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The welfare effects of fuel conservation policies in a dual-fuel car market: Evidence from India ☆

Randy Chugh *, Maureen Cropper

Department of Justice; University of Maryland and Resources for the Future, United States

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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 and car sales taxes. At levels sufficient to reduce total fuel consumption by 7%, the increased diesel and petrol fuel taxes both yield deadweight losses (net of externalities) of about 4 (2010) Rs./L. However, at levels sufficient to reduce total fuel consumption by 2%, the increased petrol fuel tax results in a deadweight loss per liter of fuel conserved that is greater than that caused by the diesel 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 large diesel fuel tax actually has a negative deadweight loss per liter of fuel conserved. The welfare effects of all three policy instruments are positive, once the external benefits of reducing fuel consumption are added to the excess burden of taxation.

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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

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* Correspondence to: 450 Fifth Street NW, Washington, DC 20530, United States.
E-mail address: randy.chugh@usdoj.gov (R. Chugh).

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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. Our results also have implications for the European car market which, like India, is characterized by diesel cars' substantial market share (Frondel 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 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.

Specifically, we estimate the welfare effects (and fuel conservation impacts) of raising the tax on diesel fuel to equal the tax on petrol. As indicated by the familiar Harberger formula (Harberger, 1964),[2] the excess burden of a tax on diesel fuel depends not only on the impact of the tax on the demand for diesel fuel, but on the impact of the tax on the markets for petrol fuel, petrol cars, and diesel cars, and on the rate at which these commodities are taxed. Formally the excess burden of a tax on diesel fuel is given by:

$$EB_d^f = -\frac{1}{2}\tau_d^f \tau_d^f \frac{dX_d^f}{d\tau_d^f} - \tau_d^f \tau_p^f \frac{dX_p^f}{d\tau_d^f} - \tau_d^f \tau_p^s \frac{dX_p^s}{d\tau_d^f} - \tau_d^f \tau_d^s \frac{dX_d^s}{d\tau_d^f} \tag{1}$$

where τ_d^f is the tax on diesel fuel, X_d^f is demand for diesel fuel, τ_p^f is the pre-existing tax on petrol fuel, X_p^f is demand for petrol fuel, τ_p^s is the pre-existing tax on petrol cars, X_p^s is demand for petrol cars, τ_d^s is the pre-existing tax on diesel cars, and X_d^s is demand for diesel cars.

The second and third terms in the equation reflect the gain in tax revenues as consumers switch from diesel to petrol vehicles and depend on the long-run elasticities of demand for petrol fuel and petrol cars. This gain in tax revenue is, however, offset by the loss in sales taxes on diesel cars. The excess burden of taxing diesel fuel depends empirically on all four tax rates, and on own and cross-price elasticities of demand.

The full welfare effect of the diesel tax equals the excess burden in Eq. (1) plus the external effects of burning diesel and petrol fuels which, following Parry et al. (2014), we assume are proportional to the amount of fuel consumed. The full welfare effect of a tax on diesel fuel is given by:

$$W_d^f = EB_d^f + \frac{dX_d^f}{d\tau_d^f} E_d^f + \frac{dX_p^f}{d\tau_d^f} E_p^f \tag{2}$$

where EB_d^f is excess burden as defined in Eq. (1), E_d^f is the external damage associated with consumption of diesel fuel, and E_p^f is the external damage associated with consumption of petrol fuel. The excess burden of taxing diesel fuel may, therefore, be offset by the external benefits of reducing diesel fuel consumption, net of any increase in damages due to petrol consumption.[3]

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

1.1. 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

[1] For context, 2010 motor vehicle sales were 10.4 million in the U.S. and 13.6 million in China (Bloomberg.com, 2010).
[2] For a more recent application see Goulder and Williams (2003).
[3] The equations for the welfare effects of taxing petrol fuel or diesel cars are analogous to those for diesel fuel and are therefore not presented here.

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 model 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 five fuel conservation policies: (1) a large diesel fuel tax that equalizes the prices of petrol and diesel fuel; (2) a diesel car tax that reduces market share of diesel cars by the same amount as policy 1; (3) a small diesel fuel tax that results in the same decrease in fuel consumption as policy 2; (4) a large increase in the petrol fuel tax that results in the same decrease in fuel consumption as policy 1; and (5) a small increase in the petrol fuel tax that results in the same decrease in fuel consumption as policies 2 and 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. We also quantify the externality abatement benefits associated with each policy based on recent work by Parry et al. (2014).

The relative efficiency of the diesel fuel tax and the petrol fuel tax depends on the level of fuel conservation they achieve. At levels sufficient to reduce total fuel consumption by 7%, the increased diesel and petrol fuel taxes both yield deadweight losses (net of externalities) of about 4 (2010) Rs. per liter.[4] However, at levels sufficient to reduce total fuel consumption by 2%, the increased petrol fuel tax results in a deadweight loss per liter of fuel conserved that is greater than that caused by the diesel 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 large diesel fuel tax actually has a negative deadweight loss per liter of fuel conserved.[5] The welfare effects of all three policy instruments (i.e., Eq. (2)) are positive, once the environmental benefits of reducing fuel consumption are added to the excess burden of taxation.

