LIGHT VEHICLES: POLICIES FOR REDUCING THEIR ENERGY USE AND ENVIRONMENTAL IMPACTS

MARC LEDBETTER
MARC ROSS[1]

1991

American Council for an Energy-Efficient Economy
1001 Connecticut Avenue, N.W. #801
Washington, DC 20036

[1]University of Michigan
Department of Physics
Ann Arbor, MI 48109

TABLE OF CONTENTS

I. INTRODUCTION

The transportation sector in the United States is an important focus of both energy and environmental policy because it is a large consumer of energy, primarily oil, and a large source of air pollution emissions linked with both urban smog and global warming. About a quarter of all energy and 70% of all oil consumed in the United States is consumed in the transportation sector. Some 96 percent of the energy consumed in the transportation sector is from oil, 61% of which is attributable to automobiles and light trucks.[Footnote 1]

Furthermore, transportation fuel use is responsible for about 35% of U.S. carbon dioxide emissions. Automobiles and light trucks alone account for about 22% (280 million metric tons of carbon) of these emissions, making them, among final users of energy, the single largest contributor of carbon dioxide emissions in the United States.[Footnote 2] Cars and light trucks also emit about 40% of U.S. carbon monoxide emissions and large fractions of other important urban air pollutants (Gordon, 1991).[Footnote 3] Given their dominance of both energy and environmental problems in the transportation sector, this paper focuses on light vehicles.

Since 1973, new car fuel economy doubled, from 14 to 28 miles per gallon, and light truck fuel economy increased 60% from 13 to 21 mpg (Heavenrich, Murrell, & Dillard, 1990). Had this improvement not occurred, cars and light trucks (which now consume 6.5 million barrels of oil per day) would be consuming an additional 4 million barrels per day, more than twice as much as is being produced in Alaska, and over half our current level of imports. Avoiding 4 million barrels per day of oil consumption means the United States lowered its retail fuel bill by at least $60 billion per year, lowered its trade imbalance by at least $25 billion, and is emitting about 170 million less metric tons of carbon in the form of carbon dioxide. (About 1300 million metric tons of carbon are emitted annually as a result of fossil fuel combustion in the United States.)

Unfortunately, the fifteen-year trend of rising new vehicle fuel economy that has almost held fuel consumption by light vehicles in check has come to a halt. Low gasoline prices, a cessation in the fuel economy standards, and a cessation in the rise of the threshold for gas guzzler taxes, has taken the pressure off automobile manufacturers to improve fuel economy. (Due to the 1990 Gulf Crisis, the average price of gasoline rose to about $1.35 per gallon at the time of writing. In 1990 dollars, the average price of gasoline in the 1960s was about the same.) In the last few years, average new car and light truck fuel economy fell about 3% (Heavenrich & Murrell, 1990).

Making matters worse, the number of highway vehicle miles traveled (VMT) in the United States continues to grow rapidly, seemingly inexorably. Since World War II, VMT has risen steadily and rapidly, with the two major oil crises of the 1970s represented by small, temporary shifts in the upward trend (Figure 1). Recent analysis of the factors driving the growth in VMT indicates that VMT should continue to grow about 2.5% per year through the year 2000 (Ross, 1989).

Yet another factor contributing to increased oil use is the growing number of light trucks in the U.S. light vehicle fleet. On average, new light trucks achieve 21 mpg, 24% below the new car average of 27.8 mpg (test values). In 1970 they only represented 15% of new light vehicle sales, but they now represent about one third of those sales.

The large majority of light trucks are being used as passenger cars. A 1987 survey by the Bureau of the Census found that 81% of light trucks do not carry any freight (Bureau of the Census, 1990). (As defined by the Bureau, freight even includes craftsman's tools.) Thus, for most people, a truck serves the same purpose as a car, but achieves much lower fuel economy.

Vehicles are also becoming much more powerful than they were in the early 1980s. Since 1982, average automobile 0 to 60 acceleration times have fallen from 14.4 seconds to 12.1 seconds, a 16% drop (Heavenrich & Murrel, 1990). Using an EPA developed estimation procedure, we estimate this move toward fast cars has reduced average new car fuel economy by almost 10% (Heavenrich & Murrell, 1990).

Furthermore, the on-road fuel economy of new cars and light trucks is falling further behind their EPA-rated fuel economy. The on-road fuel economy is estimated to have been 15% lower than the EPA laboratory test value in 1982 (Hellman & Murrell, 1984). Analysts project that due to changes in driving patterns, primarily increasing traffic congestion, on-road fuel economy will fall 30% below test by the year 2010 (Westbrook & Patterson, 1989).

Taken together, stalled fuel economy improvements, rapidly growing VMT, increasingly powerful vehicles, traffic congestion and substitution of trucks for cars, are putting strong pressure on oil demand. Only the final stages of the replacement of inefficient cars of the '70s with today's more efficient cars is temporarily keeping oil consumption in check. At stake are national economic health, energy security, and the earth's climate. Among the many actions that can be taken to improve the situation, increasing the fuel economy of light vehicles should have a high priority.

Major changes will be required to reduce light vehicle energy use, or to even check its growth. Substantially improving light vehicle fuel efficiency will have the single largest effect on fuel consumption. As will be discussed below, it is within the range of technological and economic feasibility to improve the new car fuel economy to over 40 mpg within about ten years. Similar improvements could be achieved in light trucks. Although highly important, these major improvements, if achieved, will be largely offset by fuel consumption increases caused by growing traffic congestion and vehicle miles of travel. To achieve deep reductions in fuel use, the United States must not only improve fuel economies but slow the growth in vehicle miles of travel and provide attractive alternatives to single-occupancy vehicles.

The effect of future fuel economy improvements on global warming will of course depend on the degree of those improvements. If U.S. new light vehicle fuel economy is improved 40% by 2001, as is being proposed in Congress, carbon emissions will 120 million metric tons per year lower by the year 2005 than they would be if new light vehicle fuel economy remains at today's levels. Although this is only 9% of current U.S. carbon emissions, no other single improvement in end use energy efficiency, or plausible switch to low-carbon, nuclear, or renewable fuel, will yield reductions as large by the year 2005.

If other countries were to also substantially increase their new vehicle fuel economy, much larger reductions in CO_2 emissions would be possible. A recent EPA report to Congress estimates that increasing the world's fleet fuel economy to 50 mpg by the year 2025 would reduce projected global warming by 5% in a future scenario that assumes rapid technological change and economic growth (Lashof & Tirpak, 1989). (Note that this is not a 5% reduction in CO_2, but a 5% reduction in the projected average world temperature rise.) Again, although this may not seem large at first, one must consider the many greenhouse gases and their large number of sources. For perspective, EPA estimates that the 5% reduction is larger than the reduction in global warming that could be achieved through a near complete phaseout of CFCs by 2003, or through a rapid development of low-cost solar technology.

II. THE SCOPE FOR POLICY

We address policies in this paper that improve energy efficiency and reduce greenhouse gas emissions, while providing daily "access" for people, and maintaining or improving values such as safety and environmental quality. By daily access we mean being able to reach places to work, shop, or engage in other activities. We do not, strictly speaking, mean mobility with its implication of expanded vehicle miles or passenger miles. In a given situation, improving access may involve enabling people to travel further without increased energy use, but it may instead involve reconfiguring land use patterns so that less travel is needed.

Policy areas which bear directly on improved access are:

- land use;
- public transport;
- substitutes for transportation;
- traffic and parking management, road controls, and road design;
- driver behavior, including vehicle maintenance and driving style, and;
- improvements in light vehicles.

Land use and public transportation policies are a major focus of those interested in improved access (Pushkarev & Zupan, 1977; Burchell & Listakin, 1982; and Holtzclaw, 1990). Their potential impact is suggested by the fact that per capita gasoline use in the Toronto metropolitan area is roughly half that in Houston, Phoenix, Denver, or Detroit (Newman & Kenworthy, 1988). Yet Toronto is not that different. It is a relatively affluent, high-quality-of-life North American metropolis. The key characteristics of Toronto that appear to be responsible for Toronto's low gasoline use are regional control of land use and a well-developed, widely used public transportation system.

A major insight on provision of access is that while almost all passenger miles traveled (87%) are due to autos and light trucks, a relatively small increase in the use of public transport can lead to a major decline in driving. Recent research indicates that one new mass transit passenger mile can reduce personal vehicle miles by a factor of 5 to 10 (Holtzclaw, 1990). This large leverage is argued to be primarily a consequence of the influence mass transit can have on development patterns, i.e., on the density and distribution of housing, work sites, shopping, etc. With that kind of leverage, mass transit may eventually offer far more potential for reducing VMT than suggested by the small share of passenger miles provided by transit.

Substitutes for transportation, such as telecommunications, which enable some people to work and shop at home, and satellite places of work, which rely heavily on telecommunications, also have major potential. These are not primarily issues for public policy, but technology policies and regulation of communication systems are important to their success.

Traffic management in the form of high occupancy vehicle lanes, and car pooling assistance have had some success in reducing travel demand and fuel consumption (Burke, 1990). A key to the success of many of these programs is charging full cost for parking privileges (Replogle, 1990). Road charges in congested areas have long been considered in Europe and Asia and have been successful in Singapore, where they have been combined with provision of extensive modern public transport (Ang, 1991).

Highway controls, such as sophisticated signal management to encourage smooth traffic flow in congested areas, have been successfully developed, especially in Australia where resulting fuel savings of up to 20% were estimated (Watson, 1990). In addition, roads can be designed to mitigate stop and go driving, and the rate of vehicles entering expressways can be controlled to successfully limit congestion (Institute for Transportation Engineers, 1989). Enforcement of speed limits also contributes to efficiency.

Driving behavior is also important, but very difficult to influence. Proper vehicle maintenance, such as regular engine tuning and maintaining correct tire pressure, can contribute perhaps 10% to the fuel economy of the average car. Driving style, i.e., smooth flow as contrasted with rapid starts and rapid stops, significantly affects efficiency. Public education may be somewhat useful in this area.

While all these areas are highly important to efforts to reduce the environmental impacts and energy consumption of light vehicles, we chose in this paper to focus on policies that encourage technological improvements in light vehicles. Improving light vehicle technology will not, by any stretch of the imagination, be a sufficient means of resolving the enormous environmental and energy problems created by light vehicle use, but it may be the most important.

Some specialists have stated that the average fuel economy can be doubled again without radical changes in vehicle technology or substantial loss in the amenity provided (Bleviss, 1988; Horton & Compton, 1984). If much lighter, less powerful vehicles were acceptable, or if more radical technology were successfully developed, a much greater increase in efficiency could be achieved.

Several aspects of improving vehicle fuel economy are of interest to policy makers:

- modest modifications to conventional vehicles;
- alternative fuels;
- radical vehicle technology, such as the fuel cell vehicle, or the very light, small commuter car;
- interactions with vehicle safety, and;
- interactions with emissions of regulated pollutants.

Our emphasis will be on the first topic in the above list and its associated issues, i.e, near-term technological changes. We will also discuss some issues in the other areas.

III. MARKET WEAKNESSES

Fuel prices will clearly play an important role in spurring fuel economy improvements, as they have in the past, but we cannot assume that fuel prices alone are a strong enough motivator to improve fuel economy to levels that are cost-effective from a societal perspective. We conclude this for two reasons.

First, the cost of fuel is a relatively small part of the cost of driving a new car. At the price of gasoline that prevailed during the late 1980s, about $1.00 per gallon, annual fuel costs were only about 10% of the cost of driving for the average new car driver. (See Figure 2.) If fuel prices were twice as high, and the amount of driving remained the same, fuel costs would still only be about 20% of the cost of driving.

Second, buying a more fuel efficient car only has a small effect on annual driving costs. For example, purchasing a 35 mpg car instead of a 30 mpg car will reduce annual fuel costs only $50 per year. If the two cars are identical in every respect except fuel economy, the more fuel-efficient car will be more expensive because of additional manufacturing cost. We estimate the extra up-front cost, converted into an annual cost, is about $25 per year, making the net savings to the buyer of the 35 mpg car only $25 per year. With fuel costing twice as much, the net annual saving would still only be $75. We are not suggesting that most new car buyers do such calculations, but they are probably aware that for most cars, fuel economy performance does not greatly affect the economics of buying and owning a new car.

It is not surprising that new car buyers find fuel economy to be a secondary consideration. Many other attributes have higher priority: brand, safety, interior volume, trunk size, handling, price, reliability, etc. (McCarthy, 1989). Indeed, manufacturers have decided that fuel economy is of so little interest to buyers that they only offer it as part of a package in bottom-of-the-market vehicles (such as the Geo Metro), making it impossible for buyers to simply choose added fuel economy at extra cost while preserving the other vehicle attributes in which they are interested.

A different way of expressing these observations is that the value new-car buyers appear to place on future fuel savings is low. That is, their implicit discount rate is high, perhaps 30 to 50% (as with other household energy conservation investments), rather that the 5 to 10% real interest on most new car loans.[Footnote 4] This implicit undervaluing of future fuel costs will probably continue to characterize new vehicle purchases, except perhaps in times of fuel crises.

Other evidence that higher fuel prices won't push passenger car fuel economy into the high 30s or 40s mpg is found in industrialized countries with gasoline prices that are two to four times higher than U.S. prices. Table 1 compares fuel economies and gasoline prices in selected countries. Of course vehicle ownership and use are different in these countries than in the United States, so quantitative comparisons may be misleading. Nevertheless, it is impressive that much higher fuel prices are associated with new vehicle mpg values at most in the mid-30s.

