A UTILITY MAXIMIZATION MODEL OF DRIVER TRAFFIC SAFETY BEHAVIOR*

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Abstract—A simple utility maximization model is presented to illustrate that risk compensation is a natural part of human behavior when individuals pursue multiple goals with limited resources. In this positive economic model driver safety effort is determined by a balance between reduced risk and increased disutility cost. Changes which affect the balance induce drivers to change their own safety efforts. Under plausible conditions a change in exogenous safety, which is beyond driver control, causes a compensatory change in driver effort in the opposite direction. A sample of special seat belt use studies illustratively indicates the usefulness of the model.

In keeping with the scientific spirit of recent inquiry I present one formulation of risk compensation and some nonpolicy evidence which in my judgment indicates that this formulation is useful in understanding driver traffic safety behavior. The formulation has several predecessors most of which have generic roots in Becker's [1965] pathbreaking work in household production economics. The essence of the utility maximization model of traffic safety behavior is that the driver has safety and nonsafety goals and that the driver has some control over safety. In this sense the model is similar to Wilde's [1982] theory of risk homeostasis, but the model is different in that it focuses on the choice of and changes in safety goals. Individual optimizing behavior leads drivers to engage in more safety effort as long as the expected gain in safety is less than the expected additional cost. Optimal safety effort and safety vary systematically with factors which affect the gains and costs. In general, exogenous changes in the safety environment will affect optimal safety effort and induce risk-compensating responses by the driver. Similar utility maximization models which emphasize human behavior can be found in Viscusi [1984], Orr [1978] and Peltzman [1975]. The purpose of this paper is to illustrate the nature of this type of model and the type of evidence which supports it.

THE NATURE OF THE MODEL

The model is an economic model. Individuals possess multiple goals, safety and nonsafety, which enhance utility or well being. Because individuals face scarcity of time, energy and money and because there are several ways to achieve goals individuals must make choices and substitute among goals and among means of achieving goals. The individual will seek a utility-maximizing set of goals and means within the limits of the personal resources constraint.

The model is presented as a positive model, one to explain and predict driver behavior. A normative model in contrast would show the degree of desirability of driver behavior and outcomes. A normative model would provide criteria which would indicate the desirability of certain behavior and offer prescriptions as to what it should be.

The model is a simple theoretical model which attempts to simplify a complex world through assumptions. I assume that drivers have sufficient information to make decisions. For example, drivers realize that accident severity increases with speed, tires affect handling, and road conditions affect stopping. I assume that drivers are competent in their decision making in that they can process information even when uncertainty is involved. Lastly I assume that the utility and production functions are well-behaved, neoclassical functions which are common stock in the economics trade.

A MATHEMATICAL SKETCH OF THE DRIVER SAFETY MODEL

Probability of an Accident

A motorist will experience one of two states of the world; either an accident does not occur or an accident does occur over some period of time. The probability that a motorist is involved in an accident (p) is influenced by the driver's own safety effort (e) and exogenous safety measures (s) which are beyond immediate control. The production function is specified by $p(e, s)$ with $p_e < 0$, $p_{ee} > 0$, $p_s < 0$, $p_{ss} > 0$ and $p_{es} > 0$, where the signs of the first and second derivatives shown represent typical production conditions. For example, $p_s < 0$ means that the partial effect of an improvement in highway design would reduce the probability of an accident and $p_{ss} > 0$ means that further improvement brings about a further, but smaller reduction.

Accident Loss

The loss (L) which a motorist incurs given that an accident occurs depends on the motorist's own safety effort and exogenous safety factors also; $L(e, s)$ with $L_e < 0$, $L_{ee} > 0$, $L_s < 0$, $L_{ss} > 0$ and $L_{es} > 0$. Notice that the expected loss from an accident (pL) is determined by the probability of an accident as well as the size of the loss. Also notice that the assumptions $p_{es} > 0$ and $L_{es} > 0$ reflect that the individual and exogenous, environmental safety factors are similar and are substitutes in production.

