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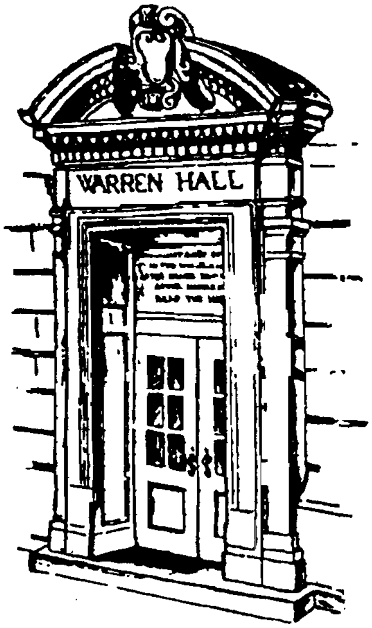

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THE KYOTO PROTOCOL, CAFE STANDARDS, AND GASOLINE TAXES

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ABSTRACT:

The Kyoto Protocol mandates that the US reduce emissions of greenhouse gases to 93% of their 1990 levels by the period 2008-2012. This paper looks at the possibility of reducing carbon dioxide emissions in the transportation sector to 7% below their 1990 level by 2010. To achieve these reductions, we examine two policies: CAFE standards and gasoline taxes. The introduction of these policies individually makes the task seem daunting, yet when using the policies jointly, Kyoto Protocol objectives are achievable.

INTRODUCTION

The Kyoto Protocol requires the US to reduce the rate of emissions of greenhouse gases to 93% of their 1990 levels by the period 2008-2012. The Protocol includes six greenhouse gases, but of these, carbon dioxide (CO_2) is the most important. In 1995, energy consumption in the US was 91 quadrillion Btu per year. Transportation accounted for 27% of energy consumption (EIA, 1997a, p 101-2) and 35% of CO_2 emissions in 1995 (Davis, 1997, p 7-2). Of the energy used in the transportation sector, light-duty vehicles (passenger cars and light trucks) accounted for 59% of the total energy consumed (EIA, 1997a, p 111). Assuming that each sector will be analyzed with respect to the potential to meet the proportional reductions sanctioned by the Kyoto Protocol, we analyze policies that will allow light-duty vehicles to reduce CO_2 emissions to 93% of 1990 levels by 2010.

This paper develops a model that forecasts future energy demand and CO_2 emissions in the light-duty vehicle sector to 2010. From a base case scenario, we introduce policies which lead gasoline consumption and CO_2 emissions to meet Protocol objectives. We evaluate two policies: Corporate Average Fuel Economy (CAFE) standards and gasoline taxes. The introduction of these policies individually makes the task seem daunting, yet when combining policies, Kyoto Protocol objectives are achievable.

TRANSPORTATION POLICIES TO REDUCE EMISSIONS

CAFE Standard

The CAFE standard requires automotive manufacturers to meet sales weighted minimum fuel efficiency standards for each model year on light-duty vehicles sold in the US. The standard for passenger cars was introduced in 1978 with a sales weighted fuel efficiency minimum of 18 mpg. In that same year, domestic manufacturers produced new cars with an average fuel efficiency of 18.7 mpg. Imported cars were a more impressive 27.3 mpg. The standard slowly increased over the next 10 years, reaching 27.5 mpg in 1990 (it had previously reached 27.5 mpg in 1985, but was reduced to 26.0 mpg the following year). The CAFE standard for passenger cars has remained at 27.5 mpg to the present (AAMA, 1997, p 80).

The standard for light trucks was introduced in 1979 at 17.2 mpg for 2-wheel drive vehicles and 15.8 for 4-wheel drive vehicles. Two-wheel and 4-wheel drive vehicles were combined to one standard in 1992 at 20.2 mpg, and the standard has increased to 20.7 mpg today (AAMA, 1997, p 81). When the standard for light trucks commenced in 1979, it only applied to light trucks with a gross vehicle weight (GVW) less than 6,000 lbs. In 1980, the standard expanded to include all light trucks up to 8,500 lbs GVW. Typically, light trucks refer to Class I and II trucks, up to 10,000 lbs, but the heavier trucks are not regulated for fuel efficiency or emission standards. Light trucks greater than 8,500 GVW include some of the larger Dodge Rams, Ford Econolines, Ford F and C/K series pickups, GMC Sierra pickups, GMC Suburbans, and GMC Vanduras (Ward's Communications, 1996, p 245-52). Larger light trucks with GVW from 8,500 lbs to 10,000 lbs remain unregulated by CAFE and emission standards.

Fines for violating CAFE standards are $55/mpg per vehicle sold.[1] Manufacturers can bank and borrow fuel economy surpluses and deficits up to three years. For example, Ford Motor Company's sales weighted fuel economy in 1994 for their domestically produced light trucks was 21 mpg, 0.5 mpg above the average. In the next two years their fuel economy averages exceeded the standard by 0.2 mpg and 0.1 mpg. However, in 1997, Ford's sales weighted fuel economy

[1] The fine increased from $5 per 0.1 mpg per vehicle to $5.50 on March 6, 1997 (NHTSA, 1998).

average dropped to 19.9 mpg, 0.8 mpg below the standard. By carrying forward their surpluses from the previous three years, 0.5, 0.2, and 0.1, Ford is still in compliance in 1997. However, if they do not meet the standard in 1998, they will be fined $5.50 per 0.1 mpg that they fall short of the standard unless they file a carryback plan to demonstrate that they anticipate earning credits in future model years to offset current deficits (NHTSA, 1998). With a domestic light truck sales fleet of approximately 2 million vehicles, this is a $11 million fine for each 0.1 mpg they fall short of 20.7 mpg.

In 1997, the federal government collected $806,465 from manufacturers for passenger car violations. Panoz Auto Development Company, Inc. paid $3,850 for violations in their Model Year (MY) 1994 cars and $1,395 for MY 1995 violations. Fiat Auto paid fines of $801,220 for MY 1995 violations (NHTSA, 1998).

Gasoline Taxes

Consumers pay local, state, and federal gasoline taxes at the pump. Federal gasoline taxes were 4¢ per gallon from 1960 to 1982 (in current prices). Taxes rose to 9¢ per gallon by 1984, and stayed at that level until 1991 when they increased again to 14.1¢ per gallon. In 1994, federal taxes increased to 18.4¢ per gallon and remain at that level. State gasoline taxes increased more gradually, from an average of 6.1¢ per gallon in 1960 to 40.8¢ per gallon in 1997 (API, 1998). In 1995, state taxes ranged from a low of 7.5¢ in Georgia to a high of 25.4¢ in Nebraska (AAMA, 1997). In real terms, total state and federal taxes steadily decreased until 1982, then gradually increased to the present (see Figure 1). In 1997, the total tax component of gasoline price (40.8¢/gallon) was lower in real dollars than in 1960 (55¢/gallon).

