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Analysis of Potential Impacts of Higher Fuel Prices and Fuel Economy Standards on Transportation Demand and Surface Transportation Revenues

Prepared by: Oakridge National Laboratory
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Introduction

This paper is one of a series prepared for the National Surface Transportation Policy and Revenue Study Commission authorized in Section 1909 of SAFETEA-LU. The papers synthesize the state-of-the-practice consensus on the issues that are relevant to the Commission's charge outlined in Section 1909, and will as background material in developing the analyses to be presented in the final report of the Commission.

U.S. gasoline prices doubled from 2002 to 2005 and remain well above $2/gallon today. Heightened concerns about greenhouse gas emissions and oil dependence have inspired several Congressional proposals to significantly raise fuel economy standards. This paper presents information on the effects of both higher fuel prices and fuel economy standards on transportation demand and surface transportation revenues.

The history of fuel prices and fuel economy standards over the past three decades and their impacts on motor fuel use and motor fuel tax revenues are reviewed. The prices of gasoline and diesel fuel vary mainly with the price of oil, which today accounts for about half of their retail prices. Next, economic theory of vehicle use, efficiency and motor fuel demand and the literature quantifying those relationships is summarized. Finally alternative projections of fuel prices, fuel economy and fuel use by the Energy Information Administration and their implications for vehicle travel and fuel use, and gross fuel tax revenues are explored.

Background and Key Findings

- Vehicle travel, fuel economy and fuel use are relatively insensitive to the price of fuel (price inelastic). A 10% increase in fuel price is likely to produce a 3% decrease in fuel use and a 1% decrease in vehicle travel, in the long run. Sensitivity to fuel price is likely to decrease further over time with rising incomes.
- Fuel economy has a more powerful impact on fuel use and fuel tax revenues. A 10% increase in fuel economy is likely to produce a 9% decrease in motor fuel use and tax revenue.
- Technology will likely permit a doubling of light-duty vehicle fuel economy by 2050. If fuel economy standards required such an increase and fuel tax rates were unchanged, fuel tax revenues could be flat (in current dollars) for 40 years from 2010 to 2050.
- Over the past thirty years, the fuel economies of new vehicles and the on-road fleet have been chiefly determined by federal fuel economy standards.
- There is a small and apparently shrinking "rebound effect" that causes vehicle travel to increase slightly when increased fuel economy reduces the fuel cost per mile of travel. The rebound effect currently offsets about 10% of the potential fuel savings from fuel economy improvement.

- The response of vehicle travel to the doubling of the price of gasoline over the past few years has been small. Recent estimates suggest that a doubling of gasoline prices in the future would result in only about 5% less vehicle travel.
- Therefore, over the next twenty to thirty years the principal threat to surface transportation revenues appears to be increased vehicle fuel economy brought about by higher fuel economy standards.
- It is quite possible that by 2050 alternative energy sources, such as biofuels, hydrogen and electricity (used in "plug-in" hybrid vehicles) could claim significant shares of highway energy use. These possibilities are not addressed in this report, but it should be noted that use of public utilities (electric power or natural gas from the home) to supply alternative motor fuel would pose considerable challenges in maintaining highway trust fund revenues.
- In the past, motor fuel taxes have been adjusted to compensate for the impacts of increased vehicle fuel economy and higher fuel prices on fuel use but the adjustments have not been straightforward. In theory, adjustments could also be made in the future to maintain adequate revenues.

Fuel Prices, Fuel Economy, Vehicle Travel, Fuel Consumption and Highway Revenues Since 1970

The three decades since the "oil crisis" of 1973-74 have seen major changes in fuel prices and the relationship between vehicle travel and fuel use, with significant implications for highway revenues. The increases in passenger car and light truck fuel economy required by the Energy Policy and Conservation Act of 1975 and inspired by the oil price shock of 1973-74 (Figure 1) produced a 50% increase in on-road miles per gallon by the early 1990s. As a result, the period from 1975 to 1991 saw a decoupling of vehicle travel and fuel use that had a significant impact on highway revenues (Figure 2). Were it not for this decoupling, motorists would be consuming on the order of 70 billion gallons more motor fuel each year.