IV. POLICY MECHANISMS

Fuel Pricing

The market price of gasoline does not reflect its real cost to the U.S. economy. Some studies estimate that the national security cost of importing oil amounts to at least 30 cents per gallon (Broadman & Hogan, 1986). The costs of air pollution and the risks of climate change make the cost even higher.

Logically, these costs should be internalized through a tax on oil regardless of where it is used in the economy. A tax on transportation fuels, however, would be more practical. The potential for cost effectively increasing energy efficiency and reducing oil use in the transportation sector is large and would allow oil users the opportunity to reduce their tax bill. And taxes on transportation fuels would cause fewer problems for competitiveness than taxes in the industrial sector.

Evidence of the last few decades shows that higher gasoline prices have had a significant effect on gasoline consumption. A recent review of studies on consumer responsiveness to higher gasoline prices found a long run price elasticity of demand for gasoline of -.78 to be the most reliable (Khazzoom, 1988). The sample period from which the estimate is drawn is 1957 - 1977.

Even though this estimate reflects relatively strong changes in demand for gasoline in response to price changes, it does not contradict the preceding discussion on why higher fuel prices won't push new car fuel economy to levels substantially higher than today's. First, new car fuel economy was much lower during 1957-1977 than at present, and consequently, fuel costs as a fraction of total owning and operating costs were about 20%, twice today's level.(Motor Vehicle Manufacturers Association, 1990) There is thus reason to believe that new car fuel economy today would not be nearly so responsive to changes in gasoline prices.

Second, in addition to reflecting changes in new car fuel economy, these price elasticities reflect changes in miles of travel. A 1984 review of gasoline demand segregated the mpg and travel demand responses to changes in gasoline prices (Bohi & Zimmerman, 1984). That review referenced several 1982 cross-country comparisons that found long run gasoline price elasticities of demand for MPG to congregate around about 0.3. (When added to the reported price elasticities for travel from the same studies [about 0.5], these results are consistent with the price elasticities of demand for gasoline cited by Khazzoom.)

Even though gasoline prices have historically had a small but significant effect on fuel economy, now that the fraction of total operating costs due to fuel are much lower, we shouldn't expect new car fuel economy to be as responsive to gasoline price changes as it was in the past (Greene, 1991). Nonetheless, when combined with other public policy measures to improve fuel economy, tax-induced higher fuel prices can help improve new vehicle fuel efficiency. Furthermore, as suggested by the relatively high price elasticities for travel referred to above, fuel taxes can be important in helping slow the growth in vehicle miles of travel.

While small federal and state gas tax increases have been adopted lately, large increases, especially those not earmarked for highway improvements, are strongly opposed. Some of this opposition, particularly from consumer and low-income interests, is driven by questions of fairness. Imposing large, immediate new fuel costs on people who earn their living driving cars and trucks, or those who have made living arrangements that require long-distance driving could unfairly shoulder a disproportionate share of the tax burden. And low-income individuals, whose fuel expenses represent a higher fraction of their incomes than higher income persons, could be unfairly burdened. Any efforts to substantially raise fuel taxes needs to address these issues.

However, there is at least one way to substantially increase the apparent price of gasoline without imposing new taxes or increasing the cost of driving: by restructuring the way we pay for automotive insurance. Instead of paying for all of our automobile insurance in independently arranged contracts with insurance companies, we could pay for a large fraction of our insurance needs at the gasoline pump. The price of gasoline at the pump could include a charge for basic, driving-related, automobile insurance that would be organized by state governments and auctioned in blocks to private insurance companies. All registered drivers in the state could automatically belong. Supplementary insurance above that provided by the base insurance purchased at the pump could be independently arranged, as we presently do for all of our insurance. For example: owners of expensive cars, or people who desire higher levels of liability coverage could purchase supplemental insurance. Drivers with especially bad driving records could be required to purchase supplemental liability insurance (El-Gasseir, 1990).

Such an arrangement has several advantages:

1) Insurance costs become much more closely tied to the amount of driving done. The more miles a person drives, the more insurance he pays. Since accident exposure is closely correlated with miles driven, the proposed system would be fairer than the present system in which people who drive substantially less than the average miles per year are given

only small discounts, and people who drive substantially more than the average, don't pay any additional premium.

2) Uninsured motorists would be brought into the system. By making insurance part of the cost of gasoline, a person couldn't drive without paying for insurance. In California, for example, uninsured motorists increase premiums for insured motorists by about $150 per year. Bringing uninsured motorists into the system would substantially lower the cost of driving for insured motorists.

3) The apparent cost of gasoline at the pump would rise substantially, roughly between 50 cents to a dollar per gallon. Such a price rise would encourage the purchase of more fuel efficient vehicles and help slow the growth in vehicle miles of travel. The increase in the price of fuel would be offset by a decrease in the annual insurance premium motorists would pay directly to insurance companies, resulting in no net increase in driving costs. At least one financial analyst argues this system would result in a net decrease in driving cost because of the substantial savings in insurance brokerage and other insurance industry expenses (Tobias, 1982).

4) Unlike a gasoline tax, this system would not be regressive. Low-income persons drive substantially less miles per year

than their higher income counterparts. They would, consequently, see a substantial drop in the money they pay for auto insurance.

Another way to reform automobile insurance that would achieve similar results and would require a much simpler change in the insurance industry would be to have motorists pay for a part of their auto insurance on the basis of how many miles per year they drive, according to annual odometer readings reported to insurance companies. The National Organization for Women, which believes the current auto insurance system is biased against women, supports this approach. Pointing out that women, on average, drive about half as many miles per year as men, they argue that women are overcharged for auto insurance, and that insurance payments based on miles driven would more fairly allocate insurance costs (Butler, et. al., 1988). Although this approach would avoid the difficulty and political problems of setting up a state organized insurance pool, it would not encourage the purchase and use of more efficient autos.

Performance Standards

Fuel Economy

The Motor Vehicle Information and Cost Savings Act of 1975 set corporate average fuel economy (CAFE) standards that required the fuel economy of new cars to increase from about 14 mpg in the early 1970s to 27.5 mpg by 1985. (See Figure 3.) The Act provided flexibility to manufacturers by applying the standard to the sales-weighted average for each corporation, instead of each, individual vehicle. Further flexibility was provided by allowing manufacturers to earn credits for exceeding the standard in any year, and then allowing those credits to offset penalties in years when a manufacturer may fall short of the standard. Moreover, the Secretary of Transportation was given the discretion to set a lower standard, as was done for 1986 through 1989 on appeal from manufacturers (especially General Motors and Ford). The discretion to set standards for light trucks was also left to the Secretary of Transportation.

In hearings on the 1975 Act, the manufacturers stated that the technology to achieve 27.5 mpg was not available on the proposed time scale, and that the only way to achieve the standard would be by making the average car much smaller. They said it would "outlaw full-size sedans and station wagons" (Chrysler), "require all sub-compact vehicles" (Ford), and "restrict availability of 5 and 6 passenger cars regardless of consumer needs" (GM) (Energy Conservation Coalition, 1989). Indeed, there was some reduction in the ratio of maximum-power to weight, although almost none in interior volume, in the early 1980s. (See Figure 4.) By the mid- and late-80s, however, the manufacturers were achieving the mandated standards with vehicles of interior volume and maximum-power equal to and higher than those of the early 1970s. The CAFE standards were thus an important example of successful "technology forcing" by regulation.

Some have claimed that the CAFE regulations were unnecessary, and that the increased price of gasoline in the late '70s and early '80s was responsible for the fuel economy improvements (Mayo, 1988; Crandall et. al., 1986). This argument is unconvincing on two related grounds:

- The estimated fuel price elasticities for vehicle purchase are moderate (Bohi & Zimmerman, 1984), whereas the increase in fuel economy in that period was more rapid than that for fuel price (Figure 3).

- Statistical analysis of separate manufacturer's CAFE achievements show that "the CAFE standards were a significant constraint for many manufacturers and were perhaps twice as important an influence as gasoline prices" during that period (Greene, 1990).

GM and Ford have argued that the CAFE formulation placed them at a disadvantage because their mix of vehicles includes large cars while the Asian manufacturers' doesn't. As a consequence, they argue, it is much easier and less expensive for the Asian manufacturers to meet the standards, and the domestic, full-line manufacturers are forced to compete with new Asian large car introductions with one hand tied behind their back. Some evidence for bias against full-line manufacturers in the CAFE standards can be found in individual manufacturer CAFE trends. In recent years, with the regulated CAFE floor essentially fixed, the CAFE's achieved by domestic manufacturers have declined somewhat from '88 to '90 models (3% for both GM and Ford), while the CAFEs achieved by Asian manufacturers declined substantially more (6% on average, 9% for Toyota) as they introduced larger, less fuel-efficient cars (Murrell, & Heavenrich, 1990). Of the major manufacturers, all now have CAFEs below 30 mpg except Honda.

Most recent fuel economy legislation introduced in the U.S. Congress seeks to address this problem by changing the basis of the standards so that each manufacturer is required to improve its fuel economy by the same percentage above its base year fuel economy.

Other industrialized countries have also adopted programs to improve fuel economy. Most have adopted voluntary programs, but some, including Sweden and Japan, have adopted mandatory programs like that of the United States. (See Tables 2 and 3) Even though Japan has a mandatory fuel economy program, the average fuel economy of their new cars has slipped from 30.5 mpg in 1982 to 27.3 in 1988 as they have moved to progressively larger cars (MacKenzie & Walsh, 1990). The inability of Japan's fuel economy program to prevent this slippage is apparently a result of their fuel economy standards being based on weight classes.

Emissions

Early Clean Air Act provisions required emissions reductions in the late '60s and early '70s which could be accomplished by improved control of engine operations. While Europe continued with this weak policy, subsequent U.S. regulations required reductions of tailpipe emissions to much lower levels. By 1981 emissions of hydrocarbons (HC) and carbon monoxide (CO) were limited to 10% of the levels of 1970 and nitrogen oxides (NOx) to 25% of those levels (Table 4). This became another example of successful technology forcing. Catalytic converters and supporting control systems were rapidly developed and have proved highly effective. (See below, however, on failures of emission control systems.) The present 3-way catalyst, which oxidizes HC and CO and deoxidizes NOx, is a major accomplishment. The system requires that the exhaust contain very little oxygen or unburnt fuel, or specifically, that the initial quantities of fuel and air be correct to within 1% (or better) of the chemically correct combustion ratio. This is achieved with a closed-loop control system, in which catalytic converter operation parameters are fed back to engine controls to change the mixture of gases entering the converter.

The Overall Results: Mixed

Depending on one's perspective, the fuel economy and emissions programs could be viewed as ineffective or remarkable successes. If one were to take a static perspective, in which we compare the absolute level of emissions and fuel consumption today with the levels that existed when the regulatory programs were begun, one wouldn't declare success. Despite the fact that a new car today has approximately twice the fuel economy and 10% of the emissions of cars built 10 to 15 years ago, the overall use of gasoline has actually grown somewhat and air quality has improved only slightly. But from a dynamic perspective, where one asks oneself what fuel consumption would have been without fuel economy improvements or emission reductions, the programs have been very successful. As pointed out earlier, had average light vehicle fuel economy not risen since 1973, the United States would be consuming an additional four million barrels of oil per day. Nonetheless, it is important to explore reasons for why such large improvements in fuel economy and emissions control have not produced large, absolute reductions in emissions and fuel use.

The fuel economy picture is relatively clear. Vehicle miles traveled on highways increased 59% from 1973 to 1989 (Figure 1). In the same period, the average fuel economy of all cars on the road also improved, but not quite enough to compensate for the higher VMT. Average fuel economy grew about 45%, much less than the 100% improvement in the new-car test value. This discrepancy is primarily due to three factors: the long time required for retirement of old, inefficient vehicles, the increasing share of light trucks with their poorer fuel economy, and the increasing gap between EPA-rated fuel economy and actual, on-road fuel economy.

The on-road fuel economy of new cars and light trucks is falling further behind their EPA-rated fuel economy. The on-road fuel economy is estimated to have been 15% lower than the EPA laboratory test value in 1982 (Hellman, Murrell, & Dillard, 1984). Analysts project that due to changes in driving patterns, the on-road fuel economy will fall 30% below test by the year 2010 (Westbrook & Patterson, 1989). The reasons for the growth in this gap are increasing congestion with its stop and go driving, the increasing share of urban driving, and increased speed on open highways. In other words, the driving cycles (and their weighting) established for the federal fuel economy test procedure do not accurately reflect new driving patterns. A part of the problem is that very powerful vehicles are becoming commonplace and many are driven in high velocity/acceleration patterns different from those on the test.

The disappointment as seen from a static perspective is not that fuel economy regulation has been unsuccessful, it is that new-vehicle fuel economy is only one aspect of the problem. As discussed, increased vehicle miles of travel and changes in driving patterns also have important effects on fuel use. The conclusion for policy making is the need for a package of policies that address all these problems, so that the gains in one aspect of the problem are not cancelled by losses in another.