Our elasticity estimates also have implications for the corporate average fuel economy (CAFE) standards recently enacted by the Indian government. The Bureau of Economic Efficiency issued weight-based CAFE standards that went into effect in 2015-16, with more stringent standards to go into effect in 2020-21.[6] 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 2015-16 fuel economy standards would reduce fuel consumption by approximately 22% if consumers continued to purchase the same vehicles they bought in 2010 and drive 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 5.1%.

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.

2. Overview of the Indian car market

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 Fig. 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%.[7] 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. Fig. 2 shows the nominal 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.[8] Customs duties, excise duties, and sales

[4] Unless otherwise indicated, all prices and welfare estimates are presented in units of 2010 rupees; we drop the "(2010)" notation for the remainder of the paper.

[5] 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).

[6] http://www.egazette.nic.in/WriteReadData/2014/158019.pdf

[7] There are no diesel engines below 1250cc. Many hatchbacks have smaller engines.

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

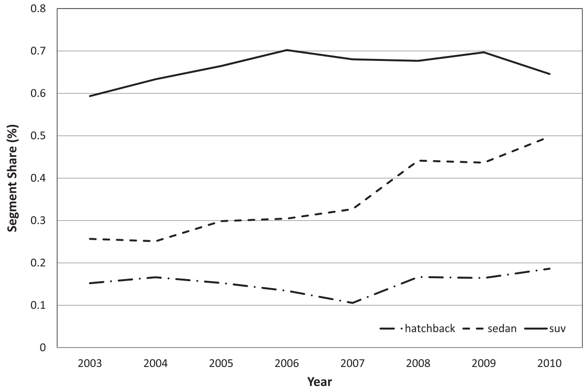

Fig. 1. Diesel Share by Passenger Vehicle Segment.
Source: Society of Indian Automobile Manufacturers.

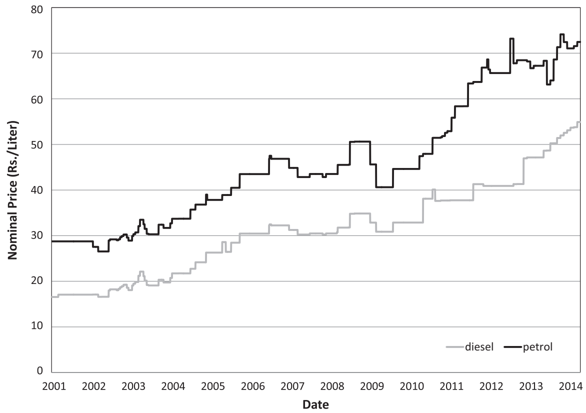

Fig. 2. Nominal Fuel Price (Rs./Liter) for Petrol and Diesel—2001-2013.
Source: Ministry of Petroleum & Natural Gas, Govt. of India

taxes were added to this to yield the retail prices shown in Fig. 2. Beginning in 2010, the base price of petrol was allowed to vary with international oil prices. The lower price of diesel in Fig. 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. Approximately 60% of diesel fuel is used for road transport (primarily for trucks and buses), 20% for power generation (both captive power generation and transmission to the grid), 12% for 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, 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 15 km/L in 2010) is about 23% higher than that of a petrol sedan (12.2 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

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	5.22	8.33	7.47	3.07	9.23
	(1.01)	(0.755)	(3.27)	(2.59)	(7.74)	(3.76)
Fuel Economy *(km/L)*	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 *(Rs. 2010/km)*	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 *(cc)*	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 *(hp/kg)*	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 *(kg-m)*	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 *(m)*	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 *(m)*	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 *(m)*	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 *(m)*	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 *(10^3 kg)*	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 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	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 *(km/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.

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 oligpolistic 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.

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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.[9]

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 model 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).

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

$$v_{ij} = -\frac{1}{\beta_i} e^{-\beta_i (y_i - r_j) - \gamma \boldsymbol{X}_{ij} - \eta_i} - \frac{1}{\alpha_i} e^{\alpha_i p_j} + \epsilon_{ij}, \tag{3}$$

where $y_i - r_j$ is annual income of household i minus the annualized rental cost of car j; $\boldsymbol{X}_{ij}$ 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.[10] 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, $\beta_i = \overline{\beta} + \nu_{i\beta}$ where $\overline{\beta}$ is the mean of β_i and $\nu_{i\beta}$ is an idiosyncratic deviation drawn from some distribution $f(\nu_\beta \mid \omega_\beta)$.[11] 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 $\boldsymbol{\theta} = \{\overline{\beta}, \overline{\alpha}, \gamma, \omega_\beta, \omega_\alpha, \sigma\}$. Individual parameters are then distributed according to the joint probability density function $g(\boldsymbol{\nu} \mid \boldsymbol{\theta})$. Assuming that $\{\epsilon_{ij}\}$ have a Type I Extreme Value distribution, the probability that household i chooses car j takes the mixed logit form,

$$Pr_{ij} = \int \frac{e^{v_{ij}/\mu}}{\sum_{j=1}^{J} e^{v_{ij}/\mu}} g(\boldsymbol{\nu} | \boldsymbol{\theta}) d\boldsymbol{\nu}, \tag{4}$$

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 Eq. (3) as follows:

[9] 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.

[10] 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.

[11] 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.