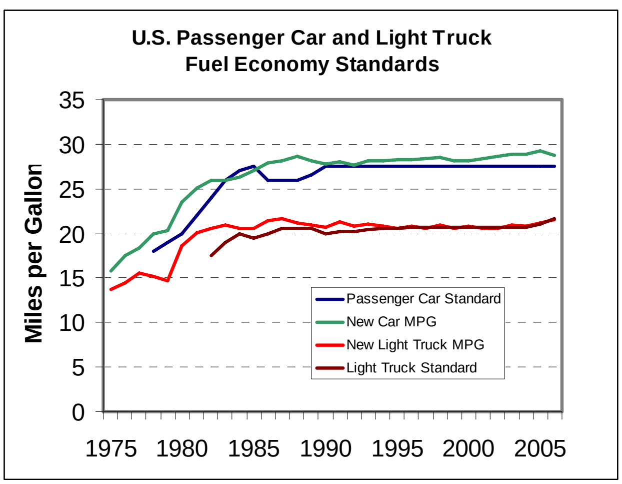

Figure 1. U.S. Passenger Car and Light Truck Fuel Economy Standards and Average New Vehicle Fuel Economy, 1975-2006. Source: Heavenrich (2006, table 1)

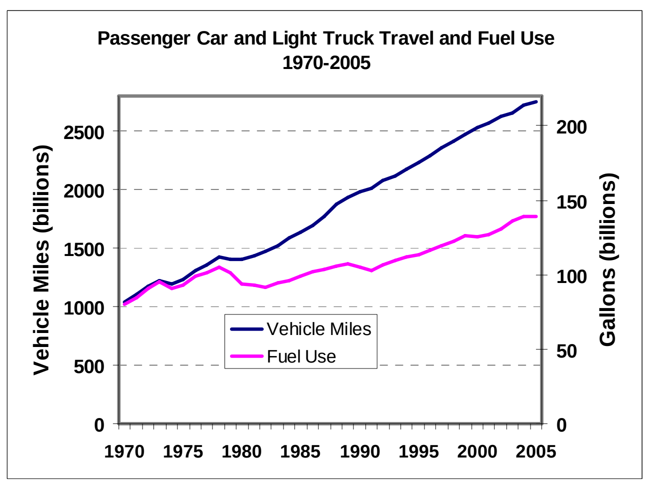

Figure 2. Fuel Economy Increases Decoupled Vehicle Travel and Fuel Use. Source: U.S. DOT/FHWA (2006, table VM-1)

Because motor fuel taxes are a fixed number of cents per gallon, the decoupling of fuel use and vehicle travel steadily eroded revenues per vehicle mile. This was amplified by inflation in highway construction and maintenance costs. In an attempt to compensate, the federal tax rate was raised from 4 cents/gallon to 9 cents/gallon in 1983, then to 14.1 cents/gallon in 1990 and to 18.4 cents/gallon in 1993 (Figure 3).

