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Randy Chugh
Maureen L. Cropper

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ABSTRACT

We estimate a model of vehicle choice and kilometers driven to analyze the long-run impacts of fuel conservation policies in the Indian car market. We simulate the effects of petrol and diesel fuel taxes and a diesel car tax, taking into account their interactions with the pre-existing petrol fuel tax. Holding constant the total amount of fuel conserved, further taxing petrol fuel creates a larger deadweight loss than taxing diesel fuel, while taxing diesel cars creates a negative deadweight loss. Diesel fuel and diesel car taxes shift new car buyers from diesel to petrol, raising revenue through the pre-existing petrol fuel tax in the process. In the case of the diesel car tax, the deadweight loss is more than fully offset by this petrol fuel tax revenue. This result reflects the size of the pre-existing petrol fuel tax and the high elasticity of diesel market share with respect to diesel car price.

Randy Chugh
Department of Justice
450 5th Street, NW
Washington, DC 20001
chugh.randy@gmail.com.

Maureen L. Cropper
Department of Economics
University of Maryland
College Park, MD 20742
and NBER
cropper@econ.umd.edu

1. Introduction

The effectiveness of fuel conservation policy—whether motivated by environmental or energy security concerns—depends on the price elasticity of fuel consumption. The higher the price elasticity, the greater the impact of a fuel tax and the greater the rebound effect associated with a fuel economy standard. In the transport sector, the long-run price elasticity of fuel consumption depends on consumers’ willingness to substitute to more fuel efficient cars in addition to their willingness to drive less. Thus, measuring long-run price elasticity requires data on vehicle choice and vehicle use. Although several studies combine these data to measure long-run price elasticity in the United States (Bento et al., 2009; Feng et al., 2013; Goldberg, 1998; Jacobsen, 2013; West, 2004), there are few such studies outside of the United States (Fullerton et al., 2014) and none of which we are aware for developing countries. This paper takes a first step in filling this gap in the literature.

Studies of fuel consumption elasticity for developing countries are generally based on aggregate, time-series data. Income elasticities are generally based on GDP and household demand is usually not separated from the demand for fuel for commercial purposes (Dahl, 2012). In contrast, we use a rich household-level dataset on new vehicle purchases, kilometers driven, and household characteristics of new car buyers in India. This level of detail allows us to estimate a theoretically consistent model of consumer behavior. One of the key contributions of this paper, therefore, is to present the first theoretically consistent fuel consumption elasticity estimates in a developing country setting. We use our model to simulate the likely effects of fuel conservation policies currently being considered by the Indian government. As discussed below, our results also have implications for the European car market which, like India, is characterized by diesel cars’ substantial market share (Fronzel et al., 2012; Vance and Mehlin, 2009; Verboven, 2002).

India is one of the world’s fastest growing car markets. New car sales quadrupled from about 600,000 in 2002 to about 2.3 million in 2010 (Society of Indian Automobile Manufacturers). The Indian passenger vehicle fleet, which stood at 22 million in 2010, is projected to increase to 112 million by 2030 (Arora et al., 2011).¹ Thus, the Indian car market is important in its own right. Because of India’s increasing importance as a contributor to world

¹ For context, 2010 motor vehicle sales were 10.4 million in the U.S. and 13.6 million in China (Bloomberg, 2010).

greenhouse gas emissions, Indian fuel conservation policy is also important from a global point of view. Early adoption of fuel conservation policy in India will have a direct effect on world oil consumption and an indirect effect by providing an example for other developing countries.

As in many European countries, diesel cars constitute a significant fraction of the Indian passenger vehicle fleet. India has historically taxed diesel fuel at a lower rate than petrol, resulting in diesel fuel's lower price at the pump. This fuel cost advantage compounds diesel cars' fuel economy advantage, resulting in substantially lower per-kilometer operating costs for diesel cars. Not surprisingly, diesel cars' share of the new car market has risen steadily, from 22% in 2002 to 34% in 2010. Because of the dual-fuel nature of the Indian car market, elasticity results cannot easily be transferred from the United States. Our model of the Indian car market allows cross-price elasticities and tax interactions to play central roles in determining the impact of differential fuel or car taxation. Our study thus contributes to the empirical tax interaction literature (West and Williams, 2004, 2005) in a unique developing country setting.

In countries such as India, where petrol is taxed more heavily than diesel, raising the tax on diesel may have lower deadweight loss than raising the tax on petrol. This is clear from the Harberger formula for the excess burden of a tax on diesel fuel:

$$-\frac{1}{2}\tau_d^2 \frac{dX_d}{d\tau_d} - \tau_p \tau_d \frac{dX_p}{d\tau_d}$$

where X_d denotes diesel fuel consumption, X_p denotes petrol fuel consumption, τ_d denotes the tax on diesel, and τ_p denotes the tax on petrol.² The larger the tax on petrol, and the higher the elasticity of demand for petrol with respect to diesel price, the larger the second term which offsets the impact of the diesel tax in the market for diesel fuel. Intuitively, as buyers shift from diesel to petrol fuel, the increase in petrol tax revenue offsets the deadweight loss from taxing diesel. Calculating the magnitude of the welfare effect in the Indian car market requires estimating long-run elasticities of demand for petrol and diesel fuel.

An alternative method of conserving fuel is to tax diesel cars more heavily than petrol cars, as suggested by an expert panel convened by the Indian government (Parikh, 2010). This policy will curtail fuel consumption by inducing buyers to switch from diesel to petrol cars,

² See, for example, Goulder and Williams (2003).

which run on more expensive fuel. Calculating the welfare impact of this policy requires a model of vehicle purchases as well as fuel consumption.

Our Approach

To analyze the impact of fuel conservation policies in the Indian car market we present a structural econometric analysis of the demand for new cars and simulate market responses to alternative policies. Using data from the JD Power APEAL survey (JD Power, 2010), we model the joint decision of which car to buy and how much to drive it in a mixed logit discrete-continuous choice framework. The method, pioneered by Dubin and McFadden (1984), provides a tractable, theoretically motivated approach to dealing with selection bias and has become a workhorse model in energy demand estimation. Their two-stage approach has been applied to the United States car market in several studies (Bento et al., 2009; Goldberg, 1998; West, 2004).

One drawback of the two-stage approach is that separate estimation of car choice and driving distance leads to two sets of model parameters, often differing in magnitude and sign. Recent contributions by Bento et al. (2009) and Feng et al. (2013) have sought to overcome this limitation by estimating vehicle choice and distance driven simultaneously. We adopt this approach using manufacturer fixed effects to account for unobserved vehicle characteristics and randomly distributed parameters to account for unobserved household heterogeneity. The model leads to a single set of parameter estimates which we use to compute theoretically consistent welfare effects.

We estimate the model for the year 2010 and simulate consumers' responses to three fuel conservation policies: a diesel fuel tax that equalizes the prices of petrol and diesel fuel, a diesel car tax that results in the same reduction in the market share of diesel cars, and an increase in the current petrol fuel tax that achieves the same decrease in fuel consumption as the diesel fuel tax.³ For each policy, we simulate changes in market shares, driving distances, and total fuel use. We compare the efficiency of policies by calculating compensating variation, government revenue, and deadweight loss per liter of fuel conserved.

³ We also examine the impacts of smaller taxes on diesel and petrol fuels that yield the same total fuel savings as the diesel car tax.

Holding constant the amount of fuel conserved, the diesel fuel tax has a deadweight loss per liter of fuel conserved that is less than half that of the increased petrol fuel tax. This reflects both the high pre-existing tax on petrol fuel and the high own-price elasticities of fuel demand in India. A tax on diesel cars that results in the same diesel market share as the diesel fuel tax actually has a negative deadweight loss per liter of fuel conserved.⁴ This negative deadweight loss is the result of the increase in petrol tax revenue, as buyers shift from diesel to petrol cars, more than offsetting the welfare cost.⁵ The diesel fuel taxes we consider are more effective at reducing fuel consumption, suggesting, in the Indian context at least, a tradeoff between fuel conservation and economic efficiency.

Our elasticity estimates also have implications for the corporate average fuel economy (CAFE) standards currently being contemplated by the Indian government. The Bureau of Economic Efficiency is contemplating weight-based CAFE standards that would go into effect in 2015-16, with more stringent standards proposed for 2020-21 (Roychowdhury, 2011). Our estimates of the long-run elasticity of diesel and petrol fuel consumption with respect to price suggest that improving vehicle fuel economy is likely to have a significant rebound effect. As we demonstrate, the proposed 2015-16 fuel economy standards would reduce fuel consumption by approximately 20% if consumers continued to purchase the same vehicles they bought in 2010 and drove them the same number of kilometers. Our model suggests that allowing for both types of adjustment, however, implies a reduction in fuel consumption of only 7.6%.

The paper is organized as follows. Section 2 discusses the new car market, fuel pricing, and fuel consumption in India. Section 3 presents our model of vehicle choice and kilometers driven and our estimation strategy. Section 4 discusses the data used to estimate the model, including the stylized facts about Indian cars and the people who buy them. Section 5 presents our estimation results. Section 6 discusses the results of policy simulations and section 7 concludes.

⁴ According to Hines (1999), the possibility of negative deadweight loss in a market characterized by multiple distortions was first discussed in Lipsey and Lancaster (1956) and Corlett and Hague (1953).

⁵ By welfare cost we mean compensating variation, the amount of money consumers must be given to restore them to their pre-tax level of utility. At the tax rates considered here, this is lower for the diesel car tax than for the diesel fuel tax.