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$$KM_{ij} = -\frac{\partial v_{ij}/\partial p_j}{\partial v_{ij}/\partial y_i} = e^{\beta_i(y_i - r_j) + \gamma \mathbf{X}_{ij} + \alpha_i p_j + \eta_i}. \tag{5}$$

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 expected log of demand for kilometers driven equation becomes

$$\mathrm{E}\left[\log(\mathrm{KM}_{ij})\right] = \int \left[\beta_i(y_i - r_j) + \gamma \mathbf{X}_{ij} + \alpha_i p_j + \eta_i\right] g(\boldsymbol{\nu}|\boldsymbol{\theta}) d\boldsymbol{\nu}. \tag{6}$$

Just as Eq. (4) takes advantage of the closed-form solution of the integral over the type I extreme value preference shock, Eq. (7) 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

$$\ell\left(\widetilde{KM}_{ij} \middle| \mathbb{1}_{ij} = 1\right) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\frac{\left[\log(\widetilde{KM}_{ij}) - E[\log(\widehat{KM}_{ij})]\right]^2}{\sigma^2}} \tag{7}$$

where $\mathbb{1}_{ij}$ is an indicator function equal to 1 if household i bought car j and 0 otherwise and $E\left[\log\left(\hat{KM}_{ij}\right)\right]$ is the right hand side of Eq. (6) 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 (Eq. (4)) and its likelihood of driving $\widetilde{KM}_{ij}$ conditional on buying car j (Eq. (7)).[12] The full information likelihood function is the product over all households:

$$L(\boldsymbol{\theta}) = \prod_{i=1}^{N}\prod_{j=1}^{J}\left[Pr_{ij}\ell(\widetilde{KM}_{ij}|\mathbb{1}_{ij} = 1)\right]^{\mathbb{1}_{ij}}. \tag{8}$$

The log-likelihood function is

$$LL(\boldsymbol{\theta}) = \sum_{i=1}^{N}\sum_{j=1}^{J}\mathbb{1}_{ij}\left[\log(Pr_{ij}\ell(\widetilde{KM}_{ij}|\mathbb{1}_{ij} = 1))\right]. \tag{9}$$

Evaluating the log-likelihood function directly would require solving the integral over the observed joint choice which is implicit in Eq. (9). In the absence of a closed-form solution, integration can be performed by simulation (Train, 2009). For any draw $\boldsymbol{\nu}_{ir}$ from the distribution $g(\boldsymbol{\nu} \mid \boldsymbol{\theta})$, 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 Eq. (9) is to weight each observation to ensure that the prominence of each vehicle model in the sample is proportional to its market share.[13] Thus, the log-likelihood to be maximized is given by

$$LL(\boldsymbol{\theta}) = \sum_{i=1}^{N}\sum_{j=1}^{J}\mathbb{1}_{ij}\left[\mathrm{w_i}\log\left(\frac{1}{\mathrm{R}}\sum_{\mathrm{r}=1}^{\mathrm{R}}\mathrm{Pr_{ijr}}\ell(\widetilde{KM}_{ijr}|\mathbb{1}_{ij} = 1)\right)\right] \tag{10}$$

where w_i is the weight applied to observation i, Pr_{ijr} is the probability that person i buys car j conditional on the r^{th} draw from the distribution, $\ell(\widetilde{KM}_{ijr} \mid \mathbb{1}_{ij}{=}1)$ is the likelihood that person i drives $\widetilde{KM}_{ij}$ conditional on buying car j and conditional on the r^{th} draw from the distribution, and the parenthetical term, therefore, is the simulated integral of the likelihood of the observed joint choice.[14]

[12] We note, however, that Eq. (4) explicitly integrates over the distribution of parameters only to demonstrate the link between the indirect utility function (Eq. (3)) and car choice probability and the conceptual role of the randomly distributed parameters. Eq. (7) implicitly integrates over the distribution of parameters, by virtue of the fact that it is a function of the right hand side of Eq. (6), for similar pedagogical purposes. In application, our model focuses on maximizing the likelihood of the observed joint choice and therefore the integral that matters is over the product of car choice probability and driving distance likelihood.

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

[14] Results presented below are based on integrals simulated using 200 shifted and shuffled Halton draws, a quasi-random scheme that provides better

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 7000 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.[15]

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.[16]

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.[17] 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 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.[18] 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, we convert the purchase price of a vehicle to an annualized rental price and 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%.

Operating cost is the fuel price divided by fuel economy. 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. Identifying the coefficient on operating cost requires that we have variation in operating cost that is independent of vehicle characteristics. Unfortunately, there is little variation in fuel prices across Indian cities which could be used to identify the

(*footnote continued*)
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 likelihood maximizing. As in Train and Winston (2007), we present standard errors that are robust to simulation noise.

[15] 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.

[16] 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).

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

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

coefficient on operating cost.[19] We therefore use the Delhi prices of petrol and diesel fuel, which in 2010 were 49.4 Rs. per liter and 36.7 Rs. per liter, respectively. This implies that variation in operating cost comes from variation in fuel economy across vehicles and the difference between the prices of petrol and diesel fuels. Our identification strategy relies on including model fixed effects in the **X** vector, implying that variation in operating cost comes from within-model variation across fuel types for models available in both fuel types (i.e., "twins").

The inclusion of model fixed effects limits the number of vehicle characteristics that we can include in our empirical model. As a sensitivity analysis, we include in Appendix B a model with manufacturer and body type fixed effects, which allows us to include a richer set of vehicle characteristics.[20] Both models include the age and gender of the household head and family size.

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 a 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

Figs. 3 and 4 illustrate 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 (66% and 34%, respectively) to two significant digits. 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 by 4.8% and kilometers driven by 6.0%.