The record on air quality regulations is more complex. Part of the story is the increase in vehicle miles traveled just mentioned, but the discrepancy between test tailpipe emissions and total emissions is much greater than the fuel-economy discrepancy. Average emissions are estimated to be larger by as much as a factor of 10 than they would be if total emissions equaled the allowed tailpipe level (U.S. EPA Motor Vehicle Emissions Laboratory, 1988). As Table 5 shows, much of the HC emissions are not from the tailpipe but from evaporation from the vehicle and from vehicle fueling. In addition, a small fraction of vehicles are probably responsible for average tailpipe emissions far in excess of the limit for new cars. These are vehicles: 1) whose emissions control systems have severely deteriorated or failed, or 2) which are old enough to have had legal high emissions when new. As suggested by Table 4, if the catalytic converter system fails, emissions will increase by a factor of 5 or more. The average CO and NOx emissions are also much higher in practice than the limits even though there is no evaporative component.

There are EPA mandated programs to address evaporative emissions and failure of vehicle emissions control systems. Recently, powerful steps have been taken to reduce evaporation into the air, but it is too soon to evaluate the effort. With respect to emissions control systems, inspection and maintenance programs have been in place many years in metropolitan areas with serious ambient pollution. Many of these programs have been disappointing: 1) The test used in most regions measures emissions while the engine idles. Many vehicles will pass an idle test but emit heavily under load. 2) The inspection is carried out in many regions at individual garages. Often the mechanic and the vehicle owner have a mutual interest in avoiding the cost of repairing the emissions control system.

A fundamental complication is that the ambient pollutant of most concern, ozone, is the result of atmospheric chemistry involving two precursors, HCs and NOx. It is believed that, for most high-ozone events, one or the other precursor is critical, i.e., reducing it would reduce ozone while reducing the other may even increase ozone levels. There is not a consensus on which, HC or NOx, is typically the more important target.

In summary, emissions are much more sensitive to things going wrong than is fuel economy. Where fuel economy can be cut 10 to 20% by an engine going out of tune, emissions can increase an order of magnitude when something goes wrong, e.g., when an oxygen sensor fails. Moreover, the fuel economy problem may be noticeable in terms of poor performance, which often induces corrective action. The same can't be said for degradation in emissions performance. The apparent failure of emissions regulations to be effective over the life of many vehicles, such that actual emissions are much higher than envisioned by the regulations' authors, is a major deficiency of present policies.

The Next Generation of Regulatory Standards

Regulatory performance standards are an important policy option for bringing motor vehicle fuel use under control. They have worked in the past, and market conditions and technological opportunities are such that they will likely work well again. The near-term technological opportunities for improving fuel economy fall into three categories:

- technological changes which add moderately to the new vehicle cost but do not affect the performance or size of the vehicle;
- technological changes with slight impacts on driving, such as electronic transmission management and continuously variable transmission for small cars, and;
- reduced performance (acceleration) and/or size (interior volume).

We will address the first two because they are the most relevant to today's policy debates. The third is less relevant because few policy makers are currently willing to consider policies that would make a car any less comfortable, drivable, or powerful than today's average car. As discussed earlier, however, there is a strong association between acceleration capability and fuel economy. Thus, a decrease in average acceleration performance would be a technically easy and effective way to improve new car fuel economy.

We have created a conservation supply curve (Figure 5) for automobile fuel economy improvement based on technologies already in some production models or well-demonstrated in prototypes (Ledbetter & Ross, 1990). These are all modifications to the standard gasoline-fueled vehicle which preserve performance and size. The supply curve shows how much fuel savings are cost-effective (x-axis) at a given gasoline price (y-axis). For example, at a gasoline price of $1.32/gal (1989$) we find that an average 44 mpg (test value) would be cost effective, and perhaps, practical to achieve by year 2000, compared with 28 mpg in 1989. The cost of these fuel-economy improvements corresponds to a retail price increase of about $750 per car. When this cost is spread over the gasoline saved over the vehicle's lifetime and discounted to present value, the cost amounts to 53 cents per gallon saved, less than half the projected price of gasoline in 2000.

Conservation supply curves usually reflect that up-front costs are incurred in making more efficient equipment. This is somewhat paradoxical for cars, since the high-fuel-economy cars on the market are cheaper, not more expensive. The market does not, in fact, offer the kind of choice illustrated by Figure 5. The reason is that manufacturers have made the marketing decision that high fuel economy should be offered at the low end of the market, associated with lower-powered and smaller vehicles rather than with technological improvements of types (1) and (2). (Some technologies of the types considered in Figure 5 are incorporated in many cars, but usually in forms that increase power rather than improving fuel economy.)

Another important feature of Figure 5 is that the added up-front expenditure for fuel economy improvement is justified by savings on gasoline. That is, money would be saved by regulatory forcing of these improvements. The analyst takes a critical step, however, in making this determination: choice of the discount rate that enables the up-front cost to be re-expressed as an ongoing cost, which can be compared with the cost of fuel. For Figure 5 we chose a 7% per year real discount rate, roughly consistent with real loan rates. (This discount rate does not, however, reflect the new-car buyer's behavior. As discussed above, the individual new car buyer has a much higher implicit discount rate for fuel-economy improvements.)

Since substantially higher fuel economies are practical and cost effective, and since society has a major interest in reducing petroleum demand, it is not surprising that stronger regulatory standards for fuel economy are actively being considered in Congress. Senator Bryan sponsored a bill that would have required each manufacturer to increase its average fuel economy 40% above its 1988 level of fuel economy by 2001. On average the bill would require new cars to reach 40 mpg. It was supported by a majority of the Senate, but failed to overcome a filibuster in late 1990. The bill was re-introduced in early 1991.

Automobile manufacturers strongly oppose the legislation, and claim, as they did in 1975 before the first CAFE standards were passed, that it is not practical to substantially improve fuel economy except by moving, on the average, to much smaller cars. Manufacturers are stonewalling on this point. Other, more compelling reasons for their opposition are: 1) major tooling investments would be needed to make the changes, especially if a moderately rapid timetable is required as proposed; 2) the required rate of improvement in fuel economy would prevent manufacturers from fully exploiting sales opportunities for low-fuel economy models already in production, and; 3) high fuel economy standards would somewhat restrict designers' options in developing new vehicles and markets, e.g., there would be a premium on streamlining and on certain kinds of transmission shift management.

It is important to address such concerns by creating a schedule of strengthened standards allowing adequate time for manufacturers to adjust, and by enacting policy packages (with components discussed elsewhere in this chapter) such that the burden of compliance would not fall entirely on the manufacturer. Policies should be enacted that motivate buyers to select high fuel economy vehicles. The underlying concept in these suggestions is that we recognize the difficulties of substantially raising vehicle fuel economy, and that an increase in the standards by itself is not a sufficient policy for boosting average fuel economy to 40 mpg or higher.

Fees and Rebates on Vehicle Purchases

The Gas Guzzler Tax

The gas guzzler tax, enacted as part of the Energy Tax Act of 1978, has been overlooked as an effective policy tool for improving fuel economy. (See Table 6.) However, there is strong evidence that the gas guzzler tax played an important role in improving fuel economy, especially between 1983 and 1986.

Figure 6 shows a plot of the average fuel economy of cars whose average fuel economy was below 21 mpg in 1980, the year before the gas guzzler tax took effect. Also plotted on the graph are the gas guzzler tax threshold and the real price of gasoline for the years 1980 through 1987. As can be seen, the fuel economy of low-mpg cars rose after the guzzler tax threshold was raised high enough to pose a tax threat. Manufacturers clearly decided it was more economic to improve fuel economy than to even pay a small gas guzzler tax. This improvement in fuel economy occurred during a period of sustained decreases in the price of gasoline. As can be seen in Figure 7, this improvement in low mpg cars occurred when the fuel economy of the remainder of the new car fleet hardly improved, suggesting that the gas guzzler tax played a major role in post-1983 fuel economy improvements.

Gas guzzler taxes have a number of desirable features. Since the tax only applies to new cars, low-income persons will be largely unaffected by the tax. And since the tax is a large penalty imposed at the point of automobile purchase, instead of very small sums stretched out over many years (as caused by a gasoline tax), it is likely to have a strong effect on the willingness of car buyers to seek higher mileage cars.

We also recommend that a gas guzzler tax be established for light trucks, and as for passenger cars, the guzzler tax threshold should be increased by the same percentage as the light truck fuel economy standard.

Drive +

An extension of the concept of the gas-guzzler tax is a system of fees and rebates that would be levied on new cars according to whether they were above or below an average level of fuel economy. Such an approach has been introduced in legislation in California, and has been dubbed, "Drive+" (Gordon & Levenson, 1990). As proposed there, fees and rebates would also be set according to whether a car's emissions were above or below an average level. Drive+ would thus encourage cars to be produced that are certified for emissions at levels below the legal limits. There is good evidence, from cars made by Volkswagen, Suzuki and others, that such low emissions can be achieved at modest cost, at least by high-fuel-economy vehicles. The program is designed to be revenue neutral, so that total rebates roughly equal total fees. The concept is just as appropriate at the federal level as it is at the state level. The Drive+ program was passed overwhelmingly by the California state legislature in 1990, but was vetoed by the Governor. Given the new governor's expressed support, it is expected to become law in 1991.

Fees and rebates at the point of purchase of a new vehicle are an important tool to improve fuel economy and emissions (Geller, 1989). Given our society's sensitivity to first cost, it is easier and more effective to adjust for market imperfections and influence new car fuel economy and emission levels at the point of capital equipment purchase than it is to adjust for imperfections in the course of operations, as, for example, with a gasoline tax.

Technology Policy

The policies discussed above indirectly encourage the creation of new technology to meet the changed economic conditions or regulatory constraints. Experience shows, however, that a more direct policy focus on new technology can be highly effective. Before considering such policies, let us briefly suggest the possibilities for new technology to meet our goals.

By new technology we mean vehicles and their energy supply systems which could radically reduce energy requirements and emissions, but which are not close to being in mass production. There are three potential types of vehicles:

1) vehicles with much higher fuel economy, but still based on gasoline or diesel fuel and still serving four or more passengers with, roughly, today's driving capabilities;

2) special-purpose vehicles requiring much less energy at the drive wheels, such as a small commuter car, and;

3) alternative-fuel vehicles including those which could flexibly operate on both gasoline and an alternative fuel.

In Group 1 the engine could be an advanced, direct-injection diesel, now entering production in Europe, which is about one third more efficient than corresponding conventional gasoline-powered engines. High-fuel-economy prototype vehicles incorporating advanced diesels have been built or partially developed by Volvo, Volkswagen, Renault, Peugeot, and Toyota, with in-use fuel economies estimated to be almost 70 mpg and higher (Bleviss, 1988).

In Group 2, there are vehicles such as the proposed Lean Machine and the demonstration electric vehicle called Impact, both developed by General Motors. The Lean Machine is a two seater with one passenger behind the driver. Both the Lean Machine and the Impact are small, have little air and tire drag, and require very little power to be delivered to the wheels in typical driving. (The fact that the Impact is an electric vehicle is incidental to this discussion.) Both of these prototype vehicles happen to have rather high acceleration performance. It is not clear if that is an important attribute for marketing such a vehicle. Safety is a critical issue for such vehicles. It may be important to consider separate lanes on high speed roadways.

In Group 3 there is an enormous range of possibilities. We mention only two of the most exciting: hybrid electric and fuel-cell vehicles. The hybrid electric is powered by both batteries and an internal combustion engine. A common configuration is for the car to use the batteries (and electric motor) on short day trips, and to use the internal combustion engine for longer trips. The batteries would be expected to be recharged overnight, when electric demand is low and there is substantial unused electricity generating capacity. The hybrid overcomes the severe disability of electric vehicles: their short daily range and long battery recharge period.

The fuel cell, essentially a large battery, has the advantage of relying on a stored fluid fuel like methanol. The fuel cell converts the chemical energy of the fuel to electricity without combustion. Extremely little, if any, emissions are associated with fuel cell operation, with the exception of carbon dioxide. Much higher efficiencies of conversion are possible than with the present kind of engine.

Emissions regulations and control is another area where new technology could have a revolutionary impact. Inexpensive equipment to measure, record, and communicate information about emissions into the air may be able to alter the strategy for regulation of emissions from its focus on design criteria and isolated tests to a focus on actual performance. To illustrate, it is now becoming possible to measure emissions from the tailpipe of a car driving down a road, using a source of light and a receiver on opposite sides of the road (Stedman, 1990). When this technology is developed, it will be possible, first, to determine quantitatively how important the most polluting cars are to overall emissions from the automobiles in a particular airshed. And second, if the problem is indeed dominated by a small number of serious offenders, it may be that identifying these offenders will become a particularly cost-effective approach to clean-up. A competing, or perhaps complementary, approach for vehicles may be to measure and record emissions performance with on-board technology that is beginning to be developed.

Technology Push and Pull Policies

The U.S. government has been highly effective in encouraging new technology in some sectors, like agriculture, commercial aircraft, and semiconductors. The tools used are, broadly, technology push and technology pull.

Technology push concerns the creation of technology: research, invention, development, and demonstration. This is not a linear sequence of activities, in which one follows the next, but a complex interaction in which new technologies are created. Technology push policies involve government support for research, development and demonstration (R, D & D) and government encouragement of private-sector R, D & D through tax incentives, patent law, etc.

