Gasoline Prices, Government Support, and the Demand for Hybrid Vehicles in the U.S.

Arie Beresteanu and Shanjun Li*

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Abstract

We analyze the determinants of hybrid vehicle demand, focusing on gasoline prices and income tax incentives. We find that hybrid vehicle sales in 2006 would have been 37 percent lower had gasoline prices stayed at the 1999 levels while the effect of the federal income tax credit program is estimated at 20 percent in 2006. Under the program, the cost of reducing gasoline consumption was $75 per barrel in government revenue and that of CO_2 emission reduction was $177 per ton. We show that the cost-effectiveness of federal tax programs can be improved by a flat rebate scheme.

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1 Introduction

Since their introduction into the U.S. market in 2000, hybrid vehicles have been in increasingly strong demand: sales grew from less than 10,000 cars in 2000 to about 346,000 in 2007. A hybrid vehicle combines the benefits of gasoline engines and electric motors and delivers better fuel economy than its non-hybrid equivalent. Therefore, the hybrid technology has been considered as a promising tool in the U.S. to reduce CO_2 emissions and air pollution and to achieve energy security. Following the recommendation of the National Energy Policy Report (2001),[1] the U.S. government has been supporting consumer purchase of hybrid vehicles in the forms of federal income tax deductions before 2006 and federal income tax credits since then. The rational for an active governmental role to promote the diffusion of the hybrid technology is grounded on environmental externalities of motor gasoline consumption, national energy interests, as well as information spillovers among consumers and firms often present in the diffusion process of new technologies (Stoneman and Diederen 1994; Jaffe and Stavins 1999).

In recent years, there have been heightened concerns over adverse environmental effects of motor gasoline consumption and increasing U.S. dependency on foreign oil.[2] To address energy security and environmental problems, different policies have been proposed such as increasing the federal gasoline tax, tightening Corporate Average Fuel Economy (CAFE) Standards, and promoting the development and adoption of fuel-efficient technologies through subsidies such as tax incentives on hybrid vehicle purchases. Many studies have examined the first two alternatives, with the majority of them finding that increasing the gasoline tax is more cost-effective than tightening CAFE standards (e.g., National Research Council 2002; Congressional Budget Office 2003; Austin and Dinan 2005; and Bento,

[1]The report was written by the National Energy Policy Development Group established in 2001 by George W. Bush. The goal of the group is to develop a national energy policy designed to promote dependable, affordable, and environmentally sound production and distribution of energy for the future.

[2]The United States imports about 60 percent of its total petroleum products. Motor gasoline consumption accounts for an estimated 60 to 70 percent of total urban air pollution and 20 percent of the annual emissions of carbon dioxide, the predominant greenhouse gas that contributes to global warming. See Parry, Harrington, and Walls (2007) for a comprehensive review of externalities associated with vehicle usage and gasoline consumption as well as discussions on policy instruments.

Goulder, Jacobsen, and von Haefen 2008). Nevertheless, tightening CAFE standards has been more politically favorable than increasing gasoline taxes.

Although several studies have looked at consumer adoption of hybrid technology, none of them investigates the effectiveness of government support on solving energy dependence and environmental problems through the diffusion of hybrid vehicles (see references below). In this paper, we analyze the determinants of hybrid vehicle purchase, paying particular attention to recent rising gasoline prices and government support programs. We investigate both the overall contribution and the cost-effectiveness of the government programs in reducing gasoline consumption and CO_2 emissions. We then examine the impact of the program's regressive nature on its cost-effectiveness by comparing it with a flat rebate program where all the buyers of the same hybrid model receive an equal subsidy. We discuss important implications of our findings for the future of the hybrid vehicle market in the U.S. as well as how to harness the potential benefit of this market for environmental protection and energy conservation.

Taking advantage of a rich data set of new vehicle registrations in 22 Metropolitan Statistical Areas (MSA) from 1999 to 2006, we estimate a market equilibrium model with both demand and supply sides in the spirit of Berry, Levinsohn, and Pakes (1995) (henceforth BLP). The demand side is derived from a random coefficient utility model and the supply side assumes that multiproduct firms engage in price competition. Following Petrin (2002), our estimation employs both aggregate market-level sales data and household-level data. The household-level data provide correlations between household demographics and household vehicle choices, based on which we construct additional moment conditions to estimate the model. Not only can these micro-moment conditions greatly facilitate the estimation of consumer preference heterogeneity as illustrated by Petrin (2002), but they also provide essential conditions for the identification of our empirical model as discussed in more detail in Section 3.2.

In addition, our estimation method does not rely on the maintained exogeneity assumption in the literature that observed product attributes are uncorrelated with unobserved product attributes. Because we observe sales of the same product in multiple markets, we use product fixed effects to control for price endogeneity due to market-level unobserved product attributes following Nevo (2001). Goolsbee and Petrin (2004) employs an alternative framework where they control for market-specific unobserved product attributes/valuations and identify consumer preference heterogeneity without resorting to the exogeneity assumption of observed product attributes.

Three recent papers have examined several issues related to hybrid vehicles. Kahn (2007) studies the effect of environmental preference on the demand for green products and finds a positive correlation between the adoption of hybrid vehicles and the percentage of registered green party voters in California. Sallee (2008) studies the incidence of tax credits for Toyota Prius and shows that consumers capture the significant majority of the benefit from tax subsidies. A more closely related study to ours, Gallagher and Muehlegger (2007) estimate the effect of state and local incentives, rising gasoline prices, and environmental ideology on hybrid vehicle sales and find all three to be important. A major difference between our study and these papers is that all of them focus on the demand of a single hybrid model or hybrid vehicles alone while we take a structural method to estimate an equilibrium model of U.S. automobile market. Our empirical model allows us to simulate what would happen to the whole market of new automobiles under different scenarios (e.g., a different federal support scheme) and to examine the response in the demand and supply sides separately.

