THE WELFARE EFFECTS OF FUEL CONSERVATION POLICIES IN THE INDIAN
CAR MARKET

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ABSTRACT

We estimate a model of vehicle choice and miles driven to analyze the impact of fuel conservation policies in the Indian car market. Taxing diesel fuel to equalize diesel and petrol prices would reduce fuel consumption in the new car market by 7% and reduce diesel cars sales by 26%. A tax on diesel cars with the same sales impact would reduce fuel consumption by only 2%. The compensating variation per liter of fuel saved is smaller for the fuel tax than for the car tax; however, the car tax has lower deadweight loss per liter of fuel saved. Our estimates of the long-run elasticities of fuel consumption with respect to fuel prices imply that the CAFE standards contemplated by the Indian government would generate a significant rebound effect. Projected fuel savings are 20% if consumers do not adjust to the change in operating costs and less than 9% once consumers adjust.

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1. Introduction

The Indian car market has grown rapidly since the economic reforms of the early 1990s. Recent years have seen a doubling of new car sales between 2002 and 2006 and again between 2006 and 2011 (SIAM various years). The passenger vehicle fleet, which stood at 22 million vehicles in 2010, is conservatively projected to increase to increase to 112 million vehicles by 2030 (Arora et al. 2011). Growth in the car market has brought with it increased foreign oil dependence, fuel consumption, and associated externalities. The Indian government has responded to local air pollution concerns with fuel quality and emissions standards. However, at the center of the policy debate—in a country that imports 80% of its oil—is what policies should be used to reduce fuel consumption. The Indian government is currently contemplating fuel economy standards and, since April 2013, has required fuel efficiency (km/L) information to be posted on all new cars.

At the same time, India taxes diesel fuel at a lower rate than gasoline (petrol). Between 2002 and 2013, petrol sold for 30 to 50% more than diesel. The gap between diesel and petrol prices, shown in Figure 1, has amplified the fuel economy advantage of diesel cars and led to a sharp rise in their sales. The diesel share of the new car market rose from 22% in 2002 to 34% in 2010. As we document below, diesel buyers, on average, drive farther than buyers of petrol vehicles. Thus dieselization has increased the fuel consumption associated with a rapidly expanding fleet.

To curb fuel consumption the Indian government is now contemplating fuel economy standards, despite the potential efficiency of taxing diesel fuel instead. The government is also considering a tax on diesel vehicles, which is more politically feasible than taxing diesel fuel. The 2010 report from the Expert Group on a Viable and Sustainable System of Pricing of Petroleum Products (Parikh 2010) considered equalizing the prices of diesel and petrol fuel, but instead recommended that "an additional excise duty on a diesel vehicle corresponding to the differential tax on the petrol should be levied."

This paper compares the welfare implications of the diesel car tax recommended by the Expert Group to a diesel fuel tax. We present a structural econometric analysis of the market for new cars and simulations of market responses to these alternative policies. Using data from the

JD Power APEAL survey, we model the joint decision of which car to buy and how much to drive it in a mixed logit discrete-continuous choice framework.

We estimate the model for the year 2010 and simulate consumers' responses to three fuel conservation policies: a diesel fuel tax that would equalize the prices of petrol and diesel fuel, a diesel car tax that would result in the same reduction in the market share of diesel cars, and a smaller diesel fuel tax that would result in the same total fuel savings as the diesel car tax. 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.

Our results quantify the efficiency of the fuel tax relative to the car tax. In 2010, a 34% diesel fuel tax would eliminate the disparity between diesel and petrol prices and reduce the market share of diesel cars from 34% to 25%. A diesel car tax of 25% would achieve the same reduction in market share. The fuel tax, which lowers the miles driven by diesel car buyers as well as shifting would-be diesel buyers to petrol cars, reduces total fuel consumption in the new car market by 7%. The car tax, which operates only by shifting diesel buyers into petrol cars, reduces total fuel consumption by only 2%.[1] Compensating variation, the amount new car buyers would have to be given to restore them to their pre-policy level of utility, is almost twice as large per liter of fuel conserved for the car tax as for the fuel tax (120 Rs./L v. 64 Rs./L).[2]

The deadweight loss of the car tax is, however, lower per liter of fuel conserved—in fact, it is negative (-27 Rs./L for the car tax, versus 12 Rs./L for the diesel fuel tax). The negative deadweight loss per liter of fuel conserved occurs because buyers who switch from a diesel to a petrol car generate enough government revenue through their consumption of petrol fuel to more than offset the welfare impact of the diesel car tax. Effectively, buyers are shifting from a market with lower tax (diesel) to a market with a higher tax (petrol).

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[1] Raising the tax on diesel fuel or taxing diesel cars would, of course, have effects outside of the market for new cars. A tax on new diesel cars would increase the lifetimes of used diesel cars. The diesel fuel tax would alter the price of used diesel relative to used petrol cars, and would reduce fuel consumption by owners of existing diesel cars.

[2] A more policy-relevant comparison from the perspective of fuel conservation is to compare the diesel car tax with the diesel fuel tax that achieves the same total fuel conservation. A diesel fuel tax of 7.6% would achieve the same reduction in petrol-plus-diesel fuel consumed by new cars. The compensating variation of the smaller fuel tax is 58 Rs./L.

The negative deadweight loss associated with the diesel car tax is possible in the case of multiple distorted markets (Goulder and Williams 2003) and should be interpreted as decreasing pre-existing deadweight loss in the market for petrol. Whether the deadweight loss is policy (and politically) relevant depends on whether the revenues from the taxes we consider are recycled. In principle, revenues from either the diesel fuel or car taxes, and the increased petrol revenues, could be used to reduce rates of the Indian income tax. If revenues are not recycled, the compensating variation of the large diesel tax is about 3.0% of average diesel car buyers' incomes; the compensating variation of the car tax about 1.6%.

Our analysis informs fuel conservation policy in several ways. In addition to pointing out the efficiency costs of each policy and its revenue-raising implications, we trace out the implications of diesel fuel and car taxes for future fuel consumption. Given the rapid growth in the Indian car market, enacting either of these policies today would have a significant cumulative effect on fuel conservation as well as on the composition of the passenger vehicle fleet. Using conservative projections of the growth in the Indian car market (Arora et al. 2011), the magnitude of fuel conservation achieved in 2030 from enacting either policy today would be 40 times as great as the reduction today. This emphasizes the benefits of enacting sensible policies when the car market is in its infancy.