2. Overview of the Indian Car Market, Fuel Pricing, and Fuel Consumption

Sales of passenger vehicles in India have been growing rapidly, from 600,000 cars in 2002 to 1.2 million in 2006 and 2.6 million in 2011 (Society of Indian Automobile Manufacturers). Hatchbacks constitute approximately 66% of new car sales, sedans approximately 17%, with the remainder accounted for by SUVs. Trends in sales of diesel passenger vehicles in the Indian car market are shown in Figure 1. Diesel vehicles accounted for 34% of new car sales in 2010, although there was significant variation across vehicle type. As relatively few diesel hatchbacks are available due to technological constraints, diesel models' share of the hatchback market has remained between 10% and 20%.⁶ Among SUVs, diesel models' share has also been relatively constant between 60% and 70%. In the sedan market, however, diesel cars' share has increased from 25% in 2003 to nearly 50% in 2010.

The increasing trend in purchase of diesel vehicles can be explained, in part, by the lower price of diesel fuel. Figure 2 shows the retail prices of diesel and petrol per liter in Delhi from 2002 to 2013. Prior to 2010, the year of our study, both diesel and petrol prices were government-determined and, as the figure suggests, shielded from variation in world oil prices. The base price received by oil companies was set by the federal government.⁷ Customs duties, excise duties, and sales taxes were added to this to yield the retail prices shown in Figure 2. Beginning in 2010, the base price of petrol was allowed to vary with international oil prices. The lower price of diesel in Figure 2 reflects lower taxes on diesel and, in some years, a discount in the price retail dealers were charged for diesel. For modeling purposes, we treat the difference between petrol and diesel prices as a difference in tax rates.

An important question is why diesel is taxed at a lower rate than petrol. Sixty percent of diesel fuel is used for road transport, primarily for trucks and buses. Approximately 20% is used for power generation (both captive power generation and transmission to the grid), 12% by agriculture, 4% by railways, and 4% for miscellaneous uses (Anand, 2012). In spite of these statistics, diesel is widely perceived to be a “poor man’s fuel.” There is also concern about the macroeconomic consequences of equalizing the price of diesel and petrol (Anand, 2012; Parikh,

⁶ There are no diesel engines below 1250cc. Many hatchbacks have smaller engines.

⁷ The base price was set equal to 80% of the import price of oil plus 20% of the export price (Anand, 2012).

2010). For both reasons, there are political pressures not to raise the tax on diesel fuel, but to tax diesel cars instead.

As discussed below, we find operating cost to be a key determinant of vehicle choice. Although diesel cars are generally more expensive than their petrol twins, their lower operating cost more than offsets the purchase price difference (Chugh et al., 2011). The fuel economy of a diesel sedan (about 14.4 km/L in 2010) is about 22% higher than that of a petrol sedan (11.8 km/L) (see Table 1). When coupled with the 30% cheaper price of diesel fuel, the diesel sedan's fuel economy advantage results in an operating cost that is approximately 60% that of a petrol sedan. In view of the lower operating cost of diesel vehicles, it is not surprising that they are driven more. In 2010, diesel sedans were driven 36% farther than petrol sedans, diesel SUVs were driven 58% farther than petrol SUVs, and diesel hatchbacks were driven 66% farther than petrol hatchbacks (see Table 2).

3. A Discrete-Continuous Choice Model of New Car Purchases

We model the purchase and use of new cars in a discrete-continuous choice framework. The method, pioneered by Dubin and McFadden (1984), provides a tractable, theoretically motivated approach to dealing with selection bias and has become a workhorse model in energy demand estimation. The key insight of their study is that if consumers with high expected electricity usage buy low operating cost appliances, then a simple regression of usage on operating cost will result in a biased estimate of the price responsiveness of electricity demand. By directly modeling the discrete choice of which appliance to purchase, the authors develop a selection correction method and recover unbiased elasticity estimates in a second stage.

This two-stage approach has been applied to the United States car market in several studies. Goldberg (1998) uses a model of vehicle choice and utilization, coupled with an oligopolistic model of supply, to study the effect of CAFE standards on car sales, prices, and fuel consumption. West (2004) follows a similar approach and considers a broader range of policies and studies their distributional effects.

One drawback of the two-stage approach is that separate estimation of car choice and distance driven leads to two sets of model parameters, often differing in magnitude and sign. As the number of kilometers driven is derived using Roy's Identity in a static utility maximization

framework, theoretical consistency requires a single set of parameters to determine both choices. This is especially important in calculating the welfare impact of policy interventions. Recent contributions from Feng et al. (2013) and Bento et al. (2009) have sought to overcome this limitation by introducing simultaneous estimation techniques.⁸

Our approach incorporates these recent modeling and estimation advances in a mixed logit, discrete-continuous choice model of which car to buy and how much to drive it. We incorporate body type and manufacturer fixed effects to account for unobserved vehicle characteristics and we allow for randomly distributed parameters to account for unobserved household heterogeneity. The model is estimated by full information maximum likelihood which leads to a single set of parameter estimates, allowing for theoretically consistent welfare calculations.

3.1 The Model

The household's decision takes the form of a standard static utility maximization problem where utility is a function of car characteristics, kilometers driven, and consumption of all other goods. The household chooses the car that yields the highest indirect utility; optimal driving distance can then be inferred by Roy's Identity.

Although the JD Power survey is conducted in several locations across the country, we model the new car market as a single, national market with the choice set being the same for all households. As data are limited to households that have purchased a new car in the survey year, the choice set does not include an outside good. Thus, households in the model are faced with the decision of which car to buy conditional on having already decided to buy a new car. This modeling approach is necessary given data limitations, but also allows for a more precise estimation of means and distributions of preferences for the subpopulation of new car buyers (see Train and Winston (2007) for further discussion).

⁸ We note two recent studies of vehicle demand in China (Li, 2014; Xiao and Ju, 2014) which use aggregate household data to analyze the impact of policies to limit vehicle emissions. Fullerton et al. (2014) estimate a model of vehicle demand and distance driven for Japan using aggregate data.

3.2 Vehicle Choice

Each household i chooses the car from choice set \mathcal{J} that yields the highest utility. Following Bento et al. (2009), household i 's utility conditional on buying car j is

$$v_{ij} = -\frac{1}{\beta_i} e^{-\beta_i(y_i - r_j) - \gamma \mathbf{X}_{ij} - \eta_i} - \frac{1}{\alpha_i} e^{\alpha_i p_j} + \epsilon_{ij}, \quad (1)$$

where $y_i - r_j$ is annual income of household i minus the annualized rental cost of car j ; \mathbf{X}_{ij} is a vector of characteristics of car j , characteristics of household i , and interactions of the two; p_j is the per-kilometer operating cost of car j ; η_i is an idiosyncratic taste for driving; and ϵ_{ij} is an i.i.d. stochastic preference shock.⁹ The coefficients β_i and α_i are assumed to follow uncorrelated random distributions, the parameters of which are estimated along with other parameters of the model. For example, $\beta_i = \bar{\beta} + v_{i\beta}$ where $\bar{\beta}$ is the mean of β_i and $v_{i\beta}$ is an idiosyncratic deviation drawn from some distribution $f(v_{i\beta}|\omega_\beta)$.¹⁰ The idiosyncratic taste for driving, η_i , is assumed to be normally distributed with mean zero; its standard deviation, σ , is estimated along with the other parameters of the model.

Let $\boldsymbol{\theta}$ represent the common set of coefficients such that $\boldsymbol{\theta} = \{\bar{\beta}, \bar{\alpha}, \gamma, \omega_\beta, \omega_\alpha, \sigma\}$. Individual parameters are then distributed according to the joint probability density function $g(\mathbf{v}|\boldsymbol{\theta})$. Assuming that $\{\epsilon_{ij}\}$ have a Type I Extreme Value distribution, the probability that household i chooses car j takes the mixed logit form,

$$Pr_{ij} = \int \frac{e^{v_{ij}/\mu}}{\sum_{j=1}^J e^{v_{ij}/\mu}} g(\mathbf{v}|\boldsymbol{\theta}) d\mathbf{v}, \quad (2)$$

where μ is the scale parameter of the i.i.d. Type I Extreme Value error term.

⁹ This functional form leads to a log-linear specification of the demand for kilometers driven. Previous discrete-continuous models, including Dubin and McFadden (1984), Goldberg (1998), and West (2004), used an indirect utility function that leads to a linear demand function for kilometers driven. The log-linear demand function provides a better fit for our data.

¹⁰ Including random coefficients on all car characteristics would result in a more general model, but comes at the cost of a higher dimensional integral requiring many more random draws to simulate. Experiments with more general specifications did not improve model fit or substantially change counterfactual predictions.

3.3 Driving Distance

Using Roy's Identity, annual driving distance can be derived from equation (1) as follows:

$$KM_{ij} = -\frac{\partial v_{ij}/\partial p_j}{\partial v_{ij}/\partial y_i} = e^{\beta_i(y_i - r_j) + \gamma X_{ij} + \alpha_i p_j + \eta_i}. \quad (3)$$

As mentioned above, household i 's idiosyncratic taste for driving, η_i , is drawn from a mean-zero normal distribution with standard deviation σ which is estimated along with the other parameters in the model. This modeling of the driving distance decision, which follows Feng et al. (2013), improves the fit of the model to the data but still allows for a more general correlation of errors as in Bento et al. (2009).