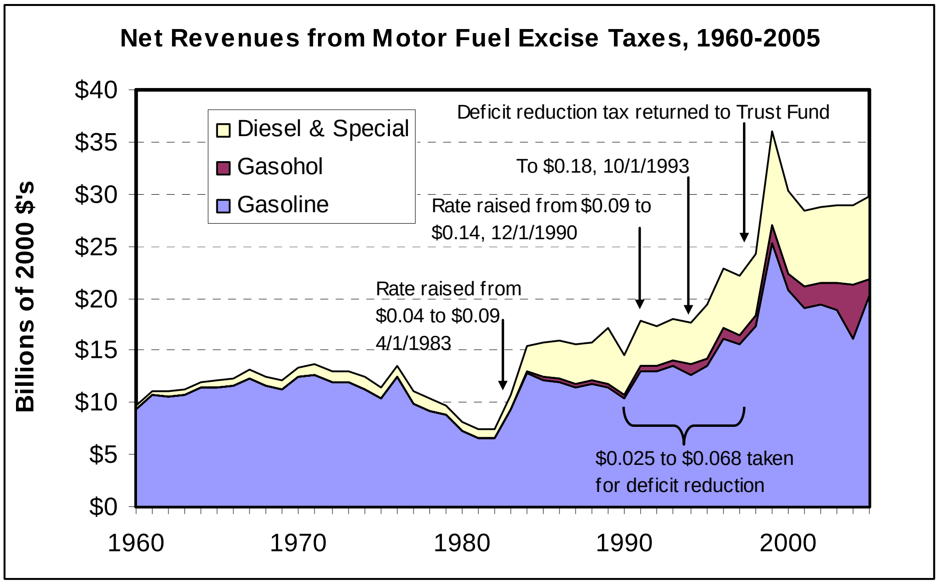

Figure 3. Net Revenues from Motor Fuel Excise Taxes, 1960-2005
Sources: U.S. DOT/FHWA (2006), tables FE-101A, FE-210

More than doubling the tax rate in 1983 restored the lost revenue but did not keep pace with rising vehicle miles of travel, which doubled between 1970 and 1990. At the same time, a greater proportion of the burden was shifted to diesel fuel users. Further increases in 1990 and 1993 were largely taken back by required contributions to deficit reduction until October, 1997. Over the fifteen year period from 1976 to 1991, the on-road fuel economy of passenger cars and light trucks increased at the rate of 2.7% per year, about 1% below the average rate of inflation over the past 50 years. Significant and sustained fuel economy improvements combined with increasing fuel prices could pose almost as great a threat to future highway motor fuel revenues as inflation. While motor fuel tax rates can be adjusted to remedy the loss of revenues, history suggests that the adjustment is not likely to be a simple, orderly process (TRB, 2006).

Past trends in the price of gasoline have been primarily driven by changes in the price of crude oil (Figure 4).[1] This will likely continue to be the case in the future. In 2001, crude oil averaged $22.95/barrel, contributing about $0.55 to the $1.42 a typical gallon of gasoline cost in that year. In 2005, crude oil averaged $50.23/barrel, adding about $1.20 to the $2.27 an average gallon of gasoline cost that year (Figure 4). The increase in the price of crude ($0.65/gallon) directly accounts for most of the increase in the price of gasoline ($0.85). About two thirds of the remaining difference can be attributed to higher refiner margins and one third to higher distribution and marketing mark-ups.

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[1] The price of gasoline includes the cost of crude oil, federal, state and local taxes, refining costs and profits, and distribution and retailing costs and profits. As a rule of thumb, the cost of crude oil can be approximately calculated by dividing the price of a barrel of crude by 42 (the number of gallons per barrel). Federal and state taxes add 18.4 cents and about 21 cents, respectively.

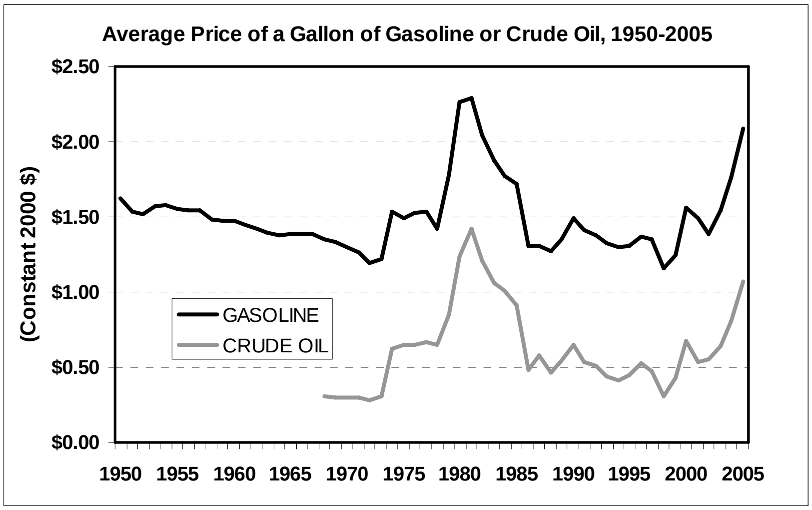

Figure 4. Real Prices of a Gallon of Gasoline and Crude Oil, 1950-2005
Source: EIA, AER 2005, table 5.24

Economic Theory

The amount of vehicle travel depends on a complex array of factors from the structure of the built environment and the supply of highway infrastructure to individuals' preferences. This section presents theoretical relationships among fuel use, fuel economy, vehicle travel and the price of fuel. Attempts to quantify these relationships are reviewed in the following section.

