for measured characters with an intermediate optimum; unless data from experimental species are grossly misleading, the change in impact following a change in mutation rate would be very slow.

References and Notes

1. H. J. Muller, *Am. J. Hum. Genet.* **2**, 111 (1950).
2. J. B. S. Haldane, *Am. Nat.* **71**, 337 (1937).
3. First NAM-NRC Genetics Committee, *The Biological Effects of Atomic Radiation* (BEAR) (National Academy of Sciences–National Research Council, Washington, D.C., 1956).
4. J. F. Crow, in *Mathematical Topics in Population Genetics*, K. I. Kojima, Ed. (Springer-Verlag, New York, 1970), pp. 128–177.
5. J. F. Crow and M. Kimura, *Proc. Natl. Acad. Sci. U.S.A.* **76**, 306 (1979).
6. Second NAM-NRC Genetics Committee, *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation* (BEIR) (National Academy of Sciences–National Research Council, Washington, D.C., 1972).
7. J. F. Crow, *Genetics* **92**, 165 (1979).
8. P. A. Samuelson, *Economics* (McGraw-Hill, New York, 1980).
9. J. F. Crow, *Hum. Biol.* **30**, 1 (1958).
10. M. Kimura, *Jpn. J. Genet.* **36**, 179 (1961).
11. ——— and T. Maruyama, *Genetics* **54**, 1337 (1966).
12. In Eq. 4, $2hspq$ is the proportion by which the average population fitness is reduced by *Aa* heterozygotes, that is the load. Likewise, sq^2 is the load component for *aa* homozygotes. The number of mutant genes eliminated per genetic death is two in homozygotes and one in heterozygotes. Thus $2hspq + 2sq^2 = n_1l_1 + n_2l_2 = nL$, with $n = \Sigma n_jl_j/\Sigma l_j$ and $L = \Sigma l_j$; where l_j is the load component associated with the *j*th genotype and n_j is the number of mutants eliminated each time an individual of type *j* fails to survive and reproduce. This makes clear the extension from Eq. 4 to Eq. 7.
13. J. L. King, *Genetics* **53**, 403 (1966).
14. M. Kimura, *Proc. Natl. Acad. Sci. U.S.A.* **54**, 731 (1965).
15. J. F. Crow, *Proc. XI Int. Congr. Genet.* **1**, 495 (1964).
16. L. L. Cavalli-Sforza and W. F. Bodmer, *The Genetics of Human Populations* (Freeman, San Francisco, 1971).
17. R. Lande, *Genet. Res.* **26**, 221 (1975).
18. ———, *Genetics* **86**, 485 (1977).
19. ———, *ibid.* **94**, 203 (1980).
20. W. H. Fleming, *SIAM (Soc. Ind. Appl. Math.) J. Appl. Math.* **36**, 148 (1979).
21. J. Felsenstein, in *Proceedings of the International Conference on Quantitative Genetics*, E. Pollak, O. Kempthorne, T. B. Bailey, Jr., Eds. (Iowa State Univ. Press, Ames, 1977), p. 277.
22. ———, *Genetics* **93**, 773 (1979).
23. *Report of the United Nations Science Committee on the Effects of Atomic Radiation* (UNSCEAR) (United Nations, New York, 1977).

24. This is paper number 2475 from the Laboratory of Genetics, University of Wisconsin. We are indebted to R. Lande for help with the intermediate optimum model and to M. Moody for assistance with some of the mathematics. W. Engels and H. Newcombe read an earlier draft and provided many helpful suggestions.

Conflicting Objectives in Regulating the Automobile

Lester B. Lave

Summary. Federal regulation of automobile safety, emissions, and fuel economy is contradictory. Safety equipment and emissions control reduce fuel economy; reducing the size of automobiles is estimated to increase fatalities by 1400 a year and significantly increase serious injuries. These secondary impacts of regulation roughly double the estimated costs of achieving the individual goals. In formulating regulations, these contradictions must be taken into account, along with the effects on the price of the vehicle and its attractiveness to buyers.

The automobile has provided an unprecedented degree of personal freedom and mobility, but its side effects, such as air pollution, highway deaths, and a dependence on foreign oil suppliers, are undesirable. The United States has tried to regulate the social cost of these side effects through a series of major federal laws. Since the laws intrude on the interaction between buyers and manufacturers, they have all caused controversy.

More fundamentally, however, each law has been aimed at a single goal, either emission reduction, safety, or fuel efficiency, with little attention being given to the conflicts and trade-offs between goals. For example, the law to control emissions also reduces fuel efficiency by 7.5 percent, and a fuel efficiency law that has forced the building of smaller cars is estimated to reduce safety by resulting in an additional 1400 fatalities a year by 1984. Seeking to achieve each goal independently has promoted confusion, intensified the pressure on manufacturers, and imposed needless costs on consumers. In this article, I sketch the quantitative trade-offs among these three goals and then estimate the social costs of the existing regulations and of some proposed regulations.

Conflicting Social Goals

The undesirable side effects associated with use of the automobile include injury, air pollution, and depleted petroleum resources. Each is, at least in major part, an externality (an interaction that adversely affects one party, without market intermediation: for example, driving a car carelessly so as to injure pedestrians). The size of the three effects depends on the design of the vehicle as well as how it is operated and maintained. This is most evident in the case of safety, where selection of a vehicle and driver behavior are the overwhelming determinants of individual risk (*1*).

Physical conflicts among goals. The interactions of safety, emissions, and fuel economy are illustrated in Fig. 1. Increases in vehicle size and weight may affect safety. For instance, side door guard beams, the energy absorbing steering column, and other safety features have added about 200 pounds to the weight of an automobile which, while increasing safety, have lowered fuel efficiency. Larger vehicles are inherently safer in a crash since there is more space to absorb the impact and protect the vehicle's occupants. Additional size and weight, however, also increase fuel consumption.