Taking account of the fact that the same randomly distributed coefficients that determine vehicle choice probabilities also determine driving distance predictions, the log of demand for kilometers driven equation becomes

$$\log(KM_{ij}) = \int [\beta_i(y_i - r_j) + \gamma X_{ij} + \alpha_i p_j + \eta_i] g(\mathbf{v}|\boldsymbol{\theta}) d\mathbf{v}. \quad (4)$$

Just as equation (2) takes advantage of the closed-form solution of the integral over the type I extreme value preference shock, equation (5) below takes advantage of the closed-form solution of the integral over the normally distributed idiosyncratic taste for driving. The likelihood of observing \widetilde{KM}_{ij} kilometers driven conditional on household i buying car j is

$$\ell(\widetilde{KM}_{ij} | \mathbb{1}_{ij} = 1) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2} \frac{[\log(\widetilde{KM}_{ij}) - \log(\widehat{KM}_{ij})]^2}{\sigma^2}} \quad (5)$$

where $\mathbb{1}_{ij}$ is an indicator function equal to 1 if household i bought car j and 0 otherwise and \widehat{KM}_{ij} is the right hand side of equation (4) without the idiosyncratic taste for driving shock.

3.4 Estimation Strategy

Household i 's likelihood of buying the car it is observed to have bought and driving the distance it is observed to have driven is the product of the probability of buying car j (equation (2)) and its likelihood of driving \widetilde{KM}_{ij} conditional on buying car j (equation(5)). The full information likelihood function is the product over all households:

$$L(\boldsymbol{\theta}) = \prod_{i=1}^N \prod_{j=1}^J [Pr_{ij} \ell(\widetilde{KM}_{ij} | \mathbb{1}_{ij} = 1)]^{\mathbb{1}_{ij}}. \quad (6)$$

The log-likelihood function is

$$LL(\boldsymbol{\theta}) = \sum_{i=1}^N \sum_{j=1}^J \mathbb{1}_{ij} [\log (Pr_{ij} \ell(\widetilde{KM}_{ij} | \mathbb{1}_{ij} = 1))]. \quad (7)$$

Evaluating the log-likelihood function directly would require solving the integrals in equations (2) and (4). In the absence of closed-form solutions, integration can be performed by simulation (Train, 2009). For any draw \mathbf{v}_{ir} from the distribution $g(\mathbf{v}|\boldsymbol{\theta})$, the log-likelihood for household i is calculated, the sum of the log-likelihoods from R separate draws is found, and the average is taken. In the limit as R approaches infinity, simulation error approaches zero. The second departure from equation (7) is to weight each observation to ensure that the prominence of each vehicle model in the sample is proportional to its market share.¹¹ Thus, the log-likelihood to be maximized is given by

$$LL(\boldsymbol{\theta}) = \sum_{i=1}^N \sum_{j=1}^J \mathbb{1}_{ij} [w_i \log(\widetilde{Pr}_{ij} \check{\ell}(\widetilde{KM}_{ij} | \mathbb{1}_{ij} = 1))] \quad (8)$$

where w_i is the weight applied to observation i and probabilities have been replaced by their simulated values.¹²

¹¹ Weights for each observation equal the ratio of the market share to the sample share of the chosen model.

¹² Results presented below are based on integrals simulated using 200 shifted and shuffled Halton draws, a quasi-random scheme that provides better coverage than pseudo-random draws. While some studies use up to 5000 pseudo-random draws, Train and Winston (2007) find 200 Halton draws to be sufficient. We follow their approach to testing for sufficient draws by calculating the value of the test statistic $g'H^{-1}g$ using 400 draws at the parameter estimates obtained using 200 draws. Under the null hypothesis that the gradient is zero, this test statistic is

4. Data and Empirical Specification

4.1 New Car Buyers and Vehicles Purchased

We estimate the model using data on household car choice and monthly driving distances from the 2010 JD Power APEAL survey, a survey of 7,000 new car buyers in India. The survey provides the make, model, and fuel type of the car purchased and the purchase price, monthly kilometers driven, and the buyer's estimate of fuel economy. It also collects data on household income, demographic characteristics, and vehicle ownership.¹³

Car characteristics data come from the magazine AutoCar India and the website DriveInside.com. Most car models are available in multiple versions (e.g., a Honda Civic LX or a Honda Civic EX). This level of detail is available in AutoCar India and DriveInside, but survey respondents report a model/fuel type only. Car characteristics for each model/fuel type are constructed as the unweighted average across all versions of each model/fuel type. Table 1 presents the sales-weighted summary statistics for all vehicle models sold in 2010. Price and fuel economy variables are taken as the average across all respondents for each model/fuel type, but are found to be similar to price and fuel economy reported in AutoCar India.¹⁴

It is important to note that the figures presented in Table 1 reflect differences in model availability across fuel types in addition to general differences between petrol and diesel cars. Of the 54 models in the dataset, 31 are available in both petrol and diesel form. Among these models, 20 were bought in substantial numbers in both petrol and diesel form, while 11 were purchased as diesels only. Counting only those vehicles that sold in substantial numbers yields a choice set of 74 cars for each buyer.¹⁵ For hatchbacks and sedans, every diesel model is available as a petrol vehicle, but a wide variety of petrol models are available for which there is no diesel counterpart. Nevertheless, some stylized facts are worth noting. Diesel cars are heavier than

distributed chi-squared with degrees of freedom equal to the number of parameters. Using this approach, we fail to reject the hypothesis that the parameters found using 200 draws are likelihood maximizing. As in Train and Winston (2007), we present standard errors that are robust to simulation noise.

¹³ The JD Power Automotive Performance, Execution and Layout Study (JD Power, 2010) is a home interview survey of new car buyers conducted in 20 cities in India within 2 to 6 months after the purchase of a new car. At least 100 households are sampled for each model covered by the survey.

¹⁴ A regression through the origin of buyers' estimates of fuel economy on published estimates of city fuel economy yields a coefficient of 1.14 (s.e.=0.010). When highway fuel economy is added to the equation, the coefficient on city fuel economy equals 1.09 (s.e.=0.099) and the coefficient on highway fuel economy is 0.034 (s.e.=0.071).

¹⁵ Any car with at least 0.01% market share is included in the survey and in our model.

petrol cars, have a lower horsepower-to-weight ratio, and, with the exception of SUVs, have higher fuel economy.

Because of their higher fuel economy and cheaper fuel, diesel cars have lower costs per kilometer driven than petrol cars.¹⁶ In 2010, diesel operating costs were 34% lower for hatchbacks, 39% lower for sedans, and 20% lower for SUVs. Predictably, the owners of diesel cars drove more. As shown in Table 2, owners of diesel hatchbacks drove 66% more than owners of petrol hatchbacks, owners of diesel sedans drove 36% more than owners of petrol sedans, and owners of diesel SUVs drove 58% more than owners of petrol SUVs.

The APEAL survey provides information on the income, age, gender, family size, and car ownership of respondents. Sedan owners, on average, have higher incomes than hatchback owners. Diesel sedan owners, on average, have lower incomes than petrol sedan owners. Family size is slightly higher among diesel households and the average age of diesel car owners is slightly lower. Family size is correlated with vehicle size: for both diesel and petrol vehicles family size is smaller on average for hatchback buyers than for sedan buyers and smaller for sedan buyers than for buyers of SUVs.

4.2 Model Specification

To operationalize the model, it is necessary to convert the purchase price of a vehicle to an annualized rental price and to construct a per-kilometer operating cost. We focus entirely on the purchase price (inclusive of sales taxes) and calculate the rental price as the annual payment on a car loan such that the loan would be paid back over the expected life of the vehicle. Vehicle survival probabilities are based on a survival curve for Indian cars estimated by Arora et al. (2011). Their survival curve assumes a maximum vehicle life of 20 years and implies an expected vehicle life of 18 years. We use a nominal interest rate of 15%, based on interest rates charged on new car loans in India, and note that about 80% of new car purchases are financed with such loans (Carazoo.com, 2011; Seth, 2009; Shankar, 2007). After adjusting for inflation, we use a real interest rate of 8.5%.

¹⁶ Operating costs are calculated using Delhi fuel prices, as described more thoroughly below.

Operating cost is the fuel price in Delhi divided by fuel economy.¹⁷ As with vehicle price, fuel economy is taken as the average self-reported fuel economy for each vehicle type, but results are robust to the use of AutoCar India fuel economy data instead. The Delhi prices of petrol and diesel fuel in 2010 were 49.4 Rs. per liter and 36.7 Rs. per liter, respectively. Our vector of vehicle characteristics includes all of the attributes listed in Table 1, make dummies, and dummies for body type (sedan and hatchback—SUV is the omitted category). Vehicle attributes include performance characteristics (engine size, torque, and the ratio of horsepower to weight), number of gears, whether the vehicle has an automatic transmission, and measures of vehicle size (length, width, height, ground clearance, and weight). We also include an index of the safety features and an index of the luxury features of the vehicle.¹⁸

To improve model fit and better characterize substitution possibilities, we interact vehicle and household characteristics and allow two of the coefficients in the indirect utility function and the idiosyncratic taste for driving to be randomly distributed. We interact family size with sedan and hatchback dummies and with the ratio of horsepower to weight and we interact buyer age with safety index. The distribution of β , the income minus rental cost coefficient, is assumed to be log-normal to reflect the positive marginal utility of consumption of all other goods and the positive wealth effect on driving distance such that $\beta = e^\tau$ with $\tau \sim N(b^\tau, \omega^\tau)$. Following the same reasoning, the distribution of α , the operating cost coefficient, is assumed to be negative log-normal such that $\alpha = -e^z$ with $z \sim N(b^z, \omega^z)$. The idiosyncratic taste for driving, η , is assumed to be distributed normally with mean zero and standard deviation σ such that $\eta \sim N(0, \sigma)$.