The remainder of this paper is organized as follows. Section 2 describes the background of the study and data used. Section 3 lays out the empirical model and the estimation strategy. Section 4 provides the estimation results. Section 5 conducts simulations and section 6 concludes.

2 Industry Background and Data

In this section, we start by describing the hybrid technology, the U.S. market of hybrid vehicles, and government support programs. We then discuss the three data sets used in this study.

2.1 Background

The level of fuel economy and emissions produced by a typical automobile is largely a reflection of low efficiency of conventional internal combustion engines: only about 15 percent of the energy from the fuel consumed by these engines gets used for propulsion, and the rest is lost to engine and driveline inefficiencies and idling. Hybrid vehicles combine power from both a gasoline engine and a electric motor that runs off the electricity from a rechargeable battery. The battery harnesses some of the energy that would be wasted in operations in a typical automobile (such as energy from braking) and then provides power whenever the gasoline engine proves to be inefficient and hence is turned off.[3]

Toyota introduced the first hybrid car, Toyota Prius, in Japan in 1997. In 2000, Toyota and Honda introduced their hybrid vehicles, Toyota Prius and Honda Insight, into the U.S. market. With rising gasoline prices, hybrid vehicles have enjoyed an increasing popularity in recent years. In 2004, as the first U.S. manufacturer into the hybrid market, Ford introduced its first hybrid model. In 2007, GM and Nissan entered the competition by introducing their own hybrid models. Table 1 shows the number of hybrid models and the sales history from 2000 to 2007. The number of hybrid models increased from 2 to 15 during this period.[4] The most popular hybrid model, Toyota Prius, accounted for 59 percent of the total new hybrid sales in 2000 and 52 percent in 2007.

Because of the improved fuel economy and reduced emissions, the hybrid technology is considered as a promising technology by the National Energy Policy Report (2001), which concludes that the demand for hybrid vehicles must be increased in order to achieve economies of scale so as to bring the cost of hybrid vehicles down. The group recommended in the report that efficiency-based income tax incentives be available for the purchase of new hybrid vehicles. These tax incentives can help offset the higher cost of hybrid vehicles

[3]Another technology, the fuel cell technology represents a more radical departure from vehicles with internal combustion engines. They are propelled by electricity created by fuel cells onboard through a chemical process using hydrogen fuel and oxygen from the air. This emerging technology holds the potential to dramatically reduce oil consumption and harmful emissions. However, fuel cell vehicles are not soon expected to be commercially viable.

[4]According to J.D. Power and Associates, there could be 44 hybrid models in the United States by 2012.

compared to their non-hybrid counterparts.[5] Following the recommendation, the government has provided a "clean fuel" tax deduction of up to $2,000 for new hybrid vehicles placed in service during 2001 to 2005. The Energy Policy Act of 2005 replaced the income tax deduction with an income tax credit of up to $3,400 for vehicles purchased after December 31, 2005. The tax credit for each model varies and is based on the improvement in fuel economy provided by that model relative to the non-hybrid counterpart. The credit begins to phase out over five subsequent calendar quarters for vehicles once the manufacturer sells a total of 60,000 eligible hybrid vehicles starting from January 1, 2006.[6] In addition, some state and local governments provide benefits to hybrid buyers such as state income tax deduction/credit, sale tax exemption, High-Occupancy-Vehicle (HOV) lane privileges and free parking.

2.2 Data

There are three data sets used in this study. The first source is the annual issues of Automotive News Market Data Book, containing characteristics and number of sales of virtually all new vehicle models sold in the U.S. from 1999 to 2006.[7] Table 2 reports summary statistics for the 1916 models in this data set. Price is the manufacturer suggested retail prices (MSRP). Size measures the "footprint" of a vehicle. Miles per gallon (MPG) is the weighted harmonic mean of city MPG and highway MPG based on the formula provided by the EPA to measure the fuel economy of the vehicle: MPG =

[5]A 2005 report by Edmunds.com finds that a hybrid model can cost about $4,000 more on average than its equivalent non-hybrid model in terms of purchase price plus ownership costs over the first five years. For example, a Toyota Prius costs $5,283 more than a Toyota Corolla. However, with the average MPG increases from 35 to 55 MPG, the saving in fuel cost is only about $2,340 over the first five years, assuming annual travel of 15,000 miles and gasoline being $3.00 per gallon.

[6]It is very likely that another program will be in place after the phase-out of the current program. Several bills regarding tax credits for hybrids have been introduced in the Congress in recent years. The phase-out works as follows: in the second and third calendar quarter after the calendar quarter in which the manufacturer reaches the 60,000 mark, tax credits for hybrid models by this manufacturer become 50 percent of their original amounts. They are then reduced to 25 percent in the fourth and fifth calendar quarter and to zero thereafter. Toyota reached the 60,000 mark in June 2006. From October 1, 2006 to the end of March, 2007, hybrid vehicles by Toyota are only eligible for 50 percent of original tax credits.

[7]Exotic models with tiny market shares such as Farrari are excluded.

1/(0.55/city MPG + 0.45/highway MPG). The vehicles are divided into 4 categories (car, van, SUV, and pickup truck) and further classified into 15 segments based on vehicle attributes and market orientations.