Table 3 presents estimation results for all parameters; model 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 cars with more torque; older drivers prefer safer cars. Larger households prefer SUVs over sedans and hatchbacks. All else equal, driving distance increases with family size and decreases with age and women drive less than men.

Estimates of the short run elasticity of VKT with respect to operating cost implied by our model are similar to those found in other studies using household data.[21] Evaluated at the mean operating cost for diesel and petrol vehicles, these elasticities are -0.68 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.[22]

The income elasticity of VKT implied by our model, which is conditional on vehicle ownership, is about 0.28.[23] 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) 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.[24] 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 7.9%, implying a long-run, own-price elasticity of consumption of -1.58. 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 −0.29. The long-run own-price elasticity of petrol consumption is −1.35; 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

[19] 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.

[20] Appendix Table B.1 through B.3, which correspond to Tables 3 through 5 in the text, present results for this alternate specification.

[21] Eq. (5) implies that the elasticity of VKT with respect to operating cost is $\alpha_i p_j$.

[22] The median number of cars owned by households in our sample is one.

[23] It is, on average, about 0.27 conditional on owning a petrol vehicle and 0.30 conditional on owning on a diesel vehicle.

[24] Bootstrapped standard errors are shown in parentheses. These standard errors are calculated by taking 500 random draws from a joint normal distribution based on the point estimates and simulation-robust covariance matrix of the parameter estimates. For each random draw, the elasticities are calculated and the standard errors are calculated from the resulting distribution of elasticities.

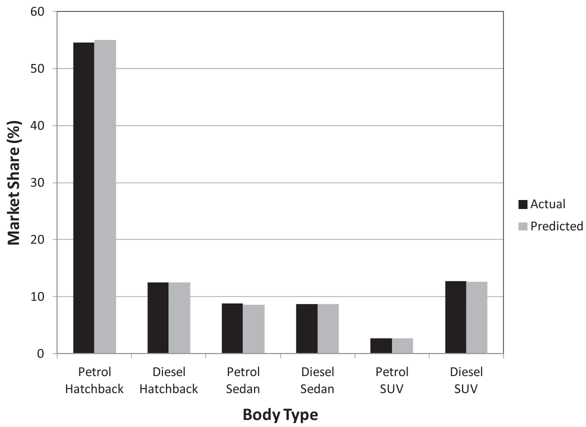

Fig. 3. Model Fit (Market Shares).
Source: Authors' calculations

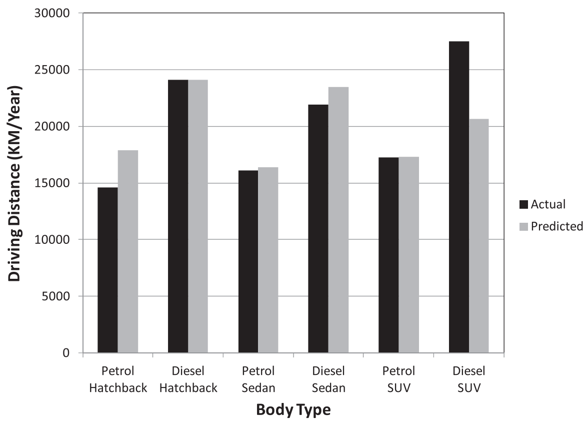

Fig. 4. Model Fit (Driving Distance).
Source: Authors' calculations

Table 3
Demand Model Parameter Estimates.

FIXED	Coefficient	Standard Error		
Age	-0.00879***	(0.00129)		
Female	-0.282***	(0.0588)		
Family Size	0.0470***	(0.00982)		
Power Ratio	0.0238	(0.122)		
Torque	0.301***	(0.0981)		
Weight	-0.343***	(0.0824)		
Family Size x Hatcback	-0.00233***	(0.000606)		
Family Size x Sedan	-0.00109***	(0.00467)		
Age x Safey Index	3.06E-05*	(2.17E-05)		
Family Size x Power Ratio	-0.00519	(0.00699)		
Scale Factor (μ)	0.782***	(0.117)		
Taste For Driving (σ)	0.863***	(0.0247)		
RANDOM	Coefficient	Standard Error	Standard Deviation	Standard Error
Income - Rent (β)	-2.93***	(0.103)	0.0589	(0.0506)
Operating Cost (α)	-1.43***	(0.109)	0.429***	(0.0639)

*$p < 10\%$, **$p < 5\%$, ***$p < 1\%$ (based on simulation-robust standared errors).
Notes: This table presents full information maximum likelihood coefficient estimates with 54 model fixed effects (not shown). Integrals are simulated using 200 shifted and shuffled Halton draws. Number of observation=6132, LL=-29946 at convergence.

Table 4
Fuel Consumption Elasticities.

