ABSTRACT

Title of dissertation: The Elephant in the Road
An Economic Analysis of the Indian Car Market

Randy Chugh, Doctor of Philosophy, 2012

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Chapter 2: The Cost of Fuel Economy in the Indian Car Market

To investigate how fuel economy is valued in the Indian car market, I compute the cost to Indian consumers of purchasing a more fuel-efficient vehicle and compare it to the benefit of lower fuel costs over the life of the vehicle. I estimate hedonic price functions for four market segments (petrol hatchbacks, diesel hatchbacks, petrol sedans, and diesel sedans) to compute 95% confidence intervals for the marginal cost to the consumer for an increase in fuel economy. I find that the associated present value of fuel savings falls within the 95% confidence interval for most specifications in all market segments for the years 2002 through 2006. Thus, I fail to consistently reject the hypothesis that consumers appropriately value fuel economy.

Also, I look at vehicle models available in both petrol and diesel form (i.e., twins). Diesel vehicles are generally more expensive than their petrol twins, but, due to higher fuel economy and lower fuel price, have sufficiently lower fuel costs to more than offset the difference. Net savings from purchasing a diesel twin are substantial. Diesel hatchback owners save the equivalent of 50% of the purchase price of their chosen vehicle; diesel sedan owners save 18% of the purchase price of theirs. In 2006, 74% of twin hatchback owners and 59% of twin sedan owners realized these savings by buying the diesel twin. Due to their lower monthly driving distance, forgone savings by owners of petrol twins are lower, but still substantial. Petrol hatchback owners could have saved 24% of the purchase price of their chosen vehicle and petrol sedan owners could have saved 10%. Owners of petrol twins are apparently willing to forgo these substantial savings in order to drive their preferred vehicle.

Chapter 3: Policy Responses to Dieselization in the Indian Car Market

The Indian car market is the fastest growing in the world. With increased mobility, however, has come increased foreign oil dependence, fuel consumption, and associated externalities. In response to this, the Indian government is contemplating fuel economy standards, but at the same time continues to subsidize diesel fuel. The result of this policy has been a diesel discount of 30%, relative to petrol, and *dieselization*, the increasing market share of diesel cars. This chapter uses a model of vehicle choice and vehicle use to compare the welfare impacts of two possible policy responses: diesel fuel taxation and diesel vehicle taxation. Using data comprised of household-level vehicle purchase and driving distance observations from the 2006, 2008, and 2010 JD Power APEAL survey, I estimate a theoretically consistent model of discrete-continuous choice which explicitly accounts for unobserved household and vehicle characteristics and correlation between vehicle choice and driving distance. I find the effect of a diesel fuel tax that eliminates the petrol/diesel price gap to be 4.6 percentage point reduction of the market share of diesel cars based on results from 2006, a 7.9 percentage point reduction based on results from2008, and an 8.6 percentage point reduction based on results from 2010. On average, a diesel car tax of 21.9% would achieve the same result. The diesel car tax option, however, does relatively little to change intensive margin incentives. A smaller diesel fuel tax, sufficient to yield the same total fuel conservation as the diesel car tax, compares favorably to both policies on efficiency grounds. While the subsidy eliminating diesel fuel tax is more efficient than the diesel car tax in terms of deadweight loss per liter of fuel conserved, the smaller diesel fuel tax actually results in a net welfare gain. This result comes from the fact that the pre-existing tax on petrol fuel raises enough revenue from those would-be diesel car buyers who are compelled to buy a petrol instead to more than compensate them back to their pre-tax utility levels. Comparing compensating variation of the subsidy eliminating diesel fuel tax to the diesel car tax, neither policy imposes a consumer welfare cost of more than 2% of new car buyers' average annual income. However, the welfare burden as a share of household income is found to be greater for the poorest households.

The Elephant in the Road
An Economic Analysis of the Indian Car Market

by

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Foreword

Chapter 2 of this dissertation includes material jointly authored with Maureen Cropper and Urvashi Narain. A shortened version was published in the November 2011 issue of *Energy Policy* (Chugh et al., 2011). I have made a substantial contribution to this work and have complied with all University of Maryland guidelines for including jointly authored and previously published research as part of my dissertation.

Dedication

This is for Carly. Everything is for Carly.

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I would also like to thank Urvashi Narain for her role in the early stages of this research project. Thanks also to Tara Kaul for tracking down back-issues of *AutoCar India* and going to great lengths to acquire them. This research has benefited greatly from seminar participants at University of Maryland and Camp Resources 2011. Thanks to Rob Williams, John Rust, John Chao, and Ginger Jin for serving on my dissertation committee and for their invaluable feedback.

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Finally, I would like to thank my advisor, Maureen Cropper. Maureen is held in high esteem by the economics profession and is widely regarded as a true scholar. For those of us lucky enough to have worked closely with her, she is an even truer friend.

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Chapter 1

Introduction

The Indian car market is among the fastest growing in the world. With increased mobility, however, has come increased foreign oil dependence, fuel consumption, and associated externalities. A recent report on vehicular pollution control (Central Pollution Control Board, 2010) finds that road vehicle-related pollution accounts for 70% of CO, 50% of HC, 30–40% of NOx, 30% of SPM, and 10% of SO2 in India's major metropolitan areas. While the majority of privately owned, non-commercial vehicles, and the major contributor to road vehicle pollution, is comprised of two-wheelers, recent studies suggest that the gap between car and motorcycle ownership is quickly closing. Dargay et al. (2007) project continued growth of the car market could lead to a car ownership rate of 110 cars per 1000 people by 2030, up from just 16 cars per 1000 people in 2010. With a population of over 1 billion people, the human health and welfare consequences of car-related pollution are staggering. In response to this, the Indian government is becoming increasingly aggresive in its approach to the regulation of transportation externalities. While many studies of car regulation have been conducted in the United States and other developed countries, little is known about how these lessons generalize to a developing country context. This dissertation seeks to fill this gap by providing results from both reduced form and structural econometric analyses of the Indian car market.

As fuel consumption is of concern for both energy security and environmental reasons, much of the Indian debate has centered on policies to increase vehicle fuel economy. One argument for fuel economy standards (as opposed to higher fuel taxes) is that consumers undervalue fuel savings; that is, they fail to buy a more fuel-efficient vehicle even though the additional purchase price is less than the present value of fuel savings. The second chapter presents results from a hedonic price function analysis designed to test this undervaluation hypothesis. To investigate how fuel economy is valued in the Indian car market, I compute the cost to Indian consumers of purchasing a more fuel-efficient vehicle and compare it to the benefit of lower fuel costs over the life of the vehicle. I estimate hedonic price functions for four market segments (petrol hatchbacks, diesel hatchbacks, petrol sedans, and diesel sedans) to compute 95% confidence intervals for the marginal cost to the consumer for an increase in fuel economy. I find that the associated present value of fuel savings falls within the 95% confidence interval for most specifications in all market segments for the years 2002 through 2006. Thus, I fail to consistently reject the hypothesis that consumers appropriately value fuel economy.

To further consider how Indian consumers value fuel economy and other vehicle characteristics, I look at vehicle models available in both petrol and diesel form (i.e., twins). Diesel vehicles are generally more expensive than their petrol twins, but, due to higher fuel economy and lower fuel price, have sufficiently lower fuel costs to more than offset the difference. Net savings from purchasing a diesel twin are substantial. Diesel hatchback owners save the equivalent of 50% of the purchase price of their chosen vehicle; diesel sedan owners save 18% of the purchase price of theirs. In 2006, 74% of twin hatchback owners and 59% of twin sedan owners realized these savings by buying the diesel twin. Due to their lower monthly driving distance, forgone savings by owners of petrol twins are lower, but still substantial. Petrol hatchback owners could have saved 24% of the purchase price of their chosen vehicle and petrol sedan owners could have saved 10%. Owners of petrol twins are apparently willing to forgo these substantial savings in order to drive their preferred vehicle.

The third chapter delves deeper into the notion of consumers' willingness to pay for preferred vehicle characteristics. Using data comprised of household-level vehicle purchase and driving distance observations from the 2006, 2008, and 2010 JD Power APEAL survey, I estimate a theoretically consistent model of discrete-continuous choice which explicitly accounts for unobserved household and vehicle characteristics and correlation between vehicle choice and driving distance. I apply the model to two potential policy responses to the increasing market share of diesel cars: diesel fuel taxation and diesel car taxation.

I find the effect of eliminating the diesel subsidy to be a 2 percentage point reduction of the market share of diesel cars based on results from 2006 and 2008. A diesel car tax of 21% would achieve the same result. Based on 2010 results, however, diesel subsidy removal results in a 9 percentage point reduction of the market share of diesel cars, a result that requires a diesel car tax of just 19% to achieve. The diesel car tax option, however, does relatively little to change intensive margin incentives. 2006 results show a reduction of diesel fuel consumption of only 7% compared to 37% for diesel subsidy elimination. Based on 2008 results, the effect would have been a 6% reduction in diesel fuel consumption from diesel car taxation vs. 34% from diesel subsidy removal. Based on 2010 results, diesel car taxation would have resulted in a 29% reduction in diesel fuel consumption vs. 59% for diesel subsidy removal. Because of consumers' ability to substitute among the wide variety of cars now available in the Indian market, neither policy imposes a welfare cost of more than 2% of new car buyers' average annual income. However, the welfare burden as a share of household income is found to be greatest for the poorest households.

Though the Indian car market is arguably in its early stages, current sales growth rates, rapid economic development, and the shear numbers of potential owners point to its increasing importance to India's, and indeed the world's, environment and economy. The studies presented here provide a first look at some policy-relevant aspects of a market that is shaping the future of Indian transportation. Though much work remains, the following chapters also offer a glimpse into the extension of lessons learned from the U.S. and Europe to a developing country context.

Chapter 2

The Cost of Fuel Economy in the Indian Car Market

2.1 Introduction

As a result of India's economic boom, the demand for passenger vehicles has grown swiftly over the last decade. In April 2002, passenger vehicle sales were approximately $50,000$; by April 2008, monthly sales had tripled to approximately $150,000$. To put these figures in perspective, January 2008 monthly sales were approximately 1 million in the United States and approximately $650,000$ in China. With such rapid growth, many in India are advocating for strong legislative action to avoid the many economic, security, and environmental concerns that may accompany the expansion of the vehicle fleet.

As fuel consumption is of concern for both energy security and environmental reasons, much of the Indian debate has centered on policies to increase vehicle fuel economy. One argument for fuel economy standards (as opposed to higher fuel taxes) is that consumers undervalue fuel savings; that is, they fail to buy a more fuel-efficient vehicle even though the additional purchase price is less than the present value of fuel savings. This hypothesis has been tested extensively in the United States. Although much of the literature suggests that consumers undervalue fuel savings (Alcott and Wozny, 2010), other studies (Sallee et al., 2010) suggest that consumers are willing to pay an extra dollar when buying a car to reduce the present value of fuel costs by a dollar. This essay examines how car buyers in India value fuel savings.

The approaches that have been used to determine whether consumers undervalue fuel economy include hedonic price methods, studies of the impact of gasoline prices on used car prices, and structural estimates of the parameters of consumers' utility functions (Greene, 2010; Helfand and Wolverton, 2010). Hedonic price methods compare what consumers must pay for additional fuel economy in the market–as estimated by a hedonic price locus–with the associated reduction in fuel expenditures (Espey and Nair, 2005).[1] If the two are equal, when evaluated at chosen vehicle bundles, the null hypothesis that consumers rationally value fuel economy cannot be rejected. The advantage of this approach is that it does not require data on market shares; however, because estimates often rely on cross-sectional variation in vehicle characteristics, multicollinearity can make it difficult to obtain precise estimates of the marginal price of fuel economy, and omitted variable bias is a concern.

The hypothesis that consumers accurately value fuel economy has also been tested using data on used car prices. Because the used car market is competitive, the prices of used cars should adjust to reflect changes in the price of gasoline (Li et al., 2009). Klier and Linn (2008) use a similar approach in the new car market. They examine whether, within a given model year, monthly variation in gasoline prices is reflected in new car prices and market shares. Indeed, if consumers correctly value fuel economy, prices should adjust fully to reflect the change in the present value of

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[1] In an oligopolistic car market, the hedonic price function represents the locus of opportunities facing car buyers, even though it is no longer the envelope of tangencies between marginal bid and marginal offer curves.

fuel expenditures (Sallee et al., 2010). This can be tested by examining variation in car and gasoline prices while holding vehicle characteristics fixed.[2]

A third approach, used by Alcott and Wozny (2010), is to examine how consumers weigh the present value of fuel expenditures against purchase price, holding other vehicle characteristics constant. This requires identifying the parameters of consumers' utility functions. Recognizing that both the demand and supply of new vehicles respond to gasoline prices, Allcott and Wozny use expected vehicle operating cost at the time when the vehicle was new to instrument for the quantity of used vehicles available on the market.

Unfortunately, approaches that have been used in the literature to examine how consumers value fuel economy are difficult to apply in India because of a lack of data (e.g., on used car prices) and insufficient variation in the price of fuel over time. In this paper, I take a simpler hedonic price approach to examine how Indian car buyers value fuel economy.

2.1.1 My Approach

I test the hypothesis that consumers accurately value fuel economy by computing the marginal price that consumers face for an improvement in fuel economy and comparing this to the present value of associated fuel savings. For each of four vehicle types (petrol hatchbacks, diesel hatchbacks, petrol sedans, and diesel sedans), I estimate hedonic price functions treating fuel economy as one of several

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[2] This test rests on assumptions about future gasoline prices. Sallee et al. (2010) assume that gasoline prices follow a random walk; hence today's price is the best estimate of tomorrow's price. According to Anderson et al. (2010) consumer forecasts of gasoline prices agree with this assumption.

performance characteristics. To account for the possible correlation between fuel economy and unobserved vehicle characteristics, I instrument for the fuel economy of, for example, petrol hatchbacks of a given make using the average fuel economy of petrol sedans of the same make. I use these estimates to compute a 95% confidence interval for the marginal price of fuel economy and ask whether the present value of fuel savings falls within this interval for the average buyer in each market.[3]

Based on these results, I cannot consistently reject the null hypothesis that the mean consumer equates the marginal price of fuel economy to the present value of fuel savings. In all markets and years, for most specifications of the hedonic price function, the present value of fuel savings falls within the 95% confidence interval of the fuel economy premium. The result is robust to the rate used to discount fuel savings (10% or 15%) and to assumptions about future fuel price expectations (that they will remain constant or increase at historic rates).

In addition to within-segment trade-offs, I examine the trade-offs faced by buyers of twins, models that are available in both petrol and diesel form. Diesel versions are generally more expensive than their petrol twins, but cost less to operate because of their greater fuel economy and the fact that diesel fuel is 30% cheaper than petrol. The savings that buyers of diesel twins realize over the life of their vehicles are substantial. Over the expected life of his vehicle, the average diesel

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[3] My hedonic analysis indicates that the new car market is segmented by vehicle size (hatchback vs. sedan) and fuel type (petrol vs. diesel). So, the cost of buying additional fuel economy is conditional on market segment. Average kilometers driven also vary by market segment. I judge rationality conditional on market segment. I thus compute the fuel savings that diesel car buyers would realize if they were to buy a more fuel-efficient diesel car, rather than the fuel savings a person in the petrol hatchback market would realize if they were to buy a more fuel-efficient diesel car.

hatchback owner saved the equivalent of 50% of the purchase price of his vehicle by selecting it over its petrol twin; the average diesel sedan owner saved 18%. The percentage of twin hatchback owners taking advantage of these savings by buying the diesel twin has risen each year from 46% in 2002 to 74% in 2006. Similarly, 17% of twin sedan owners bought the diesel twin in 2002 and this rose to 59% in 2006.

Petrol car buyers drive fewer kilometers than buyers of diesel cars, but the fuel savings from buying a diesel twin still outweigh the additional purchase price. Petrol hatchback owners could have saved 24% of the purchase price of their chosen vehicle by buying a diesel; petrol sedan owners could have saved 10%. Does this mean that buyers of petrol twins undervalue fuel economy? Diesel cars, however, differ from their petrol twins in other performance characteristics: they are generally heavier and less powerful. It is possible that petrol car buyers accurately value fuel economy but are willing to forgo potential savings to buy a more powerful car. In fact, the fuel savings forgone are a lower bound to the value rational petrol car buyers place on these differences in characteristics. I explore this further in Section 2.4

The rest of the paper is organized as follows. Section 2.2 presents stylized facts about the Indian car market. Section 2.3 presents the hedonic analysis and Section 2.4 compares the cost and fuel economy of petrol and diesel twins. Section 2.5 concludes.

2.2 Overview of the Indian Passenger Vehicle Market

Sales of passenger vehicles in India have been growing rapidly–from approximately $50,000$ cars per month in 2002 to approximately $150,000$ per month in 2008. The market is highly concentrated, with the top five manufacturers accounting for nearly 90% of the market between 2002 and 2006. Maruti Suzuki accounted for 48% of sales, Tata Motors 18%, and Hyundai 15%. Mahindra and Toyota each accounted for 4%. Figure 2.1 shows average market shares by body type and fuel type for the same period. The majority of passenger vehicles sold in India are small cars: hatchbacks constitute approximately 65% of the market, sedans about 17%, sport utility vehicles (SUVs) 12%, and vans 5%. The remainder of the market is composed of multi-use vehicles (MUVs), wagons, and coupes.

Averaged over the years 2002 through 2006, 73% of passenger vehicles ran on petrol and 27% on diesel, but the fuel breakdown varied significantly by body type. Approximately 85% of hatchbacks and 75% of sedans ran on petrol, whereas virtually all SUVs ran on diesel (only 3% used petrol). Because I examine the petrol/diesel fuel choice, the remainder of the paper focuses on hatchbacks and sedans. For hatchbacks, diesel market share has remained constant at around 15% between 2002 and 2006. For sedans, a trend of increasing diesel market share (i.e., dieselization) has taken place, from 11% in 2002 to 32% in 2006.

During the period of study fuel prices were set by the Indian government and varied little across cities.[4] In this analysis, I use fuel prices in Delhi. In 2008 petrol in

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[4] In 2006 the average price of petrol (in 2008 Rs. per liter) based on 25 Indian cities was 51.6, with a standard deviation of 2.34. (The corresponding diesel figures are Rs. 36.2 with a standard deviation of 2.01.) Since 2010 the Indian government has not controlled the price of

Delhi sold at 45 Rs. per liter (\$4.20 per gallon) and diesel at 31 Rs. per liter (\$2.90 per gallon). Diesel fuel in India is priced below petrol because of its uses in the agricultural sector. The gap between the two fuel prices has remained constant in percentage terms since around 2002, but the historic percentage gap is even greater. Between 2002 and 2008, the price of diesel and petrol (in real terms) rose by about 2 Rs. per year.

Tables 2.1 and 2.2 describe the characteristics of petrol and diesel hatchbacks and sedans. Table 2.1 describes vehicle characteristics at the model level (e.g., Honda Accord) for the period 2002 to 2006, weighted by market share. Table 2.2 summarizes the same variables at the version level (e.g., Honda Accord LX), not weighted by market share, for the period 2002 through 2008. These are the data used to estimate the hedonic price functions.

Vehicle characteristics data, which cover the period 2002 to 2008, come from AutoCar India, an Indian car industry magazine, and Segment Y, a private market research firm. Additional data on body type classification and fuel type come from Carwale, a website that provides information for car buyers (www.Carwale.com). All market share data come from SIAM statistics and the 2002–2006 waves of the J.D. Power Asia Pacific APEAL study, an annual survey of approximately $5,000$ new car buyers in India.

Throughout the paper, I focus on city fuel economy rather than highway fuel economy. AutoCar India reports both city and highway fuel economy data; however, city fuel economy data correlate much better with fuel economy data reported

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petrol; however, as of this writing, it controls the price of diesel.

by respondents in the APEAL survey. 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).[5]

How do diesel and petrol cars compare in terms of fuel economy and other performance characteristics? Diesel hatchbacks are heavier and less powerful than petrol hatchbacks (see Table 2.1) but have better fuel economy in city driving. The fact that diesel hatchbacks weigh more reflects their larger engine size: no diesel hatchbacks are produced with engines smaller than 1,250 cubic centimeters, which is larger than the mean petrol hatchback engine. On average, diesel hatchbacks have higher torque than petrol hatchbacks, but their ratio of torque to weight is lower. Diesel hatchbacks have about 1 kilometer-per-liter (kpl) greater fuel economy than petrol hatchbacks (sales-weighted). The difference in fuel economy is much greater between diesel and petrol sedans: diesel sedans have about 2.7 kpl greater fuel economy than petrol sedans. Diesel sedans have a horsepower-to-weight ratio that is only 70% of that of a petrol sedan, but have 15% more torque and a 5% higher torque-to-weight ratio.