Motor fuel consumption (F) is related to vehicle travel (V) and fuel economy (E) by the identity: F = V/E. In the long run, both the amount of vehicle travel and the fuel economy of vehicles will be affected by the price of fuel (P). The price of fuel directly affects the amount of travel through the fuel cost per mile of travel (P/E = Pe, where e = 1/E is the rate of fuel consumption in gallons per mile).[2] Taking derivatives and converting to elasticities (β) yields the following useful relationship.[3]

$$\beta_{F,P} = \frac{dF}{dP}\frac{P}{F} = \frac{d}{dP}(Ve)\frac{P}{F} = \frac{dV}{dP}\frac{Pe}{Ve} + \frac{de}{dP}\frac{PV}{Ve} = \beta_{V,P} + \beta_{e,P} = \beta_{V,P} - \beta_{E,P} \quad \textbf{(1)}$$

That is, the elasticity of motor fuel use with respect to the price of fuel ($\beta_{F,P}$) equals the elasticity of vehicle travel with respect to the price of fuel ($\beta_{V,P}$) minus the elasticity of fuel economy with respect to the price of fuel ($\beta_{E,P}$).

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[2] Economically rational consumers will consider not only the price of fuel, but the fuel cost per mile of travel in deciding how much vehicle traveling to do. The empirical evidence on whether motorists consider the fuel cost per mile or only the price of fuel is mixed. Greene et al. (1999), found that data from several U.S. Department of Energy surveys did not reject the hypothesis that household travel responded equally strongly to changes in fuel economy and the price of fuel (though in opposite directions). Small and Van Dender (2005), on the other hand, found that the response of state-level VMT to the price of gasoline alone was statistically significant, and the combined effect of fuel cost per mile was also statistically significant, but the response to fuel economy alone was not statistically significant.

[3] Elasticities are quantitative measures of the influence of one factor on another, specified as the percent change in one given a 1% change in the other.

The price of fuel also affects fuel use in the long run through fuel economy.[4] Significant fuel economy improvements typically require completely redesigning vehicles from engines and transmission to body shapes and materials. As a consequence, the full impact of fuel prices on the fuel economy of vehicles on the road evolves slowly over a period of about 15-20 years.[5] History confirms this timetable: the fuel economy improvements begun after 1975 were fully realized 15 years later in 1991 (Figure 5).

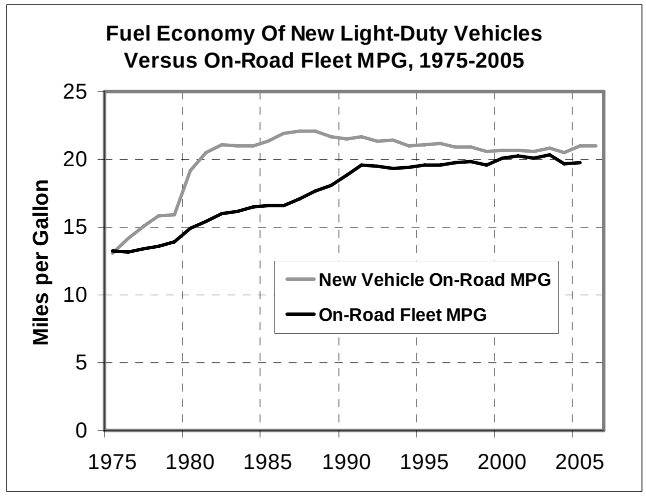

Figure 5. Fuel Economy of New Light-duty Vehicles Versus On-Road Fleet MPG, 1975-2005

Over the period of a year or less, it is a reasonable approximation to assume that the average rate of fuel consumption per mile (e) is constant and that the use of motor fuel (F) will depend on the amount of vehicle travel (V). This permits the derivation of another useful relationship between the impact of fuel economy on fuel use and the impact of fuel cost per mile on vehicle travel. Taking the derivative of fuel use with respect to the rate of fuel consumption and with some algebraic manipulation the following relationship between the elasticity of fuel use with respect to the rate of fuel consumption ($\beta_{F,e}$) and the elasticity of vehicle travel with respect to the fuel cost per mile ($\beta_{V,eP}$) can be derived.