To put these gasoline taxes in perspective, Figure 2 presents retail gasoline prices for eight OECD countries, separated into the retail price component and the tax component. While the actual pre-tax price of gasoline shows little variation, ranging from 61¢ in Canada to $1.01 in Japan, tax rates are significantly different. Currently, the UK tax is the highest, adding $3.75 to each gallon, almost ten times the US rate of 38¢ per gallon.

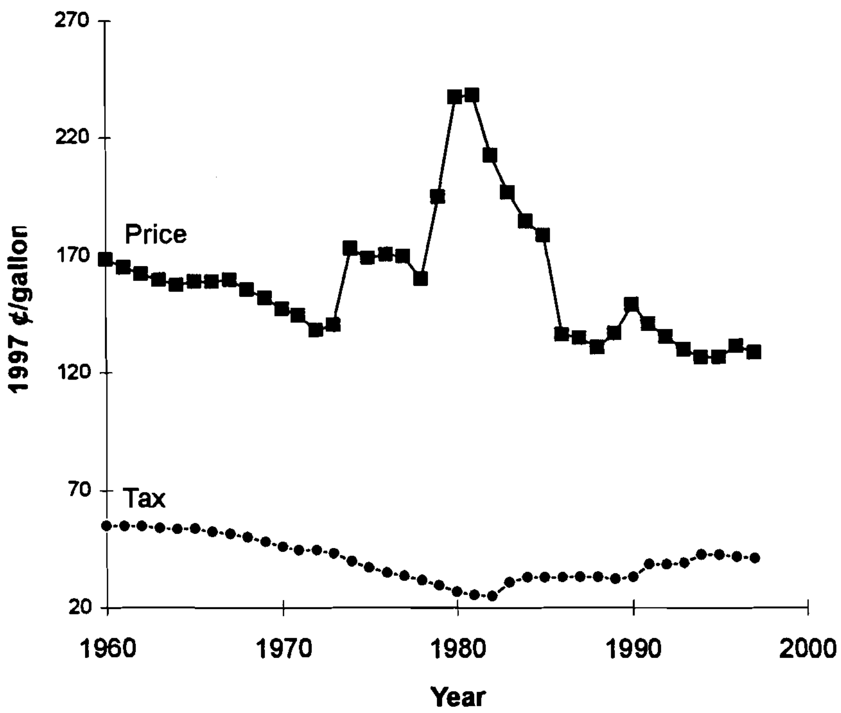

Figure 1. US Gasoline Prices and Taxes[a]

[a] Prices include federal and state taxes.
Source: API, 1998, p 9.

Gas Guzzler Tax

Consumers pay a Gas Guzzler Tax on new car purchases if the car's combined city/highway fuel economy rating is lower than 22.5 mpg. The tax ranges from $7,700 for cars with a fuel economy less than 12.5 mpg to $1,000 for cars with mpgs from 21.5-22.5 mpg (AAMA, 1997, p 82).

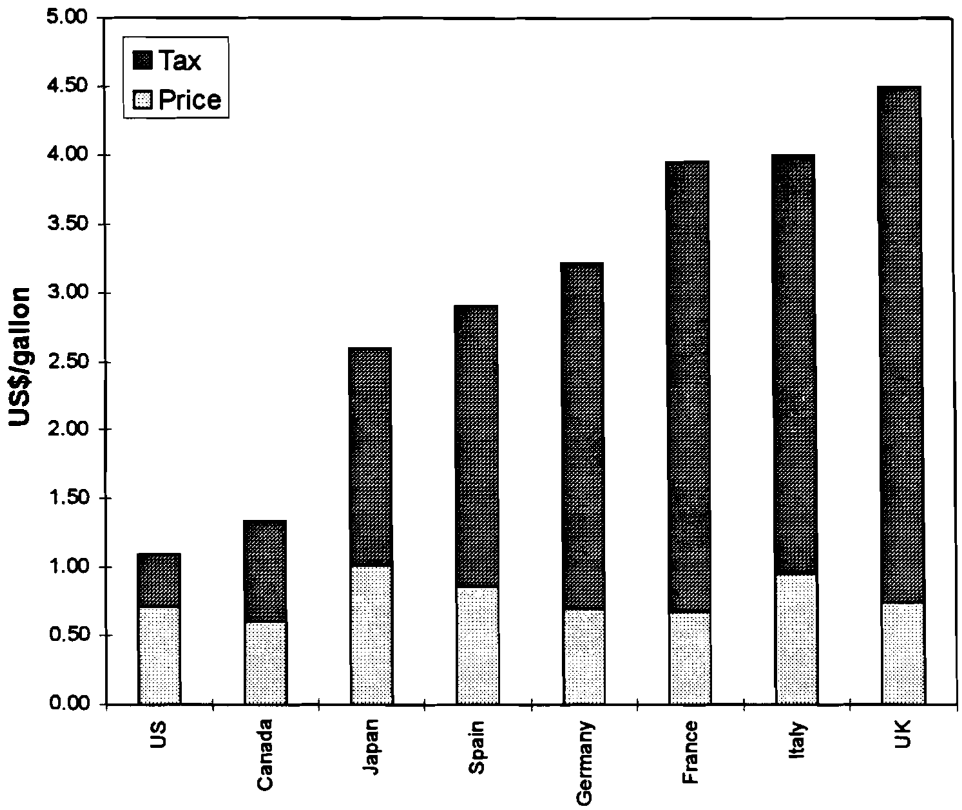

Figure 2. Gasoline Prices and Taxes, June 1998

Source: IEA, 1998, p 3.

ELASTICITY ESTIMATES FROM PREVIOUS WORK

Several studies have addressed the policy issues arising from CAFE and tax proposals. Typically, the mathematical structure includes three main variables: fuel efficiency (MPG), vehicle miles traveled (VMT), and fuel consumption (Q_f). These variables are linked through the identity: $Q_f = {}^{VMT}/_{MPG}$.

While these equations take many forms, the final result is typically an estimation of various elasticities. The model used in this paper builds on work done by Greene (1992 and 1990a), Wheaton (1982), Mayo and Mathis (1988), Blair, Kaserman, and Tepel (1984), and Nivola and

Crandall (1995). All of these papers estimate fuel efficiency and vehicle miles traveled and then typically calculate fuel consumption.

The basic equation for fuel efficiency includes the price of gasoline, income, and time. However, researchers typically include additional variables, especially when testing specific policy changes. Table 1 presents the variables used in fuel efficiency models in previous studies. All models include the price of gasoline. Most of the studies include a variable for income, measured as real GDP, per capita GDP, or disposable income . Gately (1990) and Espey (1996) use a dynamic model, including a lag of MPG on the right hand side. This allows estimates of both long- and short-run price and income elasticities for fuel efficiency. Mayo and Mathis (1988) added a variable for average highway speed to test the effect of a change in average highway speeds on demand for fuel efficiency.