Constructing and tuning an engine to reduce emissions lowers fuel economy, other factors being held constant (*2*). A small decrease in fuel economy results from the addition of equipment such as a catalytic converter because of added weight.

In order to achieve greater fuel economy, either weight must be reduced, thus reducing safety, or the engine must be retuned, thus increasing emissions. One minor interaction shown in Fig. 1 is the slight lowering of safety related to emissions control. Catalytic converters can set fire to dried leaves or other combustible material under a car.

Consumer preferences. Enhancing one attribute requires sacrificing the oth-

The author is a senior fellow in the Economics Studies Program at The Brookings Institution, Washington, D.C. 20036, and professor of economics at Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213.

0036-8075/81/0522-0893$01.75/0

ers, although the trade-offs can sometimes be mitigated by the use of more expensive technologies. Society must decide how to balance safety, emissions, fuel economy, and low cost. Balance cannot be achieved, however, without considering the individual consumer who purchases, maintains, and drives the vehicle. The average American consumer is attracted, although only weakly, by safety, repelled by emissions control, and strongly attracted by fuel economy, although this means either an increase in price or a reduction in size and weight (*3*).

Relatively few buyers have ordered optional equipment that would make their vehicles safer. Only about 14 percent of drivers and passengers fasten their seat belts. People frequently drive too fast, drive under the influence of alcoholic beverages, or take other unnecessary risks. Although regulation can require manufacturers to make vehicles still safer, the effect would be small in comparison to that achieved if occupants buckled their seat belts (*4*).

To the public, emissions control apparently means a less reliable and less fuel-efficient car, as judged by the number of pollution control systems that have been deactivated (*5*). Although fuel economy is desirable, for a given engine technology it is achieved in part by reducing the weight and size of a vehicle and the engine horsepower. Of the three attributes desired by society, only fuel economy and, to a lesser extent, safety, are also desired by the individual consumer.

Galbraith (*6*) pilloried the fins on automobiles of the 1950's, and many others have argued that American consumers do or should want cheap transportation, perhaps including enhanced reliability and safety. But when Henry Ford tried such a policy in the 1920's, he lost in the marketplace (*7*). Similar contests among manufacturers in the late 1940's and then in the 1960's and 1970's had the same result. When given a choice, the vast majority of new car buyers choose an automobile with style, power, and comfort, and these preferences have been persistent in the United States and the rest of the world. Thus it makes no sense for the National Highway Traffic Safety Administration (NHTSA) to label these desires irrational and insist that consumers are being saved money by regulations that restrict horsepower and otherwise limit choice to vehicles consumers previously rejected.

Difficulties in estimating trade-offs. In addition to consumer preferences, innovation affects the interactions shown in

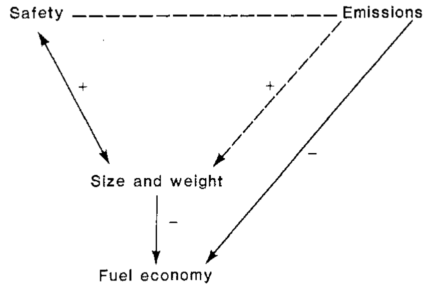

Fig. 1. Schematic representation of the interactions of safety, emissions, and fuel economy in the automobile. Arrows indicate the direction of effect, and dashed lines indicate a small or weak effect.

Fig. 1. By devoting resources to research and development, manufacturers can enhance technological trade-offs. Whether regulations have promoted innovation and thus helped achieve improvements in safety, fuel economy, and emissions control at little cost to the consumer is a controversial issue (*8*). All three attributes can be enhanced through the use of lighter materials and precision manufacturing, but only at increased cost (*9*). However, attractiveness and cost of the automobile should also be considered in formulating regulations.

Estimating the quantitative trade-offs among these attributes is difficult for five reasons. First, a large amount of engineering work is required to estimate each technological trade-off. Second, even though vast resources are spent on research and development to improve the trade-offs, estimations reflect technologies only at a particular date. Third, trade-offs depend on what has already been achieved; for example, the cost of lowering emissions of nitrogen oxides (NO_x) by 0.1 gram per vehicle-mile is much greater from a level of 5.0 grams than from 0.5 gram. Fourth, the trade-offs depend on factors such as the size and design of each vehicle and thus are relevant only for a particular model. Finally, there is a great difference in cost between designing a feature into a vehicle and adding on a device to accomplish the same purpose. For example, many safety features are expensive initially, but once automobile design has been modified, the cost is lower (*10*).

Although precise quantitative trade-offs will vary widely, trade-offs similar to those examined below will occur whatever the current technology and attributes of the vehicle.

Safety

In examining safety regulations, it is important to distinguish between features required for collision avoidance and those for injury mitigation, that is, between features intended to prevent an accident and those intended to protect occupants in case of an accident. For example, dual braking systems, which lower the probability of brake failure, are collision avoidance devices, and an energy absorbing steering column, which reduces the injury in case of a collision, is an injury mitigation device. Collision avoidance devices are aimed at an externality; they are meant to protect pedestrians and occupants of other vehicles. The case for regulating injury mitigation equipment is built primarily on a presumption of consumer ignorance, on economies of scale in manufacturing and installing the devices, and on consumer myopia (*4*).

Congress has apparently decided that paternalism is desired for automobile safety and has directed NHTSA to reduce the number of accidents and increase safety during and after collision by requiring the installation of both collision avoidance and injury mitigation devices. Estimates of the benefits and costs of safety regulations have been made (*11–13*), and some sample estimates are shown in Table 1. However, there is vast uncertainty in estimating the cost of each safety feature and the deaths, injuries, and property damage prevented by it.