The second data set contains vehicles sales data in 22 selected MSAs from 1999 to 2006. Accounting for about 15.3 percent of total U.S. vehicles sales, these MSAs are chosen from all 9 census divisions and have large variations in terms of size and average household demographics. This vehicle sales data set, purchased from R.L. Polk Company, contains total annual sales for each of the 1619 models in all 22 MSAs with the exception of Albuquerque, NM and Little Rock, AR, where we have sales data only from 2001 to 2006. In total, we have 34,860 observations of sales data for the 22 MSAs. These MSAs are well representative of the national data in terms of average household demographics and vehicle fleet characteristics.[8] Table 3 presents the total number of new vehicle sales, the percentage of hybrid vehicles, availability of local and state incentives, and gasoline prices in 2006. The percentage of hybrid vehicles in total new vehicle sales is highest in San Francisco and lowest in Miami among the 22 MSAs. The average market share of hybrid vehicles is 2.86 percent in the MSAs with local incentives while being 1.75 percent in the MSAs without local incentives. The last column of Table 3 gives annual average gasoline prices in each of the MSAs. They are the average of quarterly prices collected from the American Chamber of Commerce Research Association (ACCRA) data base. There are large variations in gasoline prices in both cross-sectional and temporal dimensions in the data.

Our first data set describes vehicle choices consumers face while the second data set presents consumer purchase decisions at the aggregate level in the 22 MSAs. The third data set, the 2001 National Household Travel Survey (2001 NHTS), helps link household demographics with purchase decisions. The survey, often used to study national transportation trends, was conducted by agencies of the Department of Transportation from March 2001 through May 2002 through random sampling. This data set provides detailed

[8]The correlation coefficient between model sales in the 22 MSAs and the national total is 0.94. More details on the representativeness of these MSAs are given in Li, Timmins and von Haefen (2009) .

household level data on vehicle stocks, travel behavior, and household demographics at the time of survey. There are 69,817 households and 139,382 vehicles in the data. Among all the surveyed households, 45,984 are from MSAs.

Column 1 in Table 4 shows the means of several demographics for households living in MSAs. Renter, a dummy variable, is equal to 1 for the households that living in rented houses and 0, otherwise. Children dummy is 1 for households with children. Columns 2 to 6 present the means of household demographics for different groups based on household vehicle choice. These conditional means provide additional moment conditions in our estimation where we match the predicted moments from the empirical model to these observed moments. As household incomes are categorized and top-coded at $100,000, we provide the probability of new vehicle purchase for six income groups in the second panel of Table 4. In our estimation of the empirical model, these conditional probabilities are matched by their empirical counterparts based on model predictions for 2001 and 2002.

3 Empirical Model and Estimation

In this section, we discuss our empirical model and estimation strategy, which follows recent empirical literature on differentiated products. The empirical model includes both demand and supply sides. Vehicle demand is derived from a random coefficient discrete choice model while the supply side assumes that multiproduct firms, taking product choices as given, engage in price competition.

3.1 Empirical Model

Let $(\Omega, \mathscr{A}, \mathbb{P})$ be a probability space where Ω is the set of households, $\mathscr{A}$ is the Borel set of Ω, and $\mathbb{P}$ is a distribution function. Let $i \in \mathscr{A}$ denote a household and $j \in \mathscr{J}$ denote a product where $\mathscr{J}$ is the choice set. Household i's utility from product j is a function of household demographics and product characteristics. A household chooses one product from a total of J models of new vehicles and an outside alternative in a given year. The outside alternative captures the decision of not purchasing any new vehicle in the current year. To save notation, we suppress the market index m and time index t, bearing in mind that the choice set can vary across markets and years. The utility of household i from product j (in market m at year t) is defined as

$$u_{ij} = \bar{u}(p_{ij}, X_j, \xi_j, y_i, Z_i) + \epsilon_{ij}, \tag{1}$$

where p_{ij} is the price of product j for household i. The price is computed based on the MSRP, the sales tax and federal income tax incentives for hybrid vehicles.[9] X_j is a vector of observed product attributes, ξ_j the unobserved product attribute, y_i the income of household i, and Z_i is a vector of household demographics. ϵ_{ij} is a random taste shock. The specification of the first term in the utility function is assumed to be:

$$\bar{u}_{ij} = \alpha_i p_{ij} + \sum_{k=1}^{K} x_{jk}\tilde{\beta}_{ik} + \xi_j. \tag{2}$$

α_i measures consumer i's preference for price changes. We model α_i to be inversely proportional to the income of the household $\alpha_i = \alpha / y_i$.[10] x_{jk} is the kth product attribute for product j. $\tilde{\beta}_{ik}$ is the random taste parameter of household i over product attribute k, which is a function of household demographics including those observed by econometrician (z_{ir}) and those that are unobserved (ν_{ik}):

$$\tilde{\beta}_{ik} = \bar{\beta}_k + \sum_{r=1}^{R} z_{ir}\beta_{kr} + \nu_{ik}\beta_k^u. \tag{3}$$

Although the utility specification we use is standard in the literature, it misses several

[9] MSRPs, also known as "sticker prices", are set by manufacturers and are generally constant across locations and within a model year. Although individual transaction prices are desirable in the analysis of automobile demand given that different consumers may pay different prices for the same model, these data are not easily available. MSRPs have been commonly used in this literature. The implications are discussed extensively below.

[10] This functional form for the interaction between income and price, also used in Berry, Levinsohn, and Pakes (1999), can be derived as a first-order Taylor series approximation to the Cobb-Douglas utility function originally used in BLP.

potentially important features of automobile demand. First, automobiles are durable goods and transaction costs exist in the second-hand market. Therefore, consumer expectations about future prices, as well as future gasoline price may be important factors to consider. Second, current household demand for automobiles may be affected by current vehicle holdings or past experiences. Third, the interaction between the market of new vehicles and that for used vehicles may be important as well. Incorporating these factors into the demand estimation is challenging and is left for future research. A notable recent attempt to address these issues is Bento et al. (2009) where they model both new vehicle demand and used vehicle holdings simultaneously.