	Petrol (Long Run)	Petrol (Conditional)	Diesel (Long Run)	Diesel (Conditional)	Total Fuel (Long Run)
Petrol Fuel Price	-1.35***	-0.803***	1.12***	0	-0.389***
	(0.0923)	(0.0666)	(0.143)		(0.0361)
Diesel Fuel Price	0.530***	0	-1.58***	-0.600***	-0.294***
	(0.0728)		(0.126)	(0.0494)	(0.0302)
Petrol Car Price	-0.676***	-0.0431***	1.22***	0	0.0648***
	(0.110)	(0.0181)	(0.201)		(0.0180)
Diesel Car Price	0.948***	0	-1.86***	-0.0374***	-0.15***
	(0.128)		(0.210)	(0.00990)	(0.0210)
Income	0.26***	0.329***	0.490***	0.355***	0.350***
	(0.0234)	(0.0274)	(0.0426)	(0.0317)	(0.0300)

*$p < 10\%$, **$p < 5\%$, ***$p < 1\%$ (based on simulation-robust standared errors).
Notes: This table presents long-run and conditional elasticities of fuel consumption (petrol, diesel, and total) with respect to price or income using paramter estimates presented in Table 3. 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. Bootstrapped standard errors, in parentheses, are calculated by taking 500 random draws from a joint normal distribution based on the point estimates and simulation-robust covariance matrix of the parameter estimates. For each random draw, the elasticities are calculated and standard errors are obtained from the resulting distribution of elasticities.

of *total* fuel consumption with respect to petrol for price of –0.39.[25] 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 -0.150—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 of 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 -1.01. 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 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%.[26]

Table 4 also displays elasticities of fuel consumption conditional on buying a diesel or a petrol vehicle.[27] 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 measure the welfare effects of a policy as the sum of the deadweight loss of the policy and its impact on the externalities associated with fuel consumption (Eq. (2)). As noted in Eq. (1) the deadweight loss of a diesel fuel tax depends on the level of the tax on petrol fuel and on diesel and petrol cars. In 2010, petrol was taxed at a rate of 12.7 Rs./L and diesel and petrol cars were subject to sales taxes of 22.5%. To measure the externalities associated with fuel use, we rely on the work of Parry et al. (2014) who 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, including India. If the value of a statistical life is transferred from the United States 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 Appendix A for details.).

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

[25] Formally, the impact of a marginal change in the diesel fuel tax on total fuel consumption can be expressed as $\frac{dX_d^s}{d\tau_d^f}X_d^f+\frac{dX_d^f}{d\tau_d^f}X_d^s+\frac{dX_p^s}{d\tau_d^f}X_p^f$ where X_i^s is the number of cars sold of fuel type i and X_i^fs average fuel consumption by a car of fuel type i.

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

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

Table 5
Policy simulation results.

		Pre-Policy Baseline	(POLICY 1) 34.46% Diesel Fuel Tax	(POLICY 2) 25.13% Diesel Car Tax	(POLICY 3) 8.34% Diesel Fuel Tax	(POLICY 4) 30.88% Petrol Fuel Tax	(POLICY 5) 8.23% Petrol Fuel Tax
Market Share *(%)*	petrol	66.3%	76.3%	76.3%	69.0%	58.0%	63.9%
	diesel	33.7%	23.7%	23.7%	31.0%	42.0%	36.1%
Total Fuel Consumptions *(10^6 L)*	petrol	1960	2270	2260	2040	1420	1800
	diesel	1260	720	879	1100	1560	1340
Total Fuel Conserved *(%)*			7.18%	2.35%	2.35%	7.18%	2.35%
Total CV *(10^6 Rs. 2010)*			15700	9460	4600	14200	4380
Government Revenue *(10^6 Rs. 2010)*	petrol fuel		3890	3830	1080	9370	3400
	diesel fuel		9100	0	3360	0	0
	petrol car		2370	2250	656	−1940	−550
	diesel car		−3790	3480	−1060	3060	860
Deadweight Loss/ Liter Conserved (Without Externality Abatement Benefit) *(Rs. 2010/L)*			18.0	−1.39	7.53	16.1	8.85
Externality Abatement Benefit *(10^6 Rs. 2010)*			3260	1220	1060	2660	895
Deadweight Loss/ Liter Conserved (With Externality Abatement Benefit) *(Rs. 2010/L)*			3.92	−17.5	−6.48	4.55	−2.98

Notes: This table presents policy simulation results for year 2010 using paramter 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./L and an 8.34% diesel fuel tax amounts to 3.06 Rs./L. In both cases, the existing tax on petrol fuel is assumed equal to 12.65 Rs./L. An 8.23% petrol fuel tax amounts to 3.02 Rs./L and a 30.88% petrol fuel tax amounts to 11.34 Rs./L. In both cases, the new petrol fuel tax is added to the prevailing petrol fuel prices inclusive of the pre-existing petrol fuel tax. The externality abatement benefit is calculated as 12.42 Rs. per liter of petrol fuel conserved and 13.14 Rs. per liter of diesel fuel conserved. Deadweight loss per liter without the externality abatement benefit is calculated as compensating variation per liter minus government revenue per liter. Deadweight loss per liter with the externality abatement benefit is calculated as compensating variation per liter minus government revenue per liter minus externality abatement benefit per liter.

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%.[28] Policy 2 imposes a tax on new diesel vehicles. To make this policy comparable to policy 1, we set the diesel car tax at 25.1%, 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 3.06 Rs./L (8.34%) 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).