A major controversy has focused on seat belts (*14–16*). When buckled, they protect occupants and are cost-effective, but they are used by only a small percentage of drivers. In 1974, NHTSA

Table 1. Ten safety features listed in order of estimated benefit-cost ratio. Costs are estimated through 1978 in 1975 dollars; benefits are estimated for the lifetime of the car in 1975 dollars on the basis of 1975 accident rates, injury rates, and seat belt usage. [Data from (*21*)]

Feature	Cost ($)	Benefit ($)
Improved door latches	0.81	25.27
Seat belts	43.67	128.98
Benefits at 100 percent usage*		500.00
Energy absorbing steering column	33.86	54.88
Fire prevention	13.13	11.87
High-penetration-resistance windshield glass	2.00	1.54
Side door beams	10.00	6.22
Dual braking system	36.94	20.45
Padded instrument panel	17.39	3.05
Head restraints	24.32	2.07
Improved bumpers	90.00	(54.45)
Total	272.12	199.88

*Assuming a fourfold increase in usage.

required an interlock device that prevented the engine from being started if occupants were not belted, but Congress overruled NHTSA because of consumer complaints and mechanical problems with the device.

The NHTSA has required that by the 1985 model year automobiles be designed so that occupants are protected in crash without taking protective action, such as buckling a seat belt. In particular, manufacturers must show that test dummies are subjected to forces below a defined level when the automobile hits a solid barrier head on or up to 30 degrees off center at 30 miles per hour in the crash test.

This can be accomplished in two ways. The first is a passive seat belt that buckles automatically when the door is shut. The second is the installation of air bags in the steering wheel and dash board that inflate and cushion occupants when sensors indicate a collision. Both devices can meet the NHTSA standard, but neither the air bag nor the version of the passive belt that has only a shoulder portion is as effective as the three-point seat belt. The air bags are at best marginally effective against other than front-end collisions and less than fully effective if an accident involves more than a single collision. They only become as effective as the three-point belt when a lap seat belt is also worn, and the air bags may be harmful to small children who are not wearing seat belts. Passive seat belts cost consumers about \$50 more than nonautomatic seat belts, and air bags \$220 to \$500 more (*17*). Air bags cannot be disconnected, but about 20 percent of the passive belt systems in operation are estimated to be disconnected (*14*).

If all automobiles were equipped with air bags, it is estimated that between 4900 and 10,500 deaths would be prevented each year. I use Huelke *et al.*'s best estimate of 6800 (*18, 19*). If all front seat occupants in cars with air bags also wore lap belts, an additional 2400 deaths would be averted. However, since seat belt usage is currently low, and since people would be paying a premium price for the air bags perhaps in order to avoid wearing seat belts, it is unlikely that many people would use the lap belts. Passive belts would prevent an estimated 7600 fatalities (*15*).

The initial cost of installing air bags is estimated to be \$300 to \$580, and the cost of passive belts is \$130. If the annual cost of these devices is 20 percent of their initial cost (interest plus depreciation), the air bags cost \$60 to \$116 a year over the lifetime of the car, and the passive belts cost \$26 a year. If the entire fleet of 117 million cars were equipped, the annual cost would be \$7.0 to \$13.6 billion for air bags and \$3.0 billion for passive belts. Considering only fatalities, the best estimates of the cost per life saved would be \$1.03 to \$2.0 million for air bags and \$395,000 for passive belts. If one-third to one-half of the passive belts are disconnected, this raises the cost per life saved to between \$598,000 and \$789,000.

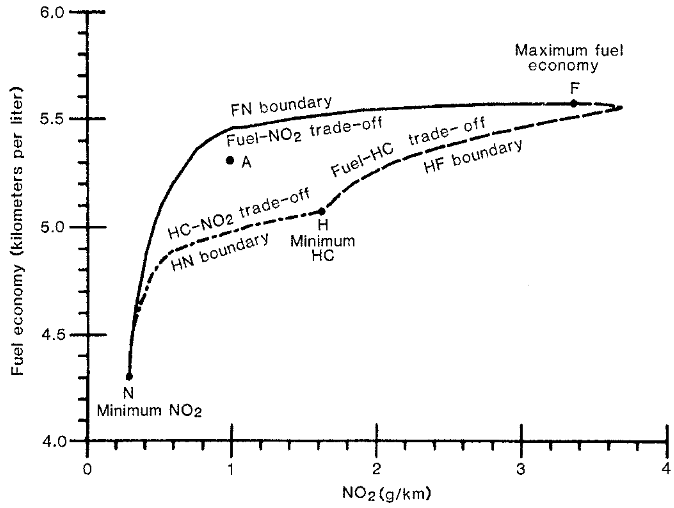

Fig. 2. Trade-offs between fuel economy and emissions. This is a plot of a predicted optimum trade-off region for a 5.7-liter V-8 engine installed in a vehicle weighing 2054 kilograms (4518 pounds). The region defines all the optimal trade-offs for fuel, NO_2, and hydrocarbons (*HC*). As an example, point A represents the best fuel economy at engine out emissions of 1.0 gram of NO_2 per kilometer and 2.3 grams HC per kilometer. Point A can also be interpreted as the minimum NO_2 obtainable for a given level of fuel economy and HC. [Modified from (*27*)]