Technology pull concerns the demand for new technology, i.e. demand for it after it reaches initial commercial status. It cannot be over-emphasized that the existence of a likely market for a new or improved process or product strongly motivates development and production of new technologies, and the apparent absence of a market strongly inhibits them. Government policies can provide technology pull through government purchases and by encouraging the private sector's propensity to purchase new technology (Ross & Socolow, 1990).

A major example of a technology-push policy is government-supported research and development on generic technologies that could form the basis for many new product developments. Modest government involvement is proving very beneficial in electrochemistry (new and improved batteries), combustion (understanding of knock and soot formation), and ceramic insulation (for the combustion chamber). It would be valuable to continue support in these areas and greatly expand the government's efforts in, e.g., engine friction and control approaches for hybrid-electric vehicles.

It may seem that it is the private sector's responsibility to conduct research on generic technologies such as those just mentioned. It is well known and well documented, however, that the private sector under-invests in research (Young, 1986). The roots of this under-investment lie in a firm's inability to prevent its competitors from capturing many of the benefits of its research. Other contributing factors are the short time horizons and the heavily cyclical earnings patterns experienced by many firms. The private sector cannot support research leading to innovation in many socially useful areas of technology, at least not nearly at a level consonant with today's needs.

An attractive example of a technology pull policy is providing extra fuel economy credits to manufacturers that produce automobiles or light trucks that attain exceptionally high levels of fuel economy. Such a provision would reward manufacturers for aggressively introducing new technology, an incentive for manufacturers to take a significant leap forward with fuel economy technologies, as opposed to taking more conservative, incremental steps. The incentive could be made especially strong for improving the fuel economy of mid-size and large cars.[Footnote 5]

A schedule of fuel economy thresholds for the major EPA automobile size classes could be established as part of a strengthened fuel-economy-standards law. The schedule could define, for each size class and for specified years, which level of fuel economy would have to be exceeded for a manufacturer to qualify for the credits. A schedule that would be consistent with fuel economy standards requiring a 40% increase in fuel economy might be as shown in Table 7. If a manufacturer produced a car that exceeded the above specified levels, it could count the fuel economy of that car (for purposes of complying with CAFE standards) as being, for example, 50% higher than its test fuel economy. Present fuel economy regulations already include similar CAFE credits for alternate fuel vehicles.

V. FUEL ECONOMY AND SAFETY

Opponents of efforts to improve automobile fuel economy have recently argued that the standards increase highway fatalities. Fuel-efficient cars are commonly equated with small, light cars. However, the record shows that fuel economy can be substantially increased without reducing vehicle weight. The average new car fuel economy began to improve sharply after 1974. Initially, much of this fuel economy improvement was due to reducing average vehicle weight. It was the easiest and cheapest way for manufacturers to improve fuel economy. But since 1980, the average vehicle weight has remained almost constant, while the fuel economy increased by about 20%. (See Figure 8.) Manufacturers were able to improve fuel economy without reducing vehicle weight by relying on technological improvements in engines, transmissions, aerodynamics and other means. The potential for making further fuel economy improvements without reducing vehicle weight remains large (Ledbetter & Ross, 1990).

Points in Figure 9 represent the weight and safety performance of 1984 to 1988 model year cars crash tested by the U.S. Department of Transportation's National Highway Traffic Safety Administration. These cars were crashed into a fixed barrier at 35 mph. The measure of safety performance is the driver head injury criterion (HIC), which reflects the potential for injury to a driver's brain. The higher the number, the higher the potential for injury. As shown here, there is no relationship between automobile weight and head injury criteria. In fact, there are some heavy vehicles that perform poorly (upper right portion of the figure) and some light vehicles that perform very well (lower left portion of the figure). A plot of the passenger side HIC yields very similar results.

Crashing a car into a fixed barrier does not necessarily measure how weight affects a car's performance in a crash. Nonetheless, Figure 9 illustrates that there are large differences in the crash worthiness of automobiles, independent of weight. A 1982 study pointed out that the differences in crash performance within weight classes were greater than the differences among weight classes (Office of Technology Assessment, 1982).

There are many existing light-weight cars that perform well in crash tests. But much safer and more fuel-efficient cars are possible. The Volvo LCP 2000, a prototype high-efficiency car, was designed with both safety and fuel economy in mind. The car weighs 1500 pounds (less than half today's average new auto weight of about 3200 pounds), achieves 63 mpg in the city and 81 on the highway, and can withstand frontal and side impacts of 35 mph, and a rear impact of 30 mph (Bleviss, 1988). U.S. regulations require only that vehicles can withstand a frontal impact of 30 mph.

The U.S. Department of Transportation's Research Safety Vehicle Program, which existed from 1977 to 1980, developed an experimental car that was both safe and fuel efficient (U.S. Department of Transportation, 1980). The program concluded that a car using then-current technology (ten years old now) could carry five passengers; achieve 43 mpg; and withstand 80 mph frontal impacts, 50 mph side impacts, and 45 mph rear impacts.

Evidence that fuel economy and automobile safety can be improved simultaneously is also found in the statistical record established in the United States. Since 1973, the average fuel economy for all cars on the road rose from 13 mpg to 20 mpg. During the same period, traffic fatalities fell from 3.5 per 100 million vehicle miles traveled to 2.4. Safer cars and highways, increased use of seatbelts, and anti-drunk driving campaigns are widely recognized as major reasons for the improvement.

Despite the evidence that improving fuel economy and automobile safety are compatible goals, adherents to the view that improved fuel economy means higher traffic fatalities cite studies of actual automobile crash data that demonstrate a relationship between car size and fatalities, or between car weight and fatalities. A common problem, however, with studies based on actual accident data is that it is difficult to separate the effects of driver behavior from vehicle characteristics when estimating the propensity of certain cars to be involved in fatal accidents. For example, the bad fatality record of a few high-performance sports cars may lead one to conclude that these cars are inherently unsafe. But dangerous driving practices of people who most commonly own and drive these cars may be partly or fully responsible for their bad safety record. Similarly, the worse-than-average safety record of a few small, inexpensive, and fuel-efficient cars may be due to the atypical driving behavior of people who tend to buy these cars, e.g., drivers of small cars tend to be young.

In summary, research has shown that with careful design, cars can be both fuel efficient and safe. Nonetheless, the results of some recent studies justify a close look at the effect of car size and weight on crash performance. If new research indicates that weight is a primary cause of lower fatality rates in large vehicles, then future fuel economy improvements should be based on approaches other than weight reduction. If new research indicates that car size, such as interior volume or wheelbase, is a primary cause, then future fuel economy improvements should focus on measures that do not decrease car size. With either approach, current and future technologies provide a broad range of ways to substantially improve auto fuel economy while simultaneously improving auto safety.

VI. CONCLUSIONS

Federal policies made a major contribution toward the fuel economy improvements achieved since 1975. But because they require no further improvements, and because real gasoline prices have fallen for years, the long upward trend in fuel economy has stalled. This cessation in fuel economy improvement puts our nation's economy and security at risk. Among the options for reducing our oil imports and carbon dioxide emissions within the next ten to twenty years, none will have greater effect than substantially improving light vehicle fuel economy. (See Figures 10 and 11.) The market could be of great assistance in pushing fuel economy levels higher, but because of large externalities and other barriers, it will not be sufficient.

In addition to fuel economy improvements, it is imperative that we slow growth in vehicle miles of travel, and offer attractive transportation alternatives to low-occupancy light vehicles. Otherwise, we could find ourselves looking back on the fifteen years that follow 1990, with the same sense of running-in-place that we get when looking back on the fifteen years since 1975.

Policies to reduce light vehicle fuel consumption will not only benefit the United States directly, but given the enormous influence U.S. policies and technologies could have on other countries, these policies could leverage large international reductions in transportation fuel use.

Acknowledgments

This work, and other research on transportation policies and technologies, was supported by the Joyce Foundation, the Educational Foundation of America, John A. Harris, IV, the Alida Rockefeller Charitable Lead Trust, the John D. and Catherine T. MacArthur Foundation, and the Lawrence Berkeley Laboratory. We also thank Howard Geller for many useful comments.

FOOTNOTES

1. The usual fraction of oil used by transportation cited from the Monthly Energy Review, Energy Information Administration, U.S. Department of Energy, is 63%. Our calculation, however, excludes secondary petroleum-based fuel burned at oil refineries and in other industries from total U.S. oil consumption, because it would not be used if the primary uses of petroleum did not exist. We believe this approach better reflects the extent to which the transportation sector is responsible for oil consumption in the United States.

2. This calculation includes both the carbon emissions resulting directly from combustion (20.2 kg C/10^9 J) and indirectly from production and transportation (2.7 kg C/10^9 J) (MacDonald, 1990).

3. Carbon monoxide also plays an important role in global warming because it destroys hydroxyl radical (OH), which oxidizes methane, another important greenhouse gas. So, a lower atmospheric concentration of OH results in a longer life for methane (MacDonald, 1990).

4. There is little quantitative information on this from automotive markets because, as mentioned below, buyers are

not offered an opportunity to spend more to get higher fuel economy. High implicit discount rates have been determined in other areas, like household appliances and industrial equipment. Auto manufacturers behave as if their marketing surveys show buyer indifference to fuel economy.

5. As pointed out above, high fuel economy has been associated with bottom-of-the-market vehicles. One of the major policy challenges is to inspire and encourage manufacturers to create "green" cars in the middle of the market.

REFERENCES

Bleviss, Deborah L. 1988. The New Oil Crisis and Fuel Economy Technologies. Westbury, CT: Quorum Books.

Bohi, Douglas and Mary Beth Zimmerman. 1984. "An Update on Econometric Studies of Energy Demand Behavior." Annual Review of Energy, Vol., 9. Palo Alto, CA: Annual Reviews Inc.

Broadman, H.G. and W.W. Hogan. 1986. "Oil Tariff Policy in an Uncertain Market." Energy and Environmental Policy Center, Harvard University.

Burchell, Robert W. and David Listakin. 1982. Eds., Energy and Land Use. Piscataway, NJ: Center for Urban Policy Research, Rutgers University.

Bureau of the Census. 1990. "Truck Inventory and Use Survey." 1987 Census of Transportation. Washington, DC. Table 4.

Burke, Monica. 1990. "High Occupancy Vehicle Facilities: General Characteristics and Potential Fuel Savings." Washington, DC: American Council for an Energy-Efficient Economy.

Butler, Patrick, et. al. 1988. "Sex-Divided Mileage, Accident, and Insurance Cost Data Show That Auto Insurers Overcharge Most Women." Journal of Insurance Regulation, vol. 6, no.3 (Part 1), and vol. 6, no. 4 (Part 2).

Crandall, R. W., et. al. 1986. Regulating the Automobile. Chapter 6. Washington, DC: The Brookings Inst.

El-Gasseir, Mohamed. 1990. "The Potential Benefits of Pay-As-You-Drive Automobile Insurance." Submission to the California Energy Commission. Docket No. 89-CR-90. Sacramento, CA.

Energy Conservation Coalition. 1989. "The Auto Industry on Fuel Efficiency: Yesterday and Today." Fact Sheet. Washington D.C.

Geller, Howard. 1989. "Financial Incentives for Reducing Auto Emissions: A Proposal for Clean Air Act Amendments." Washington, D.C.: American Council for an Energy-Efficient Economy.

Gordon, Deborah. 1991. Steering a New Course: Transportation, Energy and the Environment. Boston, MA: Union of Concerned Scientists.

Gordon, Deborah, and Leo Levenson. 1990. "Drive +: Promoting Cleaner and More Fuel-Efficient Motor Vehicles Through a Self-Financing System of State Sales Tax Incentives." Journal of Policy Analysis and Management. Fol. 9. 3, pp. 409-415. John Wiley and Sons, Inc.

Greene, David L. 1990. "CAFE or Price?: An Analysis of the Effects of Federal Fuel Economy Regulations and Gasoline Price on New Car MPG, 1978-89." The Energy Journal, Vol. 11, # 3 pp. 37-57.

Greene, David L. 1991. "Vehicle Use and Fuel Economy: How Big is the Rebound Effect?" Oak Ridge, TN: Oak Ridge National Laboratory.

Heavenrich, Robert M., J. Dillard Murrell. 1990. "Light-Duty Automotive Technology and Fuel Economy Trends Through 1990." Ann Arbor, MI: U.S. EPA Office of Mobile Sources.

Hellman, Karl . and J. Dillard Murrell. 1984. "Development of Adjustment Factors for the EPA City and Highway MPG Values." Warrendale, PA: Society of Automotive Engineers, 8400496.

Holtzclaw, John. 1990. "Explaining Urban Density and Transit Impacts on Auto Use." Testimony before the California Energy Commission, docket 89-CR-90, April 23.

Horton, E. J., and W.D. Compton. 1984. "Technological Trends in Automobiles." Science 225: pp. 587-93.

Institute of Transportation Engineers. 1989. "A Toolbox for Alleviating Traffic Congestion." Washington, DC.

Khazzoom, Daniel J. 1988. "Quantifying the Environmental Impact of a Gasoline Tax: A Study in the Use of Energy Conservation as a Strategy for Emission Abatement in the Transportation Sector." San Jose State University.

Lashof, Daniel A. and Dennis Tirpak. 1989. "Policy Options for Stabilizing Global Climate." Washington, DC: Office of Policy, Planning and Evaluation, U.S. Environmental Protection Agency.

Ledbetter, Marc and Marc Ross. 1990. "Supply Curves of Conserved Energy for Automobiles." Proceedings of the 25th Intersociety Energy Conservation Engineering Conference, New York: American Institute of Chemical Engineers.