5. Econometric Results

Figures 3 and 4 summarize the within-sample fit of the estimated model in terms of market shares and annual kilometers driven. Aggregated to body type/fuel type categories, predicted market shares match actual market shares closely. In fact, the model mirrors the market shares of petrol and diesel vehicles (67.4% and 32.6%, respectively) to two significant digits.

¹⁷ The variation across cities in diesel and petrol fuel prices is small. In 2010 the average price of petrol in 31 Indian cities was 52.86 Rs. with a standard deviation of 2.40 Rs. The average price of diesel was 38.94 Rs. with a standard deviation of 1.74 Rs.

¹⁸ The safety features of the vehicle include airbags, rear seatbelts, antilock brakes, and traction control. The luxury features include air conditioning, power steering, central locking, power windows, alloy wheels, leather seats, power mirrors, and CD player.

Annual kilometers driven are predicted accurately for four of the six vehicle categories but are over-predicted for drivers of petrol hatchbacks and under-predicted for owners of diesel SUVs. On average, the model over-predicts fuel usage and kilometers driven by 4.75%.

Table 3 presents estimation results for all parameters; manufacturer fixed effects are not shown. Many coefficients are estimated at the 0.05 significance level or better, with signs that align with prior expectations. People prefer safer and more luxurious cars, cars with more gears, heavier cars, and cars with higher ground clearance. Households prefer sedans over hatchbacks and SUVs, but this preference decreases with family size. People prefer more powerful cars (bigger engines) but smaller exterior dimensions, holding body type constant. All else equal, driving distance increases with family size and decreases with age, women drive less than men, and owners of automatics drive less than owners of manuals. Finally, driving distance is greater for safer, more luxurious cars.

Estimates of the elasticity of VKT with respect to operating cost implied by our model are similar to those found in other studies using household data.¹⁹ Evaluated at the mean operating cost for diesel and petrol vehicles, these elasticities are -0.67 for diesel car owners and -0.93 for petrol car owners. Bento et al. (2009) report elasticities of VKT with respect to operating cost of -0.74 for car owners in the US based on the 2001 Nationwide Household Transportation Survey. West (2004), using data from the 1997 US Consumer Expenditure Survey, estimates an elasticity of VKT with respect to operating cost of -0.87. Frondel et al. (2012) report a corresponding elasticity of -0.62 for one-car households in Germany based on data from 1997-2009.²⁰

The income elasticity of VKT implied by our model, which is conditional on vehicle ownership, is about 0.3.²¹ Other studies have also found low estimates of the impact of income on VKTs. Using the 1990 Nationwide Personal Transportation Survey, Bento et al. (2005) find an elasticity of distance driven with respect to income of 0.12 for two-vehicle households and 0.23 for one-vehicle households. Studies by Mannering and Winston (1985) and Train (1986)

¹⁹ Equation (3) implies that the elasticity of VKT with respect to operating cost is $\alpha_i p_j$.

²⁰ The median number of cars owned by households in our sample is one.

²¹ It is, on average, about 0.29 conditional on owning a petrol vehicle and 0.32 conditional on owning a diesel vehicle.

also suggest that income has a small effect on distance driven, holding number of vehicles constant.

Table 4 displays the elasticities of fuel consumption implied by our model. We calculate long-run elasticities by varying (e.g.) diesel fuel price, holding everything else constant, and allowing buyers to switch vehicles as well as distance driven. Raising the price of diesel fuel by 5% lowers diesel fuel consumption by 7.2%, implying a long-run, own-price elasticity of consumption of -1.44. Most of the reduction in diesel fuel consumption reflects the shift from diesel to petrol cars; conditional on buying a diesel, diesel fuel consumption falls by only 3%. Taking into account the increase in petrol consumed as buyers shift from diesel to petrol cars, the long-run elasticity of *total* fuel consumed with respect to the price of diesel is only -0.28. The long-run own-price elasticity of petrol consumption is -1.27; again, the reduction in petrol consumption is partly achieved by buyers switching to diesel cars. The associated increase in diesel fuel consumption implies a long-run elasticity of *total* fuel consumption with respect to petrol for price of -0.40.²² It is the long-run elasticities of total fuel consumption that are relevant to our evaluation of fuel conservation policies in the new car market.

Table 4 also reports the long-run elasticity of total fuel consumption in response to a change in the price of diesel cars. This elasticity is -0.128—approximately half as large as the elasticity of total fuel consumption with respect to diesel fuel price. This result agrees qualitatively with Verboven (2002) who finds that the elasticity of diesel market share in Europe is more sensitive to fuel taxes than to car taxes. Our result is also consistent with Vance and Mehlin (2009) who study the impact of fuel taxes and car taxes in Germany.

Our long-run fuel demand elasticity estimates reflect an elasticity of the market share of diesel cars with respect to diesel fuel price of -0.86. This elasticity plays a key role in our policy analysis: it is the shift of diesel car buyers to petrol cars that generates the tax revenues that offset the welfare effects of the diesel fuel tax. It is difficult to find comparable elasticities reported in the literature. Verboven (2002) estimates the elasticity of petrol market share with respect to the petrol/diesel fuel tax differential, but not with respect to diesel fuel price. Givord et

²² Formally, the impact of a marginal change in the diesel fuel tax on total fuel consumption can be expressed as $(dS_d/d\tau_d)x_d + (dx_d/d\tau_d)S_d + (dS_p/d\tau_d)x_p$ where S_i is the number of cars sold of fuel type i and x_i is average fuel consumption by a car of fuel type i .

al. (2014) examine the impact of raising the tax on diesel fuel in France to equal the tax on petrol fuel. They estimate that this would result in a decline in the diesel share of new cars purchased by 7.55% to 9.26%.²³

Table 4 also displays elasticities of fuel consumption conditional on buying a diesel or a petrol vehicle.²⁴ When the price of diesel rises by 5%, diesel car owners reduce fuel consumption by 3%; when petrol price rises by 5% petrol car owners reduce fuel consumption by 4%. Although we focus on the long-run impact of fuel taxes on the new car market, these taxes will have impacts on the used car market. Conditional elasticities may be used to give a rough estimate of these effects.

6. Policy Simulations

We use our behavioral model to explore the welfare implications of taxing diesel fuel and diesel cars and contrast this with the welfare implications of raising the tax on petrol fuel. We begin with a tax on diesel fuel that equates the prices of diesel and petrol fuel, a policy considered by the Government of India's Expert Group on Pricing Petroleum Products (Parikh, 2010). In 2010 diesel was not taxed, but petrol was taxed at a rate of 12.7 Rs./L. Policy 1 imposes a tax of 12.7 Rs./L on diesel, raising its price by 34.5%. Policy 2 imposes a tax on new diesel vehicles. To make this policy comparable to policy 1, we set the diesel car tax at 24.7%, the rate that results in the same after-tax market share for diesel vehicles as policy 1. For the diesel car tax to result in the same reduction in total fuel consumption as policy 1 would require a tax of over 80%, which we view as politically infeasible. Policy 3 examines a smaller diesel fuel tax of 2.77 Rs./L (7.54%) that results in the same total fuel conservation as policy 2.

We then contrast these results with the welfare costs of further increases in the petrol fuel tax. Policy 4 is a tax on petrol fuel that achieves the same reduction in total fuel consumption as the large diesel fuel tax (policy 1) while policy 5 is a smaller petrol fuel tax that results in the same total fuel conservation as the diesel car tax (policy 2) and the smaller diesel fuel tax (policy 3).

²³ Equalizing the taxes on diesel and petrol raises the price of diesel by about 17% in 2011, implying an elasticity of about -0.5.

²⁴ The conditional elasticity of diesel fuel consumption is the elasticity of average fuel consumption by diesel car drivers when diesel price rises.

6.1 Policy Simulation Results

For each policy, we use the model of section 3 to compute the impact of the policy on market shares, driving distances, fuel consumption, consumer welfare, and government revenue. In computing fuel consumption, government revenue, and aggregate welfare impacts, we extrapolate results from our sample to all 2010 new car buyers.²⁵ Comparisons of market outcomes and welfare results under the policy simulations are presented in Table 5. For ease of comparison we present model simulation results in the absence of any of the above policies (Pre-Policy Baseline).²⁶

Policy 1: Large Diesel Fuel Tax

The price-equalizing diesel fuel tax (policy 1) has a greater impact on fuel consumption than the diesel car tax (policy 2), reducing total fuel consumption by 7%. Sixty-six percent of this reduction in diesel fuel use occurs because people switch to petrol vehicles; the policy results in a decrease in diesel market share from 33.6% to 24.8%. The reduction in diesel fuel consumption is largely offset by a 14% increase in petrol fuel consumption. The buyers who continue to purchase a diesel car decrease their fuel consumption by about 18%. This effect accounts for 75% of the reduction in total fuel consumption.

We estimate the welfare effects of this diesel fuel tax by calculating compensating variation for new car owners in our dataset and extrapolating the results to the population of new car owners.²⁷ The compensating variation associated with the diesel tax is, on average, 6,260 Rs. per new car buyer, or about 14.4 billion Rs. in the aggregate. The burden of the tax, however, falls entirely on would-be diesel car buyers. Petrol car buyers bear none of the tax, as the price of petrol is not changed by the policy. Total compensating variation divided by the number of diesel

²⁵ 2,309,000 new passenger vehicles were purchased in India in 2010 (Society of Indian Automobile Manufacturers).