According to the Department of Transportation (DOT), 70,700 serious injuries occur annually among occupants of front seats; these include injuries in category AIS-3 (abbreviated injury scale), severe, not life threatening, through category AIS-5, critical, survival uncertain (*20*). Perhaps 32 to 58 percent of these injuries (23,000 to 41,000) would be prevented by passive restraints; the vast majority would be in the AIS-3 category (*15*). For every fatality prevented, three to five serious injuries would also be prevented. Various proposals have been made to compare serious injuries to fatalities (*11, 21*). These injuries involve substantial hospital stays and medical costs, time lost from work, often permanent disability, and major pain and suffering. The DOT's estimate of economic loss, including lost wages and medical costs, is more than \$40,000 for each injury (AIS-3 through AIS-5), and more than \$387,000 for death; these costs do not take into account pain and suffering (*22*). Although it is impossible to give confident estimates of the social cost of injury and death, I assume that society values the 23,000 to 41,000 serious injuries that could be prevented by passive restraints as about equal to the 6800 fatalities that could be prevented by air bags or the 7600 prevented by passive belts. Then the cost per fatality equivalent (that is, one fatality or three to five serious injuries) averted would be \$515,000 to \$1,000,000 for air bags and \$299,000 to \$394,500 for passive belts (after adjusting for disconnected belts).

The General Accounting Office (GAO) evaluated automobile safety regulation by isolating the safety record of each model year (*12*). The GAO found that, in comparison to earlier models, those for 1966 to 1968 were associated with 19 to 23 percent fewer deaths and serious injuries, the 1969 and 1970 models with 25 to 29 percent fewer deaths and serious injuries, and there seemed to be little change for the 1971 to 1973 models. If the pre-1966 safety levels had persisted, approximately 35,300 passenger car occupants would have been killed each year; in contrast, 27,400 automobile passengers were killed in 1977. The package of safety features required by regulation is estimated to have raised the cost of each 1969 and 1970 vehicle by between \$200 and \$300. On the basis of these estimates, the cost per fatality averted would be \$592,000 to \$889,000. If we value the social cost of serious injuries as being equal to that of fatalities averted, the cost per fatality equivalent averted would be \$296,000 to \$444,500.

Emissions

A relation between fuel economy and emissions can be traced for a particular engine size and design (Fig. 2). The curves in Fig. 2 are taken from a function fitted to data from experiments with actual engines and identify boundaries for the best fuel economy (trading off fuel economy for NO_x emissions), minimum NO_x emissions (trading off NO_x for hy-

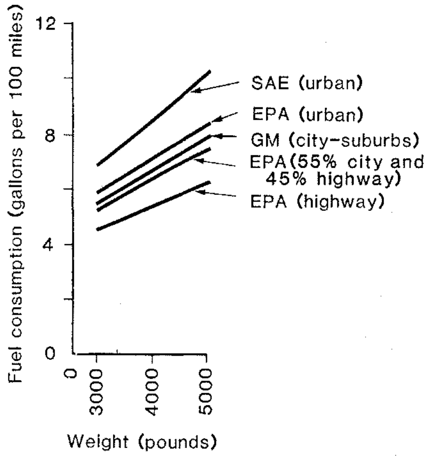

Fig. 3. Constant performance fuel consumption plotted as a function of weight for a full-size car under various driving conditions; *SAE*, Society of Automotive Engineers; *EPA*, Environmental Protection Agency; and *GM*, General Motors. [Modified from Marks and Niepoth (*2*)]

drocarbons), and minimum hydrocarbon emissions (trading off hydrocarbons for fuel economy).

In other words, for a particular engine emission control system at the best fuel economy point, NO_x emissions are 1000 percent higher and hydrocarbon emissions are 19 percent higher than they are at the points of minimum emissions. At the point of minimum NO_x emissions, fuel economy is 30 percent lower than it need be, and hydrocarbon emissions are 29 percent higher than they need be. At the point of minimum hydrocarbon emissions, fuel economy is 10 percent lower than it need be, and NO_x emissions are 433 percent higher than is achievable. A new figure could be drawn for each engine size, for each engine technology, and for each emission control system.

Fuel Economy

Fuel economy is related to vehicle weight, aerodynamic design, engine horsepower, level of emissions, and other factors. Figure 3 illustrates some trade-offs between vehicle weight and fuel economy. A change in vehicle weight is estimated to change fuel consumption in the range of 8.4 to 16.8 gallons per 100 pounds of additional weight for each 10,000 miles traveled (the average annual mileage for passenger cars), with a best estimate of 11.0 gallons. Fuel economy is proportional to the ratio of old to new vehicle weights raised to the .85 power

$$FE_R = FE_O(WT_O/WT_R)^{.85}$$

where FE_R and FE_O are the revised and original fuel economies, and WT_R and WT_O are the revised and original weights (*9*).

Figure 4 illustrates some trade-offs between engine performance and fuel economy in terms of the number of seconds required to accelerate from a stop to 60 miles per hour. Current cars generally take between 11.3 and 19.2 seconds. Less power would be associated with a longer time to accelerate to any speed. Figure 4 shows that fuel economy could be increased significantly if the consumer would accept degraded performance.

Indirect Costs of Regulation

Most analyses of federal standards for automobiles have focused on the direct costs of meeting each goal. The NHTSA, for example, estimated the cost and cost-effectiveness of many safety devices and the cost of enhanced fuel economy, and the Environmental Protection Agency estimated the cost of emissions control (*1*). Few estimates have included the indirect costs stemming from the feedback effects of one goal on another (*23*). The principal feedback effect, the desirability of the vehicle to the purchaser (*24*), cannot be estimated with confidence, but many interactions can be quantified.

Factors affecting weight. Safety features have added about 200 pounds to each car; air bags would add an additional 60 pounds, and the passive seat belts about 13 pounds (*1, 25*). Emissions control equipment has added about 50 pounds to each car.