A variable for CAFE rarely appears in these models. However, where included it takes different forms. Nivola and Crandall (1995) use a ratio of the current CAFE standard to the pre-CAFE value of new car fuel efficiency. Mayo and Mathis (1988) include the CAFE standard for each year.

The basic equation for vehicle miles traveled (VMT) is a function of fuel efficiency, price of gasoline, income, and a stock variable. Alternatively, through the identity $CPM = {}^{price}\!/_{mpg}$, cost per mile (CPM) replaces the variables for price and fuel efficiency. The stock variable can be represented by the number of drivers, the number of vehicles in use, population, or the number of registered vehicles. The number of drivers is the variable most often used, followed in frequency by vehicles in use. Greene (1992) estimated equations for vehicle miles traveled testing the use of vehicle stock versus licensed drivers and found that the results did not change with the choice of stock variable.

Table 1. Variables used in previous studies in estimations for fuel efficiency and vehicle miles traveled

MPG Models	
Espey (1996)	Price, Income, Time, Tax Index, MPG_{-1}
Nivola and Crandall (1995)	Price, CAFE, Price of steel
Gately (1990)	Price, Max Price, Time, MPG_{-1}
Mayo and Mathis (1988)	Price, Income, Speed, Cars, CAFE
Blair, et al. (1984)	Price, Income
Wheaton (1982)	Price, Income, Tax, Urbanization
VMT Models	
Nivola and Crandall (1995)	Price, Income, Drivers, MPG
Greene (1992)	Cost/Mile, Income, Drivers, VMT_{-1}
Gately (1990)	Cost/Mile, Income, Drivers
Mayo and Mathis (1988)	Cost/Mile, Income, Population, Cars, VMT_{-1}
Blair, et al. (1984)	Cost/Mile, Income, Population
Wheaton (1982)	Price, Income, MPG, Cars, Area

Table 2 presents the elasticities calculated in prior work and the ranges of elasticities surveyed by Dahl (1986). However, since each model uses different parameters, the interpretation of elasticities must be done with caution. For studies that used lagged dependent variables in MPG and VMT, both short-run and long-run elasticities are reported. For studies that did not use this dynamic framework, the direct elasticity estimate is reported. Nivola and Crandall (1995) estimated separate equations for passenger cars and light trucks and found differing elasticities. For the most part, the elasticity estimates in the individual papers concur with the survey by Dahl (1986).

Table 2. Elasticity estimates from previous studies

	Greene (1992)	Gately (1990)	Wheaton (1982)	Mayo and Mathis (1988)	Dahl (1986)	Nivola and Crandall (1995)
SR	.08			.21	.17 [.06,.21]	
$\eta_{MPG,P}$		.0023	.32,.33			PC .39 LT .59
LR	21			.90	.57 [.32,.69]	
SR					-.07 [-.03,-.08]	
$\eta_{MPG,I}$		.01	-.21,-.20			
LR					-.21	
SR					-.32 [-.10,-.50]	
$\eta_{VMT,P}$			-.50,-.54			PC -.10 LT -.10
LR					-.55 [0,-1.8]	
SR	.05			.25	.26 [.06,.98]	
$\eta_{VMT,I}$		.92,.52	.54,.46			PC .42 LT .52
LR	.12			.30	.60 [.54,4.9]	
SR						
$\eta_{VMT,MPG}$			.06,.10		.27 [.06,.50]	PC .012 LT .043
LR						
SR	-.10,-.12			-.22		
$\eta_{VMT,CPM}$		-.07,-.09				
LR	-.25,-.33			-.26		

NOTES:

- This table reports the price (P) and income (I) elasticities of demand for fuel efficiency (MPG) and vehicle miles traveled (VMT), as well as the cost per mile (CPM) elasticity for vehicle miles traveled.
- The CPM elasticity should be equal to the price elasticity minus the MPG elasticity (i.e. $\eta_{VMT,CPM} = \eta_{VMT,P} - \eta_{VMT,MPG}$).
- Numbers reported in the middle of the rows come from models without a lagged dependent variable, implying that the elasticity is a one period, full adjustment.
- From the Dahl (1986) article, average elasticities are reported, followed by ranges in brackets.
- In the Nivola and Crandall (1995) book, they calculated separate elasticities for passenger cars (PC) and light trucks (LT).

Other studies have taken a more general approach to estimating fuel demand and often arrive at very different results. Goldberg (1996) examined the effect of CAFE, gasoline taxes, and gas guzzler taxes on product mix, prices, and fuel consumption by combining a demand side model with an oligopolistic supply model. Goldberg found that a stronger gas guzzler tax was the best policy, followed by stricter CAFE standards, and finally increasing gasoline taxes. She estimated that the gasoline tax would have had to be increased by 780% of its current value to achieve fuel consumption reductions equivalent to those achieved by CAFE. This result followed from her econometric results which find mileage demand wholly unresponsive to changes in operating costs.

THE MODEL

Using meta analysis for parameterization, this paper projects fuel efficiency, total vehicle miles traveled, fuel consumption, and CO_2 emissions in the light-duty vehicle sector. Using data from 1982-1995, equations for fuel efficiency and vehicle miles traveled are calibrated, and applied to Kyoto goals for 2010. This is done separately for passenger cars and light trucks. Through the identity $Q_f = {}^{VMT}\!/_{MPG}$ we calculate fuel consumption and then CO_2 emissions.[2] Once we have established a base case with no new policies (i.e., CAFE standards remain at 27.5 for passenger cars and 20.7 for light trucks, and gasoline taxes remain at their current level), we then introduce higher CAFE standards and increasing gasoline taxes individually to force fuel consumption in 2010 to equal 93% of actual 1990 levels. Finally, we look at what levels of these policies would be necessary when used in combination to meet Kyoto objectives.

As seen from the previous studies, fuel efficiency is typically estimated as a function of the price of gasoline, income, and time. Since our aim is to meet Kyoto Protocol objectives using gasoline taxes and CAFE standards, we also include a variable for CAFE and add an additional

[2] One million gallons of gasoline emits 2424.88 metric tons of CO_2 (EIA, 1997b, p 100).

gasoline tax variable, included within the retail price variable. Equation (1) is the function used to predict fuel efficiency.

$$\ln MPG_{i,t} = A + \alpha_0 \ln MPG_{i,t-1} + \alpha_1 \ln(P+tax)_{i,t} + \alpha_2 \ln GDP_{i,t} + \alpha_3 \ln CAFE_{i,t} + \alpha_4 Time \qquad (1)$$

where i = passenger cars and light trucks and t = 1982-2010; *MPG* is the average fuel economy for all passenger cars and light trucks on the road; *P+tax* is the pre-tax price of gasoline plus additional taxes; *GDP* is real per capita income; *CAFE* is the standard in year t; and *Time* is a trend capturing technological change.[3] We have included the lag of fuel efficiency to capture long- and short-run changes in fuel efficiency.