Our results also have implications for the CAFE standards currently being contemplated by the Indian government. The Bureau of Economic Efficiency is contemplating weight-based corporate average fuel economy 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 fuel consumption with respect to fuel 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 miles. Our model suggests that allowing for both types of adjustments implies a reduction in fuel consumption of only 8.5%.

The rest of 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 miles 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.

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 (SIAM, various years). Hatchbacks constitute approximately two-thirds of new car sales, with sedans accounting for about 17% of the market and the remainder accounted for by SUVs and multi-use vehicles (MUVs). Trends in sales of diesel passenger vehicles in the Indian car market are shown in Figure 2. Diesel vehicles accounted for 34% of new car sales in 2010, although there was significant variation across vehicle types. As relatively few diesel hatchbacks are available due to technological constraints,[3] diesel models' share of the hatchback market has remained between 10% and 20%. Diesel models' share of India's biggest cars, its SUVs and MUVs, have also been relatively constant between 60% and 70%. In the sedan market, however, the share of diesel cars 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 1 shows the retail prices of diesel and petrol in Delhi from 2002 to the present. 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.[4] To this were added customs and excise duties and sales taxes. Beginning in 2010, the base price of petrol was allowed to vary with international oil prices. On average the price per liter of diesel was about 70% of the price of petrol, although the gap between petrol and diesel prices increased after the base price of petrol was allowed to vary with international oil prices.

The lower price of diesel in Figure 1 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

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[3] There are no diesel engines below 1250cc. Many hatchbacks have smaller engines.
[4] The base price was set equal to 80% of the import price of oil plus 20% of the export price (Anand 2012).

difference between petrol and diesel prices as a difference in tax rates.[5] 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). Diesel is widely perceived to be a "poor man's fuel" and, there is concern about the macroeconomic consequences of equalizing the price of diesel and petrol (Anand 2012; Parikh 2010). For these reasons, there are political pressures not to raise the tax on diesel fuel, but to tax diesel cars instead.

Why are people buying diesels? 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 percent higher than that of a petrol sedan (11.8 km/L) (see Table 1). When coupled with the 30 percent 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, 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.

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[5] The discount to retailers of diesel, referred to as "under-recovery," is essentially a subsidy from the federal government to diesel purchasers. Oil companies sell diesel fuel to dealers at a discount and are then compensated by the federal government. It is currently the case that the taxes on diesel, minus the under-recovery, are positive.

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 oligpolistic model of supply, to study the effect of Corporate Average Fuel Economy (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 miles driven leads to two sets of model parameters, often differing in magnitude and sign. As the number of miles 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, which we follow here.[6]

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 characteristics. The model is estimated by full information maximum likelihood which leads to a single set of parameter estimates, allowing for theoretically consistent welfare estimates.

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 J. D. 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

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[6] We note two recent studies of vehicle demand in China (Li 2014; Xizo 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 miles driven for Japan using aggregate data. We are fortunate to have individual household data on miles traveled and vehicle choice.

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).

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

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

where $y_i - r_j$ is annual income of household i minus the annualized rental cost of car j; 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.[7] 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 sample mean of β_i and $v_{i\beta}$ is an idiosyncratic deviation drawn from some distribution $f(v_\beta|\omega_\beta)$.[8] 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 $\boldsymbol{\theta} = \{\bar{\beta}, \bar{\alpha}, \gamma, \omega_\beta, \omega_\alpha, \omega_\gamma, \sigma\}$. Individual parameters are then distributed according to the joint probability density function

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[7] 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. We follow the more recent literature in making use of the functional form in equation (1).

[8] 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.

$g(\boldsymbol{v}|\boldsymbol{\theta})$. Assuming that $\{\epsilon_{ij}\}$ have a Type I Extreme Value distribution, the probability that household i chooses car j takes the mixed logit form,

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

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

3.3 Driving Distance

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

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

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

$$\log(\text{KM}_{ij}) = \int [\beta_i(y_i - r_j) + \gamma X_{ij} + \alpha_i p_j + \eta_i] g(\boldsymbol{v}|\boldsymbol{\theta}) \, d\boldsymbol{v}. \tag{4}$$

Just as (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 probability density function for the normally distributed idiosyncratic taste for driving. Thus the likelihood of observing $\widetilde{KM}_{ij}$ kilometers driven conditional on household i buying car j is

$$\ell\left(\widehat{KM_{ij}}\middle|\mathbb{1}_{ij}=1\right) = \frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{1}{2}\frac{[\log(\widehat{KM_{ij}})-\log(\widehat{KM_{ij}})]^2}{\sigma^2}} \tag{5}$$

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 equation (4) without the idiosyncratic taste 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,

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

The log-likelihood function is

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

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 $\boldsymbol{v}_{ir}$ from the distribution $g(\boldsymbol{v}|\boldsymbol{\theta})$, 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 prevalence of each model in the sample is proportional to its prevalence in the market.[9] Thus, the log-likelihood to be maximized is given by

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

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[9] Weights for each observation equal the ratio of the market share to the sample share of the chosen model.

where w_i is the weight applied to observation i and probabilities have been replaced by simulated values.[10]

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, the purchase price, monthly kilometers driven and the buyer's estimate of fuel economy. It also collects data on household income and demographic characteristics and information on vehicle ownership.

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 model versions of each 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.[11]

It is important to note that within-body type differences across fuel types are influenced by the difference in model availability across fuel types. 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 model/fuel types for each

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[10] 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 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 indeed likelihood maximizing. As in Train and Winston (2007), we present standard errors that are robust to simulation noise.

[11] 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).

buyer. 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. Thus the differences between petrol and diesel vehicles observed in Table 1 reflect model availability in addition to differences between diesel and petrol twins. Nevertheless, some stylized facts are worth noting. Diesel cars are heavier than 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 operating costs across body types.[12] In 2010, diesel operating costs were 34% lower, 39% lower, and 20% lower for hatchbacks, sedans, and SUVs, respectively. Predictably, the owners of lower operating cost vehicles 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 have, on average, 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

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[12] Operating costs are calculated using Delhi fuel prices, as described more thoroughly below.

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%.