Factors affecting fuel economy. To

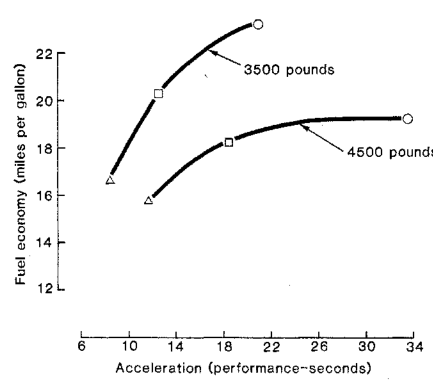

Fig. 4. Engine performance in accelerating from 0 to 60 miles per hour plotted as a function of composite fuel economy (Environment Protection Agency's test) for a base engine of 350 cubic inches with the best ratio of spark and air to fuel. The (○) represents a displacement of 150 cubic inches, the (□) 230 cubic inches, and the (△) 350 cubic inches. [Modified from Nicholson and Niepoth (*2*)]

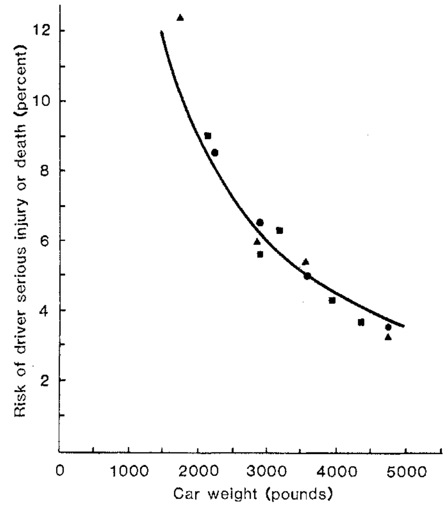

Fig. 5. Risk to an unbelted driver of serious injury or death in a two-car collision plotted as a function of car weight. Data points represent collisions between cars of different weights (●) and collisions between cars in the same weight classes from different states (▲ and ■). [Modified from (*13*)]

increase the fuel economy of new automobiles from 19 to 27.5 miles per gallon, as mandated by Congress, a reduction in vehicle weight from about 4500 pounds to 3000 pounds is needed. A doubling in fuel economy from 14 miles per gallon, the fleet weighted average, to 27.5 miles per gallon would reduce fuel consumption by 49 percent. This would mean that if cars continue to be driven an average of 10,000 miles a year, the savings would be 351 gallons of gasoline per car per year. For the entire fleet of 117 million passenger cars, the savings would be 41.1 billion gallons a year. At $1.50 a gallon, the nation would save $62 billion a year.

For every 100 pounds of weight added, the increase in gasoline consumption per vehicle would be about 11.0 gallons a year. Safety features, emissions control, and passive restraints weigh 200, 50, and 13 to 60 pounds, respectively (*26*); for a fleet of 117 million cars, the increase in fuel consumption would be in the range of 3.38 to 3.99 billion gallons at a cost of $5.1 to $6.0 billion. Safety devices account for about 76 percent, emissions control devices 19 percent, and passive seat belts 5 percent of this increase. If air bags are installed, the percentages are 64, 16, and 19, respectively.

Under experimental conditions, emissions control reduces fuel economy by 10 to 33 percent for the points of minimum NO_x and hydrocarbon emissions relative to the best fuel economy (*27, 28*). Since the average passenger car uses 714 gallons of gasoline a year, this means an increase in fuel consumption of 42.8 gallons a year. The fleet consumption is 5.01 billion gallons ($7.52 billion a year). When the weight of emissions control devices is taken into account, fuel consumption increases to 5.65 billion gallons ($8.48 billion a year).

These estimates are for fuel economy within the engine. In addition, removing lead and other compounds that raise octane requires additional refining of gasoline and loss of energy. Emissions control devices have markedly reduced the number of miles that can be traveled per barrel of fuel oil.

Some contributions that can be made to fuel economy are shown in Table 2. Increasing fuel economy above current levels becomes progressively more difficult. Thus, the 7.5 percent decline in fuel economy due to emissions control standards is large. If NO_x emissions were lowered to 0.4 gram per mile, the decline in fuel economy would double (*26, 28*). Furthermore, the 7.5 percent penalty may understate what is found in practice. The highly controlled engines need more maintenance, in the absence of which both emissions and fuel economy deteriorate.

Factors affecting safety. The reduction in weight required to achieve greater fuel economy will have a large effect on safety. A reduction in vehicle weight from 4500 pounds to 3000 pounds is estimated to increase from 4 to 6 percent the chance of a driver being seriously injured or killed in an accident, all other factors held constant (Fig. 5) (*29*). In 1977, when 42 percent of the fleet consisted of small cars, 27,400 automobile occupants were killed in accidents. If the entire fleet in 1977 had consisted of cars weighing 4500 pounds, and if the mortality rate for small cars were 50 percent higher than for large cars, 22,600 deaths would have been expected, suggesting that 4800 deaths were due to the small vehicles. If the entire fleet were 3000-pound vehicles, 34,000 fatalities would have been expected, an increase of 6600 deaths. Thus, a fleet of small vehicles would have increased the number of fatalities an estimated 11,400 a year (*30*) compared to a fleet of larger vehicles.

The combination of higher fuel prices and fuel economy standards is expected to increase the proportion of new small cars sold from about 46 percent in 1976 to 66 percent in 1985. In the absence of changes in design, the increasing proportion of small cars would suggest that there will be a substantial increase in fatalities by model year 1984 (when small cars were to have been required to meet the crash protection standard). At that time, about 53 percent of the fleet is expected to be small cars, and they would not have been required to pass the crash test. If it is assumed that the number of vehicles increases by 15 percent between 1977 and 1984, driving habits do not change, and all of the fleet were 1977 model 4500-pound cars, then an estimated 26,000 fatalities would occur each year; if all of the fleet were 1977 model 3000-pound cars, then 39,100 fatalities would be expected. If 42 and 53 percent of the fleet consisted of small cars, 31,500 and 32,900 fatalities, respectively, would be expected. Thus, the increase in the proportion of small cars in that fleet from 42 to 53 percent might result in an estimated 1400 additional fatalities in 1984.