$$\beta_{F,e} = \frac{dF}{de}\frac{e}{F} = \frac{eV}{d(eP)}\frac{eP}{V} + \frac{eV}{F} = \beta_{V,eP} + 1 \tag{2}$$

Thus, if the elasticity of vehicle travel with respect to fuel cost per mile is -0.1 (as recent evidence suggests) the elasticity of fuel use with respect to the rate of fuel consumption is 0.9. That is, 90% of the potential reduction in fuel use from an increase in fuel economy is realized, while only 10% is "taken back" by the increase in travel caused by the reduction in the fuel cost per mile of travel. In the literature, this "taking back" of the potential reduction in fuel use is called the "rebound effect", and it is measured by estimating $\beta_{V,eP}$.

The cost of fuel, however, is just one component of the cost of travel. In the long run, the monetary cost of vehicle travel includes maintenance, insurance, various fees, and the depreciation of the vehicle itself. This is significant for two reasons: (1) fuel is a relatively minor share of the long-run financial costs of vehicle travel (excluding time costs), varying between

[4] Over a period as short as one year, the fuel economy of the stock of vehicles on the road is approximately constant, determined by their masses and the technology embodied in their designs. This is only approximately true because the on-road fuel economy of vehicles can be affected by fuel prices via how they are driven and changes in the relative use of more versus less efficient vehicles. Empirically, these effects have been found to be very small, however (Greene, Kahn and Gibson, 1999; Greene and Hu, 1984).

[5] The design and tooling of vehicles is fixed two years in advance. Manufacturers redesign one-fifth to one-eighth of their product offerings each year in order to spread out capital expenditures and make efficient use of engineering resources. Thus, complete redesign of *new* vehicle offerings can be accomplished over a period of 7-10 years. These new vehicles gradually replace the existing stock of vehicles as older vehicles are retired. Simulations indicate that a cycle of fuel economy improvement requires 15-20 years for completion.

10% and 20% over the past 20 years (Ward's, 2006, p. 65); and (2) if increasing fuel economy requires adopting more expensive technologies that add to the cost of a vehicle, then in the long run the increased vehicle cost will offset to some extent the reduction in fuel costs, very likely resulting in little or no change in the long-run costs and therefore the vehicle miles of travel.

Measuring the Relationships

Recent experience with high fuel prices indicates a decreasing sensitivity of vehicle travel and to the price of fuel over time. Changes in average monthly gasoline prices and monthly highway travel over the past five years show that the relative change in VMT is one tenth of the relative change in the price of gasoline (Figure 6). While the left hand axis against which gas price changes are graphed ranges from -30% to 60%, the right axis ranges from only -3% to -6%.

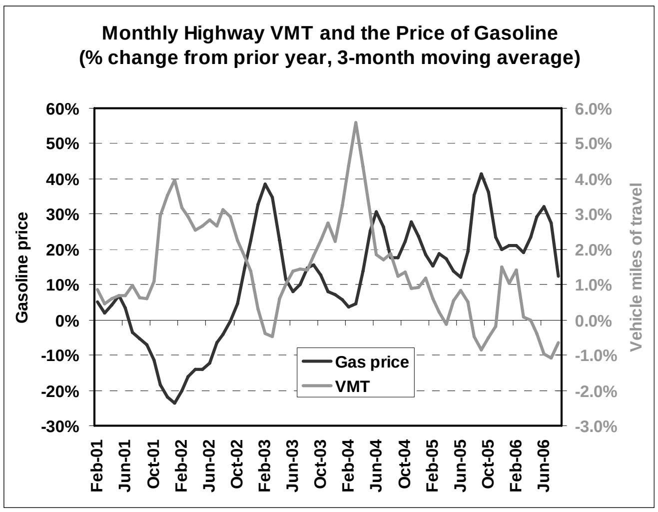

Figure 6. Relative Changes in the Price of Gasoline and Highway Vehicle Miles
Source: Davis (2007)