Operating cost is the fuel price in Delhi divided by fuel economy.[13] 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 data vs. survey data. 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.[14]

To improve model fit and better characterize substitution possibilities we interact vehicle and household characteristics and allow three of the coefficients in the indirect utility function to be random. We interact family size with sedan and hatchback dummies and with the ratio of horsepower to weight (power ratio). We interact buyer age with safety index. The distribution of 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, $\beta = e^{\tau}$ with $\tau \sim N(b^{\tau}, \omega^{\tau})$. Following the same reasoning, the distribution of the operating cost coefficient is assumed to be negative log-normal such that $\alpha = -e^{z}$ with $z \sim N(b^{z}, \omega^{z})$.

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[13] 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.

[14] 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 a CD player.

5. Econometric Results

Figures 3 and 4 summarize the within-sample fit of the estimated models in terms of market shares and annual kilometers driven. Aggregated to body- and fuel-type categories, predicted market shares match actual market shares closely. In fact, the model mirrors the within-sample shares of petrol and diesel vehicles (67.4% and 32.6%, respectively) to two significant digits. On average, the model over-predicts fuel usage and kilometers driven by 4.75%. Annual kilometers driven are predicted accurately for four of the six body-fuel type categories but are over-predicted for drivers of petrol hatchbacks and under-predicted for owners of diesel SUVs.

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; however, the preference for sedans decreases with family size; larger families prefer SUVs over hatchbacks. People prefer more powerful cars (bigger engines) but smaller exterior dimensions, holding body type constant. The coefficients in Table 3 imply that, other things 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 manual transmission cars. Finally, driving distance is greater for safer, more luxurious cars.

Table 4 displays the elasticities of fuel consumption implied by our model. We calculate elasticities by varying (e.g.) diesel fuel price holding petrol fuel price constant and allowing buyers to switch vehicles as well as distance driven when fuel price changes. 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 this reflects a shift from diesel to petrol cars; conditional on buying a diesel, fuel consumption falls by 2.3%.[15] The corresponding long-run

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

own-price elasticity of petrol is –1.27.[16] Our long-run, own-price elasticities are in line with studies in Europe (Graham and Glaister 2002; Verboven 2002). Graham and Glaister (2002) note that elasticities are higher in countries with higher fuel prices, and in countries where consumers can substitute between petrol and diesel fuels.[17] The cost of diesel and petrol in India, while high at market exchange rates, are higher than in the UK and Europe when evaluated in purchasing power parity (PPP) terms.[18]

The income elasticities in Table 4 are in line with the literature. Conditional on purchasing a diesel (petrol) vehicle the income elasticity of fuel consumed is about 0.4.[19] Given that this is conditional on vehicle ownership, the appropriate comparison with the literature is with short-run elasticities. Graham and Glaister (2002) report short-run income elasticities of fuel consumption between 0.35 and 0.55. Other studies have found low estimates of the impact of income on VKTs, conditional on car ownership.[20] Using the 1990 Nationwide Personal Transportation Survey Bento et al. (2005) find an elasticity of miles 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) also suggest that income has a small effect on distance driven, holding number of vehicles constant.

Finally, we note the high elasticity of diesel fuel consumption with respect to the price of diesel cars (-1.62). This suggests that a diesel car tax would be effective in moving buyers to petrol cars, although the impact on fuel consumption would be offset by increased petrol consumption.

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[16] We note that these elasticities reflect the switch to vehicles of a different fuel type rather than a switch to more fuel-efficient vehicles. In baseline runs, the average fuel economy of petrol and diesel vehicles purchased differs little. Average fuel economy is insensitive to changes in diesel and petrol fuel prices.

[17] We were unable to find published estimates of petrol and diesel fuel elasticities for India based on household data. Published estimates of petrol prices elasticities (e.g., Ramanathan 1999) are based on aggregate time series data, which typically yield smaller elasticities (in absolute value) than estimates based on cross-sectional household data.

[18] According to the Times of India (2011), India has the third highest fuel prices, per liter, of any country in the world, when measured in PPP terms. In 2011 the prices per liter of diesel and petrol in India were $2.46 and $3.95 in PPP terms, compared to $1.91 and $1.85 in the UK.

[19] The higher long-run income elasticity of diesel fuel consumption than petrol reflects the fact that an increase in income increases the market share of diesel vehicles. Recall that our model includes no outside good; hence, our long-run elasticities are conditional on buying a car.

[20] As noted in footnote 16, changes in fuel prices have little impact on the fuel efficiency of vehicles purchased; thus our fuel consumption elasticities are approximately equal to VKT elasticities.

6. Policy Simulations

We use our behavioral model to explore the market and welfare implications of taxing diesel fuel and taxing diesel cars. We begin with a tax on diesel fuel that equates the prices of diesel and petrol, a policy considered by the Expert Group on Pricing Petroleum Products (Parikh 2010). In 2010 diesel sold for 12.7 Rs./L less than petrol due to a lower rate of taxation. Policy 1 imposes a tax of 12.7 Rs./L on diesel, raising its price by 34.5%.[21] 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 the fuel tax. For the car tax to result in the same reduction in total fuel consumption would require a tax of over 80% on new diesel cars, which we view as politically infeasible. Because the cost of vehicle ownership is annualized in our econometric model, we annualize both the car tax charged to consumers and the revenues received by the government. Policy 3 examines an alternate diesel fuel tax of 2.77 Rs. (7.55%) that results in the same total fuel conservation as the diesel car tax.

6.1 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 revenues. In computing fuel consumption, government revenues and aggregate welfare impacts we extrapolate results from our sample to all 2010 new car buyers.[22] 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 policies (Pre-Policy Baseline).

Policy 1: Equalizing Diesel and Petrol Fuel Prices

As expected, the price-equalizing diesel fuel tax (Policy 1) has the greatest impact of the three policies on fuel consumption, reducing total fuel consumption by new car buyers by 6.99%. Sixty-six percent of the reduction in diesel fuel use under Policy 1 occurs because people switch

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[21] A natural question is how this tax compares with the value of externalities associated with fuel use. Parry et al. (2014) compute the value of externalities per liter of diesel and petrol associated with greenhouse gases, congestion, local air pollution and accidents for countries throughout the world. If the Value of a Statistical Life is transferred from the U.S. to India at market exchange rates, assuming an income elasticity of 1, the damages in 2010 are 12.4 Rs./L for petrol and 13.1 Rs./L for diesel used in passenger vehicles. See the Appendix for details.