To put this study in perspective, I note that Indian cars are lighter and less powerful than cars in the United States (Environmental Protection Agency, 2008). Between 2002 and 2006, the average weight of an Indian petrol hatchback (sales-

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[5] I do not use self-reported fuel economy data from the APEAL survey because it is reported at the model, but not the version, level.

weighted) was about 1,700 pounds; for an Indian petrol sedan it was 2,300 pounds. In the United States in 2006, the average car weighed approximately 3,500 pounds.[6] The average horsepower-to-weight ratio (in horsepower per pound) was 0.032 for the Indian petrol hatchback, 0.041 for the Indian petrol sedan, and 0.054 for an average car in the United States. In view of their lighter weight and lower horsepower ratio, it is not surprising that the average fuel economy of the Indian petrol hatchback and sedan (28.5 and 22.6 miles per gallon in city driving, respectively) was greater than that of the average U.S. car (19.4 miles per gallon).[7] Estimates of fuel economy technical frontiers, which show how fuel economy varies with vehicle characteristics, suggest that Indian cars are not necessarily as fuel efficient as U.S. cars, holding weight and horsepower constant.[8]

2.3 Hedonic Price Approach

The hedonic approach to evaluating how buyers value fuel economy asks whether consumers equate the marginal cost of buying a more fuel-efficient vehicle to the present value of fuel savings. Such a comparison tests the null hypothesis that new car buyers are willing to pay an extra rupee in purchase price to decrease the present value of fuel costs by a rupee. Formally, new car buyers face a function that describes vehicle price (P) as a function of fuel economy (kpl) and other vehicle

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[6] The EPA *car* category is comparable to hatchbacks and sedans, as it excludes SUVs, wagons, vans, and pickup trucks.

[7] The figures for the United States are the adjusted city miles per gallon as reported in Environmental Protection Agency (2008), rather than laboratory results.

[8] When a fuel economy technical frontier model estimated using Indian data is used to predict the fuel economy of an average U.S. car, predicted fuel economy is less than 16 miles per gallon.

characteristics (Z), such as weight, horsepower, and type of transmission (automatic or manual). I assume quasilinear preferences over consumption of an outside good (x) and vehicle subutility (u), which depends on Z and driving distance, but not directly on fuel economy. K denotes the vector of distances driven each year over the car's lifetime. Each buyer chooses the (Z, K, kpl) bundle that maximizes his utility (U),

$$U = x + u(Z, K). \tag{2.1}$$

If the buyer is sufficiently forward-looking, he considers the impact of kpl on the present value of fuel costs over the life of the vehicle, and thus faces the budget constraint,

$$y = x + P(kpl, Z) + \sum_{t=0}^{T} \frac{1}{(1+r)^t} K(t) \frac{p_f(t)}{kpl} \pi(t). \tag{2.2}$$

In equation 2.2, T is the life of the vehicle, r is the buyer's discount rate, $p_f(t)$ is the (expected) price of fuel in year t, and $\pi(t)$ is the vehicle's probability of survival to year t. The first-order conditions to this problem imply that, at chosen level of fuel economy, the marginal cost of an additional unit of fuel economy must equal the reduction in fuel costs resulting from the additional fuel economy,

$$\frac{\partial P}{\partial kpl} = \sum_{t=0}^{T} \frac{1}{(1+r)^t} K(t) \frac{p_f(t)}{kpl^2} \pi(t). \tag{2.3}$$

To test whether this condition is satisfied, I estimate hedonic price functions facing consumers in four vehicle markets–petrol hatchbacks, diesel hatchbacks, petrol sedans, and diesel sedans–and compute the 95% confidence intervals for the cost of a

1 kpl increase in fuel economy, evaluated at the sales-weighted mean (Z, kpl) vector for each vehicle type. I compute the associated reduction in fuel costs over the life of the vehicle based on the sales-weighted mean driving distance in each market.

Because I focus on sales-weighted mean vehicle characteristics and driving distances, ours is a test of whether car buyers choose fuel economy optimally, on average. Note also that equation 2.2 treats the new car buyer as the sole owner of the vehicle. A rational new car buyer who keeps a car until it is scrapped is equivalent to a rational new car buyer who can sell the vehicle to another rational (used) car buyer before it is scrapped. Thus the null hypothesis assumes that both the new and used car markets operate efficiently. An alternative would be to evaluate the rationality of new car buyers, conditional on prices in the used car market. Data on the used car market in India, however, are not readily available.

2.3.1 Estimation of the Hedonic Price Function

The problems involved in estimating the marginal price of fuel economy using hedonic price functions are well known. Correlation between fuel economy and vehicle characteristics, such as weight and horsepower, make precise estimation of the marginal price difficult, and correlation between fuel economy and unobserved vehicle characteristics (such as acceleration) leads to omitted variable bias, which renders estimates inconsistent (Atkinson and Halvorsen, 1984; Espey and Nair, 2005). To deal with these issues, I estimate different specifications of the hedonic price function and instrument for fuel economy. For comparison purposes, I also present ordinary least squares (OLS) results.

In each specification, the logarithm of vehicle price is expressed as a function of subsets of vehicle characteristics described in Table 2.3 (Cropper et al., 1988),

$$\log P(Z_j) = \sum_{i=1}^{n} \beta_i z_{ji} + \epsilon_j \tag{2.4}$$

where z_{ji} is the i^{th} characteristic of vehicle j.[9]

The vehicle characteristics that are most highly correlated with fuel economy, but which are valued in their own right, are vehicle weight and engine performance. Engine performance is usually measured by torque (or horsepower) and by engine size.[10] Horsepower (or torque) relative to vehicle weight determines how much "pickup" a car has (i.e., how well it accelerates). I use different combinations of engine size, torque, and the ratio of horsepower to weight to measure performance. All four specifications of the hedonic price function include fuel economy, weight, indices that measure a vehicle's luxury and safety features, and whether the car has an automatic transmission. Specification 1 uses the ratio of horsepower to weight to measure performance; specification 2 adds engine size to specification 1. Specification 3 measures performance by torque, and specification 4 adds engine size to specification 3. The data used to estimate hedonic price functions (summarized in Table 2.2) include all versions available in each market over the period 2002–2008, unweighted by sales.

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[9] Cropper et al. (1988) find that hedonic price functions that are linear in the explanatory variables perform better than functions using quadratic forms of the explanatory variables when some variables are measured with error or missing from the equation.

[10] Holding engine speed constant, horsepower is a multiple of torque.

I separate the market into sedans and hatchbacks as vehicles of very different sizes and price ranges are unlikely to be close substitutes. I also segment the market according to fuel type as the marginal price of fuel economy is likely to differ by fuel type as a result of the diesel-petrol price differential. Wald tests allow us to reject the null hypothesis that these market segments should be combined.

I instrument for fuel economy because gains in fuel economy are often achieved by sacrifices in weight, horsepower, and other desirable characteristics. Although I control for observable characteristics in the model, failure to account for correlation between higher fuel economy and unobservable attributes may bias fuel economy coefficients downward. I instrument for the fuel economy of petrol hatchbacks of a given make using the average fuel economy of petrol sedans of the same make. I instrument for the fuel economy for each petrol sedan of a given make using the average fuel economy of petrol hatchbacks of the same make. Instruments for diesel vehicles are constructed analogously. For example, the 2002 Fiat petrol hatchbacks, the Palio (which comes in 11 versions), and the Uno (which comes in 2 versions), all have the same value of the instrument, which is constructed as the average fuel economy of all 7 versions of the 2002 Fiat petrol sedan (the Siena). The 2002 Fiat Siena (all 7 versions) share the same IV value, which is equal to the average fuel economy of all 13 2002 Fiat petrol hatchbacks.

The instrument is constructed to reflect the fuel economy technology available to manufacturers at the time of vehicle design. Sedan fuel economy should be correlated with hatchback fuel economy, but not with unmeasured hatchback design characteristics, provided manufacturers' design decisions are made separately for each vehicle segment. Even if this last assumption is violated, I believe that sedan fuel economy will certainly be less correlated with unmeasured hatchback design features than the hatchback's own fuel economy.

2.3.2 Hedonic Price Function Results

Instrumental variable (IV) estimates of of the hedonic price function are presented in Tables 2.4–2.7.[11] Ordinary Least Squares (OLS) estimates and IV estimates of the fuel economy coefficients are presented for all four specifications in Table 2.8.[12] To focus the discussion, I give special attention to specification 4 which fits well in all market segments. Most coefficients are statistically significant, with expected signs. Vehicle price varies positively with weight, torque, engine size, luxury index, and automatic transmission (relative to manual). For all vehicle categories, quality-adjusted prices are approximately 20–40% lower in 2008 than in 2002. Holding vehicle characteristics constant, petrol car prices have fallen more than diesel car prices.

What is the marginal cost to consumers of buying a car with greater fuel economy? IV estimates from Table 2.8 suggest that the cost of fuel economy ranges from 1–10% of vehicle price. As expected, this is higher than the marginal cost in the OLS models, suggesting that fuel economy is negatively correlated with desirable, but unmeasured, vehicle characteristics.

I compute 95% confidence intervals for the cost of a 1 kpl increase in fuel

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[11] First stage results for specification 4 are presented in Table A.1 of Appendix A.

[12] Full OLS results are presented in Tables A.2–A.5 of Appendix A.

economy holding all other vehicle characteristics at their sales-weighted means for each year. Table 2.9 presents these cost calculations for years 2002–2006 for each market segment based on the IV results from specification 4. The marginal price of fuel economy is generally falling between 2002 and 2005. This reflects the fact that, holding vehicle characteristics constant, the real price of a car is falling in each market over this period.

2.3.3 The Savings from Improved Fuel Economy

I compute the savings from a 1 kpl increase in fuel economy using the discrete counterpart to equation 2.3,

$$\sum_{t=0}^{T} K(t) \frac{1}{(1+r)^t} \left(\frac{p_f(t)}{kpl} - \frac{p_f(t)}{kpl+1} \right) \pi(t). \tag{2.5}$$

Savings are evaluated in each market segment based on the mean monthly driving distance by buyers in that segment, averaged over the years 2002 through 2006. These monthly driving distances are $1,070$ kilometers (petrol hatchback owners), $1,870$ kilometers (diesel hatchback owners), $1,300$ kilometers (petrol sedan owners), and $1,870$ kilometers (diesel sedan owners). I use these driving distances to estimate $K(0)$ (distance driven during the first year of ownership) and then allow $K(t)$ to decline at a rate of 2.5% per year as the car ages. This is the rate at which distance driven declines in the US (Lu, 2006). Barth et al. (2007) suggest that distance driven may decline more rapidly in India, suggesting that these estimates may overstate fuel cost savings.[13]

To calculate fuel savings, I must also make assumptions about vehicle life, interest rates, and future fuel prices. The probability of a car surviving to each future age, $\pi(t)$, is based on a survival curve for Indian cars estimated by Arora et al. (2011). Their survival curve sets T equal to 20 and implies an expected vehicle life of 18 years. In contrast, the expected life of a car in the United States is 13 years (Lu, 2006). Interest rates are also higher in India than in the United States. I use a discount rate of 15% for car buyers, 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 (Shankar, 2007; Carazoo.com, 2011; Seth, 2009). As a sensitivity analysis, I also use a discount rate of 10% (the return on certificates of deposits in India in 2011).[14] Following Anderson et al. (2010), I assume that consumers expect future fuel prices to follow a random walk. This allows us to replace $p_f(t)$ in equation 2.5 with $p_f(0)$, the price of fuel at the time of vehicle purchase.[15] As a sensitivity analysis, I allow $p_f(t)$ to increase at the rate of 2 Rs. per year, approximately the average rate of increase for both diesel and petrol over the 2002–2008 period.

In addition to the 95% confidence intervals of the cost of a 1 kpl increase in fuel economy, Table 2.9 presents point estimates of the present value of corresponding

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[13] Barth et al. (2007) report that distance driven decrease with vehicle age at the rate of 794 kilometers per year, based on data from Pune. Unfortunately this is based on vehicles aged 13 years or younger, so that distance driven falls to zero at age 13. Since the expected vehicle life is 18 years, distance driven cannot decrease this rapidly.

[14] `http://articles.economictimes.indiatimes.com/2011-02-03/news/28427857_1_cd-rates-short-term-rates-policy-rates`

[15] For each model year, I construct a sales-weighted average petrol price and a sales-weighted average diesel price. I weight monthly fuel price, reported in Indiastat.com, by monthly vehicle sales.

fuel savings. Fuel savings calculations are presented for both discount rate assumptions and both fuel price expectations assumptions. Fuel savings are increasing in absolute terms over the 2002 to 2006 period as a result of increases in the real prices of both diesel and petrol. In all years, fuel savings are sensitive to discount rate and fuel price expectations assumptions. To illustrate, 2006 fuel savings are 57% higher for petrol vehicles and 70% higher for diesel vehicles using a discount rate of 10% and allowing prices to increase by 2 Rs. per year, compared to a discount rate of 15% and an assumption of constant real fuel prices.

To test the null hypothesis that consumers equate the marginal price of fuel economy to the present value of fuel savings, I subtract the fuel savings reported in Table 2.9 from the marginal price of fuel economy (based on Table 2.9) to construct 95% confidence intervals of the net costs of purchasing additional fuel economy. If zero lies within this interval, I cannot reject the null hypothesis. Figure 2.2 presents results based on a discount rate of 15% and the assumption that fuel prices are expected to remain constant. Figure 2.3 uses a discount rate of 10% and assumes that fuel prices are expected to increase at 2 Rs. per year.

The results presented in Figures 2.2 and 2.3, based on hedonic price function specification 4, show that for all four segments in all years I find no evidence of fuel economy undervaluation. In fact, in Figure 2.2 consumers in the diesel hatchback market appear to be overvaluing fuel economy in 2002 to 2004. Using other specifications of the hedonic price function (see Table 2.9) I generally fail to reject the hypothesis that consumers equate the cost of additional fuel economy to the present value of fuel savings. The only cases in which consumers undervalue fuel economy occur in the 2005 and 2006 markets for petrol hatchbacks when results from specifications 1 or 2 are combined with the 10% discount rate and increasing fuel price assumptions. Overall, these results provide little support for the argument that fuel economy standards in India are justified because consumers undervalue fuel economy.

2.4 Lowering Fuel Costs by Purchasing a Diesel Vehicle

Another way in which consumers can reduce their fuel costs is to purchase a diesel rather than a petrol car. In this section, I compare the additional cost of buying a diesel vehicle with the savings in fuel costs using data on twins–models that are available in both diesel and petrol form. More sedans than hatchbacks are available in diesel form. Of the 34 petrol sedan models available in 2006, 12 of them had diesel twins, whereas only two of 11 petrol hatchback models available in 2006 had a diesel twin. A similar pattern is reflected in market shares: in 2002, twins accounted for 62% of sedan sales and 31% of hatchback sales. In 2006, twins accounted for 54% of sedan and 19% of hatchback sales.

On average, diesel twins cost more, but have better fuel economy. Table 2.10 shows results of regressing the log of vehicle price and the log of fuel economy on a diesel dummy variable and model-year dummy variables for the hatchback and sedan markets. On average, diesel hatchbacks cost 9.5% more than their petrol twins; diesel sedans cost 7.7% more. The difference in fuel economy is large: diesel hatchbacks are on average 27%, and diesel sedans 30%, more fuel efficient than their petrol twins.

2.4.1 The Cost Savings from Buying a Diesel Twin

The cost advantage of a diesel twin is the difference between the purchase price of the petrol and diesel versions of the vehicle plus the present value of savings in fuel costs over the life of the vehicle,[16]

$$P_p - P_d + \sum_{t=0}^{T} \frac{1}{(1+r)^t} K(t) \left(\frac{p_p(t)}{kpl_p} - \frac{p_d(t)}{kpl_d} \right) \pi(t) \tag{2.6}$$

where the p and d subscripts refer to petrol and diesel, respectively.

The fuel savings of a diesel are substantial: the fuel cost per kilometer of a diesel car is about half that of its petrol twin. To illustrate, a petrol sedan that achieves average fuel economy (9 kpl) costs 5 Rs. per kilometer to operate at a petrol price of 45 Rs. per liter. Its diesel twin, with a fuel economy of 12 kpl, costs only 2.5 Rs. per kilometer because diesel fuel is one-third cheaper (30 Rs. per liter). The corresponding figures for hatchbacks are 4.5 Rs. per kilometer for petrol hatchbacks vs. 2.3 Rs. per kilometer for their petrol twins.[17] In both cases, two-thirds of the reduction in fuel costs is due to the lower price of diesel fuel and one-third to the better fuel economy of diesel vehicles.[18]

Total fuel savings from buying the diesel twin increase with driving distance.

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[16] This ignores differences in maintenance costs and survival probabilities between diesel and petrol vehicles.

[17] This is based on 10 kpl for a petrol hatchback and 13 kpl for a diesel hatchback.

[18] At 9 kpl, the petrol sedan would cost 30/9 = 3.33 Rs. per kilometer if petrol cost the same per liter as diesel. Increasing fuel economy from 9 to 12 kpl reduces the cost per kilometer from 3.33 to 2.5 Rs. So 1.67 Rs. of the 2.5-Rs. reduction in cost comes from the lower cost of diesel fuel.

For buyers who drive 2,000 kilometers per month, the present value of fuel savings is about 240,000 Rs. over the life of a hatchback and 320,000 Rs. over the life of a sedan. For buyers who drive 1,000 kilometers per month, the savings are still substantial: about 98,800 Rs. for a hatchback and 139,000 Rs. for a sedan. To obtain net savings, the difference in purchase price of the diesel and petrol vehicles (41,400 Rs. for hatchbacks and 86,600 Rs. for sedans) must be subtracted from the fuel savings.

I have calculated the net fuel savings from buying a diesel for 21 hatchback and 70 sedan models for which a twin was available over the period 2002–2006. In these computations, fuel savings are based on mean monthly driving distances for each vehicle type, using a 15% discount rate and constant fuel price expectations. Expressed as a percentage of the average price of his chosen vehicle type, the average net fuel savings realized by buyers of diesel hatchbacks was 50%. The corresponding figure for diesel sedan owners was 18%. At the same time, buyers of petrol hatchbacks gave up savings equal to 24% of the price of their cars, and buyers of petrol sedans gave up savings equal to 10% of the price of their cars.

What percentage of twin buyers realized these savings? In 2006, 74% of hatchback twin buyers bought a diesel hatchback, and 59% of sedan twin buyers bought a diesel sedan; these percentages have risen steadily since 2002. Clearly, the majority of twin buyers realized significant savings. Does this mean that the buyers of petrol twins undervalued fuel savings? As Table 2.11 shows, diesel and petrol twins differ noticeably in weight and in performance: diesel twins are generally heavier and less powerful than their petrol counterparts. It could be that buyers of petrol twins value these characteristics enough to forgo the fuel savings from buying a diesel.

2.4.2 The Value Petrol Car Buyers Place on the Petrol Twin

It is straightforward to show that the net fuel expenditure savings forgone by petrol car buyers (equation 2.6) is a lower bound to the money these buyers would have to receive to keep their utility constant if they were forced to buy the diesel twin instead. Let x^* denote the income remaining after the petrol car buyer purchases a petrol car (Z_p) and drives K^* kilometers. Let x' denote the income remaining if he drives K^* kilometers but buys the diesel twin (Z_d). If the buyer is rational, he prefers (x^*, Z_p, K^*) to (x', Z_d, K^*); that is,

$$U(x^*, Z_p, K^*) > U(x', Z_d, K^*). \tag{2.7}$$

There is, however, some amount of money, $\hat{x}$, that will make him as happy as with the petrol twin, implicitly defined by

$$U(x^*, Z_p, K^*) = U(\hat{x}, Z_d, K^*). \tag{2.8}$$

To keep his utility constant, the amount the petrol buyer would have to be given (his compensating variation) if forced to buy a diesel car is $\hat{x} - x^*$. Because $\hat{x} > x'$, $x' - x^*$ is a lower bound to this value. From equation 2.6, $x' - x^*$ equals the net value of fuel savings from buying a diesel; that is, equation 2.6 evaluated at K^*.

This implies that the lower bound to the value placed on characteristics Z_p

(vs. Z_d) is approximately $110,000$ Rs. for buyers of petrol hatchbacks and $153,000$ Rs. for buyers of petrol sedans. It is, of course, impossible to say whether this is rational. To judge how these car buyers valued fuel economy requires estimating a model of the demand for vehicle characteristics (see Alcott and Wozny (2010)).