Based on the utility function, we can derive the aggregate demand function. Define θ as the vector of all preference parameters in equations (2) and (3), and the set of individuals who choose alternative j is

$$A_j = \Big\{ i : u_{ij} = \max_{h \in \{0,1,\ldots,J\}} u_{ih} \Big\}, \tag{4}$$

where u_{ih} is defined by (1). Product 0 is defined as the outside alternative and the utility from it is normalized to be zero in the estimation. The aggregate demand for model j is given by

$$q_j = \mathbb{P}(A_j), \tag{5}$$

where $\mathbb{P}$ is the population distribution function. We assume that the random taste shock ϵ has a type I extreme value distribution and that unobserved household demographics $\nu's$ are from normal distributions with zero mean and standard deviations to be estimated. The distribution of observed household demographics Z is based on U.S. census data.

The demand side parameters can be estimated without a supply side model. However, a supply side model is needed for the counterfactual analysis where we solve for the prices in a new equilibrium based on firms' price-setting rules derived from the profit maximization problem. Following the literature, we assume that firms engage in Bertrand competition to maximize the period profit from the whole U.S. market while taking the product mix as given. To understand the effect of this assumption on our results, we also perform robustness analysis where we only rely on the demand side model, i.e., prices are assumed be fixed in Section 5.5.

The period total variable profit (total revenue minus total variable cost) of a multiproduct firm f is

$$\pi^f = \sum_{j \in \mathcal{F}(f)} \Big[p_j q_j(p, \theta) - vc_j(q_j) \Big], \tag{6}$$

where $\mathcal{F}(f)$ is the set of products produced by firm f. p_j is the price and q_j is the sales for product j. vc_j is the total variable cost of product j.[11] The first order condition of firm f with respect to p_j is:

$$\sum_{h \in \mathcal{F}} \Big[p_h - mc_h(q_j) \Big] \frac{\partial q_h(p, \theta)}{\partial p_j} + q_j(p, \theta) = 0. \tag{7}$$

The equilibrium price vector is defined, in matrix notation, as

$$p = mc(q) + \Delta^{-1} q(p, \theta), \tag{8}$$

where the elements of Δ are

$$\Delta_{jr} = \begin{cases} -\frac{\partial q_r}{\partial p_j} & \text{if product } j \text{ and } r \text{ produced by same firm} \\ 0 & \text{otherwise.} \end{cases} \tag{9}$$

Equation (8) underlies the pricing rule in a multiproduct oligopoly: equilibrium prices are equal to marginal costs plus markups, $\Delta^{-1} q(p, \theta)$. The implied marginal costs can be computed following $mc = p - \Delta^{-1} q$, where p and q are the observed prices and sales. In a

[11] We do not consider the role of the CAFE constraints on firms' pricing decision here. See Jacobsen (2007) for an examination of how firms, particularly U.S. firms underprice their fuel-efficient vehicles in order to meet the CAFE standards. In recent years, the CAFE constraints have not been binding for Toyota and Honda who produces the majority of the hybrid vehicles.

counterfactual analysis, the fixed point of equation (8) can be used to compute new price equilibrium corresponding to a change in the demand equation $q(p, \theta)$, providing that we know the relationship between mc and q. Constant marginal cost assumption has been commonly used in recent literature on estimating automobile market equilibrium (e.g., Bresnahan 1987; Goldberg 1995).[12] If marginal costs are not constant with respect to the total output level, the functional relationship between the two has to be recovered in order to find new equilibrium prices in counterfactual scenarios.

3.2 Estimation

The preference parameters in the utility function are estimated by matching the predicted sales as shown in equation (5) with observed sales in each market. The predicted sales are computed based on a random sample of households from the 2000 Census data while taking into account various government support programs for hybrid vehicles. Because the federal incentives for hybrid vehicles are in the forms of income tax deductions or income tax credits, they may vary across households depending on household tax liabilities: households with fewer tax liabilities tend to enjoy less tax benefit from buying a hybrid vehicle. To figure out tax incentives for each household, we calculate household income tax liabilities using NBER's online software TAXSIM (version 8.0). TAXSIM takes household income sources and other demographics from survey data as input and returns tax calculations as output.[13]

To illustrate our estimation strategy, which exploits the fact that we observe the demand for each product in many MSAs, we bring the market index m into the utility function and write the utility function as

$$u_{mij} = \delta_{mj} + \mu_{mij} + \epsilon_{mij}, \tag{10}$$

[12] The constant marginal cost assumption does not rule out the existence of economies of scale. A high fixed cost and constant marginal cost can still result in economies of scale.

[13] TAXSIM and an introduction by Feenberg and Coutts (1993) are available at http://www.nber.org/taxsim.

where δ_{mj}, the mean utility of product j in market m, is the same for all the households in market m. It can be further specified as follows

$$\delta_{mj} = \delta_j + X_{mj}\gamma + e_{mj}, \tag{11}$$

where δ_j is a product dummy, absorbing the utility that is constant for all households across the markets (including the utility derived from the unobserved product attributes ξ_j). X_{mj} is a vector of product attributes that vary across MSAs. It includes dollars per mile (DPM), which is the gasoline price in market m divided by the MPG of product j. DPM captures the fuel cost per mile for a vehicle. e_{mj} is the part of the mean utility that is unobserved to researchers. μ_{mij} is the household specific utility. Following notations in equations (2) and (3), the household specific utility is:

$$\mu_{mij} = \alpha \frac{p_{ij}}{y_i} + \sum_{kr} x_{mjk} z_{ir} \beta_{kr} + \sum_{k} x_{mjk} \nu_{ik} \beta_k^u. \tag{12}$$

Denote the parameters in the mean utility as $\theta_1 = \{\delta_j, \gamma\}$, and the parameters in the household specific utility as $\theta_2 = \{\alpha, \beta_{kr}, \beta_k^u\}$.