[22] 2,309,000 new passenger vehicles were purchased in India in 2010 (SIAM various years).

to petrol vehicles: about 26% of diesel buyers in the pre-policy world switch to petrol vehicles after the tax (i.e., diesel market share falls from 33.6 to 24.8%). But, this reduction in diesel consumption is largely offset by an increase in petrol consumption. The buyers who continue to purchase a diesel car decrease their fuel consumption by about 18%. They account for 75% of the reduction in total fuel consumption, which amounts to 7% of the fuel used by new car buyers.

In reality, in 2010, the diesel fuel tax of 34.5% would achieve much greater reductions in diesel fuel use in the used car market than in the new car market. Our simulations suggest that new car buyers who do not switch to petrol cars when the tax is imposed reduce their diesel fuel consumption by about 18%. A similar reduction in fuel consumption among existing diesel cars would be substantial, 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).[23]

We estimate the welfare effects of the diesel tax by calculating compensating variation for new car owners in our dataset and extrapolating the results to the population of new car owners.[24] The compensating variation associated with the diesel tax is, on average, 6260 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. Persons who would not buy a diesel prior to the tax bear none of the tax, given that the price of petrol is not changed by the policy. Total compensating variation divided by the number of persons who bought a diesel in 2010 is 18,400 Rs., or about 3.0% of the average income of diesel buyers. The welfare effects of the tax increase as a percent of income as income falls, given the low income elasticity of fuel consumption.

The ultimate regressivity of the fuel tax depends, of course, on what is done with the increased fuel tax revenues. The diesel fuel tax generates over 9.5 billion rupees in tax revenues. Because the initial diesel/petrol price difference (12.7 Rs.) is due to the higher tax on petrol, the

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[23] 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.

[24] For each random draw r from the distribution of taste parameters, compensating variation is calculated by solving the equation $\log\left(\sum_{j=1}^{J} v_{ij}(y_i - r_j, p_j, X_{ij}; \theta_r)\right) = \log\left(\sum_{j=1}^{J} v_{ij}(y_i - r_j' + CV_{ir}, p_j', X_{ij}'; \theta_r)\right)$. 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 with 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.

increase in petrol consumption generates additional tax revenues in the petrol market. [25] Subtracting both of these from compensating variation implies that the deadweight loss of the diesel tax is about 12 Rs. per liter of fuel conserved.

Policy 2: Taxing Diesel Cars

By construction, the diesel car tax results in the same shift in car ownership from diesel to petrol vehicles as the fuel tax—about 26% of diesel car buyers shift to petrol vehicles—however, their reduction in diesel fuel consumption is largely offset by increased consumption of petrol. On net, the 25% car tax results in a 2.0% reduction in total fuel consumption by new car buyers. The welfare cost of the car tax is lower, on average, than the fuel tax: compensating variation is about 3370 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. Revenues from increased sales of petrol, when added to revenues from the car tax, are greater than the amount that new car buyers must be compensated to restore them to their pre-tax level of utility.[26] 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 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 revenues of over 3 billion rupees.

Policy 3: A Diesel Fuel Tax that Achieves the Same Fuel Conservation as the Car 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

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[25] There is also a change in tax revenues 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.

[26] In evaluating the deadweight loss of the car tax, we subtract the fall in state tax revenues (see footnote 25) from the increase in fuel tax revenues.

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 7.6% (2.77 Rs.) tax on diesel would also reduce total fuel consumption by 2.0% among new car buyers. The tax would reduce the market share of diesel vehicles from 34% to 31%--an 8.8% reduction. 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; however, this is reduction 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.[27] While compensating variation per liter of fuel conserved is only slightly lower than the larger diesel fuel tax (57.7 Rs./L), deadweight loss per liter of fuel conserved is smaller (2.13 Rs./L).

Discussion

The results above are subject to two 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 both 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 both policies.

The second caveat is that we do not estimate supply-side responses to our policies.[28] It is likely that automakers might react to either policy by lowering the price of diesel cars. This would attenuate the impact of all policies in shifting buyers to petrol vehicles and would reduce fuel savings.

Both the diesel car tax and the diesel fuel tax would have impacts in the used car market. The diesel fuel tax would likely hasten the retirement of diesel (v. petrol) cars and would reduce fuel consumption by existing diesel vehicles. The tax on new diesel cars would likely increase the lifetimes of used diesel vehicles but would have no impact on the miles they are driven. We

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

[28] Estimating supply-responses is difficult in the absence of an outside good. Specifically, own-price elasticities are likely to be under-estimated in the absence of an outside good.

cannot analyze the welfare impacts of either policy on the used car market due to lack of data; [29] 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.

In a rapidly growing car market the impacts of fuel conservation policies on future fuel consumption are arguably more important than impacts on the used car market. Taxing diesel fuel by 34% in 2010 would reduce fuel consumption by less than 300 million liters in 2010; however, keeping this policy in place would reduce fuel consumption by at least 40 times this amount in 2030, due to the rapid growth of the Indian car market. 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 2010 that will be on the road in years 2010-2030.   If vehicle miles traveled by new cars remain the same as in 2010, and if vehicle miles 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 2010 vintage cars. These calculations underscore the benefits of enacting fuel conservation policies today.

Implications of Our Results for CAFE Standards

Our model results also have important implications for fuel economy standards in India. The Bureau of Economic Efficiency is contemplating weight-based corporate average fuel economy standards that would go into effect in 2015-16, with more stringent standards proposed for 2020-21 (Roychowdhury 2011). These would be weight-based standards, with heavier cars being allowed more liters per 100 km driven. Calculations based on our 2010 JD Power data suggest that the proposed 2015-16 standards would lower average liters per 100 km by 26% for

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[29] There is no survey of vehicle owners in India that is similar to the National Household Travel Survey in the US. Data on used vehicle prices and odometer readings at the time of sale can be obtained from the Internet but do not include information on buyer characteristics.

petrol and 10% for diesel cars.[30] If the households in our sample were to buy the same vehicle after the increase in fuel economy and were to drive it the same number of kilometers, fuel consumption would decline by 26% for petrol and by 10% for diesel car owners. Weighting these percentages by market shares, total fuel consumption would decline by about 20%.