Three policies could avert such a large increase in severe injuries and fatalities: (i) curtailing gasoline sales by perhaps 20 percent, (ii) enforcing a lower speed limit, and (iii) requiring all occupants to wear seat belts. A belted occupant of a 3000-pound car is estimated to be slightly safer than an unbelted occupant of a 4500-pound automobile. The most onerous option would be to curtail the availability of gasoline; requiring the use of seat belts would seem to be the least onerous.

Secondary effects. To achieve the federally mandated goal for automobile fuel economy (27.5 miles per gallon) will mean that the average vehicle in 1985 will weigh about 1500 pounds less than a 1976 vehicle; this weight reduction will achieve just under half the required fuel savings. At a saving of 11 gallons of gasoline per 100 pounds of weight reduction per year, the lightening would save 165 gallons per vehicle per year or about 19 billion gallons, or $29.0 billion, per year for the fleet. Since reducing the weight of all vehicles by 1500 pounds would increase fatalities by 11,400 a year, Congress, implicitly, has decided that the nation is willing to endure an extra fatality for each $2.6 million savings in fuel. Neither this trade-off nor those involving the extra weight of safety and emissions equipment or the fuel costs of emissions control were central issues in congressional debate.

Several other examples of these secondary impacts should underscore their

Table 2. Some techniques for improving fuel economy in passenger cars and light trucks in the mid-1980's. [Data from the National Highway Traffic Safety Administration (*8*)]

Technology	Improvement from 1978* (percent)
Weight reduction from reduction in size, materials substitution, alternative configurations for body or power train	A 10 percent reduction increases fuel economy by 8 percent at constant acceleration performance
Engine improvement	
Spark ignition efficiency:	
Optimized control	1 to 3
Engine quality	0 to 20†
Alternate engines:	
Diesel	25
PROCO‡	20
Turbocharging	Car specific; typically 5 to 10 percent
Transmission improvement	
Automatic:	
Locked-up torque converter	3 to 6
Wide-range three-speed	2
Wide-range four-speed	5
Improved efficiency	1 to 2
Improved engine transmission matching	1 to 2
Four-speed with locked-up torque converter	8 to 11
Overdrive manual	5
Improved lubricants	
Crankcase:	
Lower viscosity	1
Friction modified	1
Rear axle lower viscosity	1
Reduced parasitic losses	1 to 4
Reduced tire rolling losses	5
Improved aerodynamics	
Complete body redesign	5
Add-on devices	3

*Values are not necessarily additive. †As compared to an average 1978 engine. ‡Advanced engine being developed by the Ford Motor Company.

Table 3. Summary of primary and secondary impacts of regulation.

Regulation	Primary impact: Cost per car ($)	Primary impact: Primary social impact (savings)	Primary impact: Cost per fatality equivalent† ($)	Secondary impact*: Extra weight (pounds)	Secondary impact*: Extra fuel‡ ($ billions)	Secondary impact*: Cost per fatality equivalent† ($)
Current safety features	200 to 300	15,800 equivalent lives	296,000 to 444,500	200	2.57	247,000
Passive seat belts	130	15,200 equivalent lives	299,000 to 394,500	13	0.17	17,000
Air bags	300 to 580	13,600 equivalent lives	515,000 to 1,000,000	60	0.76	84,000
Fuel economy		19 billion gallons saved		−1500	−19.00	1,250,000
Emissions control		CO and hydrocarbons reduced 90 percent		50	0.64	
		NO_x reduced 75 percent			5.01	

*These secondary impacts describe only the changes in fuel consumption effected by the regulation. †Three to five serious injuries equal a fatality in constructing equivalent fatalities. ‡Estimated at $1.50 a gallon.

importance. The costs per death or fatality equivalent prevented by passive seat belts and air bags were estimated to be $299,000 to $394,500 and $515,000 to $1,000,000, respectively. Since the passive belts add 13 pounds and the air bags 60 pounds to the weight of a car, the devices would increase fuel consumption for the entire fleet by an estimated 0.17 and 0.76 billion gallons a year at costs of $0.26 and $1.14 billion. Thus, passive belts require the use of 11,000 additional gallons of gasoline a year by the fleet ($17,000) per life equivalent and air bags 56,000 gallons ($84,000) because of the extra weight. The estimated cost of averting a fatality or three to five serious injuries is then $316,000 to $411,500 for passive belts and $599,000 to $1,084,000 for air bags, increases of 5.7 and 4.3 percent and 16.3 and 8.4 percent, respectively.

Another example is the current package of safety features, estimated to cost $296,000 to $444,500 per fatality or three to five serious injuries averted and require the use of an additional 2.57 billion gallons of gasoline a year at a cost of $3.9 billion because of the extra weight. The additional fuel represents a cost of $247,000 per fatality or three to five serious injuries averted. Thus, the total cost per fatality or three to five serious injuries averted is $543,000 to $691,500; the additional fuel consumption adds between 83.4 and 55.6 percent to the direct estimate of cost.

Conclusion

Table 3 summarizes the effects of the regulations examined in this article. Passive seat belts appear to be a bargain relative to other safety regulations; the lower estimate for air bags is comparable to the estimated cost of current safety regulations per fatality averted. However, both features seem costly when compared to other options open to society to lower risk. In particular, if society were willing to pay $150,000 per death averted, a host of other activities would have first priority, such as improving highway construction and maintenance practices (*1, 31*). Mandatory seat belt use would be even more cost-effective.