Because we do not have data on vehicle retail prices at the MSA level and instead use MSRPs, variations in retail prices across markets enter the error term, e_{mj}, in equation (11). Moreover, e_{mj} also captures marketing efforts at the local level such as advertisement. These unobserved factors may render explanatory variables in X_{mj} in equation (11) endogeneous. For example, retailers in areas/years with high gasoline prices may offer deeper discounts for fuel-inefficient vehicles than those in areas/years with low gasoline prices. Without controlling for unobserved factors, consumer response to gasoline prices may be underestimated.[14]

Taking advantage of the multiple-market feature of our data set, we use the fuel cost per mile in MSAs that are not geographically close to a given MSA as instruments for

[14]The correlation between marketing efforts and vehicle fuel cost per mile can also arise at the national level. However, unobserved national promotions can be treated as an unobserved product attribute and therefore subsumed in product fixed effects δ_j.

endogenous variables in that MSA. Specifically, for a vehicle model in MSA m, we use the average fuel cost per mile of the same model in all the MSAs in a different census region (4 census regions in total) and that in a different division (9 divisions in total), giving rise to two excluded instruments. Similar ideas for instruments have been explored in Hausman (1996) and Nevo (2001) where data on multiple markets are available. The validity of these instruments hinges on the assumption that local promotions are not correlated across distant MSAs.

BLP shows that given a vector of θ_2, a contraction mapping technique can be used to recover the unique vector of δ_{mj} for each market that equalizes predicted market shares with observed market shares. With the recovered δ_{mj}, θ_1 can be estimated using the instrumental variable method in a linear framework following equation (11). The estimation strategy is a simulated GMM with the nested contraction mapping discussed above. We construct two sets of moment conditions, with the first set being based on equation (11):

$$\mathrm{E}\Big[e_{mj}(\theta_1, \theta_2)|L_{mj}\Big] = 0,$$

where L includes the two constructed instruments and variables in X that are assumed to be exogenous to the error term.

The second set includes 22 micro-moments which match the model predictions to the observed conditional means from the 2001 NHTS as shown in Table 4. For example, we match the predicted probability of new vehicle purchase among households with income less than \$15,000 to the observed probability in the data.

$$\mathbb{P}\Big(i \in \bigcup_{j=1}^{J} A_j|y_i < 15,000; \delta_m(\theta_2), \theta_2\Big) = 0.002,$$

where A_j is defined in equation (4). Petrin (2002) demonstrates that adding micro-moments based on household-level data can dramatically improve the estimation of preference parameters that capture consumer heterogeneity. We extend his approach of taking advantage of micro data to facilitate estimation in that we do not rely on the maintained exogeneity assumption in the literature that unobserved product attributes are uncorrelated with observed product attributes for model identification.

Instead, we take advantage of the multi-market feature of our data by using product fixed effects to deal with price endogeneity due to unobserved product attributes. This strategy of controlling for unobserved product attributes has been employed by Nevo (2000) and Nevo (2001) where sales of the same products are observed in multiple markets. A practical difference between his approach and ours is that because our first set of moment conditions is not enough to identify θ_2, the micro-moment conditions are therefore essential for the identification of our model. Goolsbee and Petrin (2004) provide an alternative empirical strategy in a multinomial probit framework that allows for market-specific unobserved attributes/valuations for the same product across markets. By employing a simulated maximum likelihood method based on household-level data, the identification of consumer heterogenous preference parameters in their model also does not rely on the exogeneity assumption of observed product attributes.

We form the objective function by stacking the two sets of moment conditions. The GMM estimators $\hat{\theta_1}$ and $\hat{\theta_2}$ minimizes: $\mathrm{J} = \mathrm{M}(\theta_1, \theta_2)'\mathrm{W}\mathrm{M}(\theta_1, \theta_2)$, where $\mathrm{M}(\theta_1, \theta_2)$ includes the two sets of moment conditions and W is the weighting matrix. The procedure involves iteratively updating θ_2 and then δ_{mj} to minimize the objective function. The estimation starts with an initial weighted matrix to obtain consistent initial estimates of the parameters and optimal weighting matrix. The model is re-estimated using the new weighting matrix.

With the estimation of the demand side, we can recover the marginal cost for each model based on firms' first order condition for profit maximization in equation (8). The first order condition can also be used to simulate new equilibrium prices in the counterfactual scenarios. To check if marginal costs are constant with respect to the output level, we estimate the following equation based on implied marginal costs:

$$mc_j = \omega_j \rho + \zeta_j, \tag{13}$$

where ω_j includes model attributes and U.S. sales. Because U.S. domestic sales of a model often do not coincide with total production of the model due to international trade and data on model-level production are not readily available, we use vehicle sales as the proxy for production. ζ_j is the error term which may include production cost from unobserved product attributes as well as productivity shocks. An endogeneity problem arises in estimating the non-constant marginal cost function given that sales are related to unobserved product attributes. Only in this context, we invoke the maintained identification assumption in the differentiated product literature that unobserved product attributes are mean independent of observed product attributes. Based on this assumption, instruments for vehicle sales are provided by the observed attributes of competing products.[15]

4 Estimation Results

We first report parameter estimates for the random coefficient model and then use these estimates to calculate price elasticities and implied price-cost margins. After that, we present estimation results from alternative estimation strategies.