Our equation for vehicle miles traveled takes the form of Equation (2).

$$\ln VMT_{i,t} = B + \beta_0 \ln VMT_{i,t-1} + \beta_1 \ln(P+tax)_{i,t} + \beta_2 \ln GDP_{i,t} + \beta_3 \ln DRIV_{i,t} + \beta_4 \ln MPG_{i,t} \qquad (2)$$

VMT is total vehicle miles traveled by passenger cars and light trucks (in millions); *DRIV* is the number of drivers; and the rest of the variables are as defined above. Again we have included the lag of the dependent variable to capture long-run changes in vehicle miles of travel. For the base case we have used the number of drivers as the stock variable. Alternatively, as discussed in the previous section, vehicles in use (*VEH*) could be adopted as the stock variable. We make this substitution in subsequent models.

From these two equations, we first forecast MPG to the year 2010, then use this estimate to forecast VMT to 2010. From these estimates, we calculate total fuel consumption through the

[3] See Appendix A for information on data sources.

identity $\ln Q_f = \ln VMT - \ln MPG$. By substituting in the equations for MPG and VMT, fuel consumption can be represented as in Equation (3):

$$\begin{aligned}\ln Q_f = &\left[\mathrm{B} + \mathrm{A}(\beta_4 - 1)\right] + \beta_0 \ln VMT_{-1} + \alpha_0(\beta_4 - 1)\ln MPG_{-1} + \left[\beta_1 + \alpha_1(\beta_4 - 1)\right]\ln(P + tax) \\ &+ \left[\beta_2 + \alpha_2(\beta_4 - 1)\right]\ln GDP + \beta_3 \ln DRIV + \alpha_3(\beta_4 - 1)\ln CAFE + \alpha_4(\beta_4 - 1)Time\end{aligned} \quad (3)$$

where i and t are implicit and Q_f is million gallons of gasoline. From this equation, the price and income elasticities are easily calculated for fuel consumption. The indirect price elasticity for fuel consumption is represented by $\eta_{Q,P} = \beta_1 + \alpha_1(\beta_4 - 1)$, a function of the price elasticities for fuel efficiency (α_1), vehicle miles traveled (β_1), and the elasticity of fuel efficiency for vehicle miles traveled (β_4). Similarly, the indirect income elasticity for fuel consumption is $\eta_{Q,GDP} = \beta_2 + \alpha_2(\beta_4 - 1)$, a function of the income elasticities for fuel efficiency (α_2), vehicle miles traveled (β_2), and the elasticity of fuel efficiency for vehicle miles traveled (β_4). Using the parameters for the MPG and VMT equations, the elasticities for fuel consumption can be calculated and compared to elasticities for fuel demand reported by Dahl and Sterner (1991).

MODEL 1: BASE CASE SCENARIO

Selection of Parameters

Our objective in the first model is to select elasticities that fall in the range of those reported in Table 2, such that our projections match forecasts for fuel consumption and vehicle miles traveled that have been estimated by other sources.

EIA (1997a) projects future energy use to the year 2020. For the transportation sector, they predict a VMT annual growth rate of 1.5% and a 1.3% increase in energy use by light-duty vehicles (EIA, 1997a, p 111). Greene's (1990b) base case scenario shows both fuel consumption and vehicle miles traveled increasing at 1.5% annually from 1990-2015.

Since the EIA (1997a) model uses a variable for drivers in their calculations, we calibrated our base case model using Equations (1) and (2) with the coefficients listed in Table 3. These values were chosen to be consistent with the elasticities reported in Tables 2 and 3 and all our parameter values fall within the middle of reported ranges. For example, the short-run average price elasticity for fuel efficiency reported by Dahl (1986) is 0.17. This corresponds to our value for α_1. Using the coefficient for MPG_{-1}, the long-run price elasticity for fuel efficiency is

$\eta_{MPG,P}^{LR} = \frac{\alpha_1}{(1-\alpha_0)}$, which in our base case equals 0.51. Similarly, we use a short-run income elasticity of -0.07, resulting in a long-run income elasticity of -0.21, identical to that reported.

Our choice of coefficient for CAFE was derived by hypothesizing that the effect of CAFE on fuel efficiency was an 85% long-run adjustment. This represents the difference between the Environmental Protection Agency's unadjusted and real-world adjusted fuel efficiency estimates for vehicles. The CAFE standard applies to the fuel efficiency numbers that are posted on new vehicles for sale. These values are calculated by the EPA from tests run on vehicles in ideal driving conditions. Actual fuel efficiencies typically reach 85% of ideal fuel efficiencies.[4] Therefore, since CAFE standards apply to new cars only, if it would take eight to fifteen years for all cars on the road to reach the 27.5 mpg standard, and even then the fuel efficiency of cars would only be 23 mpg. Hence, our short-run elasticity for CAFE is 0.28, resulting in a long-run elasticity of 0.84.

[4] The EPA adjusts downward their test results to account for the difference between controlled laboratory conditions and actual driving on the road. The EPA lowers the city estimate by 10% and the highway estimate by 22% from the laboratory test results (EPA, 1997).

Table 3. Coefficients used in Base Case Fuel Consumption Model

MPG Equation

		Our Estimates	*Other Estimates (from Table 2)*
MPG_{-1}	α_0	0.667	
Price-SR	α_1	0.17	.17 [.06,.21]
Price-LR	$\alpha_1 / (1-\alpha_0)$	.51	.57 [.32,.69]
GDP-SR	α_2	-0.07	-.07 [-.03,-.08]
GDP-LR	$\alpha_2 / (1-\alpha_0)$	-.21	-.21
CAFE	α_3	0.28	
Time	α_4	0.001	

VMT Equation

VMT_{-1}	β_0	.53	
Price	β_1	-.32	-.32 [-.10,-.50]
Price-LR	$\beta_1 / (1-\beta_0)$	-.68	-.55 [0,-1.8]
GDP	β_2	.26	.26 [.06,.98]
GDP-LR	$\beta_2 / (1-\beta_0)$	.55	.60 [.54,4.9]
Driv	β_3	.5	[.48,.91]
MPG	β_4	.1	.27 [.06,.50]

Q_f Equation

Price	$\beta_1 + \alpha_1(\beta_4 - 1)$	-.47	-.41 [-.10,-.75]
GDP	$\beta_2 + \alpha_2(\beta_4 - 1)$	.32	.41 [.32,.47]

The coefficients used in the VMT equation have similar representations. We use a short-run price elasticity of -0.32, which results in a long-run elasticity of -0.68. The short-run income elasticity of 0.26, calculates into a long-run elasticity of 0.55. These numbers correspond to elasticities reported in Table 2.

Base Case Results

Overall, the results for this base case scenario are similar to other forecasts. In our model, vehicle miles traveled increases on average 1.6% annually and fuel consumption increases 1.4% annually on average. This is consistent with predictions by EIA (1997a) and Greene (1990b). Passenger cars achieve a fuel efficiency of 23 mpg by 2010 and light trucks on the road get on average 14 mpg.