2.5 Conclusion

The debate over mitigating the environmental impact of India's rapidly expanding vehicle fleet has centered on reducing fuel consumption. One commonly cited justification for fuel economy standards, as opposed to higher fuel taxes, is the belief that consumers undervalue fuel economy when making purchasing decisions. I have addressed this concern by comparing the cost to consumers of increased fuel economy to the associated fuel savings. Based on IV estimates of hedonic price functions, I cannot consistently reject the hypothesis that the mean consumer equates the marginal price of fuel economy to the present value of fuel savings. To test this hypothesis, I have estimated the marginal cost of fuel economy to consumers in four market segments using four specifications of the hedonic price function for five model years. By comparing these results to fuel price savings calculated under two sets of alternate assumptions about the discount rate and future fuel price expectations, I put consumer rationality to the test a total of 160 times. Of the 31 instances in which I reject the hypothesis, only nine provide any evidence of fuel economy undervaluation while the remaining 22 indicate that consumers may, in fact, be overvaluing fuel economy.

To further understand the trade-offs faced by consumers, I considered the choices faced by potential buyers of twins. Diesel versions of twins are, in general, more expensive than their petrol counterparts but have sufficiently lower operating costs as to more than offset the difference in purchase price. Net savings from purchasing a diesel twin are substantial. By choosing their vehicle over its petrol twin, diesel hatchback owners save the equivalent of 50% of the purchase price of their chosen vehicle; diesel sedan owners save 18%. In 2006, 74% of twin hatchback owners and 59% of twin sedan owners realized these savings by buying the diesel twin. Because of their lower monthly driving distance, forgone savings by owners of petrol twins are lower, but still substantial: petrol hatchback owners could have saved 24% of the purchase price of their chosen vehicles, and sedan owners 10%, by buying a diesel. This does not mean that buyers of petrol twins were irrational; they may have been willing to forgo these savings to drive a more powerful petrol vehicle.

There are limits to what can be said using the data on vehicle characteristics and prices used in this paper. The next step in this analysis is to estimate models of vehicle demand and miles driven using individual household data on vehicle purchases. These models can be used to compute the welfare effects of changes in fuel taxes (e.g., the impact of equalizing the cost of diesel and petrol) and of imposing fuel economy standards. If, for example, auto manufacturers in India were to meet fuel economy standards by reducing vehicle weight and horsepower, as was done in the United States (Klier and Linn, 2008), this could result in a welfare loss to Indian consumers. To justify such an intervention, these losses should be compared to the welfare gains from reduced pollution, congestion, and dependence on foreign oil. Such a comparison of costs and benefits cannot be accomplished without first quantifying both.

Table 2.1: Sales-Weighted Model Level Summary Statistics

VARIABLES	UNITS	petrol hatchback	diesel hatchback	petrol sedan	diesel sedan
Price	10^5 Rupees 2008	4.09	4.63	8.76	8.62
	(USD 2008)	(10400)	(11800)	(22200)	(21900)
Weight	1000 kilograms	0.773	0.976	1.04	1.13
	(pounds)	(1700)	(2150)	(2300)	(2490)
Power Ratio	horsepower/kilogram	0.0707	0.0559	0.0892	0.0607
	(horsepower/pound)	(0.0321)	(0.0254)	(0.0405)	(0.0275)
Engine Size	cubic centimeters	972	1420	1540	1570
Torque	kilogram-meters	7.89	9.00	13.0	14.9
	(foot-pounds)	(57.0)	(65.1)	(94.1)	(108)
City Fuel Economy	kilometers/liter	12.1	13.0	9.60	12.3
	(miles/gallon)	(28.5)	(30.7)	(22.6)	(29.0)
Luxury Index[a]		2.04	2.16	4.71	4.11
Safety Index[b]		0.427	0.221	0.889	0.978
Automatic		0.131	0.000	0.124	0.005
Distance Driven	kilometers/month	1070	1870	1300	1870
	(miles/month)	(663)	(1160)	(808)	(1160)
# of models		43	12	72	31

Notes: Version level vehicle characteristics data come from AutoCar India and Segment Y. Model/fuel-type level market share data come from SIAM and the JD Power APEAL survey. Each model is available in multiple versions. For each year, and for each vehicle category, model/fuel-type level vehicle characteristics are constructed as the unweighted average across all available versions of each model/fuel-type. The within-year sales-weighted average of these models is calculated for each vehicle category. The resulting year-representative vehicles are averaged across years 2002 to 2006 and presented above.

[a] *Luxury index* is defined as the sum of www.Carwale.com luxury rating(0-none, 1-luxury, or 2-super luxury) and the dummy variables for air conditioning, power steering, central locking, power windows, alloy wheels, leather seats, power mirrors, and CD player.

[b] *Safety index* is defined as the sum of the dummy variables for airbags, rear seat belts, antilock braking system, and traction control.

Table 2.2: Version Level Summary Statistics (Standard Deviations in Parentheses)

VARIABLES	UNITS	petrol hatchback	diesel hatchback	petrol sedan	diesel sedan
Price	10^5 Rupees 2008	4.71	4.84	14.3	13.0
		(1.42)	(0.758)	(15.8)	(9.24)
Weight	1000 kilograms	0.907	0.991	1.19	1.22
		(0.155)	(0.0950)	(0.219)	(0.170)
Power Ratio	horsepower/kilograms	0.0749	0.0603	0.0946	0.0666
		(0.00906)	(0.00900)	(0.0191)	(0.0175)
Engine Size	cubic centimeters	1160	1570	1810	1810
		(244)	(220)	(580)	(317)
Torque	kilogram-meters	9.81	10.8	16.1	18.4
		(2.32)	(2.85)	(6.04)	(8.47)
City Fuel Economy	kilometers/liter	11.0	13.1	8.70	11.6
		(1.42)	(1.12)	(1.37)	(1.67)
Luxury Index[a]		2.91	2.48	5.82	5.50
		(1.73)	(1.47)	(2.56)	(2.62)
Safety Index[b]		0.775	0.781	1.71	1.61
		(0.727)	(0.766)	(1.41)	(1.46)
Automatic		0.041	0.000	0.212	0.146
		(0.199)	(0.000)	(0.409)	(0.354)
# of versions		244	64	411	158

Notes: Version level vehicle characteristics data come from AutoCar India. For each vehicle category, the unweighted average across all available versions from years 2002 to 2008 is presented above with standard deviations in parentheses.

[a] *Luxury index* is defined as the sum of www.Carwale.com luxury rating(0-none, 1-luxury, or 2-super luxury) and the dummy variables for air conditioning, power steering, central locking, power windows, alloy wheels, leather seats, power mirrors, and CD player.

[b] *Safety index* is defined as the sum of the dummy variables for airbags, rear seat belts, antilock braking system, and traction control.

Table 2.3: Explanatory Variables

Variable	Description
Price	Price of vehicle in Delhi inclusive of taxes and fees in 2008 rupees
Weight	Weight of vehicle in thousands of kilograms
Power Ratio	Ratio of horsepower to vehicle weight (horsepower/kilograms)
Engine Size	Volume of engine (cubic centimeters)
Torque	Engine torque (kilogram-meters)
Luxury Index	The sum of Carwale.com luxury rating (0-none, 1-luxury, or 2-super luxury) and the dummy variables for air conditioning, power steering, central locking, power windows, alloy wheels, leather seats, power mirrors, and cd player
Safety Undex	The sum of the dummy variables for airbags, rear seat belts, antilock braking system, and traction control
Automatic	A dummy variable for transmission type (0-manual or 1-automatic)
City Fuel Economy	Fuel economy measured under urban driving conditions in kilometers per liter

Table 2.4: Hedonic Price Function IV Estimation Results–Petrol Hatchback

VARIABLES	(1) ln(Price)	(2) ln(Price)	(3) ln(Price)	(4) ln(Price)
City Fuel Economy	0.0316*	0.0155	0.0935***	0.0899***
	(0.0179)	(0.0302)	(0.0314)	(0.0285)
Weight	0.975***	1.099***	0.593***	0.548***
	(0.119)	(0.102)	(0.147)	(0.130)
Power Ratio	10.93***	12.77***		
	(1.069)	(1.669)		
Engine Size		-0.000200		0.000473
		(0.000192)		(0.000290)
Torque			0.0744***	0.0274
			(0.0125)	(0.0229)
Luxury Index	0.0721***	0.0713***	0.0852***	0.0845***
	(0.00512)	(0.00505)	(0.00669)	(0.00646)
Safety Index	-0.0294**	-0.0296**	-0.0349*	-0.0286*
	(0.0131)	(0.0127)	(0.0181)	(0.0166)
Automatic	0.155***	0.143***	0.163***	0.173***
	(0.0361)	(0.0395)	(0.0501)	(0.0511)
y2003	-0.0684***	-0.0759***	-0.0328	-0.0293
	(0.0254)	(0.0257)	(0.0344)	(0.0336)
y2004	-0.125***	-0.132***	-0.0924**	-0.0927***
	(0.0265)	(0.0273)	(0.0366)	(0.0353)
y2005	-0.208***	-0.218***	-0.174***	-0.163***
	(0.0251)	(0.0268)	(0.0342)	(0.0346)
y2006	-0.149***	-0.159***	-0.125***	-0.115***
	(0.0256)	(0.0280)	(0.0354)	(0.0363)
y2007	-0.268***	-0.273***	-0.305***	-0.278***
	(0.0258)	(0.0251)	(0.0355)	(0.0355)
y2008	-0.290***	-0.300***	-0.326***	-0.289***
	(0.0246)	(0.0257)	(0.0331)	(0.0381)
Constant	-0.580*	-0.410	-0.868*	-0.894*
	(0.346)	(0.462)	(0.522)	(0.519)
Observations	236	236	236	236
R^2	0.881	0.888	0.781	0.794

Notes: This table presents hedonic price function IV estimation results using petrol hatchbacks for years 2002 to 2008. To analyze sensitivity of results, we present four different specifications. Standard errors are in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 2.5: Hedonic Price Function IV Estimation Results–Diesel Hatchback

VARIABLES	(1) ln(Price)	(2) ln(Price)	(3) ln(Price)	(4) ln(Price)
City Fuel Economy	0.0734***	0.0873***	0.0633***	0.0830***
	(0.0182)	(0.0181)	(0.0192)	(0.0193)
Weight	1.308***	1.180***	0.784***	0.753***
	(0.158)	(0.189)	(0.175)	(0.188)
Power Ratio	6.721***	5.412***		
	(1.189)	(1.335)		
Engine Size		0.000127**		0.000156***
		(6.23e-05)		(5.99e-05)
Torque			0.0213***	0.0161***
			(0.00407)	(0.00444)
Luxury Index	0.0376***	0.0385***	0.0392***	0.0399***
	(0.00688)	(0.00727)	(0.00671)	(0.00713)
Safety Index	0.000191	-0.0131	0.000624	-0.0158
	(0.0141)	(0.0156)	(0.0139)	(0.0154)
Automatic	0	0	0	0
	(0)	(0)	(0)	(0)
y2003	-0.0575**	-0.0651**	-0.0617**	-0.0700**
	(0.0293)	(0.0311)	(0.0290)	(0.0310)
y2004	-0.150***	-0.150***	-0.146***	-0.147***
	(0.0291)	(0.0305)	(0.0286)	(0.0302)
y2005	-0.0905**	-0.0672*	-0.0990**	-0.0682*
	(0.0392)	(0.0404)	(0.0392)	(0.0408)
y2006	-0.000269	0.0391	-0.0132	0.0384
	(0.0432)	(0.0453)	(0.0432)	(0.0459)
y2007	-0.144***	-0.0991**	-0.156***	-0.0978**
	(0.0408)	(0.0437)	(0.0413)	(0.0445)
y2008	-0.236***	-0.169***	-0.257***	-0.168***
	(0.0413)	(0.0493)	(0.0440)	(0.0517)
Constant	-1.091***	-1.281***	-0.260	-0.695*
	(0.351)	(0.353)	(0.384)	(0.390)
Observations	64	64	64	64
R^2	0.851	0.836	0.856	0.839

Notes: This table presents hedonic price function IV estimation results using diesel hatchbacks for years 2002 to 2008. To analyze sensitivity of results, we present four different specifications. Standard errors are in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 2.6: Hedonic Price Function IV Estimation Results–Petrol Sedan

VARIABLES	(1) ln(Price)	(2) ln(Price)	(3) ln(Price)	(4) ln(Price)
City Fuel Economy	0.0484**	0.0597***	0.0699**	0.0843***
	(0.0220)	(0.0197)	(0.0306)	(0.0304)
Weight	1.355***	0.914***	0.828***	0.742***
	(0.112)	(0.138)	(0.138)	(0.137)
Power Ratio	5.984***	3.344***		
	(0.863)	(0.960)		
Engine Size		0.000442***		0.000461***
		(6.75e-05)		(8.95e-05)
Torque			0.0485***	0.0176**
			(0.00580)	(0.00830)
Luxury Index	0.0513***	0.0453***	0.0471***	0.0437***
	(0.00481)	(0.00443)	(0.00509)	(0.00508)
Safety Index	0.0117	0.0159*	0.0198*	0.0264**
	(0.00965)	(0.00886)	(0.0111)	(0.0110)
Automatic	0.108***	0.0513	0.0785	0.0614
	(0.0407)	(0.0397)	(0.0484)	(0.0479)
y2003	-0.0256	-0.0192	-0.0114	-0.00107
	(0.0292)	(0.0268)	(0.0335)	(0.0332)
y2004	-0.149***	-0.159***	-0.147***	-0.149***
	(0.0270)	(0.0251)	(0.0301)	(0.0298)
y2005	-0.228***	-0.222***	-0.204***	-0.191***
	(0.0337)	(0.0309)	(0.0417)	(0.0413)
y2006	-0.266***	-0.261***	-0.275***	-0.258***
	(0.0281)	(0.0258)	(0.0304)	(0.0303)
y2007	-0.304***	-0.280***	-0.314***	-0.276***
	(0.0269)	(0.0247)	(0.0290)	(0.0297)
y2008	-0.391***	-0.361***	-0.407***	-0.362***
	(0.0291)	(0.0270)	(0.0306)	(0.0315)
Constant	-0.450	-0.512	-0.176	-0.529
	(0.356)	(0.325)	(0.417)	(0.418)
Observations	216	216	216	216
R^2	0.905	0.919	0.897	0.899

Notes: This table presents hedonic price function IV estimation results using petrol sedans for years 2002 to 2008. To analyze sensitivity of results, we present four different specifications. Standard errors are in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 2.7: Hedonic Price Function IV Estimation Results–Diesel Sedan

VARIABLES	(1) ln(Price)	(2) ln(Price)	(3) ln(Price)	(4) ln(Price)
City Fuel Economy	0.0973**	0.0398*	0.103***	0.0447**
	(0.0383)	(0.0210)	(0.0272)	(0.0177)
Weight	1.856***	1.146***	1.843***	0.677**
	(0.447)	(0.271)	(0.470)	(0.338)
Power Ratio	1.557	7.269***		
	(3.573)	(2.091)		
Engine Size		0.000129**		0.000201***
		(4.99e-05)		(5.24e-05)
Torque			0.00350	0.0228***
			(0.00759)	(0.00555)
Luxury Index	0.0367***	0.0418***	0.0362***	0.0411***
	(0.0104)	(0.00792)	(0.0101)	(0.00751)
Safety Index	-0.000268	-0.0208	0.000541	-0.0255
	(0.0240)	(0.0195)	(0.0237)	(0.0189)
Automatic	0	0	0	0
	(0)	(0)	(0)	(0)
y2003	0.145	-0.0165	0.158*	-0.0190
	(0.113)	(0.0727)	(0.0920)	(0.0672)
y2004	0.0308	-0.128*	0.0419	-0.140**
	(0.111)	(0.0720)	(0.0925)	(0.0677)
y2005	0.0848	-0.126	0.102	-0.128*
	(0.140)	(0.0843)	(0.109)	(0.0767)
y2006	0.136	-0.0898	0.154	-0.0976
	(0.149)	(0.0889)	(0.117)	(0.0820)
y2007	0.0714	-0.161*	0.0900	-0.164**
	(0.152)	(0.0903)	(0.117)	(0.0818)
y2008	0.0119	-0.230**	0.0318	-0.228***
	(0.162)	(0.0965)	(0.122)	(0.0859)
Constant	-1.578*	-0.462	-1.597**	0.0221
	(0.831)	(0.475)	(0.799)	(0.527)
Observations	42	42	42	42
R^2	0.914	0.943	0.909	0.947

Notes: This table presents hedonic price function IV estimation results using diesel sedans for years 2002 to 2008. To analyze sensitivity of results, we present four different specifications. Standard errors are in parentheses, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 2.8: OLS and IV Hedonic Price Function City Fuel Economy Coefficients

		(1)	(2)	(3)	(4)	Observations
Petrol hatchback	OLS	0.0144**	0.000870	0.0128	0.00381	244
		(0.00673)	(0.00739)	(0.00776)	(0.00860)	
	IV	0.0316*	0.0155	0.0935***	0.0899***	236
		(0.0179)	(0.0302)	(0.0314)	(0.0285)	
Diesel hatchback	OLS	0.0358***	0.0363***	0.0281**	0.0292***	64
		(0.0107)	(0.0103)	(0.0110)	(0.0104)	
	IV	0.0734***	0.0873***	0.0633***	0.0830***	64
		(0.0182)	(0.0181)	(0.0192)	(0.0193)	
Petrol sedan	OLS	0.0472***	0.0442***	0.0264**	0.0260**	411
		(0.0114)	(0.0114)	(0.0107)	(0.0106)	
	IV	0.0484**	0.0597***	0.0699**	0.0843***	216
		(0.0220)	(0.0197)	(0.0306)	(0.0304)	
Diesel sedan	OLS	0.0137	0.0273***	0.00866	0.0239**	158
		(0.0103)	(0.00983)	(0.0112)	(0.0107)	
	IV	0.0973**	0.0398*	0.103***	0.0447**	42
		(0.0383)	(0.0210)	(0.0272)	(0.0177)	

Notes: This table presents OLS and IV fuel economy coefficient estimates for all four hedonic price function specifications. Standard errors are in parentheses, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 2.9: Fuel Economy Premium vs. Present Discounted Value of Fuel Savings

	2002	2003	2004	2005	2006
Petrol hatchback					
FE Premium	42600	38600	36800	35300	37500
	[14400, 70800]	[13400, 63700]	[13500, 60000]	[12800, 57800]	[13500, 61500]
PDV of fuel savings					
$r = 0.15$, constant p_f	16675	17980	21022	21850	23087
$r = 0.15$, increasing p_f	20972	22310	25680	26404	27579
$r = 0.10$, constant p_f	21278	22943	26824	27881	29460
$r = 0.10$, increasing p_f	27779	29495	33873	34772	36256
Diesel hatchback					
FE Premium	40800	41400	38100	35300	42500
	[22200, 59400]	[21500, 61300]	[19800, 56400]	[20800, 51700]	[24800, 60300]
PDV of fuel savings					
$r = 0.15$, constant p_f	16405	16050	17918	25691	27174
$r = 0.15$, increasing p_f	23160	22129	23984	33322	34801
$r = 0.10$, constant p_f	20933	20480	22864	32782	34674
$r = 0.10$, increasing p_f	31155	29678	32042	44328	46215
Petrol sedan					
FE Premium	77100	79400	74700	65300	68500
	[19900, 134000]	[21600, 137000]	[19300, 130000]	[19000, 112000]	[18000, 114000]
PDV of fuel savings					
$r = 0.15$, constant p_f	30863	34722	37241	43735	45093
$r = 0.15$, increasing p_f	38816	43085	45494	52851	53866
$r = 0.10$, constant p_f	39382	44306	47520	55807	57540
$r = 0.10$, increasing p_f	51415	56960	60008	69600	70814
Diesel sedan					
FE Premium	45500	35400	33200	31600	35400
	[11600, 79500]	[11000, 59800]	[9590, 56800]	[10300, 53000]	[10700, 60000]
PDV of fuel savings					
$r = 0.15$, constant p_f	16393	21130	21259	28381	27294
$r = 0.15$, increasing p_f	23143	29133	28456	36812	34954
$r = 0.10$, constant p_f	20918	26962	27127	36215	34827
$r = 0.10$, increasing p_f	31132	39072	38017	48971	46418

Notes: FE premium results are based on hedonic price function IV estimates presented in Tables 2.4-2.7 (specification 4). Delta method 95% confidence intervals are presented in brackets. All values are in 2008 Rupees. Present discounted value of fuel savings is calculated using vehicle survival probability and declining annual driving distances discussed in text. Calculations are presented for interest rates of 15% and 10% as well as constant p_f and increasing p_f.