4.1 Parameter Estimates

Table 5 provides two sets of estimation results. In columns 2 and 3, the fuel cost variable, DPM, is assumed to be exogenous while in columns 4 and 5 the possible endogeneity of DPM is controlled for. We use two instruments as discussed in the previous section: the average DPM of the same vehicle in MSAs of different census divisions, and that in MSAs of different regions. In both cases, the coefficient on DPM is negative and estimated precisely, implying that a vehicle with better fuel efficiency hence smaller DPM is valued more than a less fuel-efficient vehicle, *ceteris paribus*. The identification of this coefficient is based on the cross-MSA sales variations in response to differences in gasoline prices across MSAs: a fuel-efficient vehicle should be more popular in a high gasoline price area than otherwise, all else equal. The coefficient estimate on DPM is larger when DPM is assumed

[15] Our estimation results, available from the authors, cannot reject the constant marginal cost assumption.

to be endogenous and instrument variables are applied than when DPM is assumed to be exogenous. This finding confirms the presence of local unobservables such as promotions that are positively correlated with vehicle fuel cost.

Local support dummy is equal to 1 for hybrid models in MSAs where local government supports such as HOV lane privilege and free meter parking are available for hybrid vehicles. The interaction terms between MSA dummies and the hybrid dummy capture unobserved heterogeneity on hybrid demands that may arise from differences in dealer availability and consumer attitudes toward hybrid vehicles. We include interaction terms between MSA dummies and vehicle type dummies (i.e., car, SUV, van, and pickup truck) to control for unobserved heterogeneity in consumer preference for each type of vehicles across MSAs. For example, consumers in MSAs with more snow and slippery driving conditions might prefer SUVs and pickup trucks, which are often equipped with a four-wheel-drive.

Table 5 also presents the estimates of the parameters in the household specific utility defined by equation (12). These parameters capture consumer heterogeneity due to observed and unobserved household demographics. The first three coefficients capture heterogeneity in consumer preference on vehicle price. The coefficient for high income groups being larger implies richer households are less price sensitive. The second four parameters are for the interaction terms between vehicle size and four demographic variables. These interaction terms allow families with different households to have different tastes for vehicle size. These coefficient estimates suggest that households living in their own houses and those with children prefer larger vehicles. Table 5 then reports the estimates of seven random coefficients, which measure the dispersion of heterogeneous consumer preference. These coefficients are the standard deviations of consumer preferences for the corresponding product attributes. For example, the preference parameter on DPM has a standard normal distribution with mean -8.618 and standard deviation 5.768. The estimates suggest that over 93 percent of the households have a negative preference parameter on DPM. The random coefficients ultimately break the independence of irrelevant alternatives (IIA) property of standard logit models in that the introduction of a new vehicle model into the choice set will draw disproportionately more consumers to the new model from similar products than from others.

4.2 Elasticities and Price-cost Margins

Based on the parameter estimates for the demand side, we compute own- and cross-price elasticities. A sample of these elasticities are reported in Table 6. One obvious pattern from this table is that the demand for cheaper products tends to be more price sensitive. Moreover, cross-price elasticities are larger among similar products, suggesting that substitutions occur more often across similar products than dissimilar ones when prices change. For example, the cross-price elasticities for Toyota Corolla suggest that when its prices increase, consumers are most likely to switch to Toyota Camry and Toyota Prius (Corolla's hybrid counterpart) among the 10 competing models in the table.

We recover the marginal cost for each product from firms' first order conditions based on the demand side estimates and the Bertrand competition assumption in the supply side. We then can compute price-cost margins as $\frac{p_j - mc_j}{p_j}$, some of which are reported in the last column of Table 6. Among the 8 non-hybrid models, Cadillac Escalade, the most expensive product, has the largest margin of 33.67 percent. Interestingly, although Toyota Prius is cheaper than Toyota Camry hybrid, it has a smaller price sensitivity and a higher margin.[16] Overall, there appears to be a large variation in the estimates of both elasticities and price-cost margins. Among the 1,619 products, the sales weighted average own-price elasticity is -8.40 while the weighted average price-cost margin is 17.72 percent. Our estimate of average margins is closest to Petrin (2002)'s estimate of 16.7 percent which is based on 185 vehicle models per year sold from 1981 to 1993 including cars, vans and pickup trucks. The average benchmark margin in BLP is estimated at 23.9 percent for cars sold between 1971 and 1990 while Goldberg (1995) recovers a much larger estimate of 38 percent for cars from 1983 to 1987, both of which are based on about 110 models per year.

Since the preference parameter on the fuel cost of driving, DPM, is one of the key

[16] To the extent that some consumers advertise themselves as environmentalists by driving hybrid vehicles (Kahn (2007)), Prius's distinct appearance makes the model less substitutable than other hybrid models such as Toyota Camry hybrid which has the same look as the non-hybrid Camry.

parameters of interest, it is helpful to verify whether the parameter estimate is in line with simple calculations based on fuel costs of driving and price elasticities. Take a Toyota Camry as an example. Its average fuel cost of driving in the 22 MSAs is 9.47 cents per mile. Our demand model predicts that a 1.5 cent increase in the fuel cost of driving for Toyota Camry alone would result in a 9.74 percent decrease in its sales, holding vehicle prices fixed. To compare the model prediction with a back-of-the-envelop calculation, assume vehicle miles traveled to be 12,000 per year, vehicle lifetime to be 15 years, and a discount factor of 0.98. The increase in total discounted fuel cost during vehicle lifetime is therefore about $235, 1.18 percent of the price of the vehicle. Our estimated price elasticity being 9 implies that an increase of 1.18 percent in vehicle price would cause about 10.62 percent in reduction in quantity demanded. We take comfort in the fact that our model prediction of 9.74 percent decrease is close to that from the above intuitive calculation.