However, using the number of drivers rather than vehicles in use may underestimate fuel consumption by the light truck sector. In this first model, we let the number of drivers increase by 1% annually for both cars and light trucks, whereas cars in use have been increasing at less than 1% in the 1990s, while light trucks in use are increasing at 2-3%. This problem is reflected in the estimates for average vehicle miles traveled by individual vehicles. In 1995, both passenger cars and light trucks, on average, drove approximately 11,000 miles per year. Under the base case scenario, the average annual miles for passenger cars increases to 14,800 miles while the light truck average decreases to 9,900 miles per year. While this mileage differential is possible, we also utilize a "vehicles in use" model which has different characteristics.

MODEL 2: VEHICLE MODEL VERSUS DRIVER MODEL

Using the same parameters as in the base case scenario, we substitute vehicles in use for number of drivers in the VMT equation. Unlike gasoline prices, income, and population, forecasts of vehicles in use are not widely available. Furthermore, forecasts for cars and light trucks separately are not found in the literature. We developed a relationship to forecast vehicles in use with equations capturing both the shift between consumption of passenger cars and light trucks, and the overall demand for vehicles as functions of the price of gasoline (including taxes) and income (see Appendix A for estimation results).[5] These equations capture the shift toward light trucks with low gasoline prices (i.e. low taxes) and high incomes, and project a shift away from light trucks with higher gasoline taxes.

Using this model, the growth in total vehicle miles traveled remains the same at 1.6%, but the growth in fuel consumption is much higher (1.9% instead of 1.4%). This is consistent with estimates by the EPA when taking into consideration the growth in the light truck market. As well, the projected average annual vehicle miles traveled by cars and trucks is more representative of current growth rates, both reaching 13,000 miles traveled annually by 2010. Figure 3 shows the increase in fuel consumption comparing the two cases with number of drivers and vehicles in use. The increase in fuel consumption is more rapid with the vehicle model, exceeding the driver model by 9% in 2010. Fuel consumption predictions with the vehicle model also better capture recent increased demand for light trucks.

INTRODUCTION OF POLICIES TO MEET KYOTO OBJECTIVE

Now that a base case has been established for both models, policies are introduced to force fuel consumption and CO_2 emissions to reach 93% of 1990 levels by 2010. Stricter CAFE standards and increased gasoline taxes are initially introduced individually to determine what levels of each are necessary to reach Kyoto objectives. All policies are introduced in 1999 and a

[5] We thank Timothy Mount for his suggestion of this estimating method.

certain level is added each year to 2010.[6] For example, in the driver model, using only the CAFE standard, 2 mpg need to be added each year from 1999 to 2010 to reach our objective. This increases the new passenger car CAFE standard from 27.5 mpg in 1998 to 52 mpg in 2010 and the light truck standard increases to 45 mpg by 2010. Using only a gasoline tax, 5.4¢/gallon need to be added each year to adequately decrease fuel consumption. This means that the price of

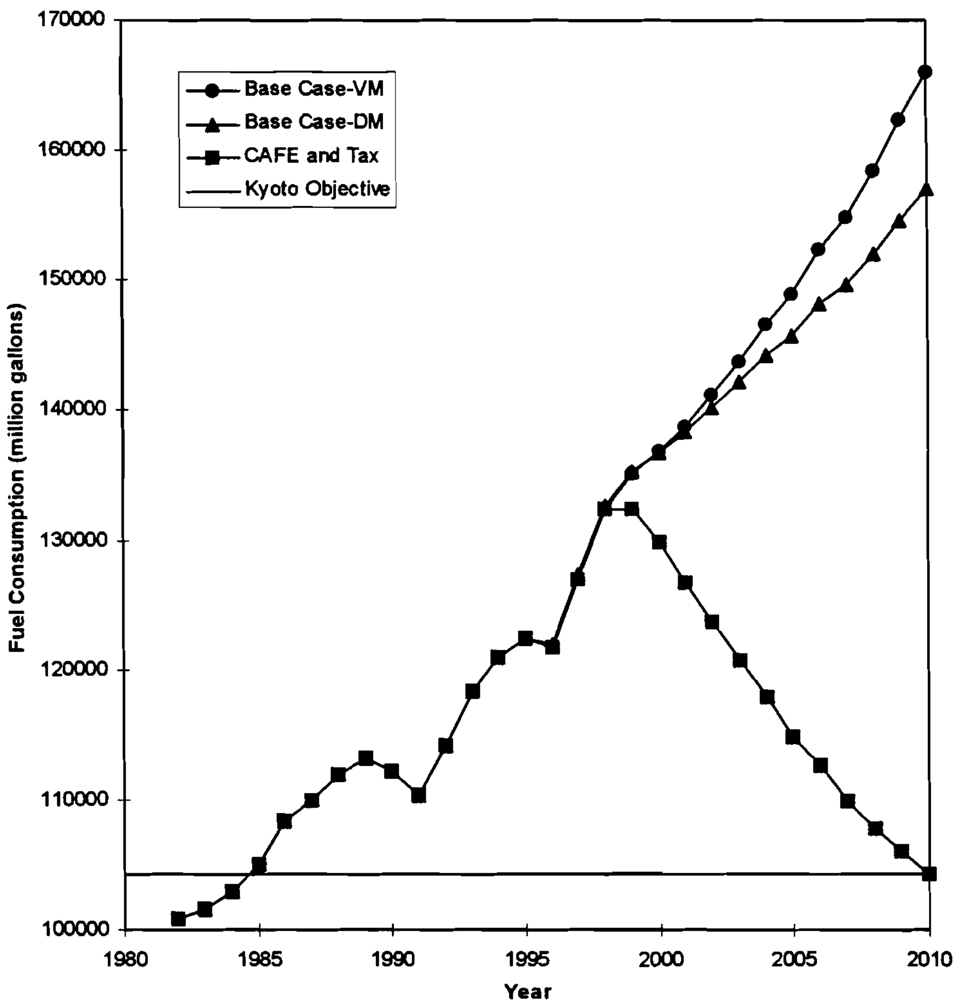

Figure 3: Fuel Consumption Scenarios

[6] We chose to start the policies in 1999 since the CAFE standard for 1998 has already been announced.

gasoline increases from $1.16/gallon in 1998 to $1.91/gallon in 2010 (in 1996$). Tables 4a and 4b present the CAFE and gasoline tax increases necessary for the driver and vehicle models and the resulting increase in 2010. As expected, the levels needed under the vehicle model are significantly greater, 15% higher than with the driver model.