The secondary effects of regulation are large relative to the primary effects. For example, note the additional fuel costs associated with current safety features (Table 3). Although one secondary impact of the fuel economy regulations is an estimated increase in fatalities, society would have to be willing to pay $2.6 million per fatality in order to forgo the fuel economy standards. Finally, the fuel economy penalties of emissions control are 48 gallons or $72 per car per year; this amount is greater than the annual increase in price for the equipment and its maintenance; thus, it is the fuel costs that dominate the estimated cost of emissions control.

Table 3 illustrates the conflicts among safety, emissions, and fuel economy regulations as well as the importance of estimating the secondary impacts of each regulation. In particular, the fuel economy standard highlights the interdependence between fuel economy and NHTSA's new safety standards. The added cost to emissions control of increased fuel consumption is large enough so that consideration should be given to delaying the imposition of tighter standards and perhaps even returning to 1978 standards.

Abating emissions is a difficult goal to evaluate. Costs of reducing all emissions are unnecessarily large compared to a strategy of stringent emissions control only in areas with pollution problems. However, the fundamental question at issue is the value of clean air, even in polluted areas. There can be no doubt about the whiskey-colored haze created by automobile emissions and the associated poor visibility and eye irritation. However, there are serious doubts that significant health effects are associated with levels of photochemical smog currently prevailing in even the most polluted cities (*32*). Certainly the health effects are small compared to those for suspended particulates and sulfur oxides, which come primarily from stationary sources. This is a case where the secondary effects amplify a conclusion evident from the primary effects: health effects do not justify the most stringent controls mandated by Congress.

Safety features are perhaps the most difficult issue. Most features, from energy absorbing steering columns to seat belts, are for the benefit of the vehicle's occupant. Yet many individuals apparently do not value the features and rebel against buying and using them. Seat belts are ineffective because they are used by only 14 percent of occupants. The federal and state governments have resisted mandatory seat belt laws such as those imposed in most of Europe, Australia, and part of Canada and emphasized passive devices that protect the occupants in spite of themselves. Lowering speed limits to 55 miles per hour has produced a major improvement in safety, but little else has been done to alter driving habits. A much greater improvement would come from removing drivers who are drunk or otherwise incompetent to drive from the the roads.

Higher fuel prices and the implementation of safety, emissions, and fuel economy regulations have dramatized the conflicts among regulations. Analysis can clarify the implications of each regulation and trade-offs among goods, but only Congress can clarify the goals.