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, government revenue, and the external costs of fuel use. We also compute the compensating variation associated with each policy, i.e., the amount of money that new car buyers would have to receive to restore them to their pre-tax level of utility. To calculate the welfare effects of each policy we subtract the increase in government revenues

[28] We note that Policy 1 is very close to levying a Pigovian tax of 13.14 Rs./L on diesel fuel and 12.42 Rs./L on petrol fuel. When we model the Pigovian taxes, they reduce fuel use by 7.09% at a deadweight loss of 8.04 Rs./L and a welfare gain of 4.58 Rs./L.

resulting from the policy from compensating variation and add to this the change in external costs associated with the policy. All results, including reductions in the external costs of fuel use, are extrapolated from our sample to all 2010 new car buyers.[29] Comparisons of market outcomes and welfare results under the policy simulations are presented in Table 5.[30] For ease of comparison we present model simulation results in the absence of any of the above policies (Pre-Policy Baseline).

6.1.1. *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 7.18%. Sixty-nine percent of the reduction in diesel fuel use occurs because people switch to petrol vehicles: the policy results in a decrease in diesel market share from 33.7% to 23.7%. The reduction in diesel fuel consumption is, however, offset by a 15.8% increase in petrol fuel consumption. The buyers who continue to purchase a diesel car decrease their fuel consumption by 18.6%. This effect accounts for 68.5% 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.[31] The compensating variation associated with the diesel tax is, on average, 6790 Rs. per new car buyer, or about 15.7 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 car buyers in 2010 is 20,000 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, however, on what is done with the increased revenue.

To determine the welfare cost of the tax we subtract the change in government revenues from compensating variation and adjust the result for the change in externality costs. The diesel fuel tax generates over 9 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, although car sales tax revenues decline.[32] Subtracting total revenue (11.6 billion Rs.) from compensating variation implies a deadweight loss of 18.0 Rs. per liter of fuel conserved. The reduction in fuel consumption, however, reduces externality costs by 3.26 billion Rs., implying that policy 1 has a net welfare cost of 3.92 Rs./L.

6.1.2. *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 25.1% diesel car tax results in a 2.35% reduction in total fuel consumption by new car buyers. The compensating variation of the car tax is lower, on average, than the diesel fuel tax of policy 1: compensating variation is about 4090 Rs. per household per year. The compensating variation per liter of fuel conserved (117 Rs./L) is, however, almost twice that of policy 1 (68.1 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.[33] The deadweight loss per liter of fuel saved is −1.39 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 15% (approximately 300 million liters), resulting in additional tax revenue of over 3.8 billion Rs. When we take into account the reduction in externalities associated with the diesel car tax, the net welfare cost of the tax is negative—i.e., the tax yields a benefit of 17.5 Rs./L of fuel reduced.

6.1.3. *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 8.34% (3.06 Rs.) tax on diesel fuel would reduce total fuel consumption by 2.35% among new car buyers. The tax would reduce the market

[29] 2,309,000 new passenger vehicles were purchased in India in 2010 (Society of Indian Automobile Manufacturers).

[30] Standard errors are not provided for these results due to the computational burden of calculating them.

[31] 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 Eq. (3) 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.

[32] 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 1.4 billion Rs. We subtract this from the increase in fuel tax revenues in calculating deadweight loss.

[33] 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).

share of diesel vehicles from 34.0% to 31.0%. Two-thirds of the reduction in diesel consumption that results from this tax (161 million liters per year) is due to the shift to petrol vehicles. Again, this reduction is partially offset by an increase of about 85 million liters in petrol consumption. The remainder of the reduction in diesel consumption is due to a 4.96% reduction in diesel consumption by buyers who continue to purchase diesel cars.[34] While compensating variation per liter of fuel conserved is only slightly lower (60.8 Rs./L) than in the case of the larger diesel fuel tax (68.1 Rs./L), deadweight loss per liter of fuel conserved is much smaller (7.53 Rs./L compared with 18.0 Rs./L for policy 1). Once we account for the reduction in externalities associated with reduced fuel consumption the welfare cost of policy 3 is negative, i.e., the policy delivers a benefit of 6.48 Rs./L of fuel conserved.

6.1.4. 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 will shift buyers into the market for diesel, but this will generate no diesel fuel tax revenue to offset the welfare cost of the higher petrol tax. Car sales tax revenues will, however, increase because diesel cars are, on average, more expensive than petrol cars. The analysis of policies 4 and 5 demonstrates the importance of empirical analysis when theory is ambiguous. Policy 4, which saves as much fuel as the larger diesel fuel tax (policy 1), creates a slightly smaller deadweight loss per liter of fuel saved than policy 1 (16.1 Rs./L for policy 5 v. 18.0 Rs./L for policy 1). Policy 5, which reduces total fuel consumption by the same amount as the smaller diesel fuel tax (policy 3), creates a slightly larger deadweight loss per liter of fuel saved than policy 3 (8.85 Rs./L for policy 5 v. 7.53 Rs./L for policy 3). However, when the impact of the taxes on externality costs are taken into account, the diesel fuel taxes perform better than the taxes on petrol fuels: the welfare cost of the large diesel fuel tax (3.92 Rs./L saved) is slightly lower than the petrol fuel tax (4.55 Rs./L saved). The small diesel fuel tax generates benefits of 6.48 Rs./L while the small petrol tax generates benefits of 2.98 Rs./L of fuel conserved.

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.[35] 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.[36]

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).[37] 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.[38]

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. In 2014 the Bureau of Economic Efficiency issued weight-based CAFE standards that went into effect in 2015–16, with more stringent standards for 2020–21. These are weight-based 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 2015-16 standards would decrease fuel consumption by 28% for petrol cars and 12% for diesel cars.[39] Weighting these percentages by market shares, total fuel consumption would decline by about 22%.

