valuation of the externalities caused by increased speed, i.e., the value of lives lost by people other than the speeding driver plus the value of the extra revenue going to foreign oil producers.

Solving (10) for S_s yields an expression similar to that for S_p, except for two additional terms:

$$(11) \qquad S_s = V_T^5 \left[V_L \left(\frac{\partial \alpha}{\partial S} + \frac{\partial \alpha^*}{\partial S} \right) + P_L \, \frac{\partial g}{\partial S} + \frac{Q_t}{D} \, \frac{\partial P_r}{\partial S} \right]^{-.5} \, .$$

One way to estimate the optimal speed limit would be to assign values to all the parameters in (11). It is not difficult to find data on gasoline prices, and there exist studies relating highway fatality rates to driving speed and gas mileage to speed. The value of time and the value of a life are harder to determine because they cannot be observed directly, but only inferred from consumer behavior.

We propose an alternative method for calculating S_x that gets around the problem of estimating the value of a life. Our method involves observing the average speed on roads where there is no speed limit; we assume this equals S_r. With knowledge of S_r, we can solve (3) for V_l and substitute into (11) to obtain:

$$(12) \qquad S_x = \left[S_r^2(1 + \beta) - \beta \, \frac{P_G}{V_r} \, \frac{\partial g}{\partial S} + \frac{Q_l}{DV_l} \, \frac{\partial P_l}{\partial S} \right]^{-.5}$$

An important characteristic of equation (12) is that knowledge of V_l is not necessary. Knowledge of V_r is needed, but this is less controversial. Further, it will turn out that the optimal speed limit is less sensitive to V_r when S_x is calculated using (12) than when it is calculated using (11).

Interpretation of (12) is made easier by substituting for $\beta \, S_r^2$ from equation (2). This leads to equation (12a), which illustrates how the two types of externality drive a wedge between the private and social optimum:

$$(12a) \qquad S_x = \left[S_r^2 + \frac{V_l}{V_r} \, \frac{\partial \alpha^*}{\partial S} + \frac{Q_l}{DV_r} \, \frac{\partial P_l}{\partial S} \right]^{-.5}$$

If drivers are irrational or poorly informed, we could not determine S_r by observing driver behavior. The government would then have to use (11) to compute the optimum speed limit by inserting the relevant parameters. But where will they get these parameters? The standard estimates, drawn from empirical studies of the value of time and the value of a life, are based on studies of individual choice, which rely on the very same assumptions of rationality and adequacy of information. Moreover, empirical estimates of V_r and V_l vary widely and without some way of choosing among them, (11) would provide little guidance concerning the optimal speed limit. In a case like this, the government's ability to determine the social optimum might be so poor that the private optimum, while also imperfect, would be preferable.

CALCULATING THE OPTIMAL SPEED LIMIT

In this section, we present some calculations of the optimal speed limit. The purpose of these calculations is to illustrate the difference between two methods for calculating S_x (one based on (11) and one based on (12)), not to derive a precise estimate of the limit.

Table 1 displays the private and social optima that correspond to various values of V_r and V_l.[7] The optimal speed limit (the last column) covers a wide range, depending upon the assumptions. It would be difficult to choose the "best" estimate of S_x under these circumstances. The essence of our method, on the other hand, is to focus on

7. The appendix lists the values of the parameters not shown in tables 1 and 2. In table 1, $\beta = .50$.

those values of life and time consistent with the observed speed without a limit. For example, suppose S_r = 85 mph (roughly the speed on the German Autobahn).[8] The cases consistent with a private optimum of 85 mph are highlighted. The range of uncertainty about the optimum speed limit is drastically reduced.

TABLE 1

Estimates of the Private and Social Optimal Speeds

Value of time ($ per hour)	Value of life ($ per life)	Private optimum (mph)	Social optimum (mph)
$ 5	$ 100,000	60.8	56.9
5	1,000,000	53.4	48.2
5	10,000,000	29.4	24.7
10	100,000	86.0	8ⁿ
10	172,919	85.0	
10	1,000,000	75.5	?
10	10,000,000	41.5	
15	100,000	105.4	)
15	1,000,000	92.4	?
15	1,715,359	85.0	
15	10,000,000	50.9	4z.ↄ
20	100,000	121.7	113.9
20	1,000,000	106.7	96.5
20	3,257,800	85.0	73.8
20	10,000,000	58.7	49.4