Disutility Cost

Finally, let there be disutility (D) associated with driver safety effort and exogenous safety factors; $D(e, s)$ with $D_e > 0$, and $D_{ee} > 0$, $D_s \geq 0$, $D_{ss} \geq 0$ and $D_{es} \geq 0$. Driver effort can involve time, inconvenience, discomfort, energy and money, $D_e > 0$, and increases in effort can become increasingly distasteful, $D_{ee} > 0$. Disutility may depend on exogenous safety factors, $D_s \geq 0$, also and they may interact with driver effort, $D_{es} \geq 0$.

Utility Maximization

If the motorist has a resource constraint represented by income (I) and is risk neutral, then expected utility is

$$U = p(e, s)[I - D(e, s) - L(e, s)] + [1 - p(e, s)][I - D(e, s)]$$

or simply

$$U = I - D(e, s) - p(e, s)L(e, s). \tag{1}$$

Equation (1) shows that expected utility equals the probability of an accident times the payoff if an accident occurs plus the probability of no accident times the payoff if no accident occurs, or more simply, it is income less disutility less the expected accident loss. In balancing the advantages and disadvantages of safety effort the driver increases effort through voluntary use of safety belts and moderate speeds and vehicle maintenance or similar activity until

$$\frac{dU}{de} = 0$$

or

$$-D_e = p_e L + p L_e \tag{2}$$

which determines the optimal level of driver safety effort. The optimal amount of safety effort for the individual motorist is the effort for which the marginal value of the utility cost [the left-hand side of eqn (2)] just equals the marginal benefit of the reduction in

expected loss [the right-hand side of eqn (2)]. The reduction in expected loss can occur through a reduction in the probability (p) or the size of the loss (L).

The condition for the optimal level of safety effort also indicates that in general motorists will change their behavior (e) in response to a change in exogenous safety (s). To simplify let us assume that exogenous safety does not affect disutility, $D_s = D_{es} = 0$. [These technological improvements which induce drivers to increase their safety effort (e) by purchasing improved vehicles or increased usage of safety equipment are not to be confused with the required purchase or use of equipment (s).] To determine the effect of a change in exogenous safety effort on motorist safety effort treat eqn (2) as an implicit function, use the implicit function rule and find de/ds:

$$\frac{de}{ds} = -\frac{-p_{es}L - p_eL_s - p_sL_e - pL_{es}}{-D_{ee} - p_{ee}L - 2p_eL_e - pL_{ee}} < 0. \tag{3}$$

The second order condition for utility maximization is that $d^2U/de^2 < 0$ where d^2U/de^2 turns out to be equal to the denominator in eqn (3). It follows that de/ds is negative which means that an increase in exogenous safety will induce drivers to decrease their own efforts. Risk compensation (or offsetting behavior or compensating feedback) is a normal response to changes in the safety environment in the context of a simple economic model of individual utility maximization.

PREDICTIONS OF THE MODEL

As shown in eqn (2), the optimal driver safety effort is determined by a balance between disutility cost and reduction in expected accident loss. Consequently a change in any factor which affects disutility or expected loss will change optimal safety effort. Consider each of the following partial effects. Travel through picturesque countryside on a clear, traffic-free highway would reduce the disutility (D_e) of slow travel relative to travel through monotonous flatlands and increase the optimal safety effort. Improvements in the vehicle design which makes it cheaper to buy better handling and stopping (p_e) increase optimal safety effort. Improvements in seat belts which reduce the loss given accident involvement (L_e) for the same amount of disutility cost as unimproved belts increase optimal safety effort. [Including disutility associated with exogenous safety (s) reinforces the compensating response of drivers, i.e. de/ds becomes more negative.] Changes in roadway characteristics, such as from interstate to two-lane highway, increase the probability of an accident (p) and induce an increase in driver safety effort. Finally, changes which increase the loss in an accident (L), such as driving a car full of family, will increase safety effort.