²⁶ In the pre-policy baseline, diesel fuel is not taxed and the tax on petrol is 12.7 Rs./L. Diesel and petrol cars are both subject to a sales tax of 22.5%.

²⁷ For each random draw r from the distribution of taste parameters, compensating variation is calculated by solving the equation $\log(\sum_{j=1}^J v_{ij}(y_i - r_j, p_j, X_{ij}; \theta_r)) = \log(\sum_{j=1}^J v_{ij}(y_i - r'_j + CV_{ir}, p'_j, X'_{ij}; \theta_r))$. The left hand side of this equation is the indirect utility function in equation (1) without the ϵ_{ij} term. The right hand side is the counterfactual version of the left hand side, with observed values of rental price, operating cost, etc. replaced by their post-policy values, and with the income term augmented by compensating variation. Since indirect utility is not linear in income, the equation must be solved numerically. Expected compensating variation is then calculated by averaging over the results from each draw, and results are aggregated across individuals within a category (e.g. petrol car buyers). See, for example, Herriges and Kling (1999) for further discussion.

car buyers in 2010 is 18,400 Rs., or about 3% of the average income of diesel car buyers. Given the low elasticity of fuel consumption with respect to income, the burden of policy 1 on diesel car buyers, in terms of welfare cost as a fraction of income, increases as income falls.

The ultimate regressivity of this diesel fuel tax depends on what is done with the increased revenue. The diesel fuel tax generates over 9.5 billion Rs. in the diesel fuel market. Because the initial diesel/petrol price difference (12.7 Rs.) is due to the higher tax on petrol, the increase in petrol consumption generates additional tax revenues in the petrol fuel market.²⁸ Subtracting total revenue (11.8 billion Rs.) from compensating variation implies a deadweight loss of about 12 Rs. per liter of fuel conserved.

Policy 2: Diesel Car Tax

By construction, the diesel car tax results in the same shift in car ownership from diesel to petrol vehicles as the diesel fuel tax of policy 1. By shifting consumers out of diesel cars, policy 2 reduces diesel fuel consumption, but this is largely offset by increased consumption of petrol. On net, the 25% diesel car tax results in a 2% reduction in total fuel consumption by new car buyers. The welfare cost of the car tax is lower, on average, than the diesel fuel tax of policy 1: compensating variation is about 3,370 Rs. per household per year. The compensating variation per liter of fuel conserved (120 Rs./L) is, however, almost twice that of policy 1 (64 Rs./L) due to the smaller impact of policy 2 on fuel consumption.

The deadweight loss from the diesel car tax is actually negative. Revenue from increased sales of petrol fuel, when added to revenues from the diesel car tax, are greater than the amount that new car buyers must be compensated to restore them to their pre-tax level of utility.²⁹ The deadweight loss per liter of fuel saved is -27 Rs./L. Goulder and Williams (2003) note that ignoring the impact of a tax in one market on consumption in other markets with pre-existing taxes can lead to biased estimates of the deadweight loss of a tax. This is clearly the case here. In

²⁸ There is also a change in tax revenue from pre-existing car taxes as buyers switch from diesel to petrol vehicles. All states levy taxes on the purchase price of a new car. Because diesel cars are, in general, more expensive than petrol cars, state tax revenues fall by approximately 1.1 billion Rs. We subtract this from the increase in fuel tax revenues in calculating deadweight loss.

²⁹ In evaluating the deadweight loss of the diesel car tax, we include the increased petrol car tax revenue in addition to the increased diesel car tax revenue and increased petrol fuel tax revenue in our total increase in government revenue (see footnote 28).

the case of policies 1 and 2, the shift of new car buyers to petrol vehicles increases petrol consumption by over 13% (approximately 270 million liters), resulting in additional tax revenue of over 3 billion Rs.

Policy 3: Small Diesel Fuel Tax

Whether the diesel car tax is superior to the diesel fuel tax depends on the policymaker's objectives. If they are to reduce fuel consumption, the car tax is not very effective. A fairer comparison from the perspective of fuel conservation is between the diesel car tax and a tax on diesel fuel that would achieve the same reduction in total fuel consumption. A 7.54% (2.77 Rs.) tax on diesel fuel would reduce total fuel consumption by 2% among new car buyers. The tax would reduce the market share of diesel vehicles from 34% to 31%. Over 60% of the reduction in diesel consumption that results from this tax (133 million liters per year) is due to the shift to petrol vehicles. Again, this reduction is partially offset by an increase of 68 million liters in petrol consumption. The remainder of the reduction in diesel consumption is due to a 4.4% reduction in diesel consumption by buyers who continue to purchase diesel cars.³⁰ While compensating variation per liter of fuel conserved is only slightly lower (57.7 Rs./L) than in the case of the larger diesel fuel tax (64.3 Rs./L), deadweight loss per liter of fuel conserved is much smaller (2.13 Rs./L compared with 12 Rs./L for policy 1).

Policies 4 and 5: Additional Petrol Fuel Tax

Because diesel fuel is not taxed in the baseline scenario, reducing fuel consumption by increasing the tax on petrol should entail a higher deadweight loss per liter of fuel conserved than taxing diesel fuel. Raising the tax on petrol will shift buyers into the market for diesel, but this will generate no revenue to offset the welfare cost of the higher petrol tax. The analysis of policies 4 and 5 bears this out. Policy 4, which saves as much fuel as the larger diesel fuel tax (policy 1), creates a deadweight loss per liter that is more than twice as high. Policy 5, which reduces total fuel consumption by the same amount as the smaller diesel fuel tax (policy 3), creates a deadweight loss per liter of fuel saved that is five times as high.

³⁰ The reduction in diesel consumption by diesel car buyers accounts for approximately 76% of the total reduction in fuel consumed.

6.2 Discussion

The results above are subject to three caveats. The first is that, because we have data only on new-car buyers, the model we estimate includes no outside good. We cannot, therefore, estimate the impact of the policies on the total number of cars sold. To the extent that all five policies raise the cost of car ownership they are likely to reduce new car sales. Our analysis above, because it ignores this impact, is likely to understate the reduction in fuel savings from all policies.

The second caveat is that we do not estimate supply-side responses to our policies.³¹ It is likely that automakers might react to policies 1-3 by lowering the price of diesel cars. This would attenuate the impact of these policies in shifting buyers to petrol vehicles and would reduce fuel savings. Similar adjustments would be expected in the case of policies 4 and 5.

The third caveat is that all taxes would have impacts in the used car market. In 2010, fuel taxes would achieve much greater reductions in fuel use in the used car market than in the new car market, given that the stock of registered cars as of 2009 was 6.6 times the number of new cars sold in 2010 (Ministry of Road Transport and Highways, 2012).³² The diesel fuel tax would likely hasten the retirement of diesel cars and would reduce fuel consumption by existing diesel vehicles. In contrast, the tax on new diesel cars would likely increase the lifetimes of used diesel vehicles but would have no impact on the kilometers they are driven. We cannot analyze the welfare impacts of either policy on the used car market due to lack of data; however, ignoring the used car market clearly understates the fuel conservation benefits of the diesel fuel tax relative to a tax on new diesel cars.³³

6.3 Implications of Our Results for CAFE Standards

Our model results also have important implications for the size of the rebound effect associated with fuel economy standards in India. The Bureau of Economic Efficiency is contemplating weight-based CAFE standards that would go into effect in 2015-16, with more stringent standards proposed for 2020-21 (Roychowdhury, 2011). These would be weight-based

³¹ Estimating supply-responses is difficult in the absence of an outside good since own-price elasticities are likely to be under-estimated.

³² Our current dataset does not permit analysis of the impact of any of our policies on the stock of used cars, as we have data only on new car buyers.

³³ There is no survey of vehicle owners in India that is similar to the National Household Travel Survey in the US.

standards, with lighter cars being subject to stricter standards than heavier ones. Ignoring the impact of CAFE standards on vehicle choice and kilometers driven, the proposed 2015-16 standards would decrease fuel consumption by 26% for petrol cars and 10% for diesel cars.³⁴ Weighting these percentages by market shares, total fuel consumption would decline by about 20%.

We use our model to simulate the market outcome following a hypothetical fuel economy improvement sufficient to satisfy the proposed fuel economy standard. Because diesel cars have higher fuel economy than petrol cars, they will be less affected by the standard. The standard, therefore, will lead to a greater improvement in the fuel economy for petrol cars and lead to a shift from diesel to petrol vehicles. Indeed, we predict petrol market share to increase from 66% to 73%.³⁵ One might expect this to increase fuel savings, but the rebound effect in both petrol and diesel markets is sizeable. The 26% average reduction in per-kilometer operating cost for petrol vehicles leads to a 22% increase in kilometers driven. The 10% reduction in per-kilometer operating cost for diesel vehicles results in a 5% increase in kilometers driven. The net effect of these adjustments implies that the proposed CAFE standard would, once consumers adjust, reduce fuel consumption by 7.6% rather than 20%.³⁶

7. Conclusions

India, like many developing countries, has historically taxed diesel fuel at a lower rate than petrol. The Netherlands, Germany, France, and Belgium also tax diesel at a lower rate than petrol. From an efficiency perspective, increasing the tax on diesel fuel may entail a lower deadweight loss than further raising the tax on petrol. This, of course, depends on fuel demand elasticities and on the existing level of diesel and petrol taxes. In India, which currently does not tax diesel, levying a tax on diesel would reduce fuel consumption at a much lower deadweight loss per liter of fuel saved than increasing the tax on petrol.