In table 2, we use (12) to compute the optimum speed limit for various values of S_r, β, and V_r. We have proceeded by assigning values to V_t and β and deriving the values for V_t and S_v that are consistent with a private optimum of (a) 85 mph and (b) 75 mph. Several features of the results in table 2 are worth noting. First, the values for S_v are all less than the unrestricted speed, as expected. Second, when S_r = 85, the optimum speed limit is above 70, which is well above the current limit of 55. Third, the value of S_v does not seem very sensitive to changes in V_t. For example, comparing the first and second cases in the table yields an arc-elasticity of the speed limit with respect to V_t of .1 in absolute value. If instead the optimal speed limit were calculated directly from equation (11), the elasticity would be .5, five times as high as our estimate. Thus, by restricting ourselves to combinations of V_r and V_t consistent with observed speeds, the importance of V_t is greatly diminished. Finally, the value of S_v is quite sensitive to changes in S_r. If S_r were 75 mph, the value for S_v would fall from 75.5 to 65.3 (for V_t = $15, β = .5), an elasticity of about 1.15.

8. 85 mph may be an overestimate of the private optimum for American drivers, due to differences between the U.S. and Germany in driving habits and the technical capabilities of cars. As noted above, our calculations are meant to be illustrative.

TABLE 2

Sensitivity of the Optimal Speed Limit
to Variations in the Parameters

Value of Time[a]	β	Implied Value of Life	Optimum Speed Limit
Unrestricted Speed = 85 MPH			
10	.50	172,919	79.3
15	.50	1,715,359	75.5
20	.50	3,257,800	73.8
100	.50	27,936,843	70.2
15	.25	1,429,466	78.5
15	.75	2,001,253	72.9
Unrestricted Speed = 75 MPH			
15	.50	3,031,575	65.3
15	.25	2,526,313	68.7
15	.75	3,536,838	62.4

[a] Recall that these dollar values represent the disutility of time spent driving, which explains their exceeding the average wage.

The Costs of a Suboptimal Speed Limit

The government imposed the national 55-mph speed limit ostensibly to conserve gasoline. More recently, the 55-mph limit has been justified by its effect in saving lives. Assuming that it does, we might ask what is the cost per life saved by imposing the 55-mph speed limit when compared to the socially optimal speed limit obtained using (12).

Measurement of the lifesaving cost of a suboptimal speed limit requires dividing the benefits from imposing the limit into those associated with saving lives and those from other sources, such as lower gas consumption. The lifesaving cost equals the total cost minus the benefits not associated with saving lives. Dividing this cost by the number of lives saved yields the cost per life saved, which can be compared with the benefit per life saved, V_l.

Algebraically, lifesaving cost can be expressed as

$$C = D \int_{S_o}^{S_i} \left(\frac{V_T}{S^2} - P_G \frac{\partial g}{\partial S} - \frac{Q_l}{D} \frac{\partial P_c}{\partial S} \right) dS.$$

where S_o is the actual speed limit (say, 55) and S_i is the optimal speed limit. The term V_T/S^2 is the time cost of going one mph slower over a distance of one mile. The other term, $[P_G(\partial g/\partial S) + (Q_l/D)(\partial P_c/\partial S)]$, is the benefit from saving gas plus the benefit from decreasing the revenue going to foreign oil producers.

To illustrate how C would be calculated, we use an example from table 1 where $V_t = \$15/\text{hour}$ and $S_c = 75.5$ mph. Letting $D = 676$ billion miles (the number of miles traveled in the U.S. in 1976 on main rural and interstate urban roads, from [Motor Vehicle Manufacturers Association (1978), p. 60], we calculate the lifesaving cost of a 55-mph speed limit as approximately \$29.6 billion per year.

The reduction in the probability of being killed by reducing the speed limit from 75.5 to 55 is equal to 1.38×10^{-5} per mile, or $(\partial\alpha/\partial S + \partial\alpha^*/\partial S)(75.5\text{-}55)$.[9] This implies about 9,330 lives are saved per year by having a 55-mph rather than a 75.5-mph speed limit. The cost per life saved is thus about \$3.2 million, or \$1.5 million per life above the value individuals place on their own lives (since $V_t = \$1.7$ million). How does this compare with the cost of other ways of saving lives? A survey of the cost of saving lives in 57 cases of federal safety efforts [Graham and Vaupel (1981)] reveals only 12 that are more expensive.