MacDonald, Gordon. 1990. "The Future of Methane as an Energy Source." Annual Review of Energy, vol. 15. Palo Alto, CA: Annual Reviews Inc.

MacKenzie, James and Michael Walsh. 1990. Driving Forces: Motor Vehicle Trends and their Implications for Global Warming, Energy Strategies, and Transportation Planning. Washington, DC: World Resources Institute.

Mayo, John, and John Mathis. 1988. "The Effectiveness of Mandatory Fuel Efficiency Standards in Reducing the Demand for Gasoline." Applied Economics, 20, pp. 211-219. Chapman and Hall, Ltd.

McCarthy, Patrick S., and Richard Tay. 1989. "Consumer Evaluation of New Car Attributes." Transportation Research. Vol. 23A, #5, pp. 367-375.

Motor Vehicle Manufacturers Association. 1990. "MVMA Facts and Figures '90." Detroit, MI: Motor Vehicle Manufacturers Association.

Murrell, J. D. and R.M. Heavenrich. 1990. "Downward Trend in Passenger Car Fuel Economy - a View of Recent Data." Technical Report EPA/AA/CTAB/90-01. Ann Arbor, MI.: U.S. EPA office of Mobile Sources.

Newman, Peter G. and Jeffrey R. Kenworthy. 1988. Cities and Automobile Dependence: A Sourcebook. Aldershot, England: Gower Technical.

Office of Technology Assessment, U.S. Congress. 1982. "Increased Automobile Fuel Efficiency and Synthetic Fuels." Washington, D.C.

Pushkarev, Boris S. and Jeffrey M. Zupan. 1977. Public Transportation and Land Use Policy. Bloomington, IN: Indiana University Press.

Replogle, Michael. 1990. "U.S. Transportation Policy: Let's Make it Sustainable." Washington, D.C.: Institute for Transportation and Development Policy.

Ross, Marc. 1989. "Energy and Transportation in the United States." Annual Review of Energy, Vol. 14. Palo Alto, CA: Annual Reviews Inc.

Ross, Marc and Robert Socolow. 1990. "Technology Policy and the Environment." presented at "Toward 2000: Environment, Technology and the New Century," Annapolis, MD. Washington, D.C.: World Resources Institute.

Stedman, Donald. 1990. University of Denver, private communication.

Tobias, Andrew. 1982. The Invisible Bankers. New York: Pocket Books.

U.S. Department of Transportation. 1980. "The Safe, Fuel-Efficient Car: A Report on its Producibility and Marketing."

U.S. EPA Motor Vehicle Emissions Laboratory. 1988. MOBILE4 Workshop, Ann Arbor, MI, Nov. 30.

Watson, Prof. H.C. 1990. University of Melbourne, private communication.

Westbrook, F., and P. Patterson. 1989. "Changing Driving Patterns and Their Effect on Fuel Economy." Presented at the May SAE Government/Industry Meeting, Washington, D.C. Warrendale, PA: Society of Automotive Engineers.

Young, J.A. 1986. "Global Competition -- The New Reality: Results of the President's Commission on Industrial Competitiveness," The Positive Sum Strategy, R. Landau and N. Rosenberg, eds., Washington, D.C.: National Academy Press.

B.W. Ang. 1991. "Traffic Management Systems and Energy Savings: The Case of Singapore." Transportation and Energy in Developing Countries: Experiences and Options, D. Bleviss and M. Birk, eds. New York: Quorum Books. (forthcoming)

TABLE 1

A COMPARISON OF 1988 NEW CAR VEHICLE FUEL ECONOMIES AND GASOLINE PRICES

	New Vehicle Fuel Economy (MPG)	Gas Price (U.S. $)
United States	28.3	0.95
West Germany	30.9	2.18
France	35.8	3.04
Japan	27.3	3.47
Norway	31.8	3.09
Italy	34.1	3.90

Sources: World Resources Institute and Lawrence Berkeley Laboratory

TABLE 2

European Agreements for Improved New Car Fuel Economy

Country	Requirements
U.K.	Compulsory reporting of fuel consumption data. 10 percent increase in mpg (9.1 percent reduction in fuel consumption) from 1978 levels, by 1985, for passenger cars only (diesels excluded).
France	Compulsory reporting of fuel consumption data. Mean fuel consumption in new automobiles to be less than 7.5 liters/100 km (greater than 31 mpg) by 1985.
West Germany	Ten to twenty percent reduction in fuel consumption in new autos, relative to 1978, by 1985.
Italy	Ten percent lower consumption in new autos, from 1978 levels, by 1985.
Sweden	New Car Fleet Averages: 8.5 l/100 km (28 mpg) by 1985 7.5 l/100 km (31 mpg) by 1990 Voluntary, but will be made mandatory in the event of noncompliance.

NOTE: All above fuel consumption targets are voluntary, except Sweden, as noted.

Table 3

JAPANESE NEW CAR FUEL EFFICIENCY STANDARDS
Liters/100 km (mpg)

	Inertia Weight (kg)			
	625	750-875	1000-1250	1500-2000
1978 Actual	5.38 (44)	6.94 (34)	9.01 (26)	13.16 (18)
1985 Mandated	5.05 (46)	6.25 (38)	8.00 (29)	11.76 (20)
% Improvement	6.1	9.9	11.2	10.6

Table 4

FEDERAL TAILPIPE EMISSION CONTROL STANDARDS FOR AUTOMOBILES AND LIGHT TRUCKS[a]

Model Year	Automobiles HC[c]	Automobiles CO	Automobiles NOx	Light Trucks[b] HC[c]	Light Trucks[b] CO	Light Trucks[b] NOx
pre-control[d]	10.6	84	4.1	8.0	102	3.6
1972-1974	3.0	28	3.1	-	-	-
1975-1976	1.5	15	3.1	2.0	20	3.1
1984-1987	0.41	3.4	1.0	0.8	10	2.3
1988-1993	0.41	3.4	1.0	0.8	10	1.2
1994[e]	0.25	3.4	0.4	0.25	3.4	0.4

<u>KEY</u>

HC:	Hydrocarbons
CO:	Carbon Monoxide
NOx:	Nitrogen Oxides

<u>NOTES</u>:

(a) Standards for non-diesel fuel engines, certified for five years or 50,000 miles.

(b) Before 1984, trucks include all less than 8500 gross vehicle weight. After 1984, above standards apply to trucks from 0 to 3750 loaded vehicle weight (curb weight + 300 lbs.). HC, CO, and NOx standards for light trucks with LVW from 3751-5750 must meet 0.32, 4.4, and 0.7, respectively. Standards for light trucks with LVW greater than 5750 are 0.39, 5.0, 1.1, respectively.

(c) Before 1994, listed standards apply to all hydrocarbon emissions. After 1994 the listed standard applies to non-methane hydrocarbons (the pre-1994 standard continues to apply to total hydrocarbons in 1994 and afterwards).

(d) Estimate by Motor Vehicle Manufacturers Association.

(e) 1994 and later standards from 1990 Clean Air Act Amendments. Standards listed here are Tier 1, 50,000 mile/5 year, non-diesel standards. Many changes in emissions standards are not reflected here. Refer to law for more detail.

TABLE 5

TYPICAL LIGHT DUTY VEHICLE EMISSION RATES[a]
(grams/mile)

	from vehicle tailpipe	evaporation from fueling facilities[b]	evaporation from vehicle	total	tailpipe standard for cars
HC[c]	1.9[d]	0.5[e]	0.6[f]	3	0.41
CO	20[d]			20	3.4
NOx	1.6[g]			1.6	1.0

a) Light-duty gasoline fueled vehicles.
b) Refinery and distribution system losses not included.
c) Non-methane.
d) Fleet estimate from MOBILE4 (U.S. EPA Motor Vehicle Emissions Laboratory). Emissions vary strongly with model year, tampering, maintenance.
e) Emissions are strongly dependent on season and region. Estimates adapted from Argonne National Laboratory.
f) During both running and parking. Emissions vary strongly with season and region. Crude estimate based on preliminary MOBIL4 analyses.
g) Author's estimate.

Table 6

GAS GUZZLER TAX, ENERGY TAX ACT OF 1978

MPG	1980	1981	1982	1983	1984	1985	1986 & After
0-12.5	$550	$650	$1200	$1550	$2150	$2650	$3850
12.5-13.0	550	650	950	1550	1750	2650	3850
13.0-13.5	300	550	950	1250	1750	2200	3200
13.5-14.0	300	550	750	1250	1450	2200	2700
14.0-14.5	200	450	600	1000	1150	1800	2250
15.0-15.5	0	350	600	800	1150	1500	2250
15.5-16.0	0	350	450	800	950	1500	1850
16.0-16.5	0	200	450	650	950	1200	1850
16.5-17.0	0	200	350	650	750	1200	1500
17.0-17.5	0	0	350	500	750	1000	1500
17.5-18.0	0	0	200	500	600	1000	1300
18.0-18.5	0	0	200	350	600	800	1300
18.5-19.0	0	0	0	350	450	800	1050
19.0-19.5	0	0	0	0	450	600	1050
19.5-20.0	0	0	0	0	0	600	850
20.0-20.5	0	0	0	0	0	500	850
20.5-21.0	0	0	0	0	0	500	650
21.0-21.5	0	0	0	0	0	0	650
21.5-22.0	0	0	0	0	0	0	500
22.0-22.5	0	0	0	0	0	0	0

*The tax rate has been doubled as of January 1991.

Table 7

PROPOSED SCHEDULE: MINIMUM FUEL ECONOMIES TO EARN EXTRA FUEL ECONOMY CREDITS*
(MPG)

	1996	1997	1998	1999	2000	2001
Subcompact	43.0	44.5	46.0	47.5	49.0	50.5
Compact	41.0	42.5	44.0	45.0	46.5	48.0
Mid-size	37.5	39.0	40.0	41.0	42.5	44.0
Large	33.0	34.0	35.0	36.5	37.5	39.0

*Minicompacts and two-seaters are left out of this schedule because the kinds of cars that fall under these classes are very diverse, and their fuel economies are widely divergent.