³⁴ These are average figures based on 2010 JD Power data. The standard reported by Roychowdhury (2011) is liters per kilometer = $0.0025 \times \text{kerbweight (in kilograms)} + 3.171$. These figures correspond to a 36% increase in fuel economy for petrol cars and a 15% increase for diesel cars.

³⁵ These calculations ignore any pricing response by vehicle manufacturers.

³⁶ This rebound effect is similar in magnitude to that reported by Frondel et al. (2012) for Germany.

In this paper, we have estimated a structural econometric model of new car purchasing decisions and driving behavior for the Indian car market, using data for 2010. We have used this model to calculate the welfare effects of raising the taxes on diesel and petrol fuels and on diesel cars, allowing consumers to adjust the vehicle they buy as well as kilometers driven in response to taxes.

At 2010 prices, levying a tax of 7.5% on diesel fuel would reduce total fuel consumption by 2%, at a deadweight loss of 2.1 Rs./L saved. Increasing the tax on petrol by 5% would save the same amount of fuel, but at a deadweight cost of 13 Rs./L saved. The difference reflects the fact that some consumers adjust to the diesel fuel tax by switching to petrol cars. The extra revenue generated in the petrol fuel market, through the pre-existing petrol fuel tax, offsets the deadweight loss of the tax in the diesel fuel market. Given the fact that diesel is not taxed in 2010, there is no corresponding revenue in the diesel market when the petrol fuel tax is raised. Levying a tax of 34% on diesel fuel to equate diesel and petrol prices in 2010 would result in a reduction in total fuel consumption of 7%. This would also be achieved at a lower deadweight loss than the increase in the petrol tax needed to result in the same total fuel savings.

Raising the sales tax on diesel cars to reduce fuel consumption actually has a negative deadweight loss per liter of fuel saved. An increase in the tax on diesel cars of 25% would shift 26% of diesel car buyers to petrol cars and raise enough revenue, through the pre-existing petrol fuel tax, to more than fully offset the welfare cost. The impact of the diesel car tax on fuel consumption is, however, modest—the elasticity of total fuel consumption with respect to the diesel car tax is less than half of the elasticity with respect to a tax on diesel fuel.

The fuel conservation benefits of taxing diesel fuel are substantial. Taxing diesel fuel by 34% in 2010 would reduce fuel consumption by about 300 million liters in 2010. Keeping this policy in place would reduce fuel consumption by at least 40 times this amount in 2030. We base this statement on simple back-of-the envelope calculations. Using conservative assumptions about income growth, Arora et al. (2011) project new car sales in India from 2010 to 2030, estimating that sales will reach at least 9,000,000 cars by 2030. Together with a survival curve for passenger vehicles, these projections yield estimates of the stock of vehicles purchased beginning in 2010 that will be on the road in years 2010-2030. If vehicle kilometers traveled by new cars remain the same as in 2010, and if vehicle kilometers traveled decline by 2.5% each

year as a car ages (Chugh et al., 2011), total fuel consumption by passenger vehicles in 2030 will be 40 times consumption levels in 2010. A diesel tax that reduces fuel consumption by 300 million liters today will, if kept in place, save 12 billion liters in 2030 alone. It will also save over 4.8 billion liters over the life of 2010 vintage cars. These calculations underscore the benefits of enacting fuel conservation policies today.

Table 1. Sales-Weighted Vehicle Summary Statistics

	Petrol Hatchback	Diesel Hatchback	Petrol Sedan	Diesel Sedan	Petrol SUV	Diesel SUV
Price (10^5 Rs. 2010)	3.94 (1.01)	5.22 (0.755)	8.33 (3.27)	7.47 (2.59)	3.07 (7.74)	9.23 (3.76)
Fuel Economy (km/L)	14.2 (1.06)	15.9 (0.576)	12.2 (0.828)	15.0 (0.983)	12.7 (0.280)	11.9 (0.753)
Operating Cost (Rs. 2010/km)	3.51 (0.265)	2.31 (0.0850)	4.05 (0.276)	2.46 (0.185)	3.88 (0.0998)	3.10 (0.193)
Engine Size (cc)	1.06 (0.160)	1.31 (0.0664)	1.51 (0.257)	1.40 (0.210)	1.21 (0.155)	2.45 (0.186)
Power Ratio (hp/kg)	0.0745 (0.00680)	0.0653 (0.00498)	0.0938 (0.0124)	0.0698 (0.0107)	0.0796 (0.00308)	0.0529 (0.0185)
Torque (kg-m)	0.0949 (0.0180)	0.172 (0.0295)	0.141 (0.0326)	0.190 (0.0457)	0.103 (0.0165)	0.232 (0.0514)
Gears	4.93 (0.268)	5 (0)	5.01 (0.117)	5.02 (0.138)	5.01 (0.149)	5 (0)
Automatic	0 (0)	0 (0)	0.0156 (0.127)	0.0100 (0.104)	0 (0)	0.0172 (0.137)
Length (m)	3.56 (0.173)	3.76 (0.0844)	4.35 (0.168)	4.25 (0.144)	3.49 (0.200)	4.46 (0.152)
Width (m)	1.57 (0.0775)	1.69 (0.00939)	1.70 (0.0376)	1.68 (0.0418)	1.48 (0.0515)	1.78 (0.0588)
Height (m)	1.55 (0.0748)	1.52 (0.0479)	1.50 (0.0515)	1.52 (0.0331)	1.80 (0.0179)	1.89 (0.0862)
Ground Clearance (m)	1.68 (0.0531)	1.67 (0.0556)	1.68 (0.0876)	1.66 (0.0706)	1.60 (0.0373)	1.85 (0.124)
Weight (10^3 kg)	0.900 (0.118)	1.09 (0.0415)	1.12 (0.115)	1.16 (0.112)	0.927 (0.0941)	1.75 (0.163)
Safety Index	1.35 (0.597)	1.12 (0.401)	2.20 (0.779)	1.68 (0.719)	1.02 (0.298)	1.50 (0.641)
Luxury Index	3.63 (1.32)	3.37 (0.865)	5.73 (1.60)	4.64 (1.25)	0.0901 (1.19)	3.93 (1.90)
# Models	21	8	20	13	2	10

Notes: This table presents sales-weighted means with standard deviations in parentheses. Version level vehicle characteristics data come from AutoCar India and DriveInside.com. Model/fuel-type level vehicle characteristics are constructed as the unweighted average across all available versions of each model/fuel-type. The sales-weighted average of these is calculated for each vehicle category. Price and fuel economy data are averaged over all JD Power APEAL survey respondents that purchased each vehicle type. Luxury index is defined as the sum of the dummy variables for air conditioning, power steering, central locking, power windows, alloy wheels, leather seats, power mirrors, and CD player. Safety index is defined as the sum of the dummy variables for airbags, rear seatbelts, antilock braking system, and traction control.

Table 2. Demographic Summary Statistics

	Petrol Hatchback	Diesel Hatchback	Petrol Sedan	Diesel Sedan	Petrol SUV	Diesel SUV
Income (10^5 Rs. 2010)	5.05 (2.63)	5.12 (2.56)	6.95 (3.03)	5.96 (2.86)	5.88 (3.14)	6.67 (2.95)
Family Size	4.72 (1.55)	4.93 (1.51)	5.02 (1.63)	5.18 (1.63)	5.54 (1.56)	5.43 (1.61)
Age (years)	38.0 (11.4)	36.1 (10.7)	37.2 (10.4)	36.5 (9.18)	37.9 (10.2)	36.9 (9.84)
% Female	0.0867 (0.281)	0.0330 (0.179)	0.0469 (0.211)	0.0332 (0.1793)	0.0153 (0.123)	0.0281 (0.165)
Driving Distance (km/month)	14500 (16000)	24000 (25200)	16600 (18000)	22500 (22200)	16600 (16800)	26300 (25100)
# Observations	2354	575	1173	903	131	996

Notes: This table presents unweighted means with standard deviations in parentheses. Owner demographics come from the 2010 JD Power APEAL survey.

Table 3. Demand Model Parameter Estimates

FIXED	Coefficient	Standard Error		
Hatchback	0.00465*	(0.00305)		
Sedan	0.0140***	(0.00500)		
Age	-0.00872***	(0.00131)		
Female	-0.293***	(0.0585)		
Family Size	0.0499***	(0.0101)		
Engine Size	0.0270***	(0.00338)		
Power Ratio	0.0478	(0.0627)		
Torque	0.00474	(0.0112)		
Length	-0.0463***	(0.00792)		
Width	-0.0610***	(0.00802)		
Height	-0.0155***	(0.00406)		
Ground Clearance	0.0423***	(0.00560)		
Weight	0.0181**	(0.00903)		
Gears	0.0234***	(0.00290)		
Automatic	-0.0146***	(0.00489)		
Safety Index	0.00494***	(0.00149)		
Luxury Index	0.00295***	(0.000518)		
Family Size \times Hatchback	-0.00272***	(0.000540)		
Family Size \times Sedan	-0.00150***	(0.000589)		
Age \times Safety Index	2.29E-05	(3.03E-05)		
Family Size \times Power Ratio	-0.00474	(0.00751)		
Scale Factor (μ)	0.910***	(0.0776)		
Taste For Driving (σ)	0.859***	(0.0225)		
RANDOM	Coefficient	Standard Error	Standard Deviation	Standard Error
Income—Rent (β)	-2.87***	(0.0977)	0.0274	(0.0322)
Operating Cost (α)	-1.44***	(0.107)	0.441***	(0.0551)

*p<10%. **p<5%, ***p<1% (based on simulation-robust standard errors)

Notes: This table presents full information maximum likelihood coefficient estimates with 12 make fixed effects (not shown). Integrals are simulated using 200 shifted and shuffled Halton draws. Number of observations= 6132, LL = -30496 at convergence.