The prediction of a 20 percent reduction in fuel consumption, however, ignores the impact of CAFE standards on vehicle choice and on kilometers driven. We use our model to estimate the impact of CAFE standards by increasing the liters per 100 kilometers for each vehicle in the choice set according to the CAFE formula. This, correspondingly, reduces operating cost per kilometer driven. The results of our simulation are shown in Table 5. The greater improvement in the fuel economy of petrol (v. diesel) vehicles leads to a shift from diesel to petrol vehicles; indeed, we predict petrol market share to increase from 66% to 73%. One might expect this to increase fuel savings; however, the rebound effect in both petrol and diesel markets is sizeable. The 26% average reduction in fuel cost per mile for petrol vehicles leads to a 22% increase in liters consumed. (See Table 5.) The 10% reduction in average diesel fuel costs per km results in a 5% increase in km driven for diesel vehicles. The net effect of these adjustments implies that the proposed CAFE standard would, once consumers adjust, reduce fuel consumption by 8.5% rather than 20%.

7. Conclusions

The Indian government is taking steps to reduce the increased fuel consumption that is accompanying rapid motorization. Raising the tax on diesel fuel to equal the tax on petrol would be a natural way to achieve this; however, such a tax would have consequences that extend far beyond the passenger vehicle market. Only 5 percent of diesel fuel in India in consumed by passenger vehicles. Due to its use in agriculture and freight transport, diesel is widely regarded as the fuel of the poor. For this reason, increasing the tax on diesel fuel is politically difficult. We therefore compare a tax on new diesel cars, suggested by the Expert Group on a Viable and Sustainable System of Pricing of Petroleum Products (Parikh 2010) with a diesel fuel tax. The Expert Group called for "an additional excise duty on a diesel vehicle corresponding to the

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[30] The standard reported by Roychowdhury (2011) is Liters per Km = 0.0025*Kerbweight (in kg.) + 3.171. These figures correspond to a 36% increase in fuel economy for petrol cars and a 15% increase for diesel cars.

differential tax on petrol." We interpret this as a car tax that has the same effect on diesel market share as a fuel tax that equates the prices of diesel and petrol.

To analyze the effects of these policies we estimate a structural econometric model of new car purchasing decisions and driving behavior. Our simulations suggest that in 2010 eliminating the petrol/diesel price gap with a diesel fuel tax of 34% would reduce diesel market share by 26%. A diesel car tax of 25% would have the same impact on the market share of diesel vehicles. The car tax would reduce total (i.e., diesel plus petrol) fuel consumption in the new car market by 2.0%. The compensating variation associated with the tax would be approximately 120 Rs. per liter of fuel conserved; however, the deadweight loss of the car tax is negative. This occurs because of the pre-existing tax on petrol. As consumers who would have purchased diesel vehicles shift to petrol vehicles petrol consumption increases by over 12% (approximately 240 million liters), resulting in additional tax revenues of over 3.0 billion rupees. This must be subtracted from compensating variation to calculate the deadweight loss of the diesel car tax.

The diesel fuel tax of 34% would, of course, achieve a greater reduction in total fuel consumption—about 7% in the new car market—by providing new car buyers who continue to buy diesel cars an incentive to drive fewer miles. These buyers reduce fuel consumption by about 18%, and account for 75% of the total reduction in fuel consumption. The deadweight loss of the large diesel fuel tax is larger per liter of fuel saved than the car tax—approximately 12 Rs. per liter—but the compensating variation per liter of fuel saved is much lower (approximately 64 Rs. per liter).

A fairer comparison might be between the car tax and a smaller tax on diesel fuel that would achieve the same reduction in fuel consumed in the new car market, a tax of approximately 7.6%. This diesel tax also has a negative cost per liter of fuel saved and a welfare cost to consumers of approximately 58 Rs. liter of fuel conserved. Both diesel fuel taxes would, however, result in additional fuel savings by used diesel vehicles, which would swamp any savings in the new car market given the size of the diesel vehicle fleet. The diesel car tax, in contrast, would likely raise the price of used diesel cars, but would provide no incentive to reduce kilometers traveled by diesel car owners.

Our results also have important implications for fuel economy standards in India. Our estimates of the price elasticity of demand for fuel, conditional on owning a car of a given fuel type are -.0.8 for petrol and -0.6 for diesel fuel.[31] The high price elasticity of miles driven with respect to fuel price suggests that the fuel economy standards currently being contemplated by the government are likely to result in a substantial rebound effect. The Bureau of Economic Efficiency is contemplating weight-based corporate average fuel economy standards that would go into effect in 2015-16, with more stringent standards proposed for 2020-21 (Roychowdhury 2011). These would be weight-based standards, with heavier cars being allowed more liters per 100 km driven. Calculations based on our 2010 JD Power data suggest that the proposed 2015-16 standards would lower average liters per 100 km by 26% for petrol and 10% for diesel cars. This reflects the fact that diesel cars are, on average, heavier than petrol cars. The greater improvement in fuel economy of petrol vehicles would likely lead to a shift from diesel to petrol vehicles; however, the rebound effect in both markets is substantial. Our estimates suggest that it is approximately 58%.

This suggests that attention be paid to the possibility of raising diesel taxes. Diesel taxes would have repercussion throughout the economy; however, several countries tax diesel fuel for transport at a different rate than diesel fuel in other sectors (e.g., agriculture) and the same could be done in India. A recent study by Datta (2010) suggests that an economy-wide tax on diesel would not be regressive. Were this to be adopted, it would be a far more efficient way of reducing fuel consumption than other policies that the government is considering.

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[31] Long-run elasticities, which allow buyers to switch fuel type, are -1.27 for petrol and -1.44 for diesel.