Once the increases are estimated individually, we allow both CAFE and gasoline taxes to adjust and estimate the necessary levels when the policies are used jointly. It is interesting to note that when the policies are used jointly, less than 50% of each is necessary to achieve our goal. In the vehicle model, only 43% of initially established CAFE and gasoline taxes would be necessary to meet our objective. Figure 4 presents the locus of points of varying percentages that reduce fuel consumption and CO_2 emissions to 93% of 1990 levels. From this diagram, levels of each policy can be chosen that will fulfill Kyoto obligations. If, for example, policy makers favored using both policies equally, only 43% of the initial levels of each is needed (this is represented by the solid lines in Figure 4). However, if policy makers feel that their constituents feel more favorably towards the CAFE standard, rather than gasoline taxes, a higher rate of CAFE standard could be used with a slightly lower tax (a 58% CAFE and a 29% tax represent a 2 to 1 preference for CAFE standards - see dashed lines in Figure 4).

The shape of this isoquant depends mainly on the price elasticities in each equation (α_1 and β_1), the CAFE elasticity (α_3), and the fuel efficiency elasticity of vehicle miles traveled (β_4). With some algebraic manipulation, the relationship between the tax rate and the CAFE standard is represented by Equation (4).

$$\ln(P + tax) = C - \frac{\alpha_3(\beta_4 - 1)}{\alpha_1(\beta_4 - 1) + \beta_1} \ln CAFE \qquad (4)$$

Table 4a. Policies Needed to Meet Kyoto Objectives: Increases per Year

	Driver Model	Vehicle Model
Only CAFE	2.03 mpg	2.35 mpg
Only Gas Tax	5.4 ¢/gallon	6.1 ¢/gallon
Equal Preference	0.88 mpg (44%) 2.4 ¢/gallon (44%)	1.00 mpg (43%) 2.6 ¢/gallon (43%)
CAFE Preferred	1.20 mpg (59%) 1.6 ¢/gallon (29%)	1.36 mpg (58%) 1.8 ¢/gallon (29%)
Tax Preferred	0.60 mpg (29%) 3.2 ¢/gallon (59%)	0.68 mpg (29%) 3.5 ¢/gallon (58%)

NOTE: All policies begin in 1999 and continue through 2010. The increases per year accumulate to 2010, implying that the CAFE standard in 2010 in the only CAFE policy for the driver model would be 52 mpg for passenger cars (starting at 27.5 mpg in 1998 and increasing by 2.03 mpg per year for 12 years) and 45 mpg for light trucks (see Table 4b).

Table 4b. Fuel Efficiency and Gasoline Tax Rates in 2010 with Policy

		Driver Model			Vehicle Model		
		PC (mpg)	**LT (mpg)**	**Tax (¢/gal)**	**PC (mpg)**	**LT (mpg)**	**Tax (¢/gal)**
	1998	27.5	20.7	0	27.5	20.7	0
Only CAFE	**2010**	52	45	--	56	49	--
Only Tax	**2010**	--	--	65¢	--	--	73¢
Equal	**2010**	38	31	29¢	40	33	31¢

where C is a constant. More specifically, in 2010, Equation (4) can be rewritten as (4').

$$\ln\left(126+12(tax)\right)=C-\frac{\alpha_3(\beta_4-1)}{\alpha_1(\beta_4-1)+\beta_1}\left\{\ln\left(27.5+12(\Delta CAFE)\right)+\ln\left(20.7+12(\Delta CAFE)\right)\right\} \qquad (4')$$

where \$1.26/gallon is the predicted price of gasoline in 2010, the tax and CAFE standard are multiplied by the number of years that the policies are in place, and 27.5 mpg and 20.7 mpg are the original CAFE standards for passenger cars and light trucks, respectively. The coefficient on CAFE will always be negative as long as $\beta_4<1$, and the degree of curvature of the isoquant will vary depending on the magnitudes of the other elasticities, but remain convex.

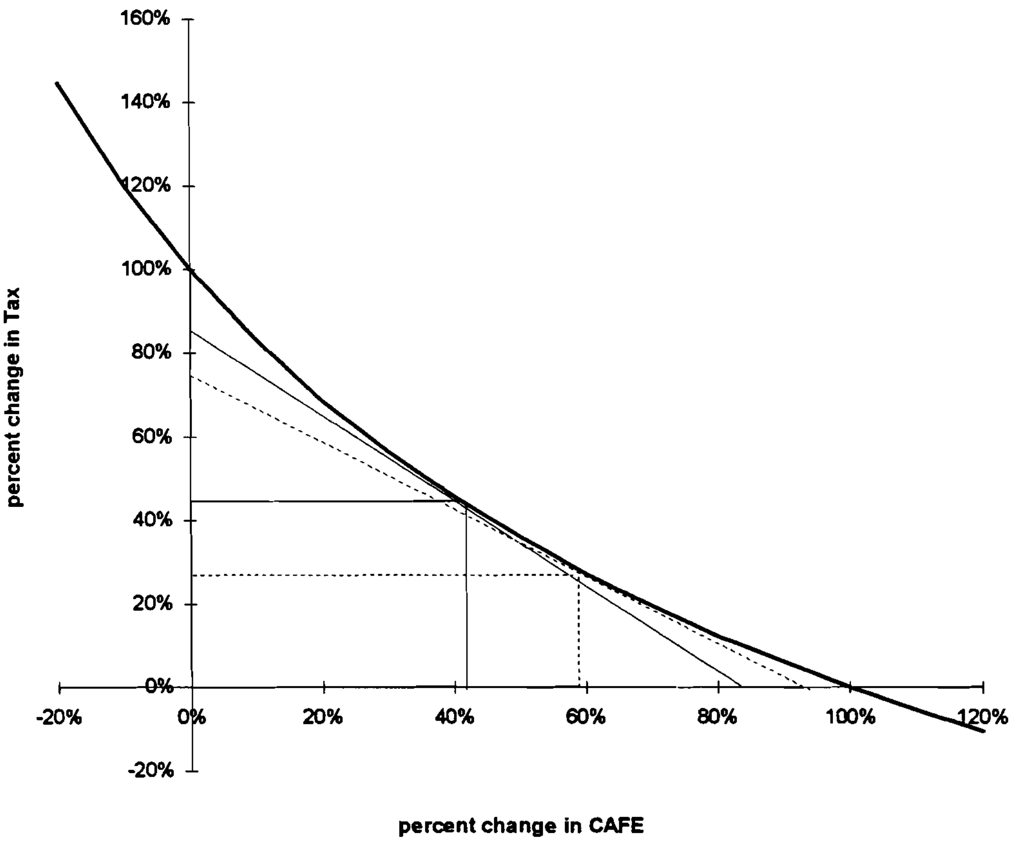

Figure 4. CAFE/Tax Isoquant

CO_2 EMISSIONS

As mentioned previously, the estimate for CO_2 emissions (in metric tons) can be directly derived from our estimates of fuel consumption through the identity $CO_2 = 2424.88Q_f$, where 2424.88 metric tons carbon per million gallons of gasoline are emitted. Figures 5a and 5b present CO_2 emissions from the base case results for the vehicle and driver models. These figures are separated into emissions from light trucks and passenger cars. In the driver model (Figure 5b), CO_2 emissions from light trucks never reaches the level of passenger cars. However, this is inconsistent with EPA predictions. The EPA has estimated that CO_2 emissions from light trucks will surpass that of passenger cars before the year 2000 (Bradsher, 1997). The vehicle model is a better predictor of this result. Figure 5a shows that around 2005, CO_2 emissions from light trucks will be equal to passenger car emissions at 180 million metric tons and they exceed passenger car emissions by 23% in 2010. From the vehicle model, emissions from light trucks and passenger cars are predicted to be 230 and 185 million metric tons, respectively by 2010. The EPA predicts levels of 250 and 150 million metric tons in 2010 for light trucks and passenger cars, respectively (Bradsher, 1997).