We use our model to simulate the market outcome following a hypothetical fuel economy improvement sufficient to

[34] The reduction in diesel consumption by diesel car buyers accounts for approximately 71% of the total reduction in fuel consumed.

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

[36] It is difficult to say much about how the omitted outside option and supply side response would differentially affect our results across the various policies considered here. Our intuition, however, is that ignoring these factors has a larger impact for the more extreme policies. For example, more consumers would prefer to choose the outside option under a 34.5% diesel fuel tax than under an 8.34% diesel fuel tax. By not including that preferred option, it is likely the case that our welfare and deadweight loss calculations are more biased toward larger (in absolute value) values for the large tax policies than for the small tax policies.

[37] 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.

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

[39] These are average figures based on 2010 JD Power data. The standard for 2015-16 is a weight-based standard specifying that liters per 100 kilometers cannot exceed 0.0024*kerbweight (in kilograms) + 3.0014. These figures correspond to a 38% increase in fuel economy for petrol cars and a 14% increase for diesel cars.

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 74%.[40] One might expect this to increase fuel savings, but the rebound effect in both petrol and diesel markets is sizeable. The 28% average reduction in per-kilometer operating cost for petrol vehicles leads to a 26% increase in kilometers driven. The 12% reduction in per-kilometer operating cost for diesel vehicles results in a 8% increase in kilometers driven. The net effect of these adjustments implies that the 2015-16 CAFE standard would, once consumers adjust, reduce fuel consumption by 9% rather than 22%.[41]

7. Conclusions

India, like many developing countries, has historically taxed diesel fuel at a lower rate than petrol. The Netherlands, Germany, France, and Belgium have also taxed 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. It may also lead to greater welfare gains than taxing petrol, depending on the external costs per mile of burning diesel v. petrol.

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. Several results stand out.

If the goal of fuel and car taxation policy is to reduce fuel consumption, this is most effectively done by taxing fuel rather than cars. Levying a tax of 34% on diesel fuel or an additional tax of 31% on petrol fuel reduces fuel consumption by 7.2%.[42] A tax on diesel cars of 25% reduces fuel consumption by only 2.4%. It is clear that a car tax provides no incentive to drive fewer miles—it works only by shifting diesel car buyers to petrol cars, which run on more expensive fuel—but we have quantified the magnitude of this effect. To achieve the same fuel reduction as the car tax requires a tax of 8.3% on diesel fuel or 8.2% on petrol.

The deadweight loss of taxation reflects the loss in consumer surplus in the market in which the tax is imposed, net of any additional government revenues received as a result of the tax. If there were no car sales taxes in India, raising the tax on diesel fuel from its 2010 base of zero would yield a smaller deadweight loss per liter of fuel saved than increasing the tax on petrol: raising the tax on diesel shifts car buyers into petrol cars, and petrol fuel is taxed at a higher rate than diesel. There are, however, car sales taxes of 23% in the year of our study. Because diesel cars are, on average, more expensive than petrol cars, this shift to petrol cars lowers car sales tax revenue. The net effect of these impacts is to cause the deadweight loss per liter of fuel saved by the large diesel tax to equal 18 Rs. while the excess burden of the larger petrol fuel tax is 16 Rs. The results are reversed for the smaller fuel taxes: the deadweight loss of the diesel tax is 7.5 Rs./L while it is 8.9 Rs./L for the petrol tax.

There are however, changes in external costs associated with fuel taxes: taxing diesel reduces the average externality per liter of fuel saved by about 14 Rs., while taxing petrol reduces it by about 12 Rs. Diesel fuel has slightly higher external costs per liter of fuel burned (13 Rs./L v. 12 Rs./L for petrol) and taxing diesel shifts consumers into the fuel with the lower external costs. Taking external costs into account implies that the welfare costs of the large taxes on diesel and petrol are about 3.9 Rs./L and 4.6 Rs./L, respectively, while there is actually a net welfare benefit from the smaller fuel taxes.

Finally, the tax on diesel cars, while not very effective in reducing fuel consumption, has a negative deadweight loss of -1.4 Rs./L—the increase in tax revenues is actually greater than the loss in consumer surplus—and a positive welfare benefit of 18 Rs./L.

Appendix A. Externality Costs of Petrol and Diesel Fuels

We base our estimates of the externality costs of petrol and diesel fuels on a recent study by Parry et al. (2014). The authors quantify the social cost of local and global air pollution, traffic congestion, and road traffic accidents for various countries, including India. For health damages (damages associated with local air pollution and accidents), we combine Parry et al.'s estimates of physical damages per liter of fuel with a value of a statistical life (VSL) for India of $150,000 (in 2010 US dollars). This corresponds to a base VSL of $3.9 million (the base value used by Parry et al.) and an income elasticity of the VSL of one. The corresponding VSL in 2010 rupees (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 (Interagency Working Group on Social Cost of Carbon 2013). The resulting components of externality costs (abatement benefits) per liter of diesel and petrol are as follows(Table A1):

[40] These calculations ignore any pricing response by vehicle manufacturers.

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

[42] Both taxes are calculated as a percent of the net of tax fuel price in 2010 (36.72 Rs./L), although the petrol fuel tax is added to an existing tax of (12.65 Rs./L). The same is true of the diesel car tax—it is calculated as a percent of the base price of the vehicle, but imposed on top of a 22.5% sales tax applied to all vehicles.