The literature on the effect of fuel prices on vehicle travel and fuel use is large, including aggregate national, state level and household level analyses. It has produced a relatively reliable quantification of these relationships. Reviews of the literature on the price elasticity of gasoline demand and its components can be found in Espey (1996), Dahl (1995), Dahl and Sterner (1990), and Dahl (1986). In general, the more recent the study, the smaller the sensitivity of fuel demand to price. Dahl (1995) found that more recent estimates of the price elasticity of gasoline demand averaged -0.6, while earlier studies were typically in the range of -0.7 to -1.0. Espey (1996) reported an average of -0.5 for studies whose data were primarily post-1974. Using state-level data for 1970-1991, Haughton and Sarkar (1996) estimated long-run gasoline price elasticities in the range of -0.23 to -0.35. These results suggest that demand for gasoline has become less sensitive to price over time.

The fuel price elasticity of vehicle travel, has also been extensively measured. Most studies use the fuel cost per mile (fuel price divided by fuel economy) as the measure of fuel cost, thereby constraining the elasticity of fuel price to be equal and opposite in sign to the elasticity of fuel economy. The most recently published study indicates that the impact of fuel price and fuel economy has been decreasing over time as incomes increase (Small and Van Dender, 2007). For the time period from 1966-2001, the study found a long-run rebound effect consistent with previously published studies, about -0.22. But for the more recent period from 1997-2001, the long-run rebound effect had shrunk to -0.12, and the estimated short-run elasticity of fuel cost-per-mile was only -0.03. Evidence from the latest run-up in gasoline prices supports the findings of Small and Van Dender on the sensitivity of vehicle travel to the price of fuel. Considering the period from 2001 to 2006, Hughes, Knittel and Sperling (2007) found a short-run fuel price elasticity of vehicle travel of -0.04. Based on the Small and Van Dender (2006) results, and taking into consideration the effects of the higher cost of vehicles with improved fuel economy and the likelihood that states and the federal government would raise motor fuel excises taxes to maintain highway revenues; Greene (2005) projected a net rebound effect of -0.02 for the year 2015. This implies that a doubling of fuel economy would result in only a 2% increase in vehicle travel.

Estimates of the elasticity of highway motor fuel use with respect to the price of fuel on the order of -0.6 to -0.5 are probably too high for future impacts. The most recent evidence indicates that the elasticity of vehicle travel with respect to fuel price is on the order of -0.1 today. If the overall motor fuel price elasticity were -0.5, this would imply a fuel price elasticity of fuel economy of -0.4. Of the three elasticities, the fuel price elasticity of fuel economy is the most uncertain because of the difficulty of disentangling the effects of fuel price from those of the fuel economy standards in the historical data. The one study that explicitly incorporated the effects of the CAFE standards from 1978-1989, found elasticities of fuel economy with respect to the price of gasoline of +0.1 for manufacturers for whom the standards were a binding constraint and +0.2 for manufactures (mostly Japanese) for whom the CAFE standards did not appear to be a binding constraint (Greene, 1990). These results would suggest an overall price elasticity of gasoline demand on the order of -0.1 – (+0.2) = -0.3, consistent with the findings of Haughton and Sarkar (1996).

Projections, Potentials and Possibilities

Technology is likely to enable a doubling of light-duty vehicle fuel economy before 2050. The National Research Council (NRC, 2002) report on fuel economy standards indicated that fuel economy increases on the order of 25-40% by 2015 would be cost effective. The National Commission on Energy Policy (2004) suggested increases of 40% to 80% might be justified by the need to improve energy security and reduce greenhouse gas emissions. The Massachusetts Institute of Technology's Laboratory for Energy and the Environment (Bandivadekar and Heywood, 2004) estimated that the fuel economy of conventional gasoline engine vehicles could be improved by up to 50% over the next twenty years and that advanced hybrids could more than double the fuel economy of today's conventional vehicles, holding size and performance constant. Assuming an elasticity of fuel use with respect to fuel consumption per mile of -0.9 implies that a doubling of fuel economy would reduce fuel use by 45%.