As shown in eqn (3), the driver will react to changes in exogenous safety factors by compensating to offset, at least in part, for the change in the safety environment $(de/ds < 0)$. If a driver encounters a thunderstorm while traveling 55 m.p.h. on a two lane highway, then we predict that the driver reacts by taking actions such as slowing to 48 m.p.h., turning off the radio and placing both hands on the steering wheel. Risk compensation is not safety enhancing in all circumstances, however. An exogenous improvement in vehicle crashworthiness or highway guardrail design (L_s) that left other factors unaffected would decrease driver safety effort perhaps in the form of less concentration. In this sense, risk compensation is symmetric as it leads to offsetting reactions which can increase or decrease safety depending on the initial effect of the exogenous change.

EVIDENCE FROM SEAT BELT USE STUDIES

The evidence reviewed is purposely selected to focus on variation in driver safety effort and to avoid issues inherent in broad policy analysis. The review is by no means exhaustive even of seat belt use studies. I choose three seat belt use studies which are

special in terms of research method, yet still consistent with related, general findings of other studies. The first is a study by Blomquist [1977] in which I use multivariate probit analysis of more than 1800 drivers to investigate the determinants of reported use of manual seat belts. Use was expected to be greater for drivers with higher expected net private benefits of belt use. The net benefits depend on driving conditions and driver characteristics. The results are described in terms of the partial effects of each factor. Higher costs were found to lower the probability of belt use; short trips, high value of time and extra adjustments due to multiple car users were factors that increased cost. Greater expected effectiveness of belts, the expected physical benefits, was found to increase the probability of belt use; older age, male driver or higher rural speed limit were factors which increased the expected effectiveness. Higher value of the expected physical benefits was found to raise the probability of belt use; higher future labor earnings and better health status were factors which increased value.

The second is a pilot study by Graham, Henrion and Morgan [1981] of shoulder belt use. Use was observed on interstate highways between Baltimore and Pittsburgh on Labor Day, 1981. The key to this study is that observations were made on a long trip under normal conditions and after a severe thunderstorm made driving more dangerous. Use is expected to be greater after the severe storm because the expected accident loss is much larger and other determining factors are virtually unchanged—an approximate controlled experiment. They found belt use by drivers increased significantly from 13% before the storm to 30% after the onset of the storm.

The third is a study by Wasielewski and Evans [1983] who focus on the differences in driver behavior between small and large cars. Since the injury loss in an accident is greater for small cars which tend to be less crashworthy, belt use is expected to be greater in small cars. Based on analysis of over 2500 observations collected through photographs and matched with Michigan vehicle registration and driver license information, it is found that drivers of small cars do wear belts more than drivers of large cars. The expected partial effect of car size on belt use is found after controlling for driver age.

Each of the three safety belt use studies finds use determined by factors that correspond to factors in the driver utility maximization model. Belt use is found to be greater the larger are the net private benefits of use. This evidence is by no means the extent of what is known about belt use. Much of what else is known, however, is consistent with the utility maximization model. Greater use of belts on interstates than on city streets and greater use of passive belts than of manual belts are examples; see, for example, Fháner and Hane [1973] or Stowell and Bryant [1978].

CONCLUDING REMARKS

In this paper I have presented a utility maximization model of driver safety behavior in which risk compensation is inherent. Drivers choose safety goals, target levels of accident risk, based on the perceived net benefits of safety effort. When subjected to a change in the driving environment, motorists, alter their behavior by partly compensating for any change in risk and by altering the safety goals. I view the model as broadly complementary with Wilde's risk homeostasis theory in that utility maximization focuses on the choice of safety goals and risk homeostasis focuses on maintenance of those goals.

Seat belt use studies provide support for the model in that use varies with factors which affect the net benefits of belt use. This evidence indicates that qualitatively drivers respond as expected. There are two qualifications, however, which I hasten to add. The first is that we do not know if drivers respond fully to changes in net benefits because we do not know omnipotently the effectiveness, value and costs for each driver. If a driver increases belt use in a small car but according to the driver's own values does not increase belt use enough, we cannot tell. The second is that even if drivers do respond fully and even if our positive model works well in explaining individual safety behavior, it is not necessary that drivers behave in a socially optimal way. While there is theory and evidence that indicates that private benefits and costs of safety effort are already taken into account, it may be possible to design and implement safety policy which

incorporates private optimization and which improves outcomes according to chosen policy criteria.

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