4.3 Alternative Specifications

The results discussed above are based on the empirical model where product fixed effects are used to control for unobserved product attributes and national level promotions, both of which can be correlated with observed product attributes. To examine the importance of this strategy, we estimate the model without including product fixed effects and instead employ the maintained exogeneity assumption in the literature that observed product attributes are uncorrelated with the unobserved product attributes. In the estimation, we add vehicle size, horsepower as well as 15 vehicle class dummies, which would be otherwise subsumed in product dummies.

Table 7 presents two sets of estimation results without using product dummies. One set is based on the assumption that DPM is exogenous while the other is from the model where the endogeneity of DPM due to local promotions is dealt with using DPM in other MSAs as instruments. In both cases, we control for the endogeneity of the vehicle price variable with two instruments constructed based on observed product attributes.[17] It is worth noting

[17] We construct two "distance" measures for each product. The distance measures reflect how differentiated a product is from other products within the firm and outside the firm. The measures are based on

that the presence of national level promotions that are correlated with product attributes such as vehicle fuel efficiency would render both sets of instruments invalid.

The model where the endogeneity of DPM is controlled for suggests a larger consumer response to the fuel cost per mile. The parameter estimates from this model imply that the sales-weighted average own-price elasticity and price-cost margin are respectively, -9.06 and 18.26 percent, similar to -8.40 and 17.72 percent from our preferred model in the previous section. However, the results suggest that consumers are about twice as sensitive to the fuel cost of driving as what is implied by the results in the previous section. This finding suggests that the exogeneity assumption regarding observed product attributes may be violated.

5 Simulations

In this section, we conduct simulations to examine the effect of rising gasoline prices and federal tax incentives on the diffusion of hybrid vehicles. We compare the current income tax incentive program with a rebate program in terms of their cost-effectiveness and their effects on industry profits. Our simulations assume that product offerings would stay the same under different scenarios.[18] To the extent that both run-ups of the gasoline price and federal tax incentives strengthen consumer incentives to purchase hybrid vehicles and therefore increase firms' incentive to offer more hybrid models, our static analysis would under-estimate the true effects of these two factors.

distances between two products in a Euclidean space where different weights are applied to different dimensions of the product-characteristics space. The weights are the coefficients of the corresponding product attributes in a hedonic price regression.

[18]The decision of product choice, although an interesting topic, is out of scope of this paper. A structural approach to this topic involves modeling a dynamic game where the model should contend with several key facts about the auto industry: the industry consists of several big players that act strategically; each of them produces multiple products; and products are differentiated.

5.1 Gasoline Prices

Understanding how consumers' vehicle choice decisions respond to changes in gasoline prices has important implications for policies that aim to address energy security and environmental problems related to gasoline consumption. We study the effect of changes in gasoline prices on hybrid vehicle sales by simulating the market outcomes under different gasoline price scenarios. In preforming the simulations, we solve new equilibrium prices under each scenario based on the estimates of demand parameters and product marginal costs, assuming multiproduct firms engage in price competition. We then estimate sales for the 22 MSAs under new equilibrium prices.

The first simulation investigates what would have happened if gasoline prices from 2001 to 2006 had been the same as those in 1999 in each of the 22 MSAs. Column (2) in Table 8 presents the effects of gasoline price changes on prices of five hybrid models and their non-hybrid counterparts in 2006. The average gasoline price in the 22 MSAs weighted by vehicle sales was \$1.53 in 1999 and \$2.60 in 2006. If gasoline prices had stayed at the 1999 levels, the five selected hybrid models in 2006 would have been 4 to 10 percent cheaper because they would have been in weaker demand given that the savings in fuel cost would be smaller. For their non-hybrid counterparts, the changes in prices are smaller in magnitude as the differences in fuel cost would be smaller. The prices of Ford Escape and Toyota Highlander, for example, would have been higher with gasoline prices staying at the 1999 levels while three more fuel-efficient vehicles would have been slightly cheaper. Column (4) in Table 8 shows the effect of gasoline price changes on sales. The decrease in sales in the 22 MSAs for the five hybrid models ranges from 21 to 38 percent have gasoline prices stayed at the 1999 levels. The effect on more fuel-efficient hybrid models such as Honda Civic hybrid and Toyota Prius, is more significant. On the other hand, without the gasoline price increase in 2006, the sales of regular Ford Escape would have increased by about 25 percent while that of Honda Civic and Toyota Corolla would have dropped by 15 and 6 percent, respectively.

Table 9 presents the effect of rising gasoline prices on total sales of hybrid vehicles in the

22 MSAs from 2001 to 2006. Column (1) lists the annual average gasoline price weighted by vehicles sales. Gasoline prices have been continuously increasing over the years except in 2002. In the absence of these increases, the sales of hybrid vehicle would have been significantly less.[19] This simulation shows that the gasoline price is indeed an important factor in hybrid vehicle purchase decisions. The $1.07 increase in the gasoline price in 2006 over that in 1999 explains almost 37 percent of hybrid vehicle sales. To speak to the record high gasoline price of $4 per gallon observed in mid-2008, we also simulate the effect of more dramatic increases in gasoline prices on hybrid vehicle sales. Columns 4 and 5 in Table 9 present the percentage increases in sales if gasoline prices were at $4 and $6 per gallon in 2006. The results show that if the gasoline price was $4 per gallon in the 22 MSAs, the sales of hybrid vehicles would have been 65 percent higher in 2006.