Figure 1

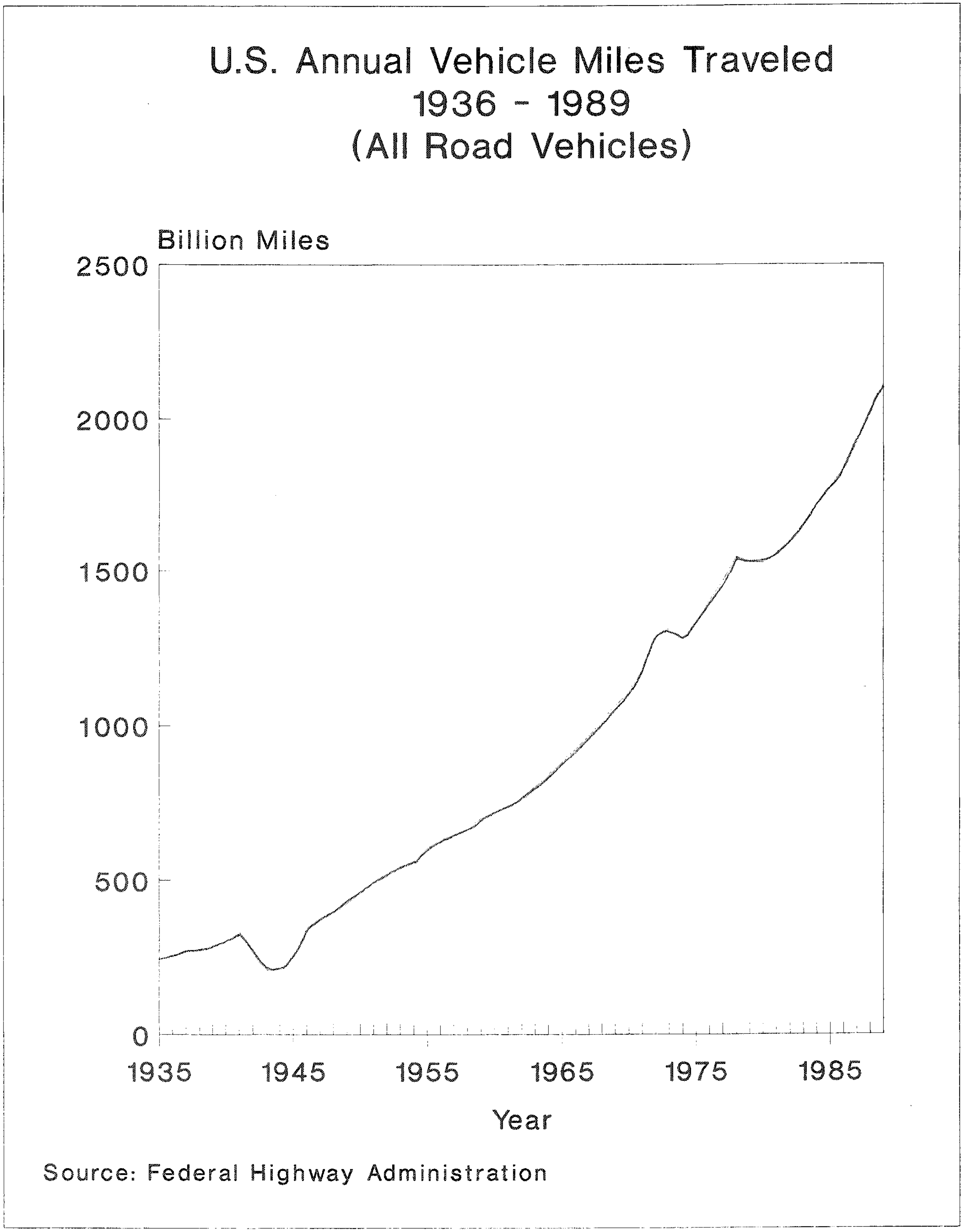
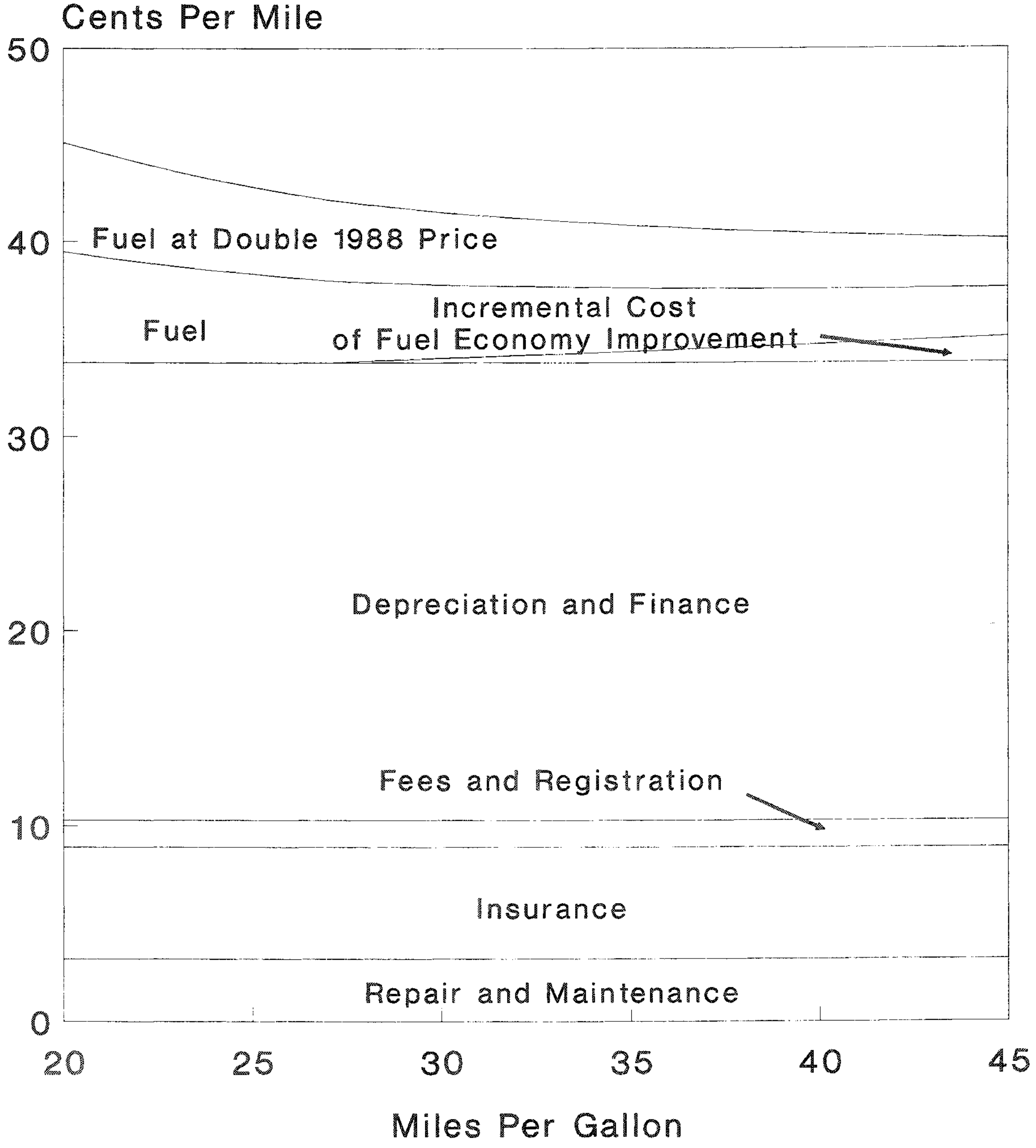

U.S. Annual Vehicle Miles Traveled
1936 - 1989
(All Road Vehicles)
Billion Miles
2500
2000
1500
1000
500
0
1935
1945
1955
1965
1975
1985
Year
Source: Federal Highway Administration

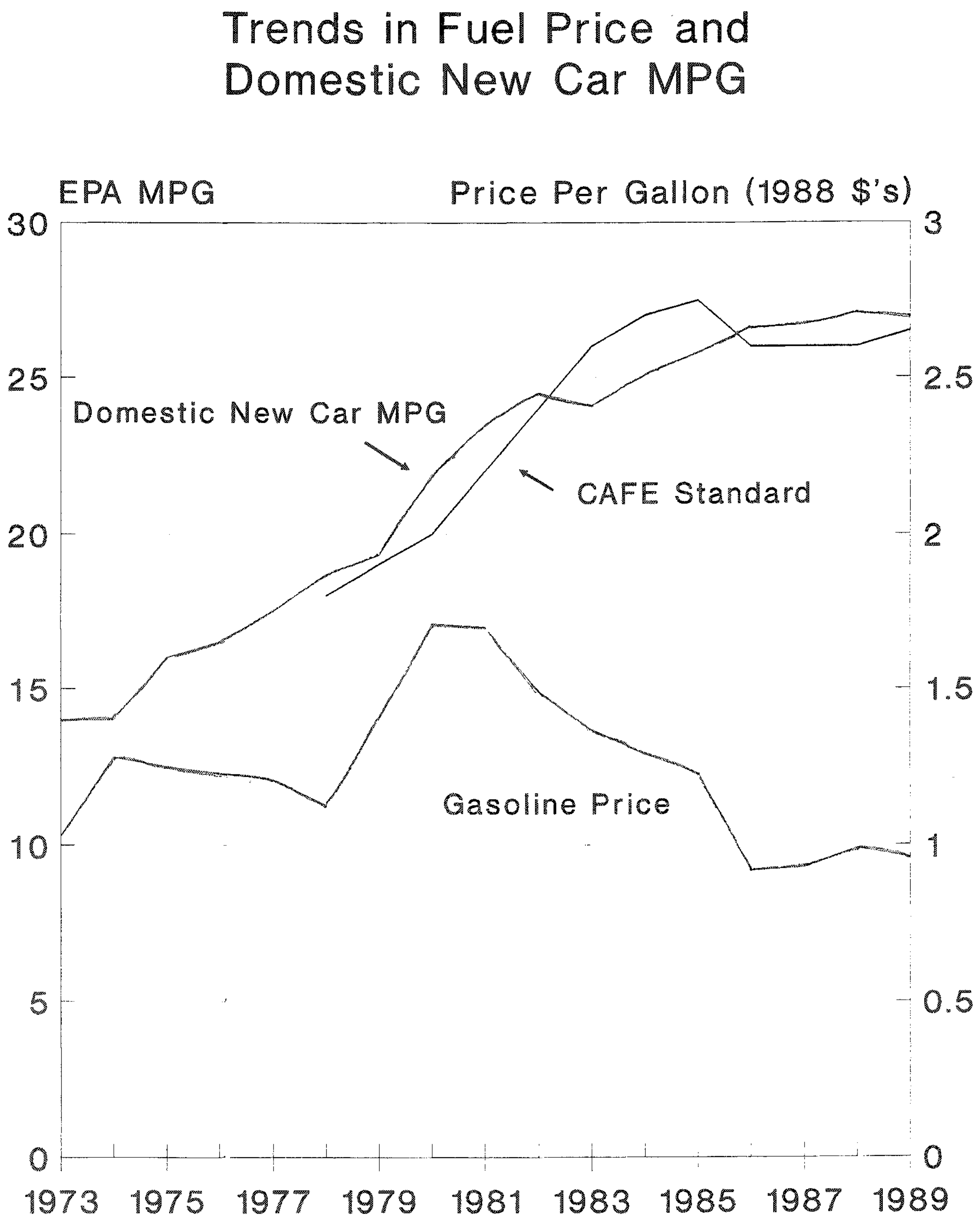
Figure 2

Costs of Owning and Operating a New Car



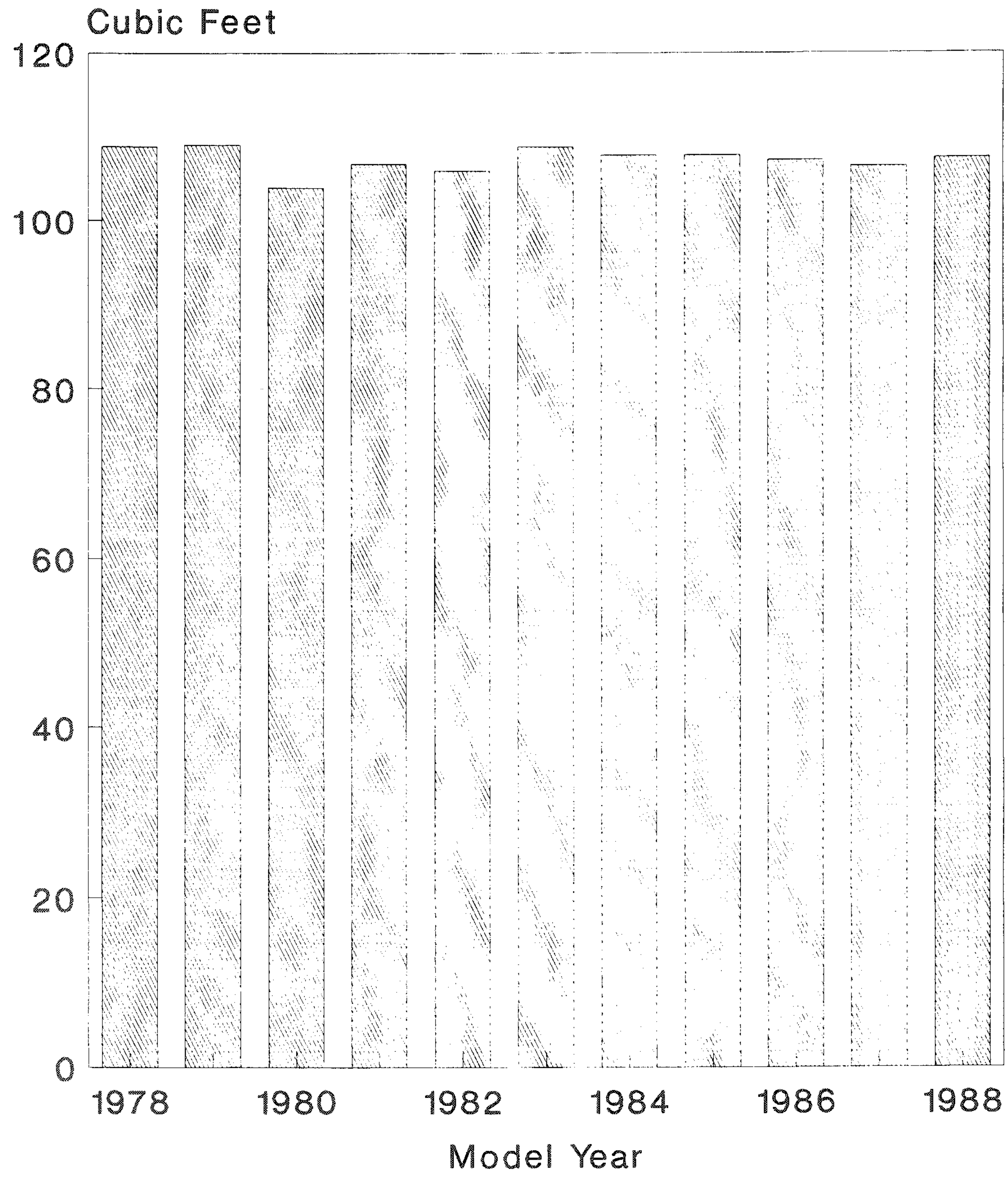
Source: ACEEE, adapted from von Hippel and Levi, 1983

Figure 3



Source: ACEEE, adapted from U.S. EPA and U.S. DOE.