Table 1. Sales-Weighted Vehicle Summary Statistics

VARIABLES	UNITS	petrol hatchback	diesel hatchback	petrol sedan	diesel sedan	petrol SUV	diesel SUV
Price	10^5 Rupees (2010)	3.94	5.22	8.33	7.47	3.07	9.23
		(1.01)	(0.755)	(3.27)	(2.59)	(7.74)	(3.76)
Fuel Economy	kilometers/liter	14.2	15.9	12.2	15.0	12.7	11.9
		(1.06)	(0.576)	(0.828)	(0.983)	(0.280)	(0.753)
Operating Cost	2010 Rupees/kilometer	3.51	2.31	4.05	2.46	3.88	3.10
		(0.265)	(0.0850)	(0.276)	(0.185)	(0.0998)	(0.193)
Engine Size	cubic centimeters	1.06	1.31	1.51	1.40	1.21	2.45
		(0.160)	(0.0664)	(0.257)	(0.210)	(0.155)	(0.186)
Power Ratio	horsepower/kilogram	0.0745	0.0653	0.0938	0.0698	0.0796	0.0529
		(0.00680)	(0.00498)	(0.0124)	(0.0107)	(0.00308)	(0.0185)
Torque	kilogram-meters	0.0949	0.172	0.141	0.190	0.103	0.232
		(0.0180)	(0.0295)	(0.0326)	(0.0457)	(0.0165)	(0.0514)
Gears		4.93	5	5.01	5.02	5.01	5
		(0.268)	(0)	(0.117)	(0.138)	(0.149)	(0)
Automatic		0	0	0.0156	0.0100	0	0.0172
		(0)	(0)	(0.127)	(0.104)	(0)	(0.137)
Length	meters	3.56	3.76	4.35	4.25	3.49	4.46
		(0.173)	(0.0844)	(0.168)	(0.144)	(0.200)	(0.152)
Width	meters	1.57	1.69	1.70	1.68	1.48	1.78
		(0.0775)	(0.00939)	(0.0376)	(0.0418)	(0.0515)	(0.0588)
Height	meters	1.55	1.52	1.50	1.52	1.80	1.89
		(0.0748)	(0.0479)	(0.0515)	(0.0331)	(0.0179)	(0.0862)
Ground Clearance	meters	1.68	1.67	1.68	1.66	1.60	1.85
		(0.0531)	(0.0556)	(0.0876)	(0.0706)	(0.0373)	(0.124)
Weight	1000 kilogram	0.900	1.09	1.12	1.16	0.927	1.75
		(0.118)	(0.0415)	(0.115)	(0.112)	(0.0941)	(0.163)
Safety Index		1.35	1.12	2.20	1.68	1.02	1.50
		(0.597)	(0.401)	(0.779)	(0.719)	(0.298)	(0.641)
Luxury Index		3.63	3.37	5.73	4.64	0.0901	3.93
		(1.32)	(0.865)	(1.60)	(1.25)	(1.19)	(1.90)
# Models		21	8	20	13	2	10

Notes: This table presents 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

VARIABLES	UNITS	petrol hatchback	diesel hatchback	petrol sedan	diesel sedan	petrol SUV	diesel SUV
Income	10^5 Rupees (2010)	5.05	5.12	6.95	5.96	5.88	6.67
		(2.63)	(2.56)	(3.03)	(2.86)	(3.14)	(2.95)
Family Size		4.72	4.93	5.02	5.18	5.54	5.43
		(1.55)	(1.51)	(1.63)	(1.63)	(1.56)	(1.61)
Age	years	38.0	36.1	37.2	36.5	37.9	36.9
		(11.4)	(10.7)	(10.4)	(9.18)	(10.2)	(9.84)
% Female		0.0867	0.0330	0.0469	0.0332	0.0153	0.0281
		(0.281)	(0.179)	(0.211)	(0.1793)	(0.123)	(0.165)
Driving Distance	kilometers/month	14500	24000	16600	22500	16600	26300
		(16000)	(25200)	(18000)	(22200)	(16800)	(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 × Hatchback	-0.00272***	(0.000540)
Family Size × Sedan	-0.00150***	(0.000589)
Age × Safety Index	2.29E-05	(3.03E-05)
Family Size × 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)

Notes: This table presents full information maximum likelihood coefficient estimates with 12 make fixed effects (not shown). Integrals simulated using 200 shifted and shuffled Halton draws. Number of observations= 6132, LL = -30496 at convergence. *p<10%. **p<5%, ***p<1%, based on simulation noise robust standard errors.

Table 4. Fuel Consumption Elasticities

	Petrol (Long Run)	Petrol (Conditional)	Diesel (Long Run)	Diesel (Conditional)
Own-Price (Fuel)	-1.27	-0.793	-1.44	-0.59
Cross-Price (Fuel)	0.461	0.0154	0.98	-0.01
Income	0.28	0.35	0.515	0.377
Own-Price (Car)	-0.596	-0.04	-1.63	-0.0344
Cross-Price (Car)	0.82	0.0136	1.08	-0.0251

Notes: All elasticities are calculated by varying price or income by 5% from baseline
values, allowing households to vary vehicle choices and miles driven. Long-run
elasticities are based on changes in total fuel consumption by all households and reflect
changes in the type of vehicle bought. Conditional elasticities are based on change in
average fuel consumption, conditional on buying a vehicle of a particular fuel type.

Table 5: Policy Simulation Results

|			(POLICY 1)	(POLICY 2)	(POLICY3)	
		Pre-Policy Baseline	34.46% Diesel Fuel Tax	24.65% Diesel Car Tax	7.54% Diesel Fuel Tax	Fuel Economy Standards
Market Share	petrol	66.4%	75.2%	75.2%	68.6%	72.9%
	diesel	33.6%	24.8%	24.8%	31.4%	27.1%
Average Fuel Consumption	petrol	1280	1290	1290	1290	1190
(L/year)	diesel	1610	1310	1600	1540	1560
Average Fuel Economy	petrol	13.8	13.8	13.8	13.8	18.2
(KM/L)	diesel	14.3	14.3	14.4	14.3	15.5
Total Fuel Consumption	petrol	1970	2240	2230	2040	1190
(10^6 L/year)	diesel	1250	751	915	1110	1560
Total Fuel Conserved *(10^6 L/year)*			225	65.6	65.6	244
Total CV *(10^6 Rs. 2010/year)*			14400	7780	3790	
CV/Liter *(Rs. 2010/L)*			64.3	119	57.7	
Δ Government Revenue *(10^6 Rs. 2010/year)*			11800	9560	3650	
Deadweight Loss/Liter *(Rs. 2010/L)*			11.8	-27.2	2.13	

Notes: This table presents policy simulation results for year 2010 using parameter estimates presented in Table 3. 2010 petrol and diesel fuel prices (in 2010 Rs./liter) were 49.37 and 36.72, respectively. Thus, a 7.55% diesel fuel tax amounts to 2.77 Rs. and a 34.46% diesel fuel tax amounts to 12.65 Rs. In both cases, the existing tax on petrol fuel is assumed to equal 12.65 Rs.