References and Notes

1. Office of Technology Assessment, *Technology Assessment of Changes in the Future Use and Characteristics of the Automobile Transportation System* (Technical report 052-003-00650-2, Government Printing Office, Washington, D.C., 1979), vol. 2.
2. C. Marks and G. Niepoth, *S.A.E. Tech. Rep. 750954* (1975); R. Nicholson and G. Niepoth, *S.A.E. Tech. Rep. 760046* (1976).
3. Safety and safety features were the fourth most important concern to consumers after purchase cost, gasoline mileage, and repair record of a car. About 75 percent of respondents to a NHTSA survey perceived safety to be of major importance, and automobile accidents to be a major cause of concern. However, this concern is shifted to automobile manufacturers. ". . . about two out of three people think that cars should be built with as many safety features as possible while only one out of four believe that cars should have only those safety features that must be built into the basic car as standard equipment, allowing the buyer to select other safety features as options" [National Highway Traffic Safety Administration, "Public attitudes toward passive restraint systems" (Summary report HS-803 567, U.S. Department of Transportation, Washington, D.C., 1978)].
4. Whether drivers trade off some of the increased safety due to design change or other attributes, as proposed by L. B. Lave [*Law and Contemporary Problems* **33**, 512 (1968)] and S. Peltzman [*Political Econ.* **83**, 677 (1975)] is not known. Such an effect is plausible in that safety is one of several attributes of driving an automobile; a driver may decide to drive a safer car faster or during hazardous conditions in order to attain other goals. Peltzman estimates the effect to be large.
5. U.S. Environmental Protection Agency, *1978 Motor Vehicle Tampering Survey* (Washington, D.C., November 1978).
6. J. K. Galbraith, *The Affluent Society* (Houghton-Mifflin, Boston, 1958).
7. The point is made by A. P. Sloan [*My Years with General Motors* (Doubleday, Garden City, N.Y., 1963), p. 163] in explaining the success of General Motors: "When first car buyers returned to the market (in 1923) for the second round, with the old car as a first payment on the new car, they were selling basic transportation and demanding something more than that in the new car. Middle income buyers, assisted by the trade-in and installment financing, created the demand, not for basic transportation, but for progress in new cars, for comfort, convenience, power, and style. This was the actual trend of American life and those who adapted to it prospered." For another discussion, see T. L. Berg, [*Mismarketing: Case Histories of Marketing Misfired* (Doubleday, Garden City, N.Y., 1970)].
8. Regulations have increased the price of vehicles, but if they also stimulated innovation, they might cause costs to drop. Although the extent of forced innovation is difficult to measure, the imposition of stringent deadlines has not been very successful in the case of emissions control [E. P. Seskin, in *Current Issues in U.S. Environmental Policy*, P. R. Portney, Ed. (Johns Hopkins Press, Baltimore, 1978), pp. 68–104; National Highway Traffic Safety Administration, *Automotive Fuel Economy Program, Third Annual Report to the Congress* (Washington, D.C., January 1979), pp. 33–7].
9. National Highway Traffic Safety Administration, "Rulemaking support paper concerning the 1981–1984 passenger auto average fuel economy standards" (U.S. Department of Transportation, Washington, D.C., July 1977).
10. ——, "The contributions of automobile regulation" (U.S. Department of Transportation, Washington, D.C., December 1979), pp. 10–17.
11. L. B. Lave and W. E. Weber, *Appl. Econ.* **2**, 265 (1970).
12. General Accounting Office, "Effectiveness, benefits, and costs of federal safety standards for protection of passenger car occupants (CED-76-121, Government Printing Office, Washington, D.C., 1976).
13. L. A. Goldmuntz, in *Seminar on Issues Affecting the Future of the Motor Vehicle* (Mitre Corporation, McLean, Va., 1979), pp. 141–167.
14. C. E. Nash, in *The Scientific Basis of Health, Safety and Environmental Regulation*, R. W. Crandall and L. B. Lave, Eds. (Brookings Institution, Washington, D.C., in press).
15. D. F. Huelke and J. O'Day, in *ibid.*
16. G. Blomquist and S. Peltzman, in *ibid.*
17. The lower figure is from C. Nash (personal communication); the higher figure is a General Motors estimate from July 1979.
18. D. F. Huelke, T. E. Lawson, R. Scott, J. C. Marsh, *S.A.E. Tech. Rep. 790323* (1979).
19. For an earlier, higher estimate, see B. Adams (Document 95-117, U.S. House of Representatives, Washington, D.C., 1977).
20. U.S. Department of Transportation, "The Secretary's decision concerning motor vehicle occupant crashes" (Washington, D.C., 6 December 1976).
21. H. Gates and L. Goldmuntz, *Automobile Safety* [draft report to the National Highway Traffic Safety Administration (Economics and Science Planning, Washington, D.C., 13 November 1978)].
22. U.S. Department of Transportation, *1975: Societal Costs of Motor Vehicle Accidents* (Washington, D.C., 1976), p. 2. The figures were converted to 1979 dollars.
23. An example to the contrary was proposed by The National Highway Traffic Safety Administration ["Rulemaking support paper concerning the 1981–1984 passenger auto average fuel economy standards" (U.S. Department of Transportation, Washington, D.C., July 1977)].
24. N. Scott Cardell and F. C. Dunbar, *Transp. Res.* **14A**, 415 (1980); L. Sherman, C. Manski, J. Ginn, *Consumer Behavior towards Fuel Efficient Vehicles* (NTIS H5-7-017-01780, U.S. Department of Transportation, Washington, D.C., 1980).
25. More recent estimates (*14*) indicate that the additional weight might be 40 pounds and near zero for air bags and passive seat belts, respectively.
26. Mitre Corporation, *Fact Book: Future of the Automobile* (McLean, Va., 1979).
27. J. F. Cassidy, "Optimum engine control calibration studies via nonlinear programming" (GMR-2862, General Motors Research Laboratories, Warren, Mich., 1978).
28. U.S. Department of Transportation, "The report by the Federal Task Force on Motor Vehicle Goals Beyond 1980" (draft report, Washington, D.C., September 1976), vol. 2.
29. Compare the figure in B. Scott [*Third International Congress on Auto Safety*, (Government Printing Office, Washington, D.C., 1975), vol. 1, suppl.] with those in J. R. Stewart and J. C. Stutts [*A Categorical Analysis of the Relationship Between Vehicle Weight and Driver Injury in Automobile Accidents* (Highway Safety Research Center, University of North Carolina, Durham, May 1978)]. Stewart and Stutts analyzed crashes in North Carolina and found that cars weighing more than 3950 pounds had half the number of fatal injuries as cars weighing 2901 to 3300 pounds; the difference was somewhat greater in single car accidents. For crashes between two cars of similar size, serious injuries or fatalities occurred in 2.35 percent of the accidents in cars weighing 1000 to 2000 pounds, in 2.33 percent of the accidents in cars weighing 2001 to 2900 pounds, in 1.92 percent of the accidents in cars weighing 2901 to 3300 pounds, in 1.65 percent of the accidents in cars weighing 3301 to 3600 pounds, in 1.53 percent of the accidents in cars weighing 3601 to 3950 pounds, and in 1.31 percent of the accidents in cars weighing more than 3951 pounds. In collisions between cars of different sizes, 4.22 percent of drivers in the smallest cars were seriously injured or killed and 0.42 percent of the drivers of the largest cars. When cars weighing 2901 to 3300 pounds collided with the largest cars, the figures are 2.10 percent and .95 percent, respectively. The 50 percent increase in the chance of serious injury estimate from Scott's data seems conservative compared to the North Carolina analysis. See also B. Campbell and D. Reinfurt, *Relationship Between Driver Crash Injury and Passenger Car Weight* (Highway Safety Research Center, University of North Carolina, Chapel Hill, November 1973).
30. The number of fatalities could be much larger because of an interaction between occupant age and size of vehicle. Most senior citizens ride in large automobiles, which tend to protect them from severe injury in case of collision. When these people are shifted to smaller, less protective vehicles, the fatality and severe injury rate might rise more than indicated in these estimates. However, the number of deaths and severe injuries would be smaller in a fleet of uniformly sized vehicles, since the occupant of a small car is much more likely to be severely injured or killed in a collision with a large car. The rapid increase in the number of small vehicles in recent years has coincided with, and presumably caused, an increase in the number of severe injuries and fatalities per 100 million passenger miles; the rate had been dropping each year before the increase in the number of small vehicles.
31. U.S. Department of Transportation, *Highway Safety Needs Report* (Washington, D.C., 1976).
32. National Academy of Sciences and National Academy of Engineering, *Air Quality and Automobile Emission Control* (National Academy of Sciences, Washington, D.C., 1974); L. B. Lave and E. P. Seskin, *Air Pollution and Human Health* (Johns Hopkins Press, Baltimore, 1977).

33. I thank E. Callison, L. Goldmuntz, W. Gouse, C. Lave, D. Nash, and R. Schwing for helpful comments. Supported by a grant from the Sloan Foundation.