CONCLUSION

The generally accepted rationale for imposing speed limits on highways is that there are external costs in driving that increase as speed increases. Based on that rationale, the parameters to be considered in calculating optimum speed limits can be named. One way to proceed with the calculation is to assume values for the parameters. Unfortunately, those values are subject to a great deal of uncertainty, especially the value of a life. In this paper, we have explored an alternative method in which key parameters are inferred from the driver's revealed preferences.

In our proposed method of calculation, it turns out that two parameters are of crucial importance: the uncontrolled speed and the ratio of external to internal costs. The value of time proves to be less important than it is when using the method where the parameters are fixed without reference to the driver's revealed preferences.

To demonstrate our method, we used (crude) available data to calculate the optimum speed limit on high quality roads, such as the interstate highways. We found that the optimum is well above 55 mph, and imposing a 55-mph speed limit is an expensive way to save lives. While the demonstration suggests that the 55-mph limit should be reconsidered, detailed calculations with more precise parameter estimates are needed, if policies are to be changed. The data needed to refine the calculations, while not currently available, should be relatively easy to collect. More important, the method is *generally* applicable; it can be used to determine the optimum speed limit on roads of all kinds, not only interstate highways.

APPENDIX
PARAMETER VALUES

Table A-1 presents the parameter values used in the calculations in tables 1 and 2. A brief discussion of some of these values follows:

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9. Assuming that the speed limit does not cause any other change in driver behavior. Peltzman acknowledges that while "the effects of a speed limit can be mitigated by less careful driving at lower speeds . . . speed limit laws do appear to work" [Peltzman (1976), p. 28].

TABLE A-1

Para. ... ter Values

Parameter	Definition	Value	Source
$\dfrac{\partial \alpha}{\partial S} + \dfrac{\partial \alpha^*}{\partial S}$	change in accident probability per mile w.r.t. speed	6.73×10^{-10} deaths/(vehicle mile) (mph)	Castle (1976)
β	accident externality ratio	.25-.75	—
P_c	price of gasoline	\$1.50/gallon	—
$\dfrac{\partial g}{\partial S}$	change in gas used per mile w.r.t. speed	.000871 gallons/ (mile)(mph)	Castle (1976)
P	price of crude oil	\$30/barrel	—
Q_I	amount of oil imported by the U.S.	8.2 million barrels/day (1978)	McCaslin (1980, p. 295)
Q	OPEC oil production	30.3 million barrels/day (1978)	McCaslin (1980, p. 294)
f_s/D	change in crude oil consumption per mile w.r.t. speed	.0000415	see below

$\partial \alpha / \partial S + \partial \alpha^* / \partial S$ was calculated from information in Castle (1976). An alternative calculation using figures on average speed and the death rate per vehicle mile for 1973 and 1974 (from 1979 *Statistical Abstract*, p. 643) yields 8.1×10^{-10}. These numbers may be on the low side because other factors that influence the accident rate (traffic density, the general level of safety, etc.) have not been held constant. In U.S. Department of Commerce (1964), the estimated change in the probability of a fatal accident on four-lane main rural highways for the range 55-67.5 mph was 3.2×10^{-10}.

Direct data on β could not be obtained. To check our assumptions, we made some rough calculations using data on traffic fatalities by cause [Motor Vehicle Manufacturers Association (1978), p. 56]. Assume that all deaths from collisions with pedestrians or bicycles and one-half of deaths from collisions with other motor vehicles involve persons other than the driver of the car at fault, and that all other deaths do i..volve that driver (or his passengers). The ratio of the first category of fatality to the second is a rough estimate of β. The average value of this ratio for 1960-77 was about .70.

$\partial g / \partial S$ was calculated using information from the U.S. Department of Transportation (1973) [as reported in Castle (1976)]. Our number may be on the high side. Ghosh, Lees, and Seal (1975) use .00062 U.S. gallons/(mi)(mph). Clotfelter and Hahn (1978) use .00080, which is calculated from [U.S. Department of Transporta-

tion (1975)]; they also mention an EPA study [U.S. Environmental Protection Agency (1974)] that implies $\partial g/\partial S$ = .00065 in the range 60-70 mph.

f_s/D is the change in crude oil consumption when average speed is increased by one mph for one mile. The change in gasoline consumption when average speed rises is $\partial g/\partial S$ ≈ .000871 gallons/(mi)(mph). To convert to barrels of crude, we assume two barrels of crude oil are used per barrel of gas and use the conversion factor 42 gallons = 1 barrel to get 1/21 barrels of oil/gallon of gas. f_s/D is then $(1/21)(\partial g/\partial S)$.

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