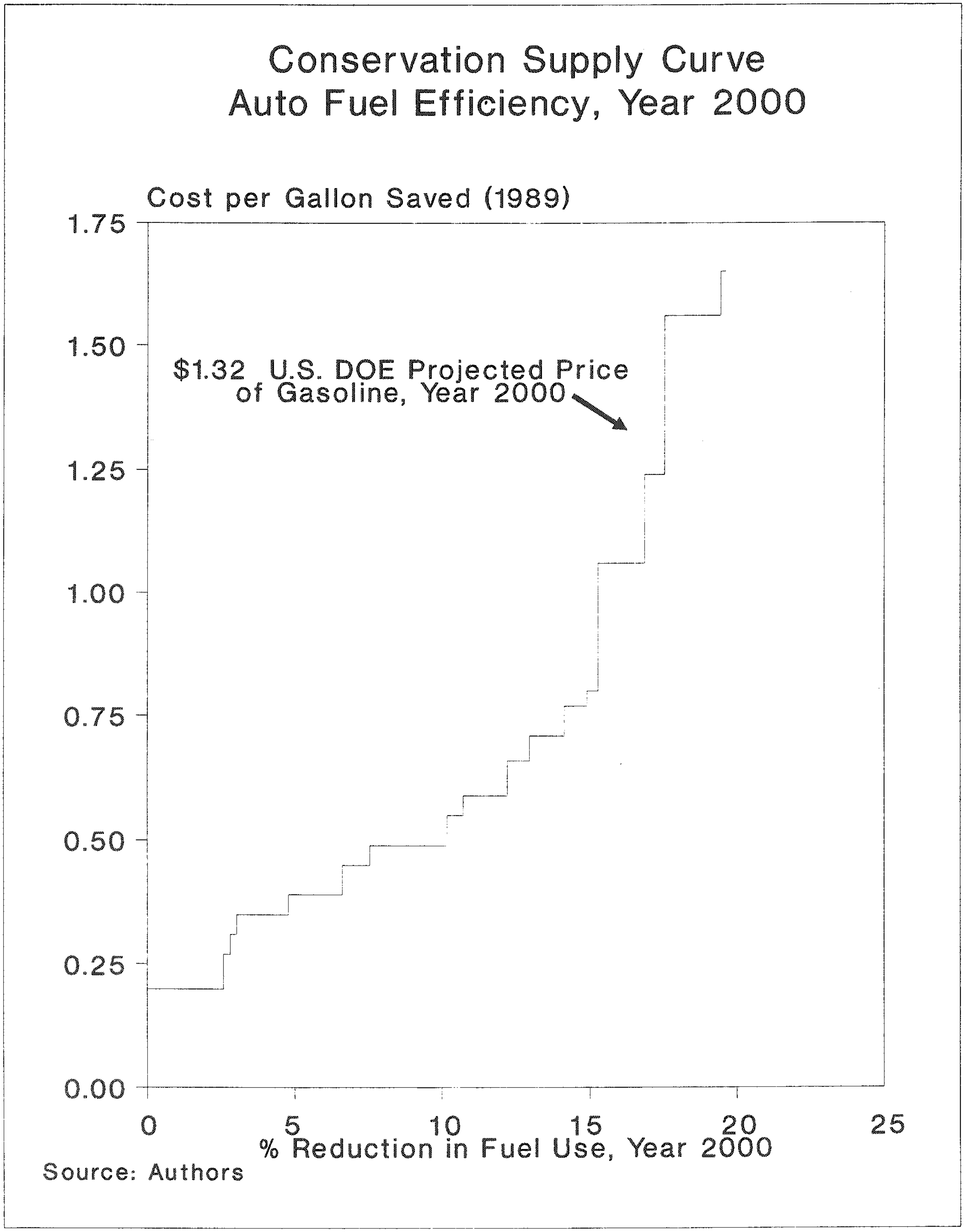
Figure 4



Average Interior Volume, New U.S. Cars 1978-1988

Source: U.S. EPA

Figure 5

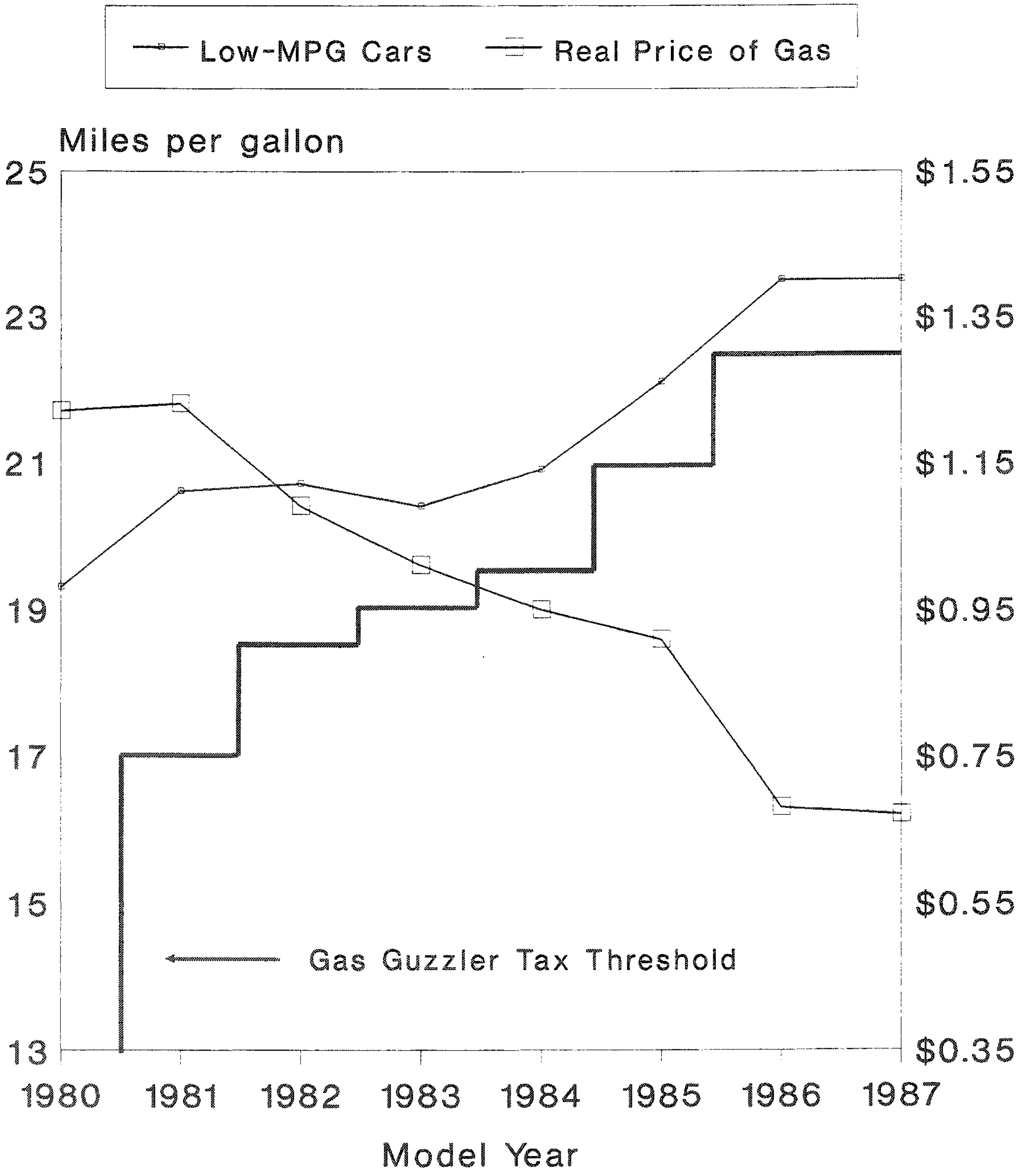


Conservation Supply Curve
Auto Fuel Efficiency, Year 2000

Source: Authors

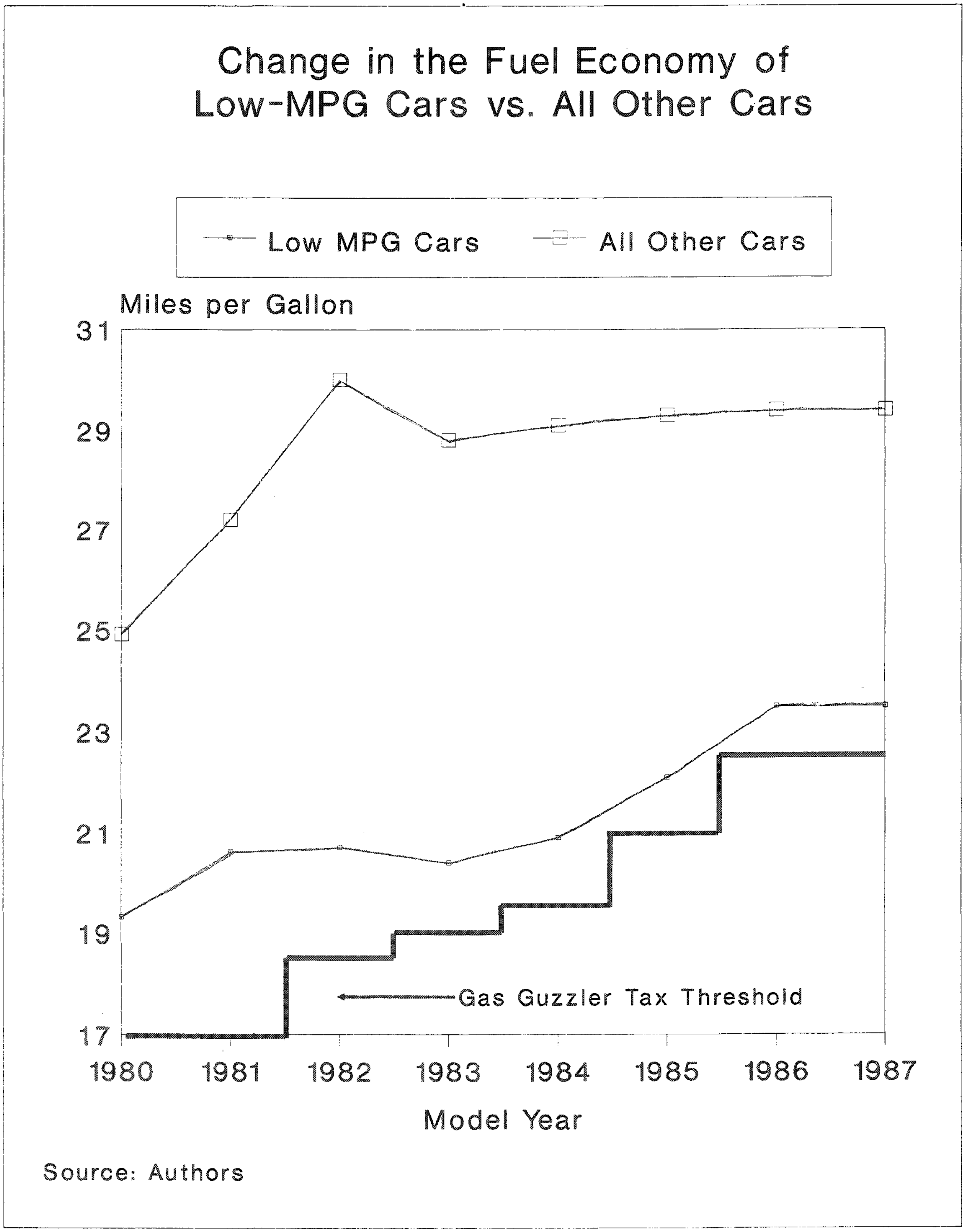
Figure 6

Change in the Fuel Economy of Low MPG Cars and the Gas Guzzler Tax



Source: Authors

Figure 7

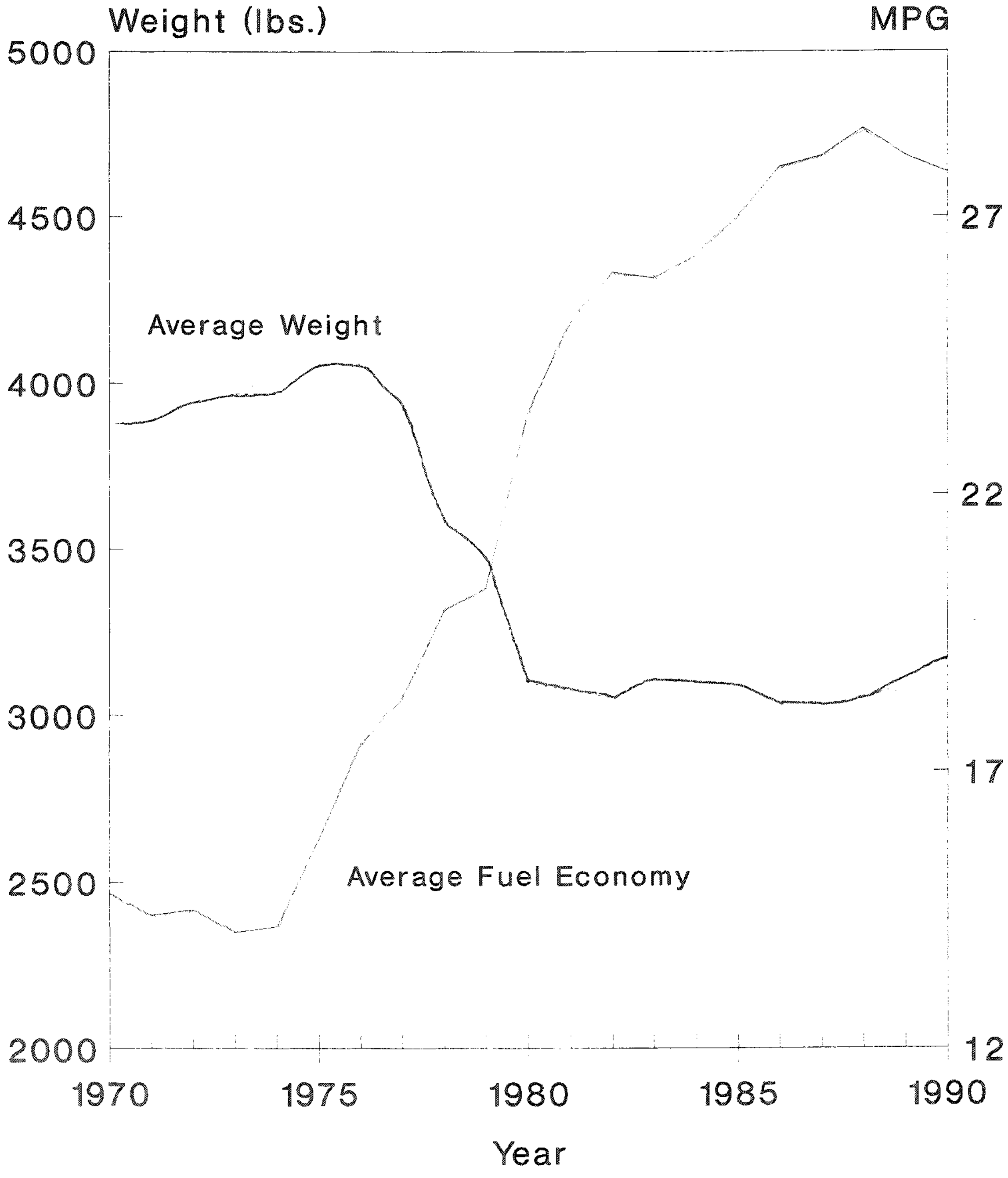


Change in the Fuel Economy of Low-MPG Cars vs. All Other Cars

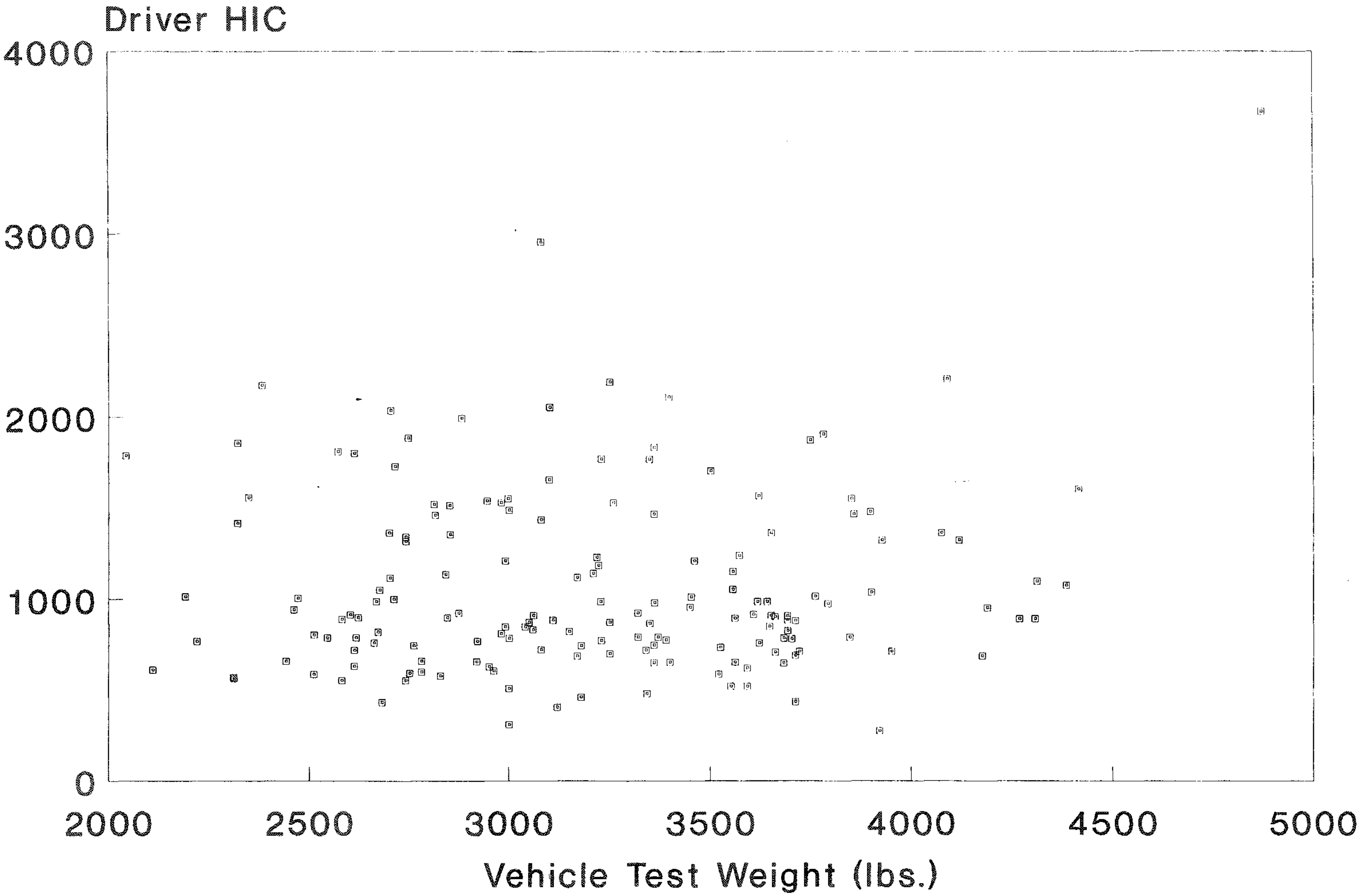
Source: Authors