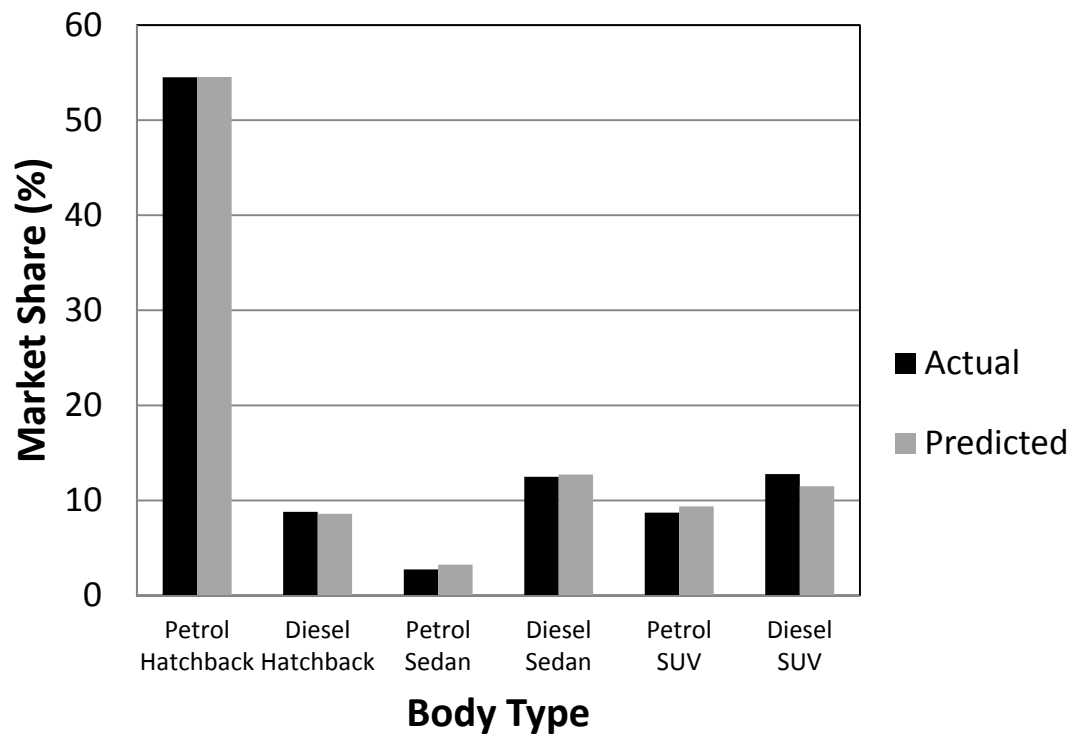Figure 1: Nominal Fuel Price (Rs./Liter) for Petrol and Diesel—2001-2013
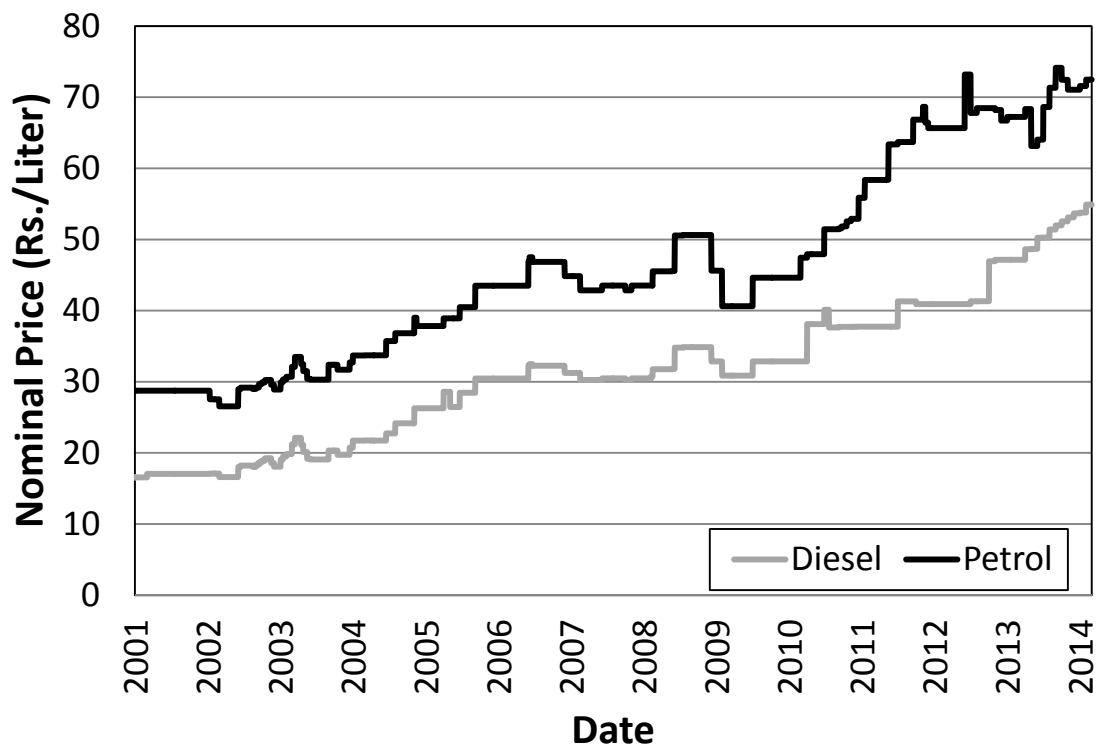
Source: Ministry of Petroleum & Natural Gas, Govt. of India