The Energy Information Administration's 2006 Annual Energy Outlook (AEO) price projections provide a wide range of possible future fuel prices. In the High Oil Price Case, world oil prices reach $90/barrel in 2030 ($3.05/gallon, 2004 $) while in the Low Oil Price Case oil costs only $28/barrel ($1.67/gallon) (Figure 7). Although prices might temporarily exceed $90/barrel, it is unlikely that prices could be sustained for a decade or more above that level because synthetic petroleum fuels from natural gas or coal can be produced at lower costs. The range in gasoline prices around the Reference Case price in 2030 is +40% to -24% (Figure 8). This is much smaller than the variation in the price of oil because oil costs make up only about half of the cost of gasoline in the United States. The range in fuel use in 2030 is much smaller, only -12.3% to +9.6% (Figure 8). Since the differences in prices are similar over the last 10-15 years of the projection, these changes can be used to calculate that the EIA expects the future price elasticity of gasoline demand to lie between -0.34 and-0.40, consistent with the historical literature.

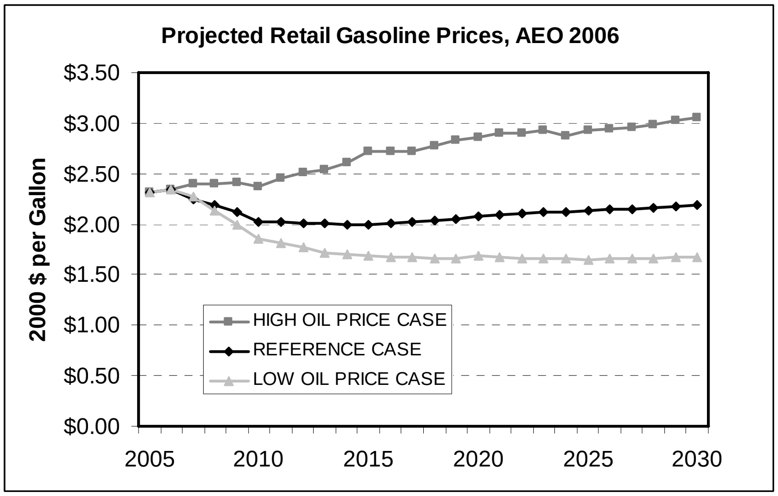

Figure 7. Retail Gasoline Price Projections of the EIA's 2006 Annual Energy Outlook
Source: http://eia.doe.gov/oiaf/archive/aeo06/reference.htm, table 3

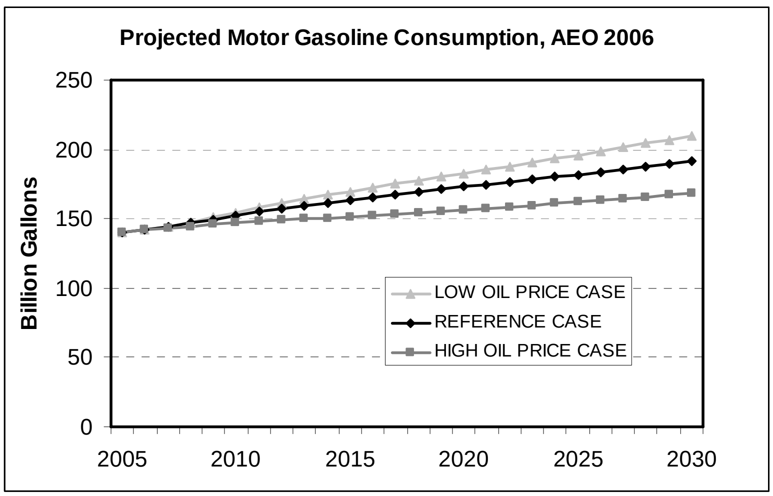

Figure 8. Motor Gasoline Use Projections of the EIA's 2006 Annual Energy Outlook
Source: http://eia.doe.gov/oiaf/archive/aeo06/reference.htm, table 11.

The implied sensitivity of highway vehicle travel to the price of fuel is even smaller. In the High Oil Price Case highway travel is only 5.7% lower than in the Reference Case. In the Low Oil Price Case it is only 5.2% higher. These projections imply a long-run price elasticity of vehicle travel with respect to the price of fuel of between -0.18 and -0.19, higher than the recent literature's estimates of historical values and higher still as estimates of future elasticities. Finally, the implied elasticities of new vehicle MPG with respect to the price of gasoline are +0.21 to +0.26, generally consistent with the discussion above.