Figure 8

U.S. Automobile Weight and Fuel Economy 1970 - 1990



Source: ACEEE, adapted from U.S. EPA



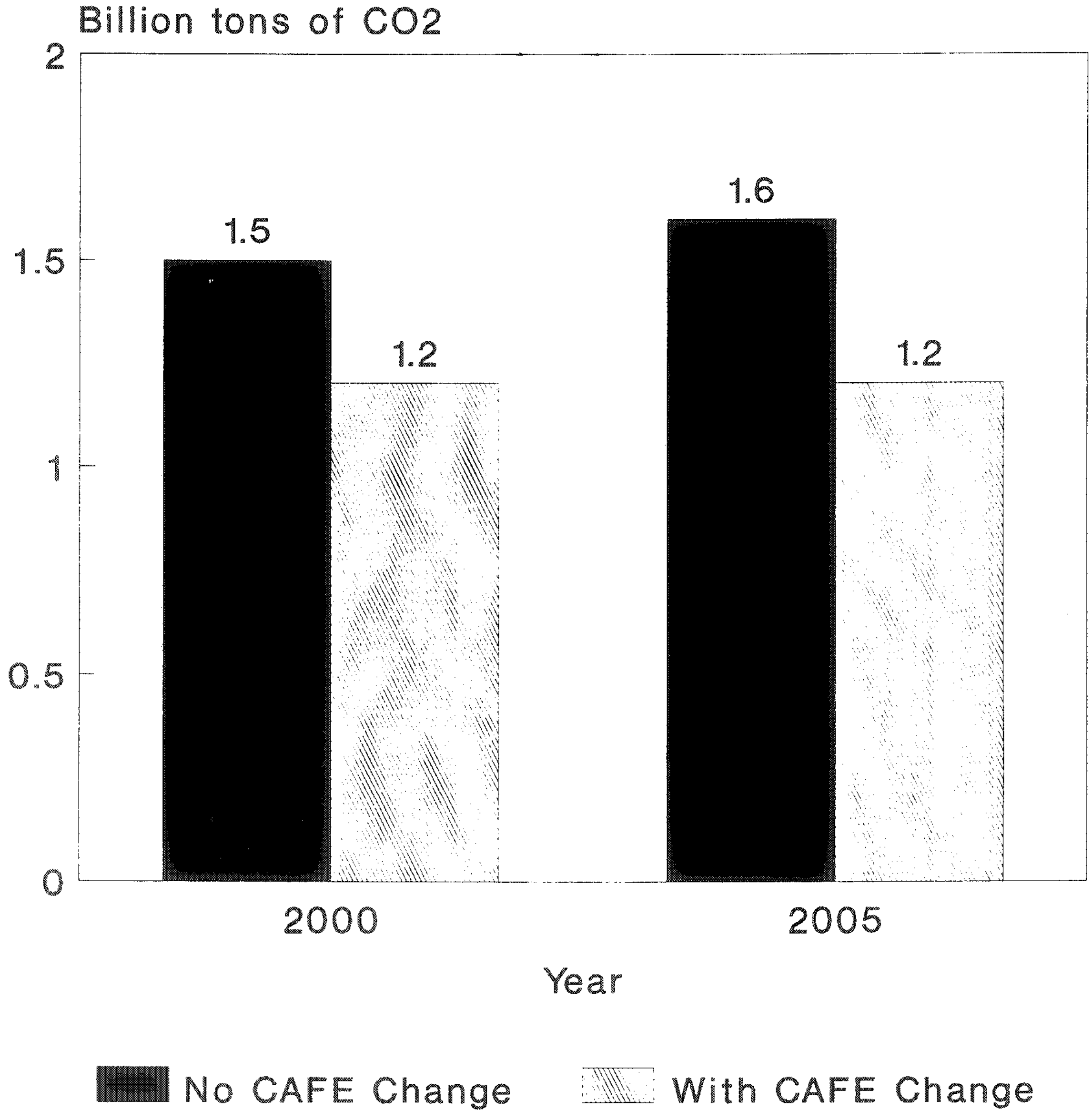
Auto Weight vs. Driver Head Injury Criterion

Source: ACEEE

Figure 9

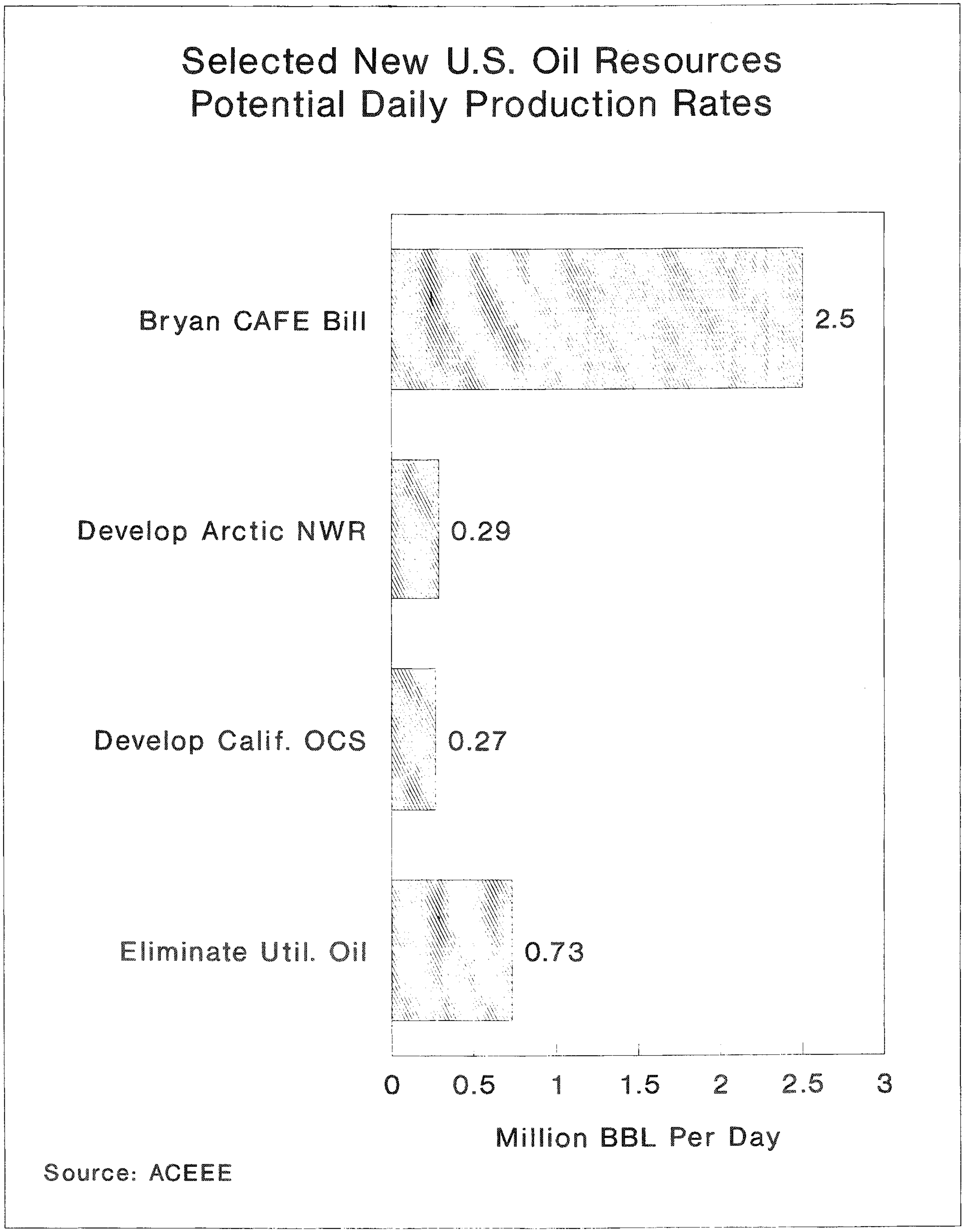
Figure 10

Projected U.S. Light Vehicle Carbon Emissions With and Without 40/30 MPG Cafe Standard by 2001



No CAFE change scenario assumes new vehicle fuel economy does not rise above current levels. Source: ACEEE

Figure 11


Selected New U.S. Oil Resources Potential Daily Production Rates

Source: ACEEE