Table 4. Fuel Consumption Elasticities

	Petrol (Long Run)	Petrol (Conditional)	Diesel (Long Run)	Diesel (Conditional)	Total Fuel (Long Run)
Petrol Fuel Price	-1.27	-0.793	0.980	0	-0.400
Diesel Fuel Price	0.461	0	-1.44	-0.590	-0.278
Petrol Car Price	-0.596	-0.0397	1.08	0	0.0520
Diesel Car Price	0.820	0	-1.63	-0.0345	-0.128
Income	0.280	0.350	0.515	0.377	0.371

Notes: All long-run elasticities and conditional, own-price elasticities are calculated by increasing price or income 5% from baseline values. Long-run elasticities are based on changes in total fuel consumption by all households and reflect changes in vehicle choice and driving distance. Conditional, own-price elasticities are based on changes in average fuel consumption conditional on owning a vehicle of a given fuel type. Conditional, cross-price elasticities are, by definition, equal to zero.

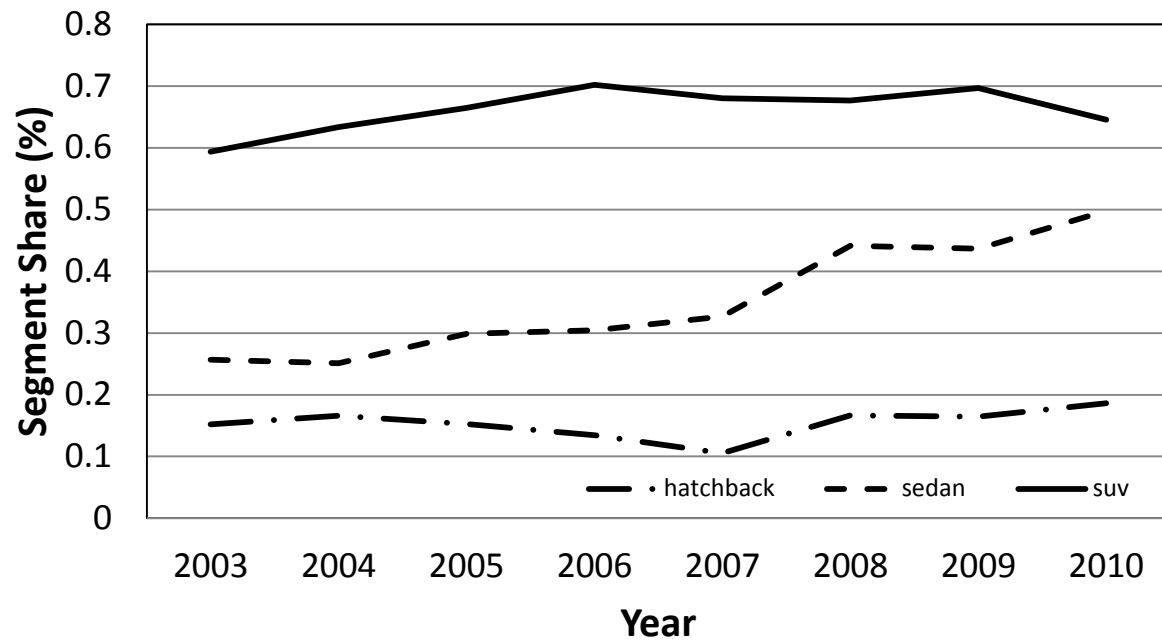
Table 5. Policy Simulation Results

			(POLICY 1) 34.46%	(POLICY 2) 24.65%	(POLICY 3) 7.54%	(POLICY 4) 20.8%	(POLICY 5) 5.1%
		Pre-Policy Baseline	Diesel Fuel Tax	Diesel Car Tax	Diesel Fuel Tax	Petrol Fuel Tax ¹	Petrol Fuel Tax ¹
Market Share (%)	petrol	66.4%	75.2%	75.2%	68.6%	59.8%	64.7%
	diesel	33.6%	24.8%	24.8%	31.4%	40.2%	35.3%
Total Fuel Consumption (10 ⁶ L)	petrol	1970	2240	2230	2040	1500	1840
	diesel	1250	751	915	1110	1490	1310
Total Fuel Conserved (%)			6.99%	2.04%	2.04%	6.99%	2.04%
Total CV (10 ⁶ Rs. 2010)			14400	7780	3790	14700	4060
Government Revenue (10 ⁶ Rs. 2010)			11800	9560	3650	10300	3230
Deadweight Loss/ Liter Conserved (Rs. 2010/L)			11.8	-27.2	2.13	19.5	12.7

¹This is in addition to the pre-existing 34.46% petrol fuel tax.

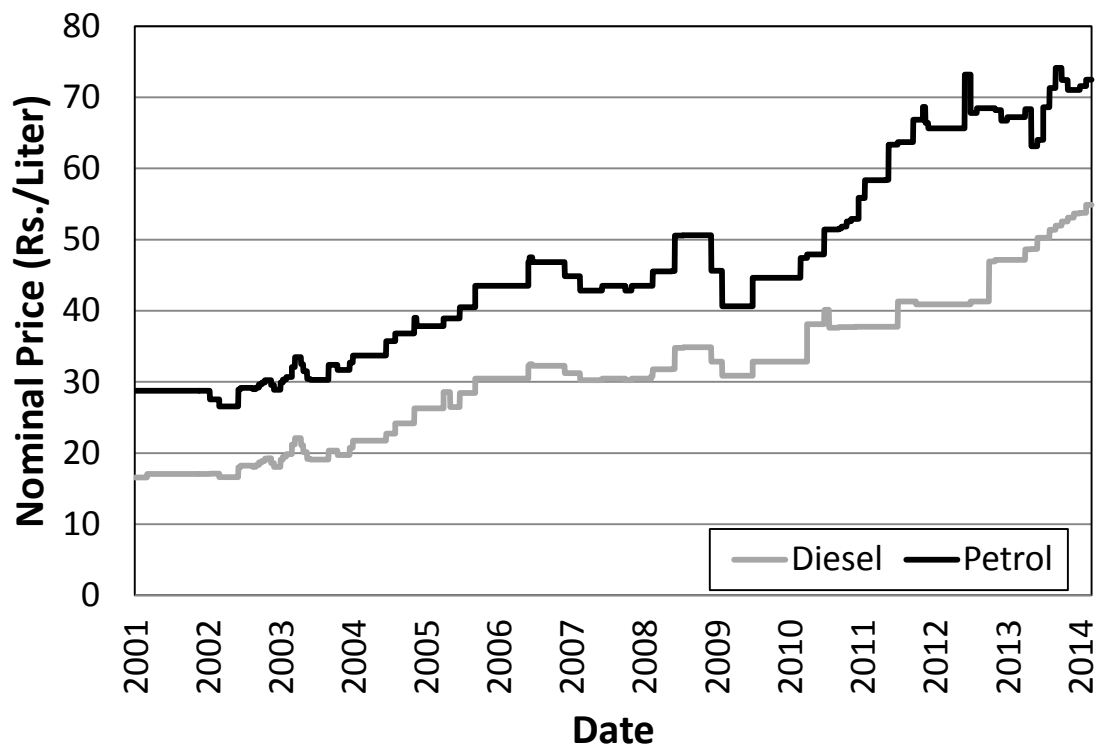
Notes: This table presents policy simulation results for year 2010 using parameter estimates presented in Table 3. 2010 petrol and diesel fuel prices (in Rs. 2010/liter) were 49.37 and 36.72, respectively. Thus, a 34.46% diesel fuel tax amounts to 12.65 Rs. and a 7.54% diesel fuel tax amounts to 2.77 Rs. In both cases, the existing tax on petrol fuel is assumed equal 12.65 Rs. A 5.10% petrol fuel tax amounts to 1.87 Rs and a 20.8% petrol fuel tax amounts to 7.63 Rs. In both cases, the new petrol fuel tax is applied to prevailing petrol fuel prices inclusive of the pre-existing 34.46%, or 9.41 Rs., petrol fuel tax. Deadweight loss per liter is calculated as government revenue per liter minus compensating variation per liter; numbers may not add up due to rounding errors.