DISCUSSION OF THE MODEL

While a CAFE standard that increased by 2 mpg per year may be technologically feasible, it may not be implemented. Producers may choose to pay the fines and continue selling vehicles with lesser fuel efficiencies. This would mean that our model underestimates fuel consumption and emissions. On the other hand, if manufacturers strive to achieve these higher fuel economy standards, prices of vehicles could rise. With higher vehicle prices, consumers would purchase

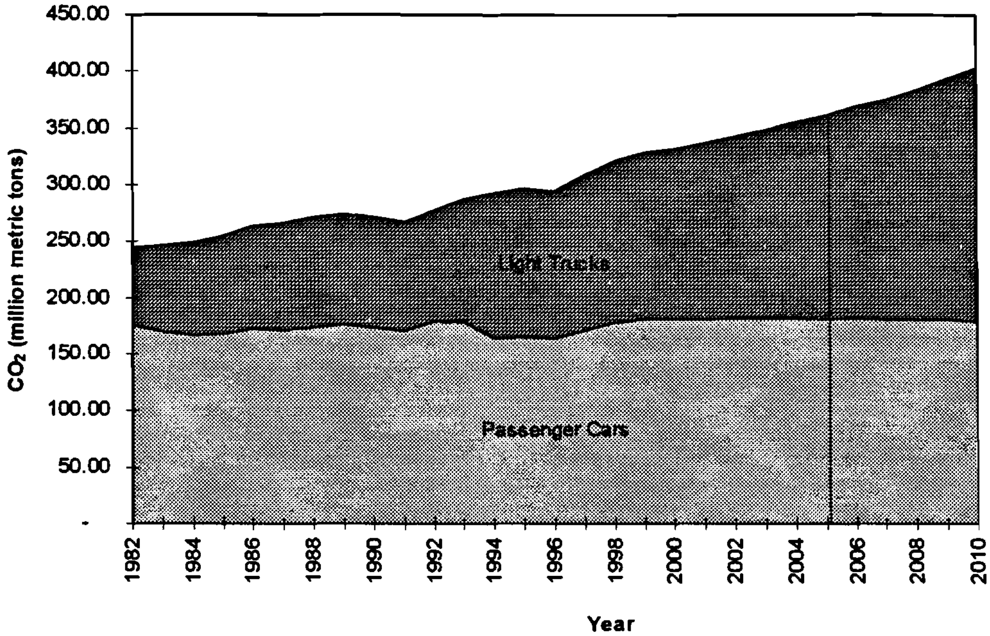

Figure 5a. Passenger Car and Light Truck Contributions to CO_2 Emissions: Base Case Vehicle Model

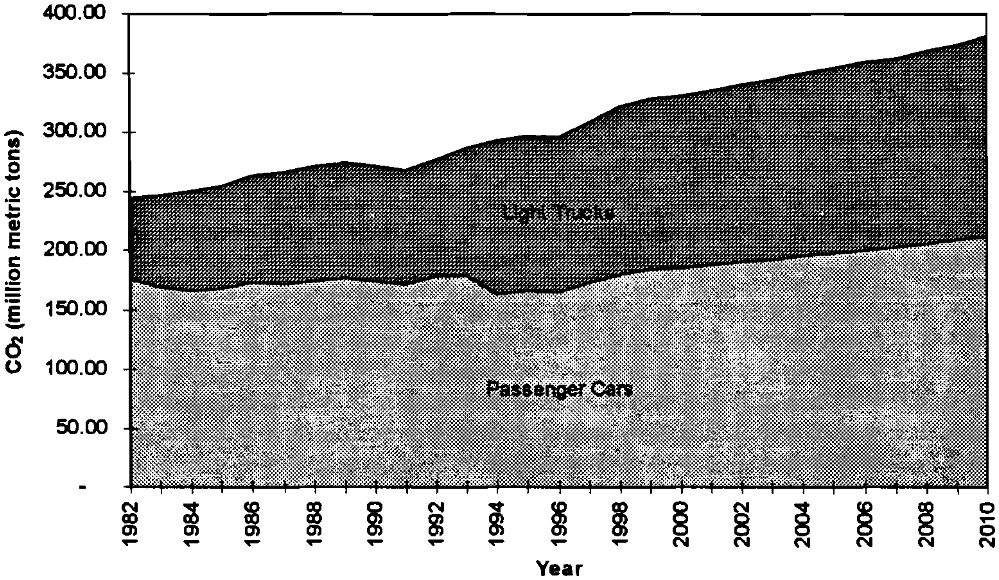

Figure 5b. Passenger Car and Light Truck Contributions to CO_2 Emissions: Base Case Driver Model

fewer vehicles, implying that our model overestimates fuel consumption and emissions. This model could be strengthened by deriving demand for vehicles as a function of the distribution of vehicle prices, which is itself a function of the CAFE standard. In general, raising CAFE a) may lower average price because the average vehicle is lighter in weight or b) increase the average price if more costly materials are used to attain lighter vehicles. Almost certainly, CAFE leads producers to lower small car prices and increase large car prices.

The final result of our model is that there is a range of policy options available that would allow the US to reduce its demand for gasoline. We have discussed the choice in a political economy framework. While this may be appropriate for implementation of policies, it is certainly not the only choice variable. Ideally, the optimal combination of policies should be the one that maximizes social welfare. This means that the policies should be equitable (i.e. the benefits and costs are shared by all) and efficient. Several papers have addressed the issue of the costs and benefits of increased CAFE standards and gasoline taxes (see Crandall, 1992 and Crandall, et al., 1986).

Table 5 presents some of the economic and environmental consequences of each policy. Both CAFE and gasoline taxes reduce consumer surplus through increased prices and reduce fuel consumption and emissions. However, CAFE may have additional costs in the form of market distortions. With an increasing demand for larger vehicles (attributable to low gasoline prices and aggressive advertising by US car producers), manufacturers may find they have to sell an increased number of smaller, more fuel efficient vehicles to counterbalance their increased sales of larger, less fuel efficient vehicles. This could create a distribution of vehicles on the road that leads to more traffic fatalities. Ultimately, the optimal policy choice should be one that monetarizes the costs and benefits listed in Table 5 and chooses the best combination of CAFE and gasoline taxes.