The EIA projections can be used to gauge the potential impacts of higher oil and gasoline prices on *gross* motor fuel tax revenues by multiplying gallons of gasoline use by $0.184 and diesel fuel use by $0.244 (these rates are assumed to be constant through 2050). The EIA projections of fuel use end in 2030 but have been linearly extrapolated to 2050 for this assessment. The potential impacts of fuel economy standards were simulated by assuming that in the Reference

Case on-road fuel economy begins to increase after 2010 and is double 2005 fuel economy levels by 2050. The stock of light-duty vehicles is getting 40 miles per gallon on the road in 2050, compared with 25 miles per gallon in the Reference Case and 28 miles per gallon in the High Oil Price Case. Heavy trucks are getting 12.0 miles per gallon in 2050 in the High MPG Case versus 7.6 MPG in the Reference Case. The elasticity of fuel use with respect to the rate of fuel consumption (gallons per mile) is assumed to be 0.9. Lower oil and gasoline prices lead to 10% higher gross motor fuel tax revenues in 2050 than in the Reference Case (Figure 9). Higher oil prices produce 10% less revenue. A doubling of fuel economy, however, reduces gross revenues by 35%, and holds them virtually constant (in current dollars) over the period 2010 to 2050.

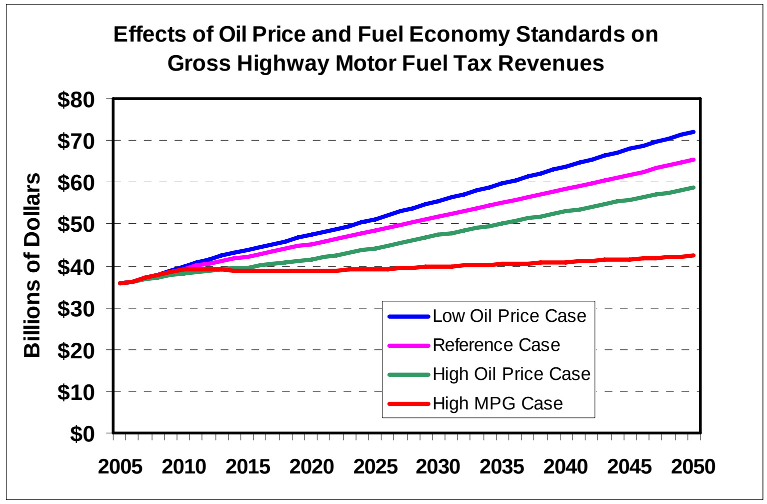

Figure 9. Potential Impacts of Higher Oil Prices and Fuel Economy Standards on Gross Motor Fuel Tax Revenues.

Other Alternative Fuels

Several additional fuels have even greater effects on the Highway Trust Fund, due to the difficulty in taxing them. These include electric power and natural gas. Natural gas is currently taxed via the supplier, when used for transportation purposes. The rate of taxation is based on whether the fuel is compressed and/or liquefied. However, one method for introducing alternative fuels that has been discussed (at least by Honda Motors) is the possibility of a "home compressor" for natural gas, which would refuel a car's gas tank overnight, from the household's natural gas pipe. How would such use be taxed under the current collection mechanism? The measurement of gas use would be masked by utility use, and the public utilities are not currently collectors of transportation excise taxes on motor fuels. Thus, introduction of home fueling for natural gas would probably have to be accompanied by a separate metering system (at a cost of several hundred dollars per household), as well as a method for collecting the excise tax from the public utility.

The same logic holds for electric power. California currently mandates the production of some "plug-in" electric-hybrid cars for general sale. These cars are designed to run on stored electric power first, relying on internal combustion only when the stored power is depleted. Under these circumstances, the cars may achieve "fuel economy" of 80 miles per gallon or more, simply by relying mostly on electric power unless they are using their vehicle for extended trips. This has a depressing effect on potential Highway Trust Fund revenues, unless a new paradigm is implemented for taxing such a use.

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