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Table A.1
Externality Abatement Benefits by Category and Fuel Type.

	Petrol	Diesel
Global Pollution ($/L)	0.800	0.090
Local Pollution ($/L)	0.009	0.020
Accident Costs ($/L)	0.158	0.158
Congestion Costs ($/L)	0.029	0.024
Total Externality Cost ($/L)	0.276	0.292
Total Externality Cost (Rs./L)	12.42	13.14

Notes: This table presents externality costs (by category and total) per liter of petrol and diesel fuel consumed. Our accident damages per liter of diesel fuel reflect Parry et al.'s (2014) assumption that accident risks are the same for all vehicle classes.

Appendix B. Robustness to Alternative Specification

Table B.1 presents demand parameter estimates using a specification that includes make fixed effects and a large number of car characteristics. Compared to the main specification, which includes model fixed effects, this specification does not control as precisely for unobservable car characteristics. However, it does allow for greater variation in operating cost since not all car models are available in both petrol and diesel variants.

Table B.2 and B.3 use this alternative specification to calculate elasticities and policy simulation results. The tax values used in Table B.3 are not identical to those used in Table 5. Instead, they are the tax values necessary to make the various policies comparable along certain dimensions (e.g. the diesel car tax of policy 2 is that necessary to result in the same diesel market share as in policy 1, policy 3 is the diesel fuel tax necessary to result in the same fuel conservation as in policy 2, etc.). A comparison of Table B.2 and B.3 to Tables 4 and 5, respectively, show little difference in terms of calculated elasticities and policy results.

Table B.1
Demand Model Parameter Estimates with Make Fixed Effects.

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 x Hatcback	-0.00272***	(0.000540)		
Family Size x Sedan	-0.00150***	(0.000589)		
Age x Safey Index	2.29E-05	-3.03E-05		
Family Size x 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 standared 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 observation=6132, LL=-30496 at convergence.

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Table B.2
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***
	(0.0594)	(0.0619)	(0.0469)		(0.0298)
Diesel Fuel Price	0.461***	0	-1.44***	-0.590***	-0.278***
	(0.0248)		(0.0601)	(0.0458)	(0.0260)
Petrol Car Price	-0.596***	-0.0397***	1.08***	0	0.0520***
	(0.0331)	(0.00430)	(0.0481)		(0.00960)
Diesel Car Price	0.820***	0	-1.63***	-0.0345***	-0.128***
	(0.0480)		(0.0693)	(0.00640)	(0.0107)
Income	0.280***	0.350***	0.515***	0.377***	0.371***
	(0.0202)	(0.0243)	(0.0367)	(0.0280)	(0.0265)

*$p < 10\%$, **$p < 5\%$, ***$p < 1\%$ (based on simulation-robust standared errors)
Notes: This table presents long-run and conditional elasticities of fuel consumption (petrol, diesel, and total) with respect to price or income using paramter estimates presented in Table B.1. 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. Bootstrapped standard errors, in parentheses, are calculated by taking 500 random draws from a joint normal distribution based on the point estimates and simulation-robust covariance matrix of the parameter estimates. For each random draw, the elasticities are calculated and standard errors are obtained from the resulting distribution of elasticities.

Table B.3
Policy Simulation Results.

		Pre-Policy Baseline	(POLICY 1) 34.46% Diesel Fuel Tax	(POLICY 2) 24.65% Diesel Car Tax	(POLICY 3) 7.54% Diesel Fuel Tax	(POLICY 4) 20.8% Petrol Fuel Tax	(POLICY 5) 5.1% Petrol Fuel Tax
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 Consumptions	petrol	1970	2240	2230	2040	1500	1840
(10^6 L)	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)*			15700	9400	4100	13500	3760
	petrol fuel		3430	3370	856	9490	3020
Government Revenue	diesel fuel		9500	0	3090	0	0
(10^6 Rs. 2010)	petrol car		2140	2000	531	−1590	−412
	diesel car		−3280	4190	−826	2400	619
Deadweight Loss/ Liter Conserved (Without Externality Abatement Benefit) *(Rs. 2010/L)*			17.3	-2.55	6.97	14.3	8.15
Externality Abatement Benefit *(10^6 Rs. 2010)*			3150	1050	910	2620	769
Deadweight Loss/ Liter Conserved (With Externality Abatement Benefit) *(Rs. 2010/L)*			3.28	−18.6	−6.91	2.66	−3.60

Notes: This table presents policy simulation results for year 2010 using paramter estimates presented in Table B.1. 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./L and an 7.54% diesel fuel tax amounts to 2.77 Rs./L. In both cases, the existing tax on petrol fuel is assumed equal to 12.65 Rs./L. A 5.1% petrol fuel tax amounts to 1.87 Rs./L and a 20.8% petrol fuel tax amounts to 7.63 Rs./L. In both cases, the new petrol fuel tax is added to the prevailing petrol fuel prices inclusive of the pre-existing petrol fuel tax. The externality abatement benefit is calculated as 12.42 Rs. per liter of petrol fuel conserved and 13.14 Rs. per liter of diesel fuel conserved. Deadweight loss per liter without the externality abatement benefit is calculated as compensating variation per liter minus government revenue per liter. Deadweight loss per liter with the externality abatement benefit is calculated as compensating variation per liter minus government revenue per liter minus externality abatement benefit per liter.

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