Table 5. Costs and Benefits of CAFE Standards and Gasoline Taxes

	CAFE	Gas Tax
Costs	• increased vehicle prices • more older cars on the road • market distortions (increased number of big vehicles supplemented by an increased number of smaller cars) • increased vehicle miles traveled	• increased gasoline prices • politically unpopular • possibly taxing poor more than rich (regressive)
Benefits	• decreased fuel consumption • decreased emissions • lower fuel economy car prices could subsidize higher fuel economy car prices (progressive)	• decreased fuel consumption • decreased emissions • increased government revenue • increased demand for fuel efficient cars

CONCLUSIONS

This paper has shown one way that the US could demonstrate its sincerity in achieving Kyoto Protocol objectives. An implementation of increased CAFE standards and higher gasoline taxes would significantly reduce CO_2 emissions in the transportation sector. The US initiated the CAFE standards twenty years ago, but has maintained the same standard for passenger cars for the last ten years and has only increased the standard for trucks by 0.2 mpg in that same time. The policy is in place, yet it requires some increase to effectively reduce fuel consumption.

Some may argue that since the Kyoto Protocol applies to overall CO_2 and greenhouse gas emissions, reductions can be made in other sectors. However, ultimately the transportation sector would have to change gasoline use levels to meet Kyoto goals. In Britain, for example, the fastest growing source of CO_2 emissions is transportation and it will account for all of the projected increase in CO_2 emissions between 1970 and 2020 and of this, two-thirds is by private vehicles (*The Economist*, 1998).

Additionally, any reductions in fuel consumption to curb CO_2 emissions will have co-benefits for local air pollution problems. Since 1970, the US has been very successful in reducing vehicle emissions of carbon monoxide, nitrogen oxides, hydrocarbons, and lead. However, in those same years, the number of miles driven has more than doubled, offsetting some of the overall emissions reductions (EPA, 1994). While technologies are still being developed to offset more of these pollutants, reductions in fuel consumption will have an immediate effect in improving local air quality.

Using CAFE standards exclusively will not give consumers sufficient economic incentive to use less fuel. A combination of increased CAFE standards and higher gasoline taxes will help the US to meet Kyoto Protocol objectives and improve air quality everywhere.

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APPENDIX 1: DATA SOURCES

Vehicle Miles of Travel (VMT):

American Automobile Manufacturers Association (AAMA), *Motor Vehicle Facts & Figures*, various years. For example, AAMA, 1997, reports VMT in the section "Annual Motor Vehicle Miles of Travel and Fuel Consumption" (AAMA, 1997, p 64). The data were collected from 1982-1995 and then forecast to 2010 from models in this paper.

Fuel Consumption (Q_f):

American Automobile Manufacturers Association (AAMA), *Motor Vehicle Facts & Figures*, various years. For example, AAMA, 1997, reports Q_f in the section "Annual Motor Vehicle Miles of Travel and Fuel Consumption" (AAMA, 1997, p 64). The data were collected from 1982-1995 and then forecast to 2010 from models in this paper.

Fuel Efficiency (MPG):

Using the data collected for VMT and Q_f, MPG was calculated for 1992-1995 and then forecast to 2010 from models in this paper.

Number of Drivers (DRIV):

American Automobile Manufacturers Association (AAMA), *Motor Vehicle Facts & Figures*, various years. For example, AAMA, 1997, reports DRIV in the section "Licensed Drivers" (AAMA, 1997, p 56). The data were collected from 1982-1995 and then increased by 1% pa to 2010.

Price of Gasoline (price):

Energy Information Administration (EIA), *Monthly Energy Review*, May 1998. The price data for 1982-1997 come from the series for All Types from Table 9.4 Motor Gasoline Retail Prices, U.S. City Average (EIA, 1998, p 114 - deflated to 1996 ¢/gallon by CPI-U). These prices include federal and state taxes. The data for 1998-2010 are from Table 12. Petroleum Product Prices. They are the sales weighted-average price for all grades, including predicted federal and state taxes, but excluding county and local taxes.

Gasoline Taxes (tax):

American Petroleum Institute (API), *How Much We Pay for Gasoline, 1997 Annual Review*, Policy Analysis and Strategic Planning Department, April 1998. Average Per Gallon Motor Fuel Taxes are reported in Table 3B (API, 1998, p 9) in 1997 ¢/gallon and then are readjusted to 1996 ¢/gallon using the CPI-U. These include federal and weighted average U.S. state taxes, but excludes local taxes.

Corporate Average Fuel Economy Standards (CAFE):

American Automobile Manufacturers Association (AAMA), *Motor Vehicle Facts & Figures*, various years. For example, AAMA, 1997, reports CAFE Standards in the sections "New Car/Truck Corporate Average Fuel Economy" (AAMA, 1997, p 80-81). The data were collected from 1982-1995 and then varied to meet Kyoto Protocol objectives.

Per Capita Income (GDP):

Economic Report of the President, 1997. The 1982-1995 GDP data come from the real GDP series in 1992$. This was then adjusted to 1996$ using the CPI-U and divided by the population estimates also given in the *Economic Report of the President*, 1997. GDP is then forecast to increase by 1.3% from 1996-2000 and by 1.5% from 2001-2010.

Vehicle in Use (VEH):

AAMA, various years. The 1982-1995 data for vehicles in use comes from the AAMA's *Motor Vehicle Facts & Figures.* This data was then forecast using equations to capture the shift between passenger cars and light trucks and total demand for vehicles with changing gasoline prices and incomes. We estimated the following equations:

$$\ln\left(\frac{SHARE}{1-SHARE}\right)_{i,t} = A + \beta_0 \ln\left(\frac{SHARE}{1-SHARE}\right)_{i,t-1} + \beta_1 \ln(P+tax)_{i,t} + \beta_2 \ln GDP_{i,t} + \varepsilon_{i,t} \qquad (1A)$$

$$\ln VEH_{i,t} = A + \alpha_0 \ln VEH_{i,t-1} + \alpha_1 \ln(P+tax)_{i,t} + \alpha_2 \ln GDP_{i,t} + \upsilon_{i,t} \qquad (2A)$$

where i=passenger cars and light trucks, t=1978-1995, SHARE is the percentage of passenger cars in use, P + tax is the average retail price of gasoline (all types) plus federal and state gasoline taxes, GDP is per capita income, and VEH is the number of vehicles in use. In equation (1A), we use a logit transformation of SHARE and estimate both using OLS. The estimated coefficients for equations (1A) and (2A) are listed in Table 1A.

Table 1A. Estimated Coefficients for Vehicle in Use Forecast

	$\ln\left(\frac{SHARE}{1-SHARE}\right)$	ln VEH
$\ln\left(\frac{SHARE}{1-SHARE}\right)_{-1}$	0.723 (0.237)	
ln VEH_1		0.672 (0.089)
ln (price + tax)	-0.087 (0.363)	-0.028 (0.024)
ln GDP	-0.796 (1.052)	0.249 (0.113)

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