Table 2.10: Differences between Petrol and Diesel Twins in Price and Fuel Economy

	Hatchback		Sedan	
VARIABLES	ln(Price)	ln(City FE)	ln(Price)	ln(City FE)
Diesel	0.0945***	0.271***	0.0767***	0.301***
	(0.0210)	(0.00921)	(0.00988)	(0.00853)
Constant	1.51***	2.37***	2.47***	2.15***
	(0.00819)	(0.00361)	(0.00475)	(0.00390)
Model-Year Dummies	YES	YES	YES	YES
Observations	343	314	689	579
R^2	0.815	0.895	0.989	0.909

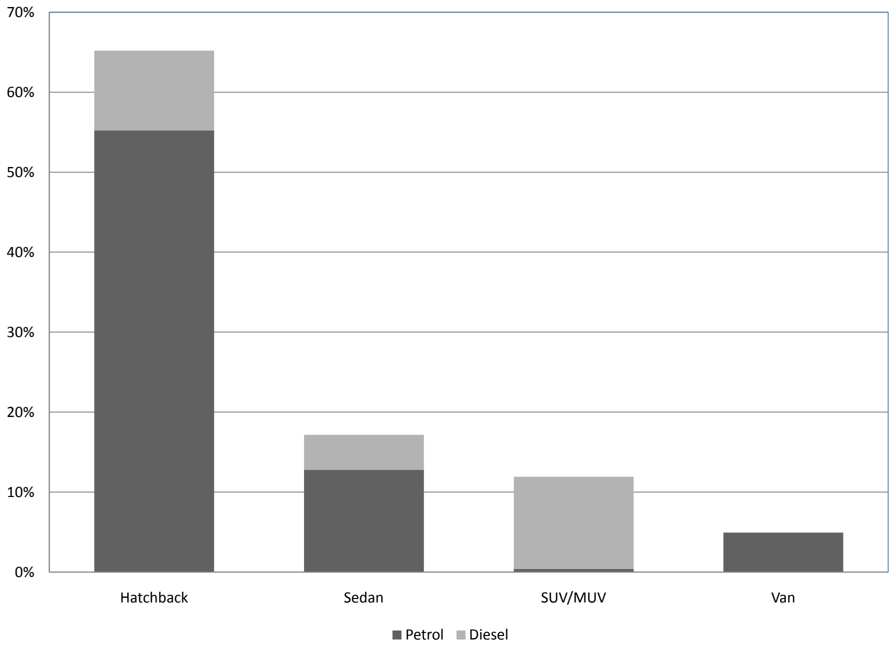
Notes: This table presents regression results using all available petrol and diesel hatchback and sedan twins for years 2002 to 2008. Standard errors are in parentheses, $***p < 0.01$, $**p < 0.05$, $*p < 0.1$.

Table 2.11: Twins-Only Version-Level Summary Statistics

VARIABLES	UNITS	petrol hatchback	diesel hatchback	petrol sedan	diesel sedan
Price	10^5 Rupees 2008	4.61	4.84	12.0	12.7
		(0.938)	(0.758)	(10.9)	(9.35)
Weight	1000 kilograms	0.957	0.991	1.15	1.22
		(0.101)	(0.0950)	(0.198)	(0.170)
Power Ratio	horsepower/kilogram	0.0761	0.0603	0.0896	0.0658
		(0.00755)	(0.00900)	(0.0168)	(0.0175)
Engine Size	cubic centimeters	1280	1570	1680	1800
		(169)	(220)	(370)	(320)
Torque	kilogram-meters	10.7	10.8	15.0	18.0
		(1.67)	(2.85)	(4.65)	(8.40)
CityFuel Economy	kilometers/liter	10.1	13.1	8.75	11.6
		(0.995)	(1.12)	(1.22)	(1.69)
Luxury Index		2.82	2.48	5.04	5.33
		(1.53)	(1.47)	(2.55)	(2.57)
Safety Index		0.730	0.781	1.40	1.49
		(0.647)	(0.766)	(1.41)	(1.38)
Automatic		0.000	0.000	0.133	0.127
		(0.000)	(0.000)	(0.341)	(0.334)
# of versions		74	64	210	150

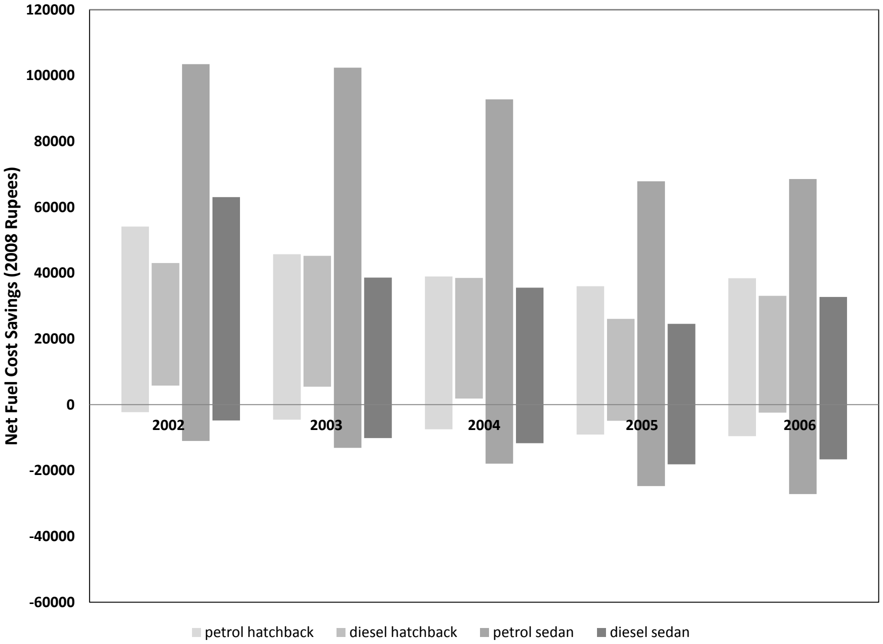
Notes: The unweighted average across all available twin hatchback and sedan version is presented above with standard deviations in parentheses.

Figure 2.1: Market Shares by Body- and Fuel-Type, Averaged Over 2002 to 2006



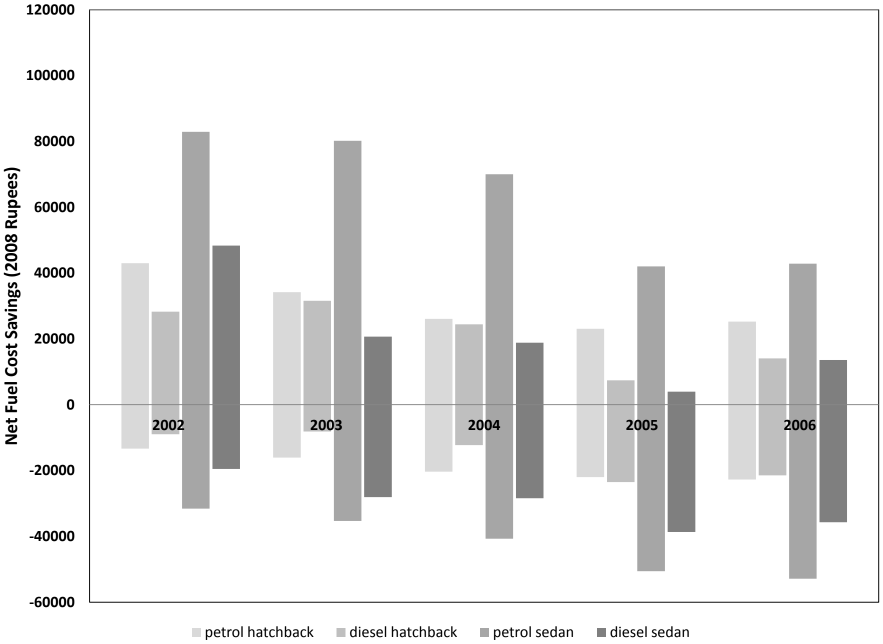
Source: Author's calculations based on annual vehicle sales data from SIAM and the J.D. Power APEAL survey

Figure 2.2: 95% Confidence Intervals of Fuel Economy Premium Minus Present Discounted Value of Fuel Savings ($r = 15\%$; constant fuel prices)



Notes: The graph presents 95% confidence intervals of hedonic price function specification 4 estimates of the price of a 1 kpl improvement in fuel economy minus the associated present discounted value of fuel savings, calculated using a 15% discount rate. Fuel prices are expected to remain constant over the life of the vehicle.

Figure 2.3: 95% Confidence Intervals of Fuel Economy Premium Minus Present Discounted Value of Fuel Savings ($r = 10\%$; increasing fuel prices)



Notes: The graph presents 95% confidence intervals of hedonic price function specification 4 estimates of the price of a 1 kpl improvement in fuel economy minus the associated present discounted value of fuel savings, calculated using a 10% discount rate. Fuel prices are expected to increase by 2 Rs. per year over the life of the vehicle.

Chapter 3

Policy Responses Dieselization in the Indian Car Market

3.1 Introduction

Since the sweeping economic reforms of 1991, the Indian car market has grown at an average rate of 15% per year.[1] Recent years have seen even more dramatic growth with 2010 sales exceeding the previous year's by 32%. During this same period of rising incomes, economic growth, and increasing demand, the market has experienced *dieselization*, the increasing market share of diesel cars. Driven by consumers' strong preference for low operating cost vehicles, the market share of diesel cars has risen from 23% in 2002 to 40% in 2010.

With increased mobility, has come increased foreign oil dependence, fuel consumption, and associated externalities. Although the Indian government has responded to transportation-related pollution with fuel quality standards, emissions standards, and is now contemplating fuel economy standards, their continued subsidization of diesel fuel may be undermining these efforts.[2] Table 3.1 presents emis-

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[1] I use 1991 as a demarcation between *pre-liberalization* and *post-liberaliztion* periods because of the magnitude of the changes ocurring in and and around that year and its prevelance as a focal point in the literature. Alternative demarcations specific to the automotive industry include 1983, the initial year of collaboration between state owned Maruti Udyog and Japanese firm Suzuki, and 1993, the year the passenger car market was delicensed. See Panagariya (2008) for a more thorough and nuanced discussion of liberalization and see Ranawat and Tiwari (2009) for its implications for the Indian car market.

[2] I use *subsidy* as a catch-all for the differential policy treatment of petrol and diesel fuels and its impact on retail prices. The major component of the difference is diesel's lower rate of excise taxation, but other interventions play an important role as well. A full discussion of the politics and mechanics of price control is beyond the scope of this chapter, but see Chaturvedi (2008) and

sions factors estimates for various pollutants (Baidya and Borken-Kleefeld, 2009) along with their associated health consequences (Central Pollution Control Board, 2010). The emissions factors indicate that although diesel cars are less pollution intensive for HC (hydrocarbons) and $CO2$ (carbon dioxide), they are far worse for NOx (nitrous oxides), PM (particulate matter), and $SO2$ (sulphur dioxide).[3]

The policy objectives of petroleum pricing are clear: provide kerosene to the poor for lighting, incentivize household use of natural gas and kerosene over firewood and dung, insulate the economy from oil shocks, and promote financial viability of domestic oil companies to minimize reliance on imports (Parikh, 2010). Recently, however, greater attention has been paid to the unintended consequences of market intervention. In addition to dieselization of the car market, these include the use of trucks for freight transport instead of far more efficient trains, adulteration of diesel fuel with kerosene, fuel shortages, and financial losses for state-owned and private oil companies alike.[4] In light of the economic and social consequences of diesel subsidization, a 2010 report from *The Expert Group on a Viable and Sustainable System of Pricing of Petroleum Products* recommended that petrol and diesel fuel prices

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Parikh (2010) for further detail.

[3] Note, however, that the emissions factors shown are in grams per kilometer. As discussed below, diesel cars are significantly cheaper to drive and are thus driven more, attenuating any pollution benefits of dieselization and exacerbating its harmful environmental and public health consequences.

[4] This is the short list. In 2008, Reliance and Essar, India's largest private fuel retailers, collectively closed over $2,500$ fueling stations (Kulshrestha, 2010); because private companies were ineligible to benefit from oil bonds and other financing schemes, their operations had become unprofitable. A 2005 report from the National Council of Applied Economic Research found that as much as 38% of subsidized kerosene winds up on the black market (NCAER, 2005). Shenoy (2010) makes the assertion that black market money is entwined with the political process, funding the campaigns of corrupt officials. On November 19, 2005, 27 year old Shanmughan Manjunath, a marketing manager for the Indian Oil Corporation, was murdered by fuel station owner Pawan Kumar Mittal for his role in disrupting the latter's adulteration scheme. It is not the only murder to result from attempted interference with the subsidy-induced black market (The Hindu, 2011).

“be market determined both at the refinery gate and retail levels.” While stopping short of advocating for an end to diesel subsidization, the group recommended “an additional excise duty on a diesel vehicle corresponding to the differential tax on the petrol should be levied.”

This chapter compares the diesel car tax recommendation of the Expert Committee to a diesel fuel tax. I present a structural econometric analysis of the market for new cars and simulations of market responses to these alternative regimes. Using data from the JD Power APEAL survey, I model the joint decision of which car to buy and how much to drive it in a mixed logit discrete-continuous choice framework. The model accounts for unobserved vehicle characteristics by including body type and manufacturer-specific constants and household heterogeneity by allowing preferences to reflect demographics and to be distributed according to sensible random distributions. Because car choice and car use decisions are determined by a common set of simultaneously estimated, randomly distributed parameters, the model accounts for correlation that might otherwise result in biased parameter estimates and behavioral predictions.

I estimate the model separately for years 2006, 2008, and 2010 and simulate the demand-side response for each of these three years. In each year, I consider the effect of a diesel fuel tax that would result in equalizing the price of petrol and diesel fuel. I then simulate the effects of a diesel car tax that would result in the same reduction in the market share of diesel cars. Finally, a smaller diesel fuel tax that would result in the same total fuel savings as the diesel car tax is considered.

For each policy, I simulate changes in market shares, driving distances, and total fuel use. I compare the relative efficiency of each policy by calculating compensating variation, government revenue, and deadweight loss per liter of fuel conserved. For these calculations, I assume the difference between diesel and petrol prices is entirely the result of a pre-existing tax on petrol. I further assume that there is no petrol car tax. Because the JD Power survey is conditional on purchasing a new car, I can not model the extent to which total vehicle sales would change and thus all estimates are conditional on total vehicle sales.

In 2006, for example, a 44.5% diesel fuel tax would eliminate the disparity between diesel and petrol prices and reduce the market share of diesel cars from 28.3% to 23.7%. To achieve the same market share outcome, a diesel car tax of 24.5% would be necessary. The diesel car tax, however, would reduce total fuel consumption by only 1.50% compared to 9.11% for the 44.5% diesel fuel tax. A 5.60% diesel fuel tax would have the same total fuel conservation effect as the diesel car tax. The deadweight loss per liter of fuel conserved is much lower for diesel fuel taxation than diesel car taxation. In fact, at the 5.60% diesel fuel tax level, deadweight loss per liter is negative. Because the pre-existing tax on petrol fuel is much higher than the proposed tax on diesel fuel, would-be diesel buyers, who are compelled to buy a petrol car instead, generate more government revenue (through their consumption of petrol fuel) than would be necessary to compensate them to their pre-tax utility levels.

These results are fairly consistent across years. In terms of total fuel conservation, a diesel fuel tax sufficient to equalize diesel and petrol fuel prices is the most effective. While this subsidy eliminating diesel fuel tax and the diesel car tax are similar in terms of compensating variation, and government revenue raised, the diesel fuel tax is superior in terms of deadweight loss per liter of fuel conserved in all years. The negative deadweight loss result discussed above for 2006 is also persistent across years 2008 and 2010.

The rest of the chapter is organized as follows. Section 3.2 presents a background discussion of dieselization in India. Section 3.3 provides an overview of the economics of discrete-continuous choice. Section 3.4 presents details on the data used and the stylized facts of Indian cars and the people who buy them. Section 3.5 presents the model, its econometric implementation, and estimation results. Section 3.7 discusses the results of policy simulations and section 3.8 concludes.

3.2 Background

3.2.1 The Environmental Impact of Diesel Cars

A recent report on vehicular pollution control (Central Pollution Control Board, 2010) finds that road vehicle related pollution accounts for "70% of CO, 50% of HC, 30–40% of NOx, 30% of SPM and 10% of SO2" in India's major metropolitan areas. While the majority of privately owned, non-commercial vehicles, and the major contributor to road vehicle pollution, is comprised of two-wheelers, recent studies suggest that the gap between car and motorcycle ownership is quickly closing. Dargay et al. (2007) project continued growth of the car market could lead to a car ownership rate of 110 cars per 1000 people by 2030, up from just 16 cars per 1000 people in 2010. Another recent study (Arora et al., 2011), which projects similar car ownership rates, projects an increase in the ratio of cars to two-wheelers from approximately 1:4 to approximately 1:2 over the same time period.

The growing contribution of cars, relative to two-wheelers, to the environmental and public health consequences of transportation related externalities is compounded by the fuel economy disparity that exists between the two vehicle types. Estimates from de la Rue du Can et al. (2009) indicate that average fuel economy in 2005 was 12.8 kilometers per liter for petrol cars, 14.0 kilometers per liter for diesel cars, and 67.5 kilometers per liter for two-wheelers. They further project that the gradual displacement of two-stroke engine two-wheelers by four-stroke engine two-wheelers will lead to an average fuel economy of 75.0 kilometer per liter by 2020; petrol and diesel car fuel economy is projected to stagnate at 14.0 and 14.5 kilometers per liter, respectively.[5]

Dieselization also compounds the impact of cars on India's environment.[6] A

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[5] The efficiency gap is, to some extent, offset by cars' greater occupancy. de la Rue du Can et al. (2009) estimate an average occupancy of 1.50 for two-wheelers and 3.18 for cars. Thus, if passenger-kilometers per liter is a more appropriate metric of efficiency than kilometers per liter, the gap is not so dramatic as indicated above.

[6] This is as good a place as any to note that dieselization is not a uniquely Indian phenomenon. A recent study of 10 European Union countries (Ajanovic, 2011) documents the ubiquity of fuel price disparities due to differential taxation. The extent to which petrol taxes exceed diesel taxes ranges from 10% in the United Kingdom to 47% in the Netherlands. The authors find diesel cars' share of the new car market increased from 10% in 1980 to 55% in 2007 while their share of the existing stock of cars went from 4% to 32% over the same time period. In the United States, one of the few OECD countries in which petrol and diesel are taxed equally, diesel cars represent just 3% of new car sales, but August 2011 sales were 20.4% higher than August 2010 sales. J.D. Power & Associates projects that diesel cars will account for 7.4% of sales by 2017 (PR Newswire, 2011). Dieselization is not universal, however. China, the world's biggest car market, has suffered diesel shortages in recent years and imposes restrictions on the sale and use of diesel fuel. Of the 7 million cars sold in 2009, only 10,000 were diesels (Industry News, 2010). Industry executives have expressed skepticism over the prospect of dieselization in China. Ian Roberston, BMW's head of sales and marketing, has asserted that China is more likely to see increasing hybrid sales than diesel sales (Jolly, 2010) and Daimler CEO Dieter Zetsche believes electric vehicles are China's only realistic option: "If you look at the population and the growth here, you quickly reach the conclusion that it would be unthinkable to provide these people with traditional gasoline- and diesel-powered vehicles. There just isn't enough oil for that."

recent study of air quality in Delhi (Narain and Krupnick, 2007) finds that an increasing proportion of diesel cars has led to higher PM10 and NO2 concentrations and lower CO and SO2 concentrations.[7] As the authors point out, however, the SO2 finding largely reflects Delhi's exceptionally stringent fuel quality standards. Thus, the empirical deviation from *a priori* expectations based on typical emissions factors estimates (see Table 3.1) are unlikely to be representative of environmental consequences of dieselization nationwide.

Previous research (Kathuria, 2002), using less recent and less detailed data than Narain and Krupnick (2007), found that environmental policies, including passenger vehicle emissions standards, did not have a significant impact on air quality. The author concludes that emissions standards targeting new cars is insufficient and that although in-use vehicle inspection is mandatory, the quality and integrity of inspection procedures is questionable. This conclusion appears to fit well with the findings of Narain and Krupnick (2007) who find fuel quality standards to have a much stronger effect on air quality than emissions standards. In the context of dieselization, the implications of these findings strongly favor diesel subsidy elimination over diesel car taxation.

3.2.2 What Drives Dieselization?

Dieselization is a dynamic process, the subtleties of which are not fully captured by the model presented here. A fully dynamic model would necessarily include,

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[7] Studies of dieselization of the European car fleet find dieselization to be associated with an increase in CO2 emissions in Spain (Gonzalez et al., 2011), and a decrease in energy use in a cross-section of 10 European Union countries (Ajanovic, 2011).

among other things, the introduction of new models in response to patterns of consumer demand and the response of consumer demand to the introduction of new models. In 2002, 25 diesel models were available while only 13 sold in significant numbers. By 2008, 48 models were available, 24 of which sold in significant numbers.[8] The findings presented here, therefore, should not be interpreted as the effect of diesel subsidization on dieselization, but instead as the effect of removing diesel subsidization conditional on a significant portion of the dynamic process having already unfolded. Figure 3.1 illustrates how dieselization breaks down across vehicle categories. As relatively few diesel hatchbacks are available, due to technological constraints, diesel models' share of the hatchback market has remained between 10% and 20%. In the sedan market, however, the share of diesel cars has increased from 10% in 2002 to nearly 45% in 2010. Sales of India's biggest cars, its SUVs, MUVs, trucks, and vans, have also been increasingly dominated by diesel models; in 2002 65% were diesels, by 2010 81% were.[9]

So why are people buying diesels? As discussed below, I find operating cost to be a key determinant of vehicle choice. Although diesel cars are generally more expensive, their lower operating cost more than offsets the purchase price difference (Chugh et al., 2011). The diesel subsidy has resulted in a diesel discount of 30%, relative to petrol, compounding diesel cars' operating cost advantage due to their approximately 30% higher fuel economy.

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[8] Availability is based on appearance in the magazine *AutoCar India*, sales are based on the J.D. Power APEAL survey.

[9] The categorization of passenger vehicles as *hatchbacks, sedans,* and *SUVs* is based on body type classifications from carwale.com, a website geared toward Indian car buyers.

3.3 Discrete-Continuous Choice

I 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.[10] The key insight of their study is that if consumers with high expected electricity usage select into 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.

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

One drawback of the two-stage approach is that separate estimation of car choice and car use leads to two sets of model parameters, often differing in magnitude and sign. As the model 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 im-

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[10] But see Brand (2005) and Economides et al. (2008) for discrete-continuous models of the health insurance and phone service markets, respectively.

pact of policy intervention. Recent contributions from Feng et al. (2005) and Bento et al. (2009) have sought to overcome this limitation by introducing simultaneous estimation techniques.

Feng et al. (2005) consider the choice between cars and SUVs and present a minimum distance method of simultaneous estimation. The authors make use of a mixed logit model of vehicle choice in which preference distributions depend on a single random taste shock. Bento et al. (2009) present an ambitious model of the car market that includes new, used, and scrap markets to explore the distributional impact of gasoline taxation. The authors employ a Bayesian estimation procedure to recover model parameters of a mixed logit model allowing all coefficients to be randomly distributed.

Spiller (2011) and Gillingham (2010) introduce further innovations to the single-stage estimation literature. Spiller (2011) explores the effect of model aggregation and unobserved vehicle attributes on gasoline demand elasticity estimates. The author further allows for allocation of vehicle miles traveled across vehicles in multi-car households. Gillingham (2010) presents a two period model in which household expectations of fuel prices and driving needs are updated over time.

My approach incorporates these recent modeling and estimation advances, subject to data limitations, in a mixed logit discrete-continuous choice model of which car to buy and how much to drive it. I incorporate body type and manufacturer fixed effects to account for unobserved vehicle characteristics and 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.

3.4 Data

Household car choice and monthly driving distance data come from the JD Power APEAL survey, an annual survey of approximately $5,000$ new car buyers. Car characteristics data come from the magazine AutoCar India. Most car models are available in multiple versions, some of which may be petrol versions while others are diesel. This level of detail is available in AutoCar India, but survey respondents are associated with 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. Tables 3.2-3.4 present sales-weighted summary statistics for all vehicle models sold in years 2006, 2008, and 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.

It is important to note that within-body type differences across fuel types are influenced by the difference in model availability across fuel types. For hatchbacks and sedans every diesel model is available in petrol versions as well, but a wide variety of petrol models are available for which there is no diesel counterpart. Thus the differences observed in Tables 3.2–3.4 reflect model availability in addition to inherent differences. Nevertheless, some stylized facts are noticeable. Diesel cars are heavier than petrol cars, have a lower power to weight ratio, and, with the exception of SUVs, have higher fuel economy. Petrol SUVs are dominated by the

Maruti Omni, a niche van-like vehicle with no diesel counterpart.

Because of their higher fuel economy and cheaper fuel, diesel cars have lower operating cost across body types. In 2006, diesel operating costs were 42% lower, 47% lower, and 28% lower for hatchbacks, sedans, and SUVs, respectively. In 2008, operating cost differences were 39%, 45%, and 30%. In 2010, they were 34%, 38%, and 18%. Predictably, the owners of lower operating cost vehicles drove more. Tables 3.5–3.7 present summary statistics for household demographics. Averaged over the three years considered, owners of diesel hatchbacks drove 69% more than owners of petrol hatchbacks, owners of diesel sedans drove 35% more than owners of petrol sedans, and owners of diesel SUVs drove 63% more than owners of petrol SUVs.

Across all three years, sedan owners have higher incomes than hatchback owners. Within these two body types, diesel owners generally have lower incomes than petrol owners. Family sizes are slightly higher among diesel households and average age of car owners is slightly lower. Family size also appears to be correlated with vehicle size; in 2006, for example, average family size was 4.54, 4.73, and 5.48 for petrol hatchbacks, petrol sedans, and petrol SUVs, respectively; a similar pattern is seen for owners of diesel cars.

The data fall quite naturally into the model described below. Richer households buy more expensive cars, bigger families buy bigger cars, households with greater driving needs buy lower operating cost vehicles. In the following section, I present the model used to capture and predict these observed correlations and behaviors.

3.5 The Model

The household's decision over which car to buy and how much to drive it takes the form of a standard static utility maximization problem where utility is some 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 survey is conducted in several locations across the country, I model the new car market as a single, national market with the choice set being the same for all households. Future work will relax this assumption and allow city- or state-specific effects to influence vehicle purchase and driving distance decisions.[11] 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 (such as a used car, motorcycle, or public transportation). 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). However, this restriction comes with some drawbacks. As consumers do not have the option of not buying a car, the model will tend to underestimate own-price elasticities lead-

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[11] Although fuel prices display little spatial variation in this time period, there are state-by-state differences in vehicle taxes and registration fees that affect vehicle prices faced by consumers in different markets. Furthermore, differences in terrain, weather, and road conditions affect operating costs and other factors such as urban density and availability of public transportation could affect driving distances. See Bento et al. (2005) for a study of urban spatial structure on mode choice and driving distance.

ing to exaggerated manufacturer markups when a supply side model is included. Preliminary results from a supply side model with firms setting prices in a differentiated Bertrand-Nash setting are sensible in some dimensions. Because the model captures only the decision of which car to buy and not the decision of whether or not to buy a car, however, markup estimates and production cost estimates are not realistic. The results presented here assume no supply-side response. Future work will explore means of avoiding these theoretical shortcomings using auxiliary data and estimation of the choice of whether or not to buy a new car.

3.5.1 Vehicle Choice

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

$$v_{ij} = -\frac{1}{\beta_i} e^{-\beta_i (y_i - r_j) - \gamma_i X_{ij}} - \frac{1}{\alpha_i} e^{\alpha_i p_j} + \epsilon_{ij} \tag{3.1}$$

where $y_i - r_j$ is annual income of household i minus 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, and ϵ_{ij} is an i.i.d. stochastic preference shock.[12] The coefficients, β_i, α_i, and γ_i, are assumed to follow uncorrelated random distributions, the parameters of which are to be

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[12] As shown below, 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 the indirect utility function $v_{ij} = (\beta_i(y_i - r_j) + \alpha_i p_j + \gamma_i X_{ij} + \frac{\alpha_i}{\beta_i})e^{-\beta_i p_j} + \epsilon_{ij}$ which leads to a linear demand for kilometers driven equation. My research makes use of the functional form in equation 3.1 because of its identifiability, ease of implementation, and prevalence in the more recent literature, though robustness of results to *a priori* equally plausible functional forms is the subject of current investigation.

estimated along with other parameters of the model. For example, $\beta_i = \bar{\beta} + \nu_{i\beta}$ where $\nu_{i\beta}$ is drawn from some distribution $f(\nu_\beta|\omega_\beta)$. The $\bar{\beta}$ and ω_β parameters are estimated; other random parameters are treated analogously.

Let θ represent the common set of coefficients such that $\boldsymbol{\theta} = \{\bar{\beta}, \bar{\alpha}, \bar{\gamma}, \omega_\beta, \omega_\alpha, \omega_\gamma\}$. Individual parameters are then distributed according to the joint probability density function $g(\boldsymbol{\nu}|\boldsymbol{\theta})$. Then, letting ϵ_{ij} have a type I extreme-value distribution, the probability that household i chooses car j takes the mixed logit form,

$$Pr_{ij} = \int \frac{e^{v_{ij}/\mu}}{\sum\limits_{j=1}^{J} e^{v_{ij}/\mu}} g(\boldsymbol{\nu}|\boldsymbol{\theta}) d\nu \tag{3.2}$$

where μ is the scale factor of the i.i.d. type I extreme-value error term.[13]

3.5.2 Driving Distance

Using Roy's Identity, annual driving distance can be derived from equation 3.1 as follows:

$$KM_{ij} = -\frac{\partial v_{ij}/\partial p_j}{\partial v_{ij}/\partial y_i} = e^{\beta_i(y_i - r_j) + \gamma_i X_{ij} + \alpha_i p_j}. \tag{3.3}$$

As the data consist of self-reported driving distances, I take the result of equation 3.3 to be predicted kilometers driven ($\widehat{KM}_{ij}$) and consider the difference between predicted driving and reported driving (KM_{ij}) to be the result of measurement

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[13] The extreme-value error term ϵ_{ij} is distributed according to the probability density function $f(\epsilon) = \frac{1}{\mu} e^{-\epsilon/\mu - e^{-\epsilon/\mu}}$ with variance $\text{var}(\epsilon) = \mu^2 \frac{\pi^2}{6}$. Since neither the level of utility nor the scale of utility is identified, μ can not be separately identified from the parameters when indirect utility takes the more common linear functional form. However, because of the nonlinear way in which α and β enter equation 3.1, μ is identified.

error.[14] Specifically, I assume a multiplicative log-normal measurement error such that $KM_{ij} = \widehat{KM}_{ij} e^{\eta_{ij}}$ where $\eta_{ij} \sim N(0, \sigma)$. The reasoning behind this modeling choice is that reported driving distance has a zero lower bound, but no upper bound. Depending on the estimate of σ, this approach will result in driving distance predictions that are systematially lower than driving distance observations, a point I return to in Section 3.6.1.

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

$$\log(KM_{ij}) = \int \left[\beta_i(y_i - r_j) + \gamma_i X_{ij} + \alpha_i p_j\right] g(\boldsymbol{\nu}|\boldsymbol{\theta}) d\nu + \eta_{ij} \tag{3.4}$$

and the likelihood of observing KM_{ij} kilometers driven conditional on household i buying car j is

$$\ell(KM_{ij}|\mathbb{1}_{ij} = 1) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\frac{[log(KM_{ij}) - log(\widehat{KM_{ij}})]^2}{\sigma^2}} \tag{3.5}$$

where $\mathbb{1}_{ij}$ is an indicator function equal to 1 if household i bought car j and 0 otherwise.

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[14] Future work will explore the possibility of modeling the difference between predicted and reported driving distance as an idiosyncratic taste for driving that also affects vehicle choice by including η_{ij} in the conditional indirect utility function. See Feng et al. (2005) and Gillingham (2010) for examples of this approach.

3.5.3 Rental and Operating Cost

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. I focus entirely on the purchase price (inclusive of 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. I 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 (Shankar, 2007; Carazoo.com, 2011; Seth, 2009). As inflation averaged about 6% during this period, I use a real interest rate of 8.5% and present sensitivity of results to alternative assumptions of 5 and 12% in the Appendix.

Operating cost is simply the Delhi fuel price divided by the fuel economy. As with vehicle price, fuel economy is taken as the average self-reported fuel economy for each vehicle type, but results are found to be robust to the use of AutoCar India data vs. survey data. The Delhi prices of petrol and diesel fuel (in 2010 Rs.) were 61.4 and 42.5 in 2006, 54.2 and 37.8 in 2008, and 51.1 and 38.1 in 2010.

3.5.4 Estimation Strategy

Household i's likelihood of buying the car it is observed to have bought and driving the distance it is reported to have driven is simply the product of its likelihood of buying car j (equation 3.2) and its likelihood of driving KM_{ij} conditional on buying car j (equation 3.4). The full information likelihood function is the product over all households,

$$L(\boldsymbol{\theta}) = \prod_{i=1}^{N} \prod_{j=1}^{J} [Pr_{ij} \ell(KM_{ij} | \mathbb{1}_{ij} = 1)]^{\mathbb{1}_{ij}}. \tag{3.6}$$

The log-likelihood function to be maximized is

$$LL(\boldsymbol{\theta}) = \sum_{i=1}^{N} \sum_{j=1}^{J} \mathbb{1}_{ij} [\log(Pr_{ij}) + \log(\ell(KM_{ij} | \mathbb{1}_{ij} = 1))]. \tag{3.7}$$

Evaluating the log-likelihood function directly would require solving the integrals of equations 3.2 and 3.3. In the absence of closed-form solutions, however, integration must be performed by simulation (Train, 2009). For any draw $\boldsymbol{\nu}_{ir}$ from the distribution $g(\boldsymbol{\nu}|\boldsymbol{\theta})$, 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, the average car choice probabilities and conditional driving distance likelihoods approach the true values. Finally, the log-likelihood to be maximized is given by

$$LL(\boldsymbol{\theta}) = \sum_{i=1}^{N} \sum_{j=1}^{J} \mathbb{1}_{ij} [\log(\widecheck{Pr}_{ij}) + \log(\check{\ell}(KM_{ij} | \mathbb{1}_{ij} = 1))] \tag{3.8}$$

where

$$\widecheck{Pr}_{ij} = \frac{1}{R} \sum_{r=1}^{R} Pr_{ijr} \tag{3.9}$$

and

$$\breve{\ell}(KM_{ijr}|\mathbb{1}_{ij}=1)=\frac{1}{R}\sum_{r=1}^{R}\ell(KM_{ijr}|\mathbb{1}_{ij}=1). \tag{3.10}$$

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 (2000) finds that 100 Halton draws achieved greater accuracy than 1000 pseudo-random draws. In their recent study on the declining market share of US car manufacturers, Train and Winston (2007) find 200 Halton draws to be sufficient. I follow their approach to testing for sufficient draws by calculating the value of the test statistic $g'H^{-1}g$ using 400 draws and the parameter estimates obtained using 200 draws. For the year 2006, I find a value of 1.25. Since "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" (Train and Winston, 2007), I fail to reject the hypothesis that the parameters found using 200 draws are indeed likelihood maximizing.

3.6 Results

The results presented here are for a specification including body type and manufacturer fixed effects. All random coefficients, other than the income minus rental cost ($y_i - r_j$) and operating cost (p_j) coefficients, are assumed to be distributed normally such that $\gamma_i \sim N(b_i^{\gamma}, w^{\gamma})$ where the means are allowed to vary by household characteristics. 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 $\tau \sim N(b^{\beta}, w^{\beta})$. Following the same reasoning, the distribution of the operating cost coefficient is assumed to be negative log-normal such that $\alpha = -e^{z}$ with $z \sim N(b^{\alpha}, w^{\alpha})$.

Tables 3.8–3.10 present estimation results for all parameters including kilometers driven measurement error (σ) and scale factor (μ); manufacturer fixed effects are not shown. Many coefficients are estimated at the 0.05 level or better and with signs aligned with prior expectations and with estimates similar across years. There are, however, some exceptions. The coefficient on luxury index, which is negative in years 2006 and 2008, turns positive in 2010. The coefficient on power ratio is not estimated with precision in years 2008 and 2010, but is found to be negative and significant at the 0.10 level in 2006. Finally, the coefficients of size metrics length, width, and height are not consistent across years. In 2006, the length coefficient is negative while the width coefficient is positive with both being estimated at the 0.10 level of statistical significance; the height coefficient is not statistically significant at conventional levels. In 2008, the length coefficient is again negative while the height coefficient is positive and the width coefficient is not statistically significant. In 2010, all three coefficients are negative and significant at the 0.01 level. These coefficients are difficult to interpret, however, especially considering the inclusion of body type indicators which show the expected preference for vehicle size.

Although the coefficients are difficult to interpret by themselves, some qualitative comparisons can be made. The fixed coefficients on interactions between family size and the hatchback dummy and sedan dummy indicate that larger families get less utility from smaller cars and drive less in them compared to smaller families. Bigger families drive more than smaller ones, women drive less than men, and driving distance decreases with age.

The coefficients on income minus rental cost and operating cost are estimated precisely in all years, but their distributions are not. Recalling that the coefficient on income minus rental cost is distributed log-normally, the mean elasticity of vehicle kilometers traveled with respect to income can be shown to be 0.0375 for 2006, 0.147 for 2008, and 0.198 for 2010. Similarly, the mean elasticity of vehicle kilometers traveled with respect to operating cost can be shown to be 1.03 for 2006, 1.03 for 2008, and 1.11 for 2010.

3.6.1 Model Fit

Figures 3.2-3.7 summarize the within-sample fit of the estimated model in terms of market share and driving distance predictions. Aggregated to body- and fuel-type categories, predicted market shares appear to match actual market shares accurately. Figures 3.2, 3.4, and 3.6, however, mask the fact that model fit actually detiorates over time. The sum of the absolute error of predicted market shares across each model/fuel-type available in each year results in 11.6 percentage points of total error for 2006, 26.4 for 2008, and 31.4 for 2010. Future work will explore the possibility of improving model fit with different specifications for each year as opposed to using the same specification for all years.

The prediction of driving distance is more difficult to asses. Although Figures 3.3, 3.5, and 3.7 seem to indicate a systematic under-prediction of driving distance, it is important to note that the model is based on the presence of a normally distributed measurement error on the log of driving distance and not driving distance itself. This implies that rather than the model under-predicting driving distance, it is the survey respondents who systematically over-estimate their true driving distance. As the bottom line results will be a function of actual driving distances and not reported driving distance, it is important not to correct for the difference between predicted driving and observed driving. The assumption of respondents over-estimating their driving distance rests on the fact that while there is a zero lower bound for driving distance reported, there is no upper bound. The estimated model implies that people over-estimate their true driving distance by 26.2% in 2006, 25.5% in 2008, and 54.0% in 2010. Whether or not this degree of over-estimation is realistic and alternative modeling approaches that might avoid this conclusiong are the subject of future investigation.

3.7 Policy Simulation

In this section, the estimated behavioral model is used to explore the market and welfare implications of two possible policy responses to dieselization: diesel fuel taxation and diesel car taxation. To compare these two very different policies, it is necessary to to have some common objective in mind. I simulate the market share of diesel cars under a diesel fuel tax that is sufficiently large to equalize the price of petrol and diesel fuel and search for the diesel car tax that would result in the same market share. A second diesel fuel tax is then found that would result in the same total fuel conservation as the diesel car tax. These comparisons are used to explore the effects of the diesel fuel taxes and diesel car taxes on market share, driving distance, fuel consumption, consumer welfare, and government revenue. Before presenting results of this exercise, I present the technical details and assumptions used.

3.7.1 Welfare Analysis

Because the structural approach taken here results in estimates of utility function parameters, I am able to perform welfare analyses of the two policy scenarios being considered. I present money-metric welfare results in terms of consumers' compensating variation (CV), the minimum payment that would be necessary to return the consumer to his pre-policy utility level. Compensating variation is implicitly defined as follows:

$$\max_{j \in \mathscr{J}} v_i(y_i - r_j^0, p_j^0, X_{ij}; \theta_i, \epsilon_{ij}^t) = \max_{k \in \mathscr{J}} v_i(y_i - r_k^1 - cv^t, p_k^1, X_{ik}; \theta_i, \epsilon_{ik}^t). \tag{3.11}$$

Since the model used here is probabilistic, it is impossible to calculate exact welfare estimates. Rather, a simulation procedure (McFadden, 1995) is used to find expected compensating variation. The simulation algorithm is as follows.

1. At iteration t, draw a vector of indirect utility function errors ϵ_{ij}^t and draws from coefficient distributions $\boldsymbol{\nu}_{it}$

2. Solve for cv^t according to equation 3.11
3. Repeat 1 and 2 until convergence. Mean and distribution of CVs can be taken from collection of simulated CVs

Although approximation methods are available (Herriges and Kling, 1999), the method used here is not prohibitively computationally intensive and results in a distribution of possible welfare results for each individual. This makes possible the evaluation of distributional implications.

3.7.2 Results

Comparisons of market outcomes and welfare results under the policy simulations are presented in Tables 3.11–3.13. In 2006, a 44.5% diesel fuel tax is necessary to equalize the price of petrol and diesel fuel. The result of this tax is found to be a reduction of the market share of diesel cars from 28.3% to 23.7%. To achieve the same market outcome, a diesel car tax of 24.5% would be necessary. In 2008, a 43.3% diesel fuel tax results in a reduction of the market share of diesel cars from 31.3% to 23.4% with a 23.3% tax on diesel cars being necessary to achieve this. In 2010, a 34.3% diesel fuel tax results in a reduction of the market share of diesel cars from 32.4% to 23.8%. I find that a diesel car tax of only 17.8% would result in this same market share reduction.

While a diesel fuel tax and a diesel car tax will induce some would-be diesel buyers to opt for a petrol car instead, a diesel fuel tax affects the per-kilometer driving cost and is found to have a greater effect on the driving behavior of those who choose to remain diesel car buyers. A diesel fuel tax sufficient to close the petrol/diesel price gap has the effect of reducing diesel fuel consumption from 437 million liters to 270 million liters in 2006. Based on 2008, diesel fuel consumption would be reduced from 540 million liters to 289 million liters. Based on 2010, the reduction is from 836 million liters to 462 million liters. Diesel fuel consumption reductions from diesel car taxation and a smaller diesel fuel tax are presented in Tables 3.11–3.13. All policies would result in an increase in petrol fuel consumption and so it is important to consider this effect when calculating changes in government revnue and total fuel conservation.

Turning to welfare results, I find a 44.5% diesel fuel tax results in an average CV of Rs. 27,000 ($539) for would-be diesel car buyers based on 2006 results. A 24.5% diesel car tax results in an average CV of Rs. 27,700 ($554) for would-be diesel car buyers. This amounts to about 3.33% of annual income for the diesel fuel tax and 3.42% of annual income for diesel car taxation, but the distributional implications are found to be regressive. Figure 3.8 shows the welfare effect on would-be diesel car buyers of different income groups. I find a welfare burden of between 5 and 6% of annual income for households of the lowest income category falling to less than 1% for households of the highest income category. Based on 2008 results, average CV for would-be diesel buyers is found to be Rs. 24,200 ($484) from a 43.4% diesel fuel tax and Rs. 25,300 ($507) from diesel car taxation. Based on 2010 results, these figures are Rs. 17,300 ($345) from a 34.3% diesel fuel tax and Rs. 17,600 ($352) from the diesel car tax. For these two years, distributional consequences are found to be similar to those discussed for 2006 (see Figures 3.9 and 3.10).

In order to compare the relative efficiency of these policies, change in government revenue is calculated and subtracted from the total CV to find deadweight loss. Tables 3.11-3.13 present deadweight loss per liter of total fuel conserved and intermediate calculations. In all years, the deadweight loss per liter of fuel conserved from a diesel fuel tax that is sufficiently large to close the petrol/diesel fuel price gap is less than that for the diesel car tax. Deadweight loss per liter from the subsidy eliminating fuel tax is 80.6 Rs. in 2006, 72.7 Rs. in 2008, and 14.6 Rs. in 2010. Deadweight loss per liter from the diesel car tax is 307 Rs. in 2006, 256 Rs. in 2008, and 208 Rs. in 2010. The lower deadweight loss in 2010 reflects the higher sensitivity to changes in income in both the indirect utility and demand for driving distance.

Deadweight loss per liter of fuel conserved is found to be lower for a diesel fuel tax than a diesel car tax. In all years, in fact, the deadweight loss per liter of a much smaller diesel fuel tax is found to be negative. This figure is -33.7 Rs./Liter in 2006, -18.9 Rs./Liter in 2008, and -57.3 Rs./Liter in 2010. This surprising result comes from the fact that the pre-existing tax on petrol is assumed to equal the total difference between petrol and diesel fuel prices while the proposed diesel fuel tax is just a fraction of this difference. Thus, those would-be diesel car buyers who are compelled to buy a petrol instead actually generate more government revenue (through their petrol fuel consumption) than would be necessary to compensate them back to their pre-tax utility levels. The result indicates that at low levels of diesel fuel taxation, the decrease in relative distortions can be welfare enhancing relative to the status quo in which only the petrol market is distorted by a tax.

3.8 Conclusion

The Indian government is taking steps to mitigate the environmental consequences of its rapid motorization. Driven by the policy objective of poverty alleviation, however, their continued subsidization of diesel fuel may be undermining these efforts. In this chapter, I have presented a structural econometric discrete-continuous choice model of vehicle purchasing decisions and driving behavior. Market simulations indicate the effect of eliminating the petrol/diesel price gap with a diesel fuel tax to be a modest reduction of the market share of diesel cars; a diesel car tax of approximately 20% would achieve the same result based on separate analyses of three years of market data. The diesel car tax option, however, does relatively little to change intensive margin incentives and would result in a much smaller reduction of diesel fuel consumption. Both policies are found to have an expected compensating variation effect of roughly 2–4% of household income on average, but these results differ across income groups. Both policies impose substantially greater costs on lower income households.

These two relatively extreme policies are contrasted to a small diesel fuel tax of about 7%. The striking finding from these policy simulations is that deadweight loss per liter of fuel conserved is actually negative; a result that is persistent across years. This result arises due to the pre-existing tax on petrol fuel which is assumed to equal the difference between petrol and diesel fuel prices. Because of this pre-existing distortion, a small diesel fuel tax pushes some would-be diesel car buyers into the market for petrols. The revenue raised from their consumption of petrol fuel more than offsets the CV necessary to restore them to their pre-tax utility levels.

While not captured in the model presented here, there are other margins along which the two policies are likely to differ. Since fuel prices affect the operating cost of all cars, not just new cars, the fuel consumption reduction advantage of diesel fuel taxation would be vastly more dramatic than the results presented here. Diesel car taxation would, of course, have an effect on the used car market too. For example, if new diesel cars become more expensive due to taxation, owners of used diesel cars may experience an increase in the value of this asset. If used diesel car owners are relatively poorer than used petrol car owners, this result could reverse the relative regressivity of diesel car taxation presented here.

In addition to exploring the issues raised in the previous paragraph, future work will explore the possibility of modeling the decision of whether or not to buy a new car. Due to data limitations, the present study is unable to quantify the market size effects of policy intervention. While the results presented here are based on data from 2006, 2008, and 2010, my data set includes survey and car data from years 2002 to 2010. Incorporating these observations into the model will almost certainly result in better identification of price and operating cost responsiveness. Finally, results presented here only include welfare effects on consumers of new cars; future work will complete the picture by providing estimates of changes in manufacturer profit.

Table 3.1: Emissions Factors (grams/kilometer) and Health Effects of Vehicle Pollutants

Pollutant	Car (Petrol)	Car (Diesel)	Health Effects
CO	2.72	2.72	Affects the cardiovascular system; may also particularly affect fetuses, sick, anemic and young children; affects nervous system, impairing physical coordination, vision and judgments, creating nausea and headaches, reducing productivity and increasing personal discomfort
HC	0.45	0.17	Potential to cause cancer
NOx	0.69	1.00	Increased susceptibility to infections, pulmonary diseases; impairment of lung function and eye, nose and throat irritations
PM	0.06	0.19	Fine particulate matter may be toxic in itself or may carry toxic (including carcinogenic) trace substance and can alter the immune system. Fine particulates penetrate deep into the respiratory system irritating lung tissue and causing long-term disorders.
CO2	242	237	
SO2	0.080	0.149	Affects lung function adversely

Source: Emissions factors are derived and reported by Baidya and Borken-Kleefeld (2009), health effects are paraphrased from Central Pollution Control Board (2010).

Table 3.2: Sales-Weighted Vehicle Summary Statistics—2006

VARIABLES	UNITS	petrol hatchback	diesel hatchback	petrol sedan	diesel sedan	petrol SUV	diesel SUV
Price	10^5 Rupees (2010)	4.92	5.24	11.3	12.1	7.68	11.2
		(1.27)	(0.560)	(4.49)	(3.10)	(7.49)	(2.84)
Fuel Economy	kilometers/liter	13.6	16.0	11.2	14.5	12.5	11.3
		(2.86)	(2.72)	(2.41)	(2.66)	(3.13)	(2.19)
Operating Cost	2010 Rupees/kilometer	4.72	2.76	5.74	3.04	5.31	3.90
		(1.09)	(0.678)	(1.33)	(0.621)	(1.72)	(0.775)
Engine Size	cubic centimeters	1050	1410	1650	1650	1210	2500
		(213)	(0)	(288)	(248)	(657)	(124)
Power Ratio	horsepower/kilogram	0.0729	0.0585	0.0930	0.0686	0.0610	0.0547
		(0.0101)	(0)	(0.0117)	(0.00890)	(0.0230)	(0.00814)
Torque	kilogram-meters	8.75	9.91	14.4	18.4	10.3	21.2
		(2.12)	(0)	(2.98)	(3.10)	(6.71)	(4.23)
Gears		4.74	5.00	4.93	4.94	4.29	4.98
		(0.360)	(0)	(0.145)	(0.0928)	(0.454)	(0.0447)
Automatic		0.0692	0	0.175	0.0623	0.0939	0
		(0.105)	(0)	(0.211)	(0.0928)	(0.196)	(0)
Length	meters	3.55	3.68	4.35	4.35	3.72	4.48
		(0.141)	(0)	(0.194)	(0.117)	(0.553)	(0.178)
Width	meters	1.54	1.67	1.69	1.69	1.52	1.75
		(0.0947)	(0)	(0.0587)	(0.0304)	(0.166)	(0.0696)
Height	meters	1.51	1.49	1.44	1.43	1.67	1.85
		(0.0873)	(0)	(0.0484)	(0.0368)	(0.0441)	(0.0816)
Ground Clearance	meters	0.168	0.170	0.170	0.160	0.174	0.183
		(0.00446)	(0)	(0.00875)	(0.0179)	(0.0154)	(0.0125)
Weight	1000 kilograms	0.833	0.980	1.10	1.20	0.969	1.76
		(0.125)	(0)	(0.151)	(0.0897)	(0.348)	(0.190)
Safety Index		1.32	1	1.62	1.75	1.38	1.24
		(0.440)	(0)	(0.784)	(0.805)	(0.783)	(0.542)
Luxury Index		2.47	2.86	5.52	5.26	1.72	3.71
		(1.26)	(0)	(1.37)	(1.07)	(2.94)	(1.35)
#Observations		1551	175	1270	305	181	765

Notes: Version level vehicle characteristics data come from AutoCar India. Each model is available in multiple versions. Model/fuel-type level vehicle characteristics are constructed as the unweighted average across all available versions of each model for each 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 3.3: Sales-Weighted Vehicle Summary Statistics—2008

VARIABLES	UNITS	petrol hatch-back	diesel hatch-back	petrol sedan	diesel sedan	petrol SUV	diesel SUV
Price	10^5 Rupees (2010)	4.65	6.31	11.0	11.0	10.8	11.3
		(1.10)	(1.75)	(4.88)	(4.35)	(9.26)	(3.85)
Fuel Economy	kilometers/liter	13.8	15.6	11.5	14.7	12.1	11.7
		(2.62)	(2.97)	(2.60)	(3.15)	(3.17)	(2.39)
Operating Cost	2010 Rupees/kilometer	4.08	2.52	4.98	2.70	4.80	3.36
		(0.850)	(0.561)	(1.18)	(0.663)	(1.35)	(0.699)
Engine Size	cubic centimeters	1050	1370	1670	1610	1470	2460
		(165)	(77.7)	(336)	(314)	(754)	(153)
Power Ratio	horsepower/kilogram	0.0711	0.0683	0.0916	0.0725	0.0715	0.0569
		(0.0075)	(0.0108)	(0.0131)	(0.0143)	(0.0276)	(0.0116)
Torque	kilogram-meters	9.12	15.1	15.1	21.0	13.1	23.6
		(1.88)	(4.10)	(3.34)	(5.70)	(7.80)	(6.52)
Gears		4.78	5.00	4.97	4.97	4.64	5.00
		(0.317)	(0)	(0.106)	(0.0638)	(0.720)	(0)
Automatic		0.0852	0	0.194	0.0670	0.191	0
		(0.119)	(0)	(0.238)	(0.183)	(0.243)	(0)
Length	meters	3.57	3.77	4.43	4.35	3.90	4.33
		(0.154)	(0.136)	(0.193)	(0.162)	(0.580)	(0.324)
Width	meters	1.54	1.67	1.72	1.71	1.59	1.76
		(0.0799)	(0.0209)	(0.0440)	(0.0273)	(0.2001)	(0.0683)
Height	meters	1.53	1.51	1.48	1.48	1.66	1.86
		(0.0738)	(0.0200)	(0.0533)	(0.0394)	(0.0358)	(0.0737)
Ground Clearance	meters	0.168	0.167	0.171	0.161	0.173	0.185
		(0.00693)	(0.0124)	(0.0105)	(0.0139)	(0.00953)	(0.0142)
Weight	1000 kilogram	0.876	1.01	1.16	1.21	1.11	1.78
		(0.126)	(0.0442)	(0.136)	(0.125)	(0.397)	(0.181)
Safety Index		1.26	1.55	1.97	1.68	1.81	1.41
		(0.327)	(0.464)	(0.817)	(0.842)	(0.951)	(0.640)
Luxury Index		3.35	3.35	5.80	5.25	3.35	3.89
		(1.33)	(1.21)	(1.66)	(1.24)	(3.81)	(1.89)
#Observations		2005	434	1363	657	257	890

Notes: Version level vehicle characteristics data come from AutoCar India. Each model is available in multiple versions. Model/fuel-type level vehicle characteristics are constructed as the unweighted average across all available versions of each model for each 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 3.4: Sales-Weighted Vehicle Summary Statistics—2010

VARIABLES	UNITS	petrol hatchback	diesel hatchback	petrol sedan	diesel sedan	petrol SUV	diesel SUV
Price	10^5 Rupees (2010)	4.16	5.29	10.4	9.79	6.31	11.4
		(1.32)	(1.09)	(4.78)	(3.92)	(7.51)	(5.13)
Fuel Economy	kilometers/liter	13.9	15.7	11.8	14.4	12.9	11.6
		(2.94)	(2.90)	(2.58)	(3.11)	(2.58)	(2.39)
Operating Cost	2010 Rupees/kilometer	3.85	2.52	4.53	2.78	4.14	3.40
		(0.903)	(0.575)	(0.965)	(0.663)	(0.879)	(0.650)
Engine Size	cubic centimeters	1050	1310	1690	1590	1200	2460
		(183)	(61.7)	(388)	(296)	(492)	(240)
Power Ratio	horsepower/kilogram	0.0733	0.0641	0.0979	0.0738	0.0684	0.0589
		(0.00802)	(0.00449)	(0.0156)	(0.0140)	(0.0214)	(0.0192)
Torque	kilogram-meters	9.42	17.0	16.1	22.3	10.3	25.9
		(2.05)	(2.86)	(4.62)	(6.05)	(5.18)	(6.30)
Gears		4.78	5.00	4.98	5.03	4.76	5.03
		(0.339)	(0)	(0.230)	(0.247)	(0.716)	(0.0718)
Automatic		0.0718	0	0.186	0.0639	0.0544	0.0906
		(0.135)	(0)	(0.202)	(0.149)	(0.123)	(0.167)
Length	meters	3.59	3.79	4.46	4.39	3.69	4.55
		(0.214)	(0.106)	(0.206)	(0.190)	(0.397)	(0.195)
Width	meters	1.57	1.68	1.73	1.72	1.50	1.79
		(0.0859)	(0.0120)	(0.0501)	(0.0467)	(0.143)	(0.0626)
Height	meters	1.55	1.52	1.48	1.48	1.72	1.87
		(0.0723)	(0.0395)	(0.0472)	(0.0317)	(0.0750)	(0.0841)
Ground Clearance	meters	0.168	0.166	0.168	0.163	0.166	0.189
		(0.00722)	(0.0066)	(0.0104)	(0.0119)	(0.00866)	(0.0157)
Weight	1000 kilogram	0.896	1.11	1.19	1.25	0.971	1.81
		(0.140)	(0.0466)	(0.169)	(0.169)	(0.263)	(0.158)
Safety Index		1.28	1.24	2.30	2.09	1.33	1.75
		(0.573)	(0.446)	(0.826)	(0.834)	(0.740)	(0.742)
Luxury Index		3.31	3.41	6.11	5.74	1.45	4.88
		(1.51)	(1.06)	(1.53)	(1.37)	(2.90)	(2.09)
#Observations		2404	596	1176	730	233	1095

Notes: Version level vehicle characteristics data come from AutoCar India. Each model is available in multiple versions. Model/fuel-type level vehicle characteristics are constructed as the unweighted average across all available versions of each model for each 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 3.5: Summary Demographic Statistics—2006

VARIABLES	UNITS	petrol hatch-back	diesel hatch-back	petrol sedan	diesel sedan	petrol SUV	diesel SUV
Income	10^5 Rupees (2010)	6.16	5.33	10.3	9.39	7.16	8.57
		(4.84)	(4.17)	(6.96)	(6.68)	(6.39)	(6.38)
Family Size		4.54	4.94	4.73	5.07	5.48	5.45
		(1.57)	(1.67)	(1.48)	(1.60)	(1.82)	(1.70)
Age	years	37.5	34.6	37.4	35.8	36.4	36.9
		(11.7)	(9.53)	(11.1)	(10.9)	(9.64)	(9.84)
% Female		0.0825	0.0400	0.0488	0.0328	0.0332	0.0248
		(0.275)	(0.197)	(0.216)	(0.178)	(0.180)	(0.156)
Driving Distance	kilometers/month	1140	2060	1340	2000	1480	2240
		(1080)	(1500)	(1030)	(1340)	(1100)	(1460)
#Observations		1551	175	1270	305	181	765

Notes: Standard deviations in parentheses. Demographic information comes from the 2006 JD Power APEAL survey.

Table 3.6: Summary Demographic Statistics—2008

VARIABLES	UNITS	petrol hatch-back	diesel hatch-back	petrol sedan	diesel sedan	petrol SUV	diesel SUV
Income	10^5 Rupees (2010)	5.93	6.09	8.68	7.87	7.27	7.45
		(4.10)	(3.96)	(5.59)	(5.35)	(6.02)	(5.16)
Family Size		4.73	4.97	4.87	5.06	5.33	5.48
		(1.72)	(1.67)	(1.60)	(1.61)	(1.63)	(1.98)
Age	years	37.5	36.2	38.1	37.3	38.1	37.4
		(11.3)	(10.5)	(10.8)	(10.1)	(10.7)	(9.60)
% Female		0.0763	0.0369	0.0631	0.0198	0.0311	0.0236
		(0.266)	(0.189)	(0.243)	(0.139)	(0.174)	(0.152)
Driving Distance	kilometers/month	1110	1770	1310	1710	1400	2080
		(997)	(1350)	(1010)	(1160)	(1080)	(1460)
#Observations		2005	434	1363	657	257	890

Notes: Standard deviations in parentheses. Demographic information comes from the 2008 JD Power APEAL survey.

Table 3.7: Summary Demographic Statistics—2010

VARIABLES	UNITS	petrol hatch-back	diesel hatch-back	petrol sedan	diesel sedan	petrol SUV	diesel SUV
Income	10^5 Rupees (2010)	5.29	5.29	7.78	6.66	5.35	7.01
		(3.59)	(3.50)	(4.89)	(4.26)	(4.07)	(4.56)
Family Size		4.73	4.93	5.06	5.15	5.56	5.43
		(1.56)	(1.49)	(1.65)	(1.59)	(1.62)	(1.61)
Age	years	38.0	35.9	37.2	36.2	37.5	36.8
		(11.4)	(10.7)	(10.4)	(9.12)	(10.0)	(9.72)
% Female		0.0861	0.0319	0.0459	0.0384	0.0129	0.0265
		(0.281)	(0.176)	(0.209)	(0.192)	(0.113)	(0.161)
Driving Distance	kilometers/month	1370	2210	1670	1960	1410	2600
		(1960)	(2550)	(2560)	(2090)	(1550)	(2770)
#Observations		2404	596	1176	730	233	1095

Notes: Standard deviations in parentheses. Demographic information comes from the 2010 JD Power APEAL survey.

Table 3.8: Demand Model Parameter Estimates—2006

FIXED	Coefficient	(Standard Error)
Hatchback Dummy	0.00792*	(0.00450)
Sedan Dummy	0.01466*	(0.00816)
Age	-0.00747***	(0.00118)
Female Dummy	-0.244***	(0.0483)
Family Size	0.0743***	(0.00866)
Gears	0.00556*	(0.00319)
Automatic	-0.00110	(0.000901)
Safety Index	0.0000615*	(0.000358)
Luxury Index	-0.00104*	(0.000612)
Family Size×Hatchback Dummy	-0.000764*	(0.000462)
Family Size×Sedan Dummy	-0.000608*	(0.000363)
Age×Safety Index	-0.00000409	(0.00000506)
Family Size×Power Ratio	-0.0115	(0.00768)
KM Measurement Error(σ)	0.789***	(0.00888)
Scale Factor(μ)	1.77***	(0.201)

RANDOM	Coefficient	(Standard Error)	Standard Deviation	(Standard Error)
Income−Rent(β)	-5.37***	(0.593)	1.44***	(0.233)
Operating Cost(α)	-1.53***	(0.0877)	0.00658	(0.100)
Engine Size	0.00167	(0.00127)	0.00128*	(0.000748)
Power Ratio	-0.0425*	(0.0245)	0.148*	(0.0838)
Torque	0.000281	(0.000171)	0.0000369	(0.0000300)
Length	-0.0243*	0.0133	0.000413	(0.000318)
Width	0.0114*	0.00661	0.00356	(0.00232)
Height	0.00604	0.00383	0.000881*	(0.000534)
Ground Clearance	0.0928*	(0.0524)	0.0233	(0.0145)
Weight	0.0110*	(0.00621)	0.00590*	(0.00346)

Notes: This table presents full information maximum likelihood coefficient estimates with 10 make fixed effects (not shown). Integrals simulated using 200 shifted and shuffled Halton draws. Number of Observations= 4454, $LL = -18226$ at convergence. *-p< 10%, **-p< 5%, ***-p< 1%.

Table 3.9: Demand Model Parameter Estimates—2008

FIXED	Coefficient	(Standard Error)		
Hatchback Dummy	0.00939***	(0.00195)		
Sedan Dummy	0.0190***	(0.00284)		
Age	-0.00473***	(0.000793)		
Female Dummy	-0.208***	(0.0385)		
Family Size	0.0384***	(0.00511)		
Gears	0.0115***	(0.00173)		
Automatic	0.00119	(0.00147)		
Safety Index	0.00316***	(0.000861)		
Luxury Index	-0.000446**	(0.000222)		
Family Size×Hatchback Dummy	-0.00159***	(0.000289)		
Family Size×Sedan Dummy	-0.00139***	(0.000299)		
Age×Safety Index	-0.0000194	(0.0000157)		
Famil ySize×Power Ratio	-0.00891*	(0.00537)		
KM Measurement Error(σ)	0.646***	(0.0149)		
Scale Factor(μ)	0.948***	(0.0919)		
RANDOM	Coefficient	(Standard Error)	Standard Deviation	(Standard Error)
Income−Rent(β)	-3.88***	(0.102)	0.00488	(0.0534)
Operating Cost(α)	-1.33***	(0.0562)	0.391***	(0.0238)
Engine Size	-0.00555**	(0.00222)	0.0184	(0.00244)
Power Ratio	-0.0164	(0.0351)	0.00732	(0.0239)
Torque	-0.000263	(0.0000524)	0.00000898	(0.0000998)
Length	-0.0201***	(0.00282)	0.00150	(0.00299)
Width	0.00497	(0.00440)	0.00510	(0.00808)
Height	0.00838**	(0.00346)	0.0106	(0.00665)
Ground Clearance	0.0771***	(0.0230)	0.0171	(0.0399)
Weight	0.0143***	(0.00389)	0.00755	(0.00482)

Notes: This table presents full information maximum likelihood coefficient estimates with 11 make fixed effects (not shown). Integrals simulated using 200 shifted and shuffled Halton draws. Number of Observations= 5865, $LL = -25906$ at convergence. *-p< 10%, **-p< 5%, ***-p< 1%.

Table 3.10: Demand Model Parameter Estimates—2010

FIXED	Coefficient	(Standard Error)
Hatchback Dummy	0.0000365	(0.00147)
Sedan Dummy	0.0142***	(0.00243)
Age	-0.00735***	(0.000838)
Female Dummy	-0.253***	(0.0355)
Family Size	0.0458***	(0.00626)
Gears	0.0154***	(0.00168)
Automatic	-0.00169	(0.00269)
Safety Index	0.00173**	(0.000770)
Luxury Index	0.00296***	(0.000344)
Family Size×Hatchback Dummy	-0.00281***	(0.000339)
Family Size×Sedan Dummy	-0.00203***	(0.000354)
Age×Safety Index	0.0000129	(0.0000162)
Family Size×Power Ratio	0.00108	(0.00558)
KM Measurement Error(σ)	1.00***	(0.00914)
Scale Factor(μ)	0.772***	(0.0675)

RANDOM	Coefficient	(Standard Error)	Standard Deviation	(Standard Error)
Income−Rent(β)	-3.45***	(0.0851)	0.0357	(0.0619)
Operating Cost(α)	-1.17***	(0.0702)	0.0123	(0.138)
Engine Size	0.0164***	(0.00225)	0.00192	(0.00403)
Power Ratio	0.0323	(0.0339)	0.000636	(0.0247)
Torque	-0.000216***	(0.0000551)	0.0000271	(0.0000942)
Length	-0.0512***	(0.00578)	0.00733***	(0.00210)
Width	-0.0368***	(0.00506)	0.000263	(0.00520)
Height	-0.0223***	(0.00309)	0.000188	(0.00760)
Ground Clearance	0.179***	(0.0298)	0.00208	(0.0421)
Weight	0.0315***	(0.00431)	0.000401	(0.00197)

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= 6475, $LL = -32013$ at convergence. *-p< 10%, **-p< 5%, ***-p< 1%.

Table 3.11: Policy Simulation Results—2006

		Status Quo	5.60% Diesel Fuel Tax	44.5% Diesel Fuel Tax	24.5% Diesel Car Tax
Market Share	petrol	71.7%	72.4%	76.3%	76.3%
	diesel	28.3%	27.6%	23.7%	23.7%
Average Driving Distance	petrol	1020	1020	1020	1020
(*km*/*month*)	diesel	1350	1300	987	1350
Total Fuel Consumption	petrol	826	834	879	879
(10^6 L)	diesel	437	411	270	366
Total Fuel Conserved (10^6 L/year)			18.9	115	19.0
Average CV (Rs. 2010/year)			833	5500	5470
Δ Government Revenue (10^5 Rs. 2010/year)			11300	61000	64000
Deadweight Loss/Liter (Rs. 2010/L)			-33.7	80.6	307

Notes: This table presents policy simulation results for year 2006 using parameter estimates presented in Table 3.8. 2006 petrol and diesel fuel prices (in 2010 Rs./liter) were 61.4 and 42.5, respectively. Thus, a 5.60% diesel fuel tax amounts to 2.38 Rs. and a 44.5% diesel fuel tax amounts to 18.9 Rs. In both cases, the existing tax on petrol fuel is assumed to equal 18.9 Rs.

Table 3.12: Policy Simulation Results—2008

		Status Quo	8.12% Diesel Fuel Tax	43.3% Diesel Fuel Tax	23.3% Diesel Car Tax
Market Share	petrol	68.7%	70.5%	76.6%	76.6%
	diesel	31.3%	29.5%	23.4%	23.4%
Average Driving Distance (*km/month*)	petrol	970	970	967	966
	diesel	1370	1280	971	1365
Total Fuel Consumption (10^6 L)	petrol	864	886	962	962
	diesel	540	479	289	402
Total Fuel Conserved (10^6 L/year)			39.1	152	39.1
Average CV (Rs. 2010/year)			1180	5020	5060
Δ Government Revenue (10^5 Rs. 2010/year)			1830	63500	65100
Deadweight Loss/Liter (Rs. 2010/L)			-18.9	72.7	256

Notes: This table presents policy simulation results for year 2008 using parameter estimates presented in Table 3.9. 2008 petrol and diesel fuel prices (in 2010 Rs./liter) were 54.2 and 37.8, respectively. Thus, an 8.12% diesel fuel tax amounts to 3.07 Rs. and a 43.3% diesel fuel tax amounts to 16.4 Rs. In both cases, the existing tax on petrol fuel is assumed to equal 16.4 Rs.

Table 3.13: Policy Simulation Results—2010

		Status Quo	6.85% Diesel Fuel Tax	34.3% Diesel Fuel Tax	17.8% Diesel Car Tax
Market Share	petrol	67.6%	69.6%	76.2%	76.2%
	diesel	32.4%	30.4%	23.8%	23.8%
Average Driving Distance (*km*/*month*)	petrol	978	978	977	977
	diesel	1320	1250	990	1330
Total Fuel Consumption (10^6 L)	petrol	1330	1370	1490	1490
	diesel	836	740	462	611
Total Fuel Conserved (10^6 L/year)			56.2	206	56.2
Average CV (Rs. 2010/year)			922	3690	3590
Δ Government Revenue (10^5 Rs. 2010/year)			24500	82300	71200
Deadweight Loss/Liter (Rs. 2010/L)			-57.3	14.6	208

Notes: This table presents policy simulation results for year 2010 using parameter estimates presented in Table 3.10. 2010 petrol and diesel fuel prices (in 2010 Rs./liter) were 51.1 and 38.1, respectively. Thus, a 6.85% diesel fuel tax amounts to 2.61 Rs. and a 34.3% diesel fuel tax amounts to 13.1 Rs. In both cases, the existing tax on petrol fuel is assumed to equal 13.1 Rs.

Figure 3.1: Dieselization Across Passenger Vehicle Segments

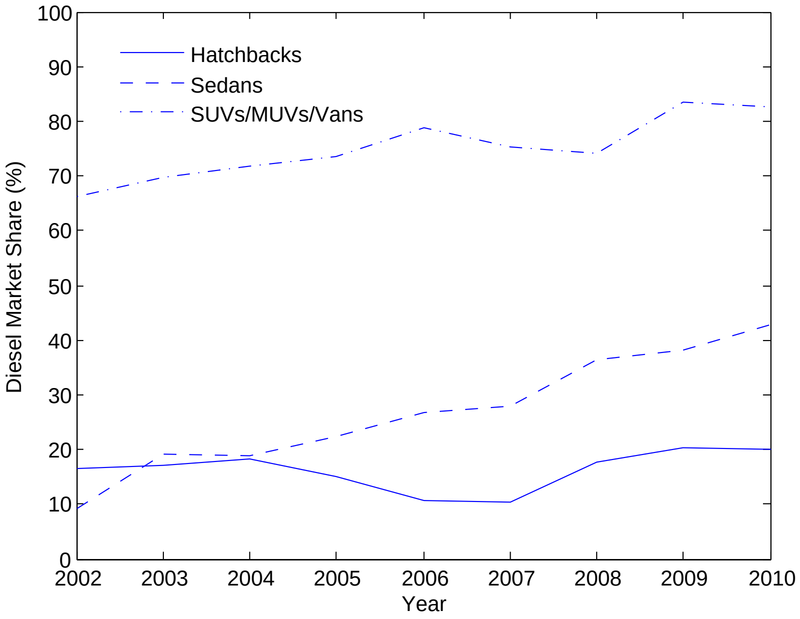


Figure 3.2: Model Fit (Market Shares)—2006

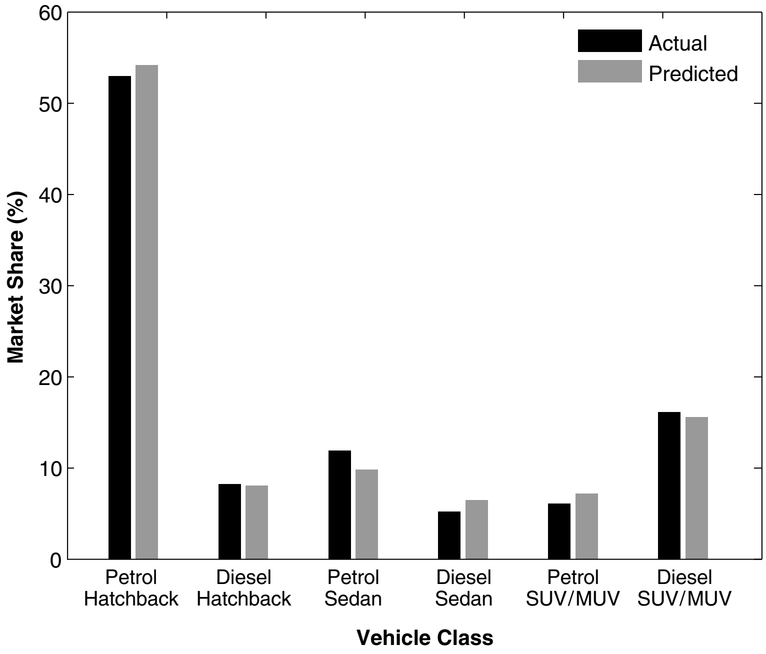


Figure 3.3: Model Fit (Driving Distance)—2006

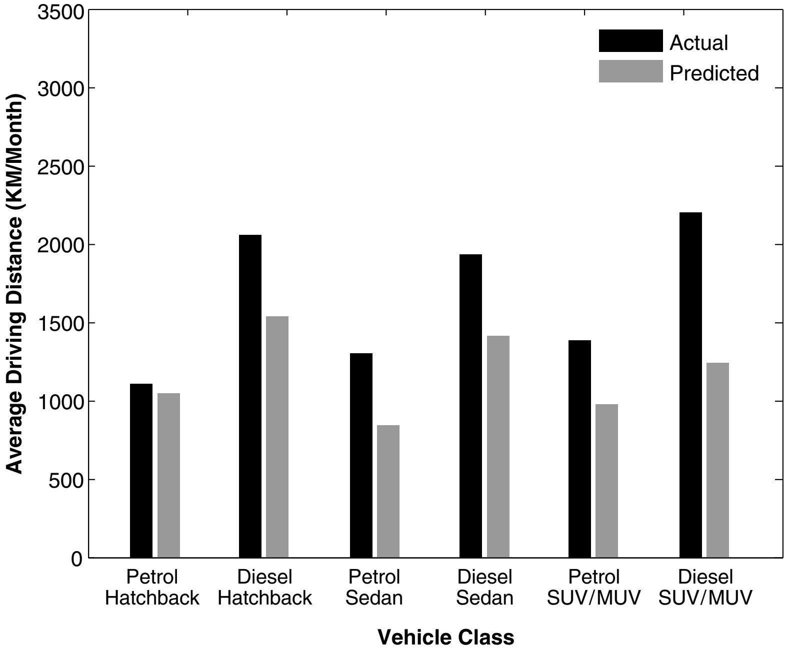


Figure 3.4: Model Fit (Market Shares)—2008

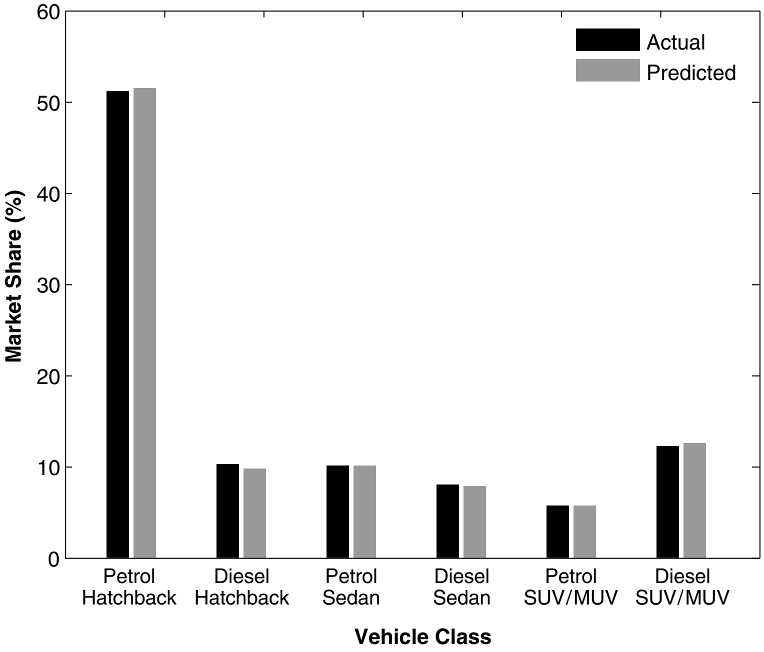


Figure 3.5: Model Fit (Driving Distance)—2008

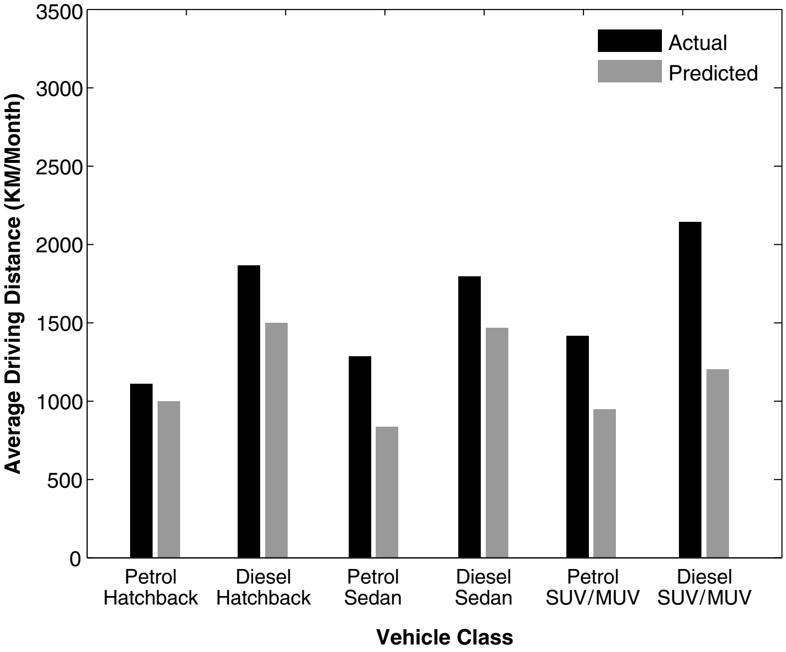


Figure 3.6: Model Fit (Market Shares)—2010

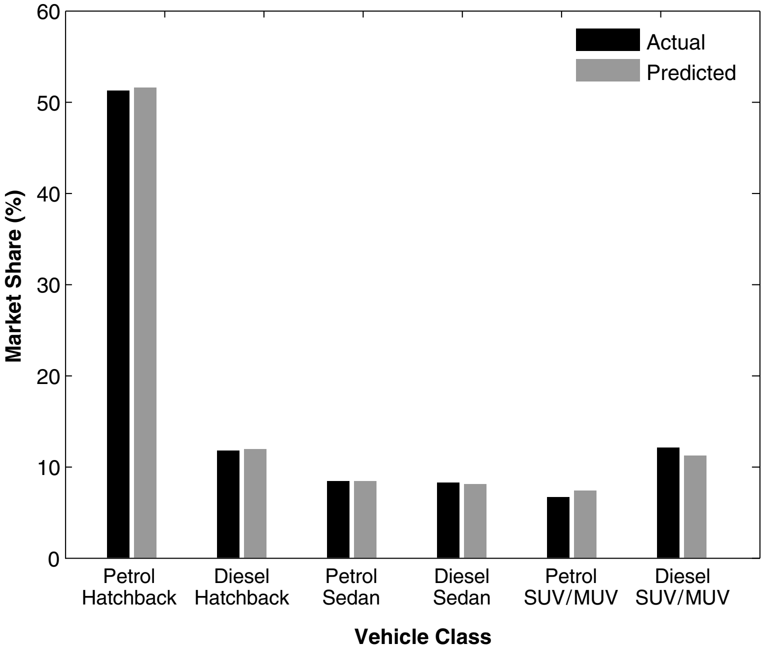


Figure 3.7: Model Fit (Driving Distance)—2010

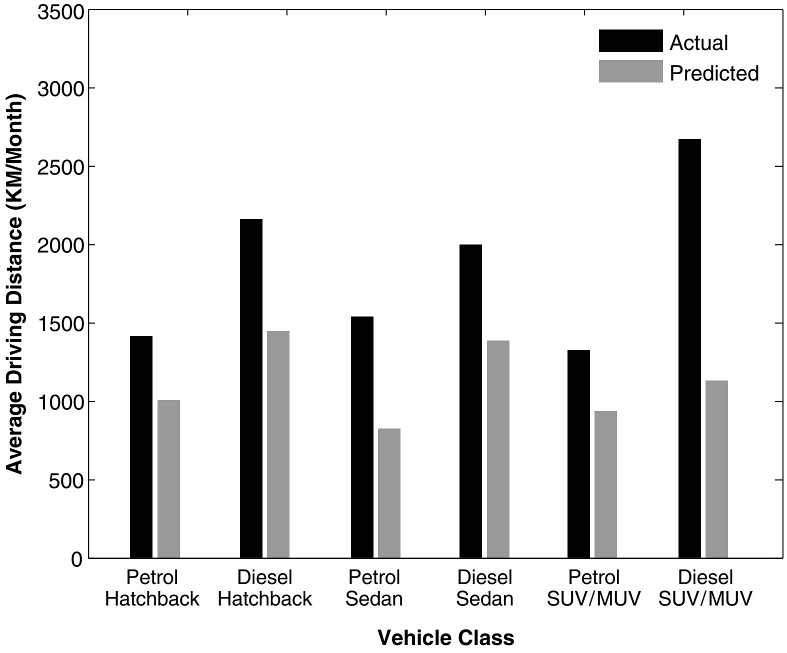


Figure 3.8: Expected Compensating Variation For Diesel Buyers (44.5% Diesel Fuel Tax vs. 24.0% Diesel Car Tax)—2006

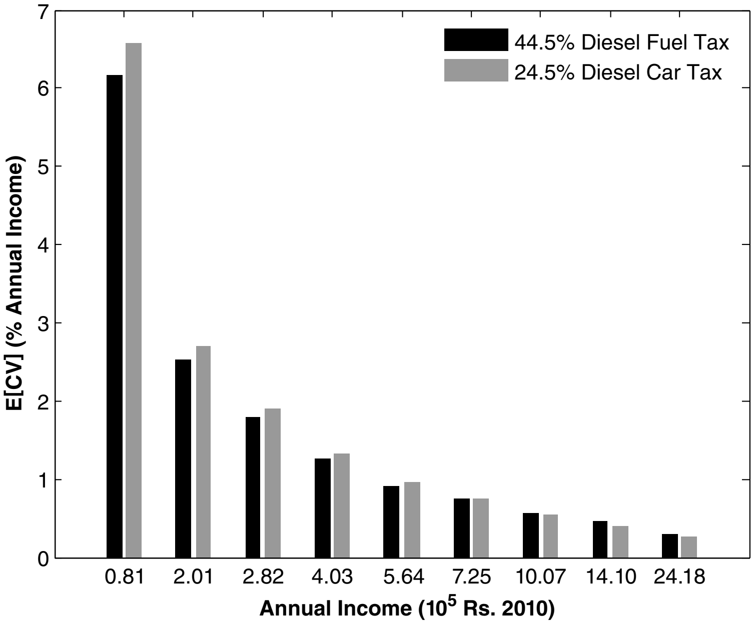


Figure 3.9: Expected Compensating Variation For Diesel Buyers (43.3% Diesel Fuel Tax vs. 22.9% Diesel Car Tax)—2008

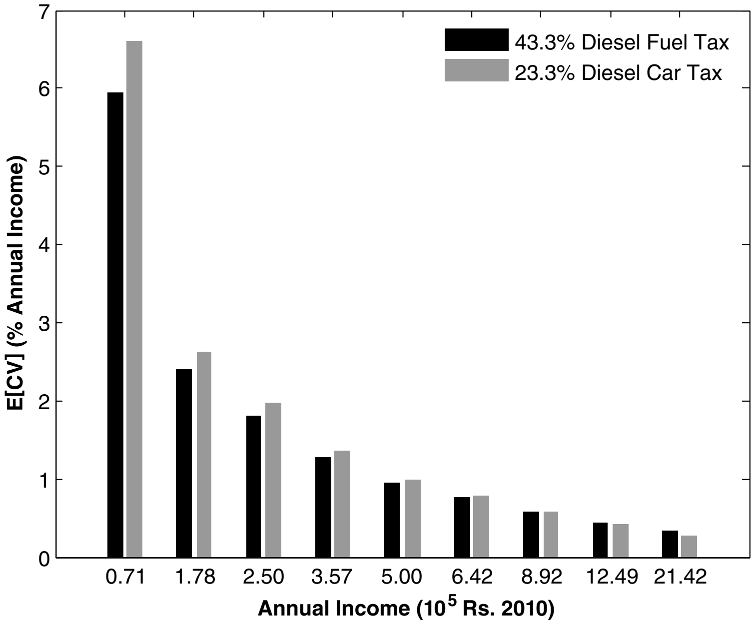
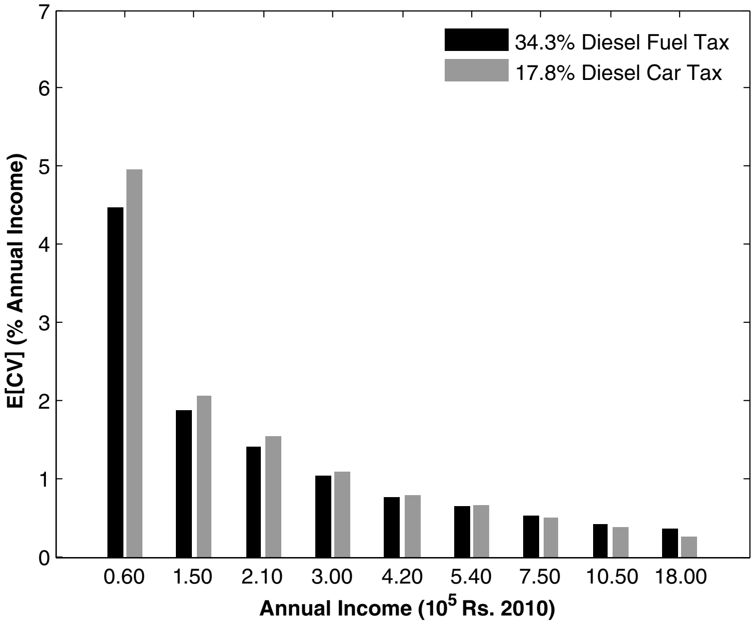


Figure 3.10: Expected Compensating Variation For Diesel Buyers (34.3% Diesel Fuel Tax vs. 17.5% Diesel Car Tax)—2010



Appendix A

Chapter 2 Supplement–OLS and IV First Stage Results

Table A.1: Hedonic Price Function IV Estimation First Stage Results (Specification 4)

VARIABLES	Petrol Hatchbacks: City Fuel Economy	Diesel Hatchbacks: City Fuel Economy	Petrol Sedans: City Fuel Economy	Diesel Sedans: City Fuel Economy
IV	0.490***	0.441***	0.285***	1.22***
	(0.0862)	(0.0839)	(0.0640)	(0.292)
Weight	-2.34***	-1.79	-1.73**	-5.03
	(0.705)	(1.63)	(0.789)	(3.60)
Engine Size	-0.00865***	0.00104	-0.00000368	-0.00230**
	(0.00100)	(0.000635)	(0.000662)	(0.000990)
Torque	0.636***	0.0294	-0.0725	0.180***
	(0.110)	(0.0413)	(0.0632)	(0.0458)
Luxury Index	-0.0285	0.0696	0.0283	0.0179
	(0.0399)	(0.0674)	(0.0362)	(0.101)
Safety Index	0.0317	0.270	-0.251***	0.0552
	(0.101)	(0.146)	(0.0723)	(0.259)
Automatic	-0.707***		-0.970***	
	(0.270)		(0.293)	
y2003	-0.235	-0.166	-0.704***	-2.20***
	(0.205)	(0.301)	(0.200)	(0.681)
y2004	-0.343	-0.316	-0.534***	-2.23***
	(0.211)	(0.303)	(0.197)	(0.685)
y2005	-0.427**	-1.50	-1.137***	-3.19***
	(0.203)	(0.322)	(0.211)	(0.623)
y2006	-0.502**	-1.72***	-0.504**	-3.11***
	(0.202)	(0.344)	(0.201)	(0.650)
y2007	-0.210	-1.58***	-0.488**	-3.14***
	(0.214)	(0.322)	(0.209)	(0.636)
y2008	-0.448**	-1.59***	-0.366	-3.41***
	(0.213)	(0.409)	(0.233)	(0.685)
Constant	12.8***	8.52***	9.66***	5.40
	(0.998)	(2.33)	(1.04)	(5.93)
Observations	236	64	216	42
R^2	0.699	0.699	0.546	0.843

Notes: This table presents first stage results of IV estimation of hedonic price function specification 4. Standard errors are in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.2: Hedonic Price Function OLS Estimation Results–Petrol Hatchback

VARIABLES	(1) ln(Price)	(2) ln(Price)	(3) ln(Price)	(4) ln(Price)
City Fuel Economy	0.0144**	0.000870	0.0128	0.00381
	(0.00673)	(0.00739)	(0.00776)	(0.00860)
Weight	0.872***	1.161***	0.393***	0.379***
	(0.0657)	(0.0977)	(0.100)	(0.0992)
Power Ratio	9.905***	13.63***		
	(0.912)	(1.301)		
Engine Size		-0.000335***		-0.000325**
		(8.58e-05)		(0.000140)
Torque			0.0479***	0.0779***
			(0.00713)	(0.0147)
Luxury Index	0.0724***	0.0709***	0.0833***	0.0834***
	(0.00506)	(0.00492)	(0.00547)	(0.00542)
Safety Index	-0.0276**	-0.0300**	-0.0179	-0.0178
	(0.0123)	(0.0120)	(0.0138)	(0.0136)
Automatic	0.134***	0.129***	0.100***	0.0873**
	(0.0338)	(0.0328)	(0.0377)	(0.0378)
y2003	-0.0712***	-0.0799***	-0.0466*	-0.0479*
	(0.0242)	(0.0236)	(0.0270)	(0.0268)
y2004	-0.143***	-0.144***	-0.129***	-0.126***
	(0.0256)	(0.0249)	(0.0288)	(0.0285)
y2005	-0.221***	-0.231***	-0.198***	-0.202***
	(0.0247)	(0.0241)	(0.0276)	(0.0274)
y2006	-0.166***	-0.172***	-0.163***	-0.169***
	(0.0247)	(0.0240)	(0.0277)	(0.0276)
y2007	-0.277***	-0.281***	-0.297***	-0.309***
	(0.0254)	(0.0247)	(0.0285)	(0.0287)
y2008	-0.302***	-0.312***	-0.331***	-0.350***
	(0.0243)	(0.0237)	(0.0271)	(0.0281)
Constant	-0.208	-0.198	0.477***	0.677***
	(0.145)	(0.141)	(0.137)	(0.161)
Observations	244	244	244	244
R^2	0.881	0.888	0.850	0.853

Notes: This table presents hedonic price function OLS estimation results using petrol hatchbacks for years 2002 to 2008. To analyze sensitivity of results, we present four different specifications. Standard errors are in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.3: Hedonic Price Function OLS Estimation Results–Diesel Hatchback

VARIABLES	(1) ln(Price)	(2) ln(Price)	(3) ln(Price)	(4) ln(Price)
City Fuel Economy	0.0323***	0.0319***	0.0252**	0.0249**
	(0.0103)	(0.0101)	(0.0105)	(0.0101)
Weight	1.10***	0.925***	0.527***	0.374**
	(0.139)	(0.166)	(0.138)	(0.145)
Power Ratio	7.63***	6.80***		
	(1.15)	(1.21)		
Engine Size		0.000110*		0.000137**
		(0.0000584)		(0.0000551)
Torque			0.0253***	0.0226***
			(0.00377)	(0.00374)
Luxury Index	0.0432***	0.0455***	0.0436***	0.0462***
	(0.00663)	(0.00660)	(0.00659)	(0.00637)
Safety Index	0.00801	-0.000570	0.00728	-0.00352
	(0.0139)	(0.0143)	(0.0138)	(0.0139)
Automatic	0	0	0	0
	(0)	(0)	(0)	(0)
y2003	-0.0781***	-0.0884***	-0.0806***	-0.0937***
	(0.0290)	(0.0288)	(0.0289)	(0.0280)
y2004	-0.160***	-0.160***	-0.154***	-0.155***
	(0.0294)	(0.0287)	(0.0293)	(0.0279)
y2005	-0.153***	-0.149***	-0.154***	-0.150***
	(0.0331)	(0.0324)	(0.0330)	(0.0315)
y2006	-0.0728**	-0.0581	-0.0777**	-0.0590*
	(0.0353)	(0.0354)	(0.0352)	(0.0344)
y2007	-0.215***	-0.195***	-0.221***	-0.196***
	(0.0327)	(0.0337)	(0.0327)	(0.0327)
y2008	-0.299***	-0.257***	-0.320***	-0.268***
	(0.0353)	(0.0410)	(0.0364)	(0.0404)
Constant	-0.379	-0.328	0.476**	0.434*
	(0.237)	(0.233)	(0.229)	(0.219)
Observations	64	64	64	64
R^2	0.877	0.885	0.878	0.891

Notes: This table presents hedonic price function OLS estimation results using diesel hatchbacks for years 2002 to 2008. To analyze sensitivity of results, we present four different specifications. Standard errors are in parentheses, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table A.4: Hedonic Price Function OLS Estimation Results–Petrol Sedan

VARIABLES	(1) ln(Price)	(2) ln(Price)	(3) ln(Price)	(4) ln(Price)
City Fuel Economy	0.0472***	0.0442***	0.0264**	0.0260**
	(0.0114)	(0.0114)	(0.0107)	(0.0106)
Weight	1.87***	1.63***	0.815***	0.842***
	(0.0899)	(0.126)	(0.112)	(0.112)
Power Ratio	8.99***	7.40***		
	(0.679)	(0.899)		
Engine Size		0.000107***		-0.000140***
		(0.0000404)		(0.0000525)
Torque			0.0506***	0.0639***
			(0.00334)	(0.00599)
Luxury Index	0.0579***	0.0605***	0.0668***	0.0652***
	(0.00566)	(0.00572)	(0.00535)	(0.00534)
Safety Index	-0.0188	-0.0108	0.00942	0.00571
	(0.0127)	(0.0130)	(0.0120)	(0.0120)
Automatic	0.179***	0.181***	0.174***	0.168***
	(0.0301)	(0.0300)	(0.0288)	(0.0287)
y2003	0.00226	0.00733	0.0110	0.00635
	(0.0367)	(0.0365)	(0.0350)	(0.0348)
y2004	-0.121***	-0.122***	-0.126***	-0.126***
	(0.0355)	(0.0352)	(0.0339)	(0.0336)
y2005	-0.198***	-0.197***	-0.213***	-0.217***
	(0.0377)	(0.0376)	(0.0362)	(0.0360)
y2006	-0.212***	-0.212***	-0.245***	-0.254***
	(0.0356)	(0.0353)	(0.0340)	(0.0339)
y2007	-0.279***	-0.272***	-0.301***	-0.316***
	(0.0355)	(0.0354)	(0.0340)	(0.0342)
y2008	-0.352***	-0.348***	-0.375***	-0.387***
	(0.0366)	(0.0364)	(0.0351)	(0.0351)
Constant	-1.254***	-1.027***	0.124	0.156
	(0.190)	(0.207)	(0.171)	(0.170)
Observations	412	411	411	411
R^2	0.919	0.921	0.927	0.928

Notes: This table presents hedonic price function OLS estimation results using petrol sedans for years 2002 to 2008. To analyze sensitivity of results, we present four different specifications. Standard errors are in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.5: Hedonic Price Function OLS Estimation Results–Diesel Sedan

VARIABLES	(1) ln(Price)	(2) ln(Price)	(3) ln(Price)	(4) ln(Price)
City Fuel Economy	0.0137	0.0273***	0.00866	0.0239**
	(0.0103)	(0.00983)	(0.0112)	(0.0107)
Weight	1.19***	0.858***	0.673**	0.375
	(0.203)	(0.198)	(0.271)	(0.255)
Power Ratio	7.70***	6.88***		
	(1.14)	(1.06)		
Engine Size		0.000289***		0.000310***
		(0.0000555)		(0.0000585)
Torque			0.0206***	0.0182***
			(0.00415)	(0.00384)
Luxury Index	0.0974***	0.0839***	0.102***	0.0874***
	(0.00800)	(0.00780)	(0.00840)	(0.00821)
Safety Index	-0.0194	0.00858	-0.0135	0.0158
	(0.0216)	(0.0206)	(0.0229)	(0.0217)
Automatic	0.320***	0.318***	0.340***	0.336***
	(0.0487)	(0.0448)	(0.0514)	(0.0472)
y2003	0.0496	0.0605	0.0826	0.0907*
	(0.0506)	(0.0466)	(0.0531)	(0.0487)
y2004	0.000737	-0.00652	0.0195	0.00980
	(0.0513)	(0.0472)	(0.0544)	(0.0500)
y2005	-0.135***	-0.135***	-0.117**	-0.119**
	(0.0512)	(0.0472)	(0.0546)	(0.0502)
y2006	-0.168***	-0.165***	-0.144***	-0.144***
	(0.0521)	(0.0480)	(0.0552)	(0.0506)
y2007	-0.239***	-0.211***	-0.230***	-0.201***
	(0.0506)	(0.0469)	(0.0543)	(0.0502)
y2008	-0.324***	-0.300***	-0.317***	-0.292***
	(0.0507)	(0.0469)	(0.0550)	(0.0507)
Constant	-0.158	-0.355	0.615*	0.314
	(0.301)	(0.279)	(0.369)	(0.343)
Observations	158	158	158	158
R^2	0.936	0.946	0.928	0.939

Notes: This table presents hedonic price function OLS estimation results using diesel sedans for years 2002 to 2008. To analyze sensitivity of results, we present four different specifications. Standard errors are in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Appendix B

Chapter 3 Supplement–Estimation Results Under Alternative Interest Rate Assumptions

Table B.1: Demand Model Parameter Estimates—2006 ($r = 0.05$)

FIXED	Coefficient	(Standard Error)		
Hatchback Dummy	0.00842***	(0.00252)		
Sedan Dummy	0.0194***	(0.00557)		
Age	-0.00739***	(0.00104)		
Female Dummy	-0.256***	(0.0477)		
Family Size	0.0764***	(0.00717)		
Gears	0.00562***	(0.00170)		
Automatic	0.00397***	(0.00141)		
Safety Index	0.000175	(0.000603)		
Luxury Index	-0.00169***	(0.000539)		
Family Size×HatchbackDummy	-0.000982***	(0.000319)		
Family Size×SedanDummy	-0.000826***	(0.000287)		
Age×Safety Index	-0.000000480	(0.00000505)		
Family Size×Power Ratio	-0.00405	(0.00320)		
KM Measurement Error (σ)	0.788***	(0.00885)		
Scale Factor (μ)	1.64***	(0.172)		
RANDOM	Coefficient	(Standard Error)	Standard Deviation	(Standard Error)
Income−Rent (β)	-4.95***	(0.288)	1.26***	(0.117)
Operating Cost (α)	-1.52***	(0.0698)	0.00452	(0.0996)
Engine Size	0.00303**	(0.00139)	0.00168***	(0.000592)
Power Ratio	-0.0322	(0.0215)	0.0186*	(0.0101)
Torque	-0.000168	(0.000134)	0.000281***	(0.0000851)
Length	-0.0349***	(0.00978)	0.000275	(0.000226)
Width	0.0230***	(0.00646)	0.000754	(0.00110)
Height	0.00668**	(0.00319)	0.000569	(0.000658)
Ground Clearance	0.103**	(0.0409)	0.0335**	(0.0151)
Weight	0.0229***	(0.00765)	0.00584***	(0.00189)

Notes: This table presents full information maximum likelihood coefficient estimates with 10 make fixed effects (not shown). Integrals simulated using 200 shifted and shuffled Halton draws. Number of Observations= 4454, $LL = -18239$ at convergence. *-p< 10%, **-p< 5%, ***-p< 1%.

Table B.2: Demand Model Parameter Estimates—2006 ($r = 0.12$)

FIXED	Coefficient	(Standard Error)		
Hatchback Dummy	0.0122***	(0.00317)		
Sedan Dummy	0.0264***	(0.00662)		
Age	-0.00751***	(0.00102)		
Female Dummy	-0.256***	(0.0472)		
Family Size	0.0747***	(0.00706)		
Gears	0.00776***	(0.00209)		
Automatic	0.00572***	(0.00185)		
Safety Index	0.000588	(0.000828)		
Luxury Index	-0.00234***	(0.000677)		
Family Size×Hatchback Dummy	-0.00131***	(0.000370)		
Family Size×Sedan Dummy	-0.00109***	(0.000337)		
Age×Safety Index	0.00000105	(0.00000741)		
Family Size×Power Ratio	-0.00544	(0.00399)		
KM Measurement Error (σ)	0.788***	(0.00916)		
Scale Factor (μ)	2.0922***	(0.215)		
RANDOM	Coefficient	(Standard Error)	Standard Deviation	(Standard Error)
Income−Rent (β)	-4.85***	(0.250)	1.26***	(0.107)
Operating Cost (α)	-1.50***	(0.0686)	0.0207	(0.101)
Engine Size	0.00310	(0.00190)	0.00260***	(0.000755)
Power Ratio	-0.0851***	(0.0322)	0.000129	(0.00954)
Torque	-0.000161	(0.000188)	0.000398***	(0.000116)
Length	-0.0469***	(0.0117)	0.000213	(0.000288)
Width	0.0289***	(0.00739)	0.000348	(0.00155)
Height	0.00882**	(0.00421)	0.000518	(0.000882)
Ground Clearance	0.155***	(0.0576)	0.0257	(0.0168)
Weight	0.0356***	(0.0105)	0.00354***	(0.00107)

Notes: This table presents full information maximum likelihood coefficient estimates with 10 make fixed effects (not shown). Integrals simulated using 200 shifted and shuffled Halton draws. Number of Observations= 4454, $LL = -18242$ at convergence.
*-p< 10%, **-p< 5%, ***-p< 1%.

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