Figure 1: Diesel Share by Passenger Vehicle Segment



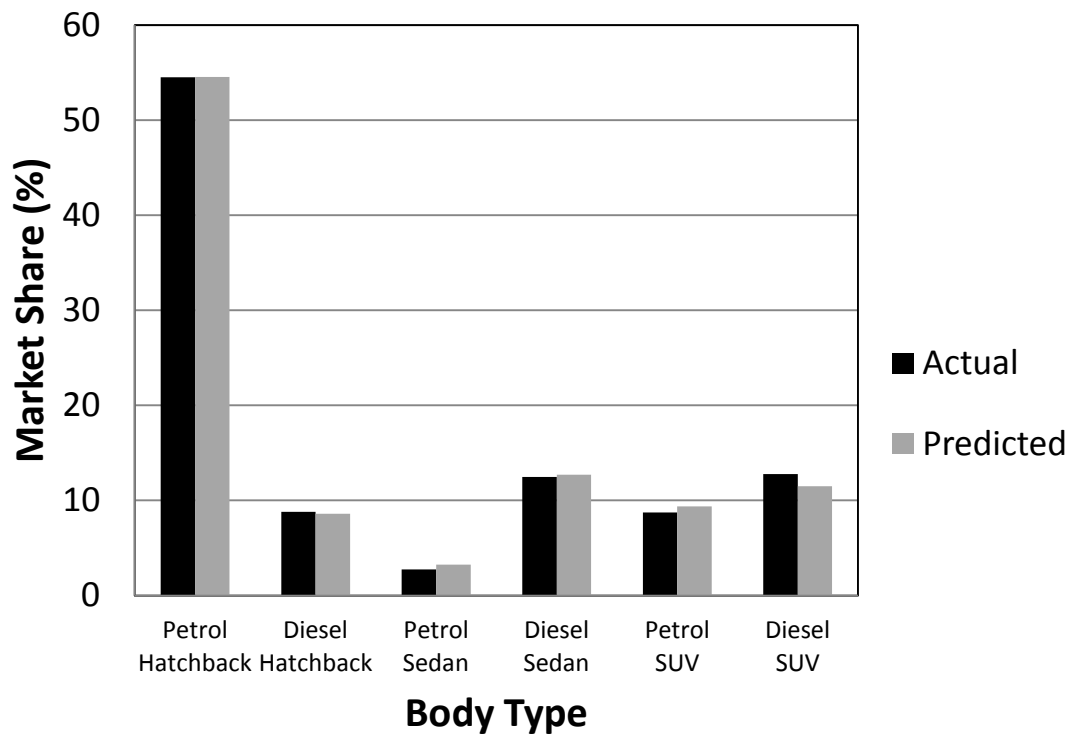
Source: Society of Indian Automobile Manufacturers (SIAM) (various years)

Figure 2: Nominal Fuel Price (Rs./Liter) for Petrol and Diesel—2001-2013



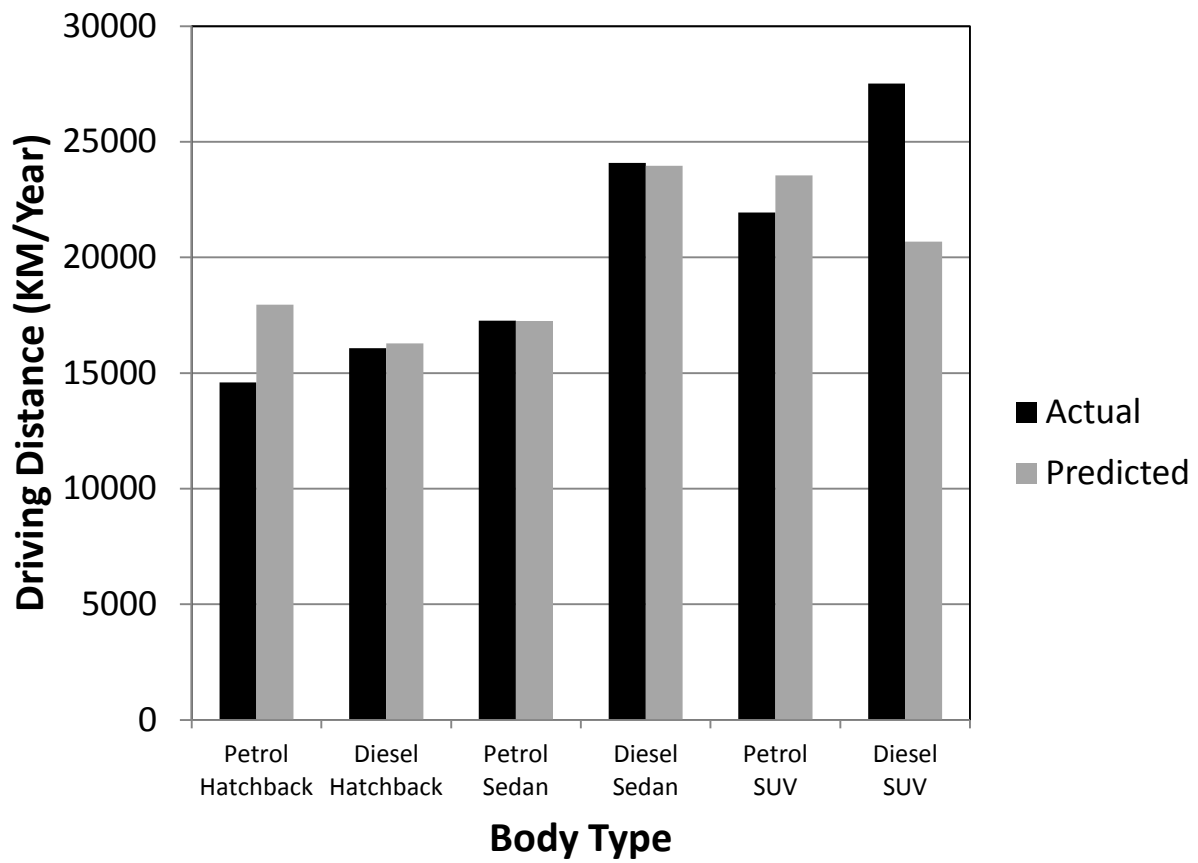
Source: Ministry of Petroleum & Natural Gas, Govt. of India

Figure 3: Model Fit (Market Shares)



Source: Authors' calculations

Figure 4: Model Fit (Driving Distance)



Source: Authors' calculations

References

- Anand, M. (2012). *Diesel Pricing in India: Entangled in Policy Maze*. National Institute of Public Financing and Policy.
- Arora, S., Vyas, A., & Johnson, L. R. (2011, February). Projections of Highway Vehicle Population, Energy Demand, and CO2 Emissions in India to 2040. *Natural Resources Forum*, 35(1), 49-62.
- Bento, A. L., Goulder, L., Jacobsen, M., & Haefen, R. v. (2009). Distributional and Efficiency Impacts of Increased U.S. Gasoline Taxes. *American Economic Review*, 99(3), 1-37.
- Bento, A. M., Cropper, M. L., Mobarak, A. M., & Vinha, K. (2005, August). The Effects of Urban Spatial Structure on Travel Demand in the United States. *The Review of Economics and Statistics*, 87(3), 466-478.
- Carazoo.com. (2011, March 7). *Car Loans - More Than Meets the Eye*. Retrieved May 25, 2013, from carazoo.com: www.carazoo.com/article/1606200801/Car-Loans---More-Than-Meets-the-Eye
- Chaturvedi, B. K. (2008). *Report of the High Powered Committee on Financial Position of Petroleum Companies*. Government of India, Petroleum Ministry.
- Chugh, R., Cropper, M., & Narain, U. (2011, November). The Cost of Fuel Economy in the Indian Passenger Vehicle Market. *Energy Policy*, 39, 7174-7183.
- Datta, A. (2010). The Incidence of Fuel Taxation in India. *Energy Economics*, 32, S26-S33.
- Dubin, J., & McFadden, D. (1984, March). An Econometric Analysis of Residential Electric Appliance Holdings and Consumption. *Econometrica*, 52(2), 345-362.
- Feng, Y., Fullerton, D., & Gan, L. (2005, August). Vehicle Choices, Miles Driven and Pollution Policies. *NBER Working Paper Series*, 1153.
- Gillingham, K. (2010). How Do Consumers Respond to Gasoline Price Shocks? *Working Paper*.
- Goldberg, P. K. (1998, March). The Effects of the Corporate Average Fuel Efficiency Standard in the U.S. *The Journal of Industrial Economics*, 46(1), 1-33.
- Herriges, J., & Kling, C. (1999, February). Nonlinear Income Effects in Random Utility Models. *The Review of Economics and Statistics*, 81(1), 62-72.
- McFadden, D. (1995). Computing Willingness-to-Pay in Random Utility Models. *Working Paper*.
- Parikh, K. S. (2010). *Report of the Expert Group on a Viable and Sustainable System of Pricing of Petroleum Products*. Government of India.

- Seth, Y. (2009, January 7). *Auto Lenders Set to Revise Interest Rates*. Retrieved May 25, 2013, from [financialexpress.com: www.financialexpress.com/news/auto-lenders-set-to-revise-interest-rates/407419/](http://financialexpress.com/news/auto-lenders-set-to-revise-interest-rates/407419/)
- Shankar, N. (2007, October 17). *Auto Loan Interest Rates Slashed by Bank of India*. Retrieved May 25, 2013, from [rupeetimes.com: www.rupeetimes.com/news/car_loans/auto_loan_interest_rates_slashed_by_bank_of_india_1079.html](http://rupeetimes.com/www.rupeetimes.com/news/car_loans/auto_loan_interest_rates_slashed_by_bank_of_india_1079.html)
- Train, K. (2000). Halton Sequences for Mixed Logit. *Working Paper*.
- Train, K. (2009). *Discrete Choice Methods with Simulation*. Cambridge University Press.
- Train, K., & Winston, C. (2007, November). Vehicle Choice Behavior and the Declining Market Share of U.S. Automakers. *International Economic Review*, 48(4), 1469-1496.
- West, S. (2004). Distributional effects of alternative vehicle pollution control policies. *Journal of Public Economics*, 88, 735-757.
- West, S. and Williams, R. (2004). Estimates from a Consumer Demand System: Implications for the Incidence of Environmental Taxes. *Journal of Environmental Economics and Management*, 47(3): 535-558.
- West, S. and Williams, R. (2005). The Cost of Reducing Gasoline Consumption. *American Economic Review*, 95(2): 294-299.
- Xiao, J. and Ju, H. (2014). Market Equilibrium and the Environmental Effects of Tax Adjustments in China's Automobile Industry. *Review of Economics and Statistics*, 96(2): 306-317.