5.2 Federal Tax Incentives

In this section, we conduct simulations to investigate the effect of federal income tax incentives on hybrid vehicle purchases. We first simulate the would-be market outcomes in the absence of these incentives during the period. Table 10 presents the effects of the income tax incentives on both prices and sales of several selected hybrid models in 2005 and 2006. Column (1) shows the price of each model in 2006 dollars while column (2) gives the total sales in the 22 MSAs. Column (3) lists the average tax benefit received by buyers of each model. In 2005, the $2,000 tax deduction yields $371 income tax return for Ford Escape hybrid buyers on average. In 2006, hybrid buyers are eligible for up to $2,600, $2,100, $650 and $3,150 tax credit for the purchase of a Ford Escape hybrid, Honda Civic hybrid, Honda Accord hybrid and Toyota Prius, respectively. The tax credit program is more generous for most hybrid models than the tax reduction program. For example, buyers of Ford Escape hybrid on average received $1,960 income tax return for their purchase in 2006, comparing to only $371 in 2005.

[19] Although the average gasoline price in 2002 was about the same as that in 1999, the sales of hybrid vehicles would have been less in our simulation. This is because gasoline prices actually dropped in 2002 in several MSAs with strong demand for hybrid vehicles such as San Francisco, San Diego, and Seattle.

Without tax incentives, both prices and sales of these hybrid models would be reduced. The supply price of a 2005 Ford Escape hybrid would be \$190 (0.67 percent) lower as shown in column (4), comparing to the \$371 tax benefit received by an average buyer. For Toyota Prius, the supply price would drop by \$197 (0.89 percent) in 2005 in the absence of income tax deductions, comparing to \$522 tax benefit received by Prius buyers on average. These numbers suggests that buyers capture about 50-60 percent of the government subsidy and the supplier about 40-50 percent. This finding also holds for other hybrid models based on average tax benefits received by buyers in column (3) and price decreases in the absence of government subsidy in column (4).[20] The effect of tax incentives on hybrid vehicle sales in 2005 is less than 4 percent for the five hybrid models shown in the table. However, the effect of more favorable tax incentives in 2006 is much more significant: for 2006 Toyota Prius, about 25 percent of its sales can be attributed to the tax credit policy in place.

Table 11 presents the effect of tax incentives on total hybrid sales in the 22 MSAs from 2001 to 2006. Column (2) gives average tax returns received by hybrid buyers in 2006 dollars. They are decreasing from 2001 to 2005 due to two facts. First, while the tax deduction is kept at a nominal level of \$2,000, the inflation is about 14 percent over this period. Second, the number of households subject to Alternative Minimum Tax (AMT) increases significantly. These households are not eligible for the full tax benefit when buying hybrid vehicles. In 2006, federal government support, in the form of income tax credits, is much stronger: the tax benefit received by each hybrid buyer is \$2,276 on average. Based on column (3), about 20 percent of the total hybrid sales in the 22 MSAs could be explained by tax credits, comparing to less than 5 percent in previous years. It is interesting to note that hybrid sales, although smaller, would still be growing dramatically over time even without tax incentives. Columns(4) and 5 present the average tax benefit received by hybrid vehicle buyers and the changes in hybrid vehicle sales in percentage if federal income tax incentives

[20]Our estimates show that buyers of Toyota Prius in 2006 capture about 63 percent of total federal tax incentives. Sallee (2008) estimates that buyers of 2006 Toyota Prius get at least 73 percent of total tax subsidies using detailed retail price data. In order to explain the finding that consumers capture the significant majority of the benefit from federal tax subsidies in the case of Toyota Prius, whose production was capacity constrained in 2006, he suggests a model where current vehicle prices influence future demand (e.g., due to goodwill).

had been doubled. In 2006, each hybrid vehicle buyer would have received $4,754 in tax benefit and the sales of hybrid vehicles would have been about 23 percent larger than the observed sales in 2006.

5.3 Gasoline Consumption and CO_2 Emissions

In 2005, U.S. motor gasoline consumption was 9.16 million barrels per day, accounting for about 45 percent of total U.S. petroleum consumption according to the Department of Energy. Total CO_2 emissions from motor vehicle usage was 3.78 million tons per day, accounting for about 20 percent of total U.S. CO_2 emissions. Therefore, having a more fuel-efficient vehicle fleet is an important step toward solving energy security and climate change problems. In the previous two subsections, we have studied the effects of two important factors, gasoline price run-ups and income tax incentives, on the the diffusion of hybrid vehicles in recent years. We now turn to the implications of two policy alternatives, federal gasoline taxes and income tax incentives, on total U.S. gasoline consumption and CO_2 emissions.

Table 12 presents policy impacts on four variables: average MPG of new vehicles sold in 2006, total new vehicles sales in 2006, total gasoline consumption, and total CO_2 emissions. Both total gasoline consumption and CO_2 emissions are calculated for the 2006 cohort of new vehicles during the lifetime of these vehicles. Column (1) shows that the average MPG of new vehicles in 2006 would have been 23.09 in the absence of federal income tax credits, compared to observed 23.19, while the doubling of the incentives would have increased the average MPG from 23.19 to 23.31. To compare the effectiveness of the tax incentives with that of a higher gasoline tax, we examine an increase in the federal gasoline tax of 10 cents, 25 cents, and 1 dollar.[21] The simulation results suggest that an increase of 10 cents in gasoline taxes would generate the same impact on the average MPG with that produced

[21] Among industrial countries, the U.S. has the lowest gasoline tax (41 cents per gallon on average including 18 cents of federal tax). Meanwhile, Britain has the highest gasoline tax of about $2.80 per gallon. In simulations, we assume that these gasoline tax increases would generate equivalent increases in gasoline prices. To the extent that the gasoline industry is not perfectly competitive, results from these simulations should be viewed as upper bounds of the