Figure 2: Dieselization Across Passenger Vehicle Segments
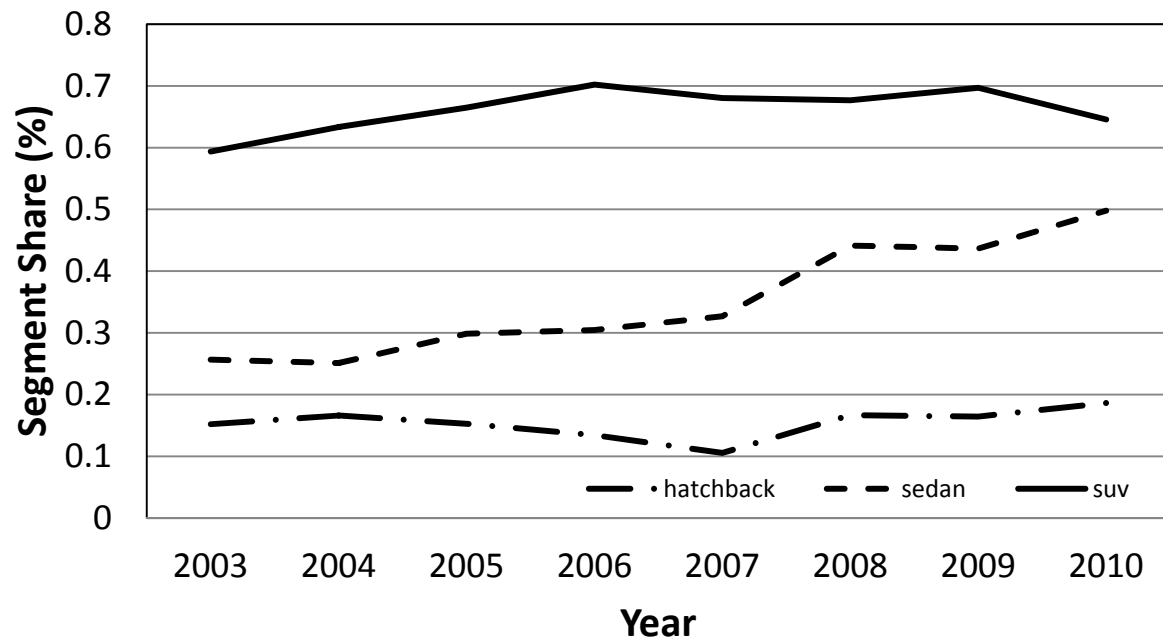
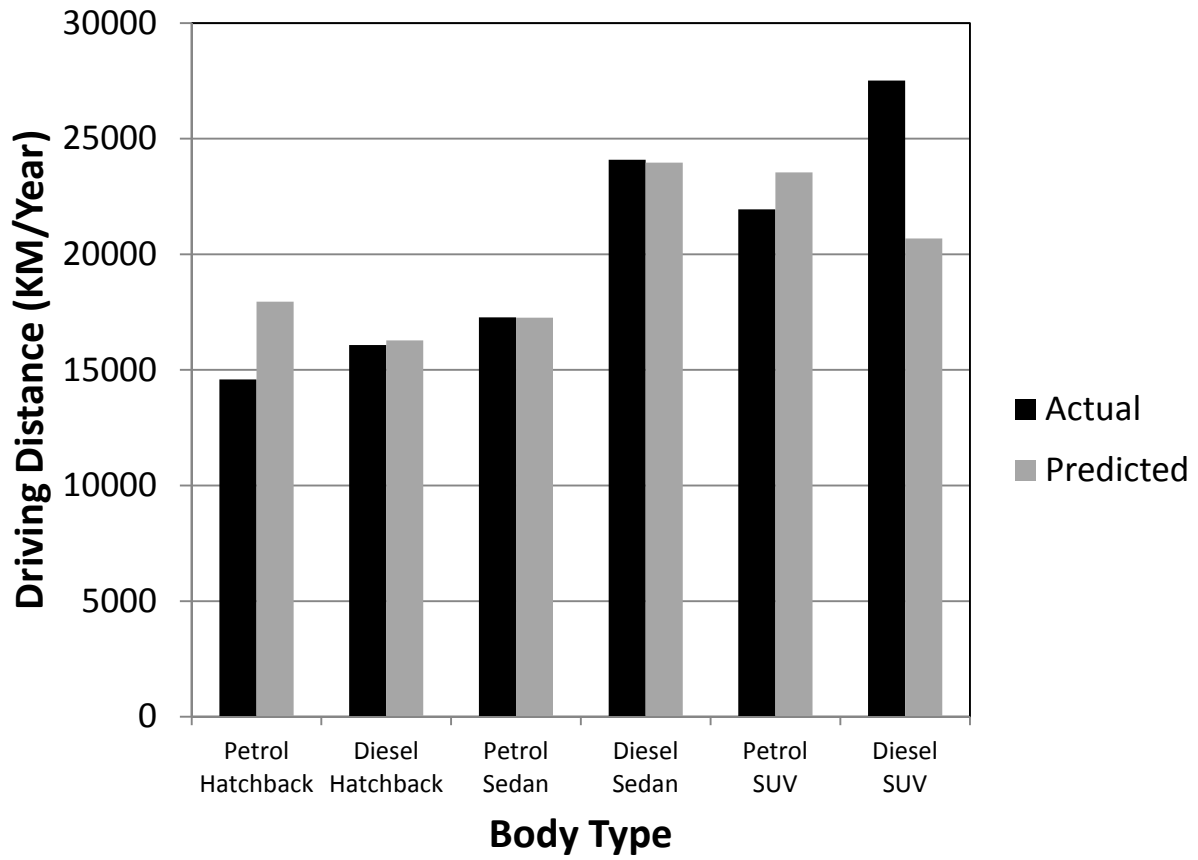Source: Society of Indian Automobile Manufactorers (SIAM) (various years)

Figure 3: Model Fit (Market Shares)

Source: Authors' calculations

Figure 4: Model Fit (Driving Distance)

Source: Authors' calculations

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APPENDIX

Optimal Externality Taxes

The externalities associated with motor vehicles include local and global air pollution, traffic congestion and road traffic accidents. We base our estimates of optimal externality taxes on petrol and diesel on a recent study by Parry et al. (2014) that quantifies all four categories of externalities for various countries. For health damages (damages associated with local air pollution and accidents) we use Parry et al.'s estimates of physical damages per liter of fuel. We value health damages using a Value of a Statistical Life for India of $150,000 2010 USD. This corresponds to a base VSL of $3.9 million 2010 USD (the base value used by Parry et al.) and an income elasticity of the VSL of one. The corresponding VSL in Rs. (6,750,000 Rs.) is in line with studies of the VSL in India (Bhattacharya et al 2007; Madheswaran 2007). The value of global pollution is based on the US Social Cost of Carbon of $35/ton CO_2 in 2010 (US Interagency Working Group on the Social Cost of Carbon 2013). We use Parry et al.'s (2014) estimate of congestion costs.

The resulting components of externalities per liter of diesel and petrol consumed in passenger vehicles are:[32]

	Petrol	Diesel
Global pollution	.080/Liter	.090/Liter
Local pollution	.009/Liter	.020/Liter
Accident costs	.158/Liter	.158/Liter
Congestion costs	.029/Liter	.024/Liter
Total Externality (USD)	.276/Liter	.292/Liter
Externality in Rs.	12.42/Liter	13.14/Liter

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[32] Our accident damages per liter of diesel fuel reflect Parry et al. (2014)'s assumption that accident risks are the same for all vehicle classes and the fact that KPL per vehicle purchased differs little between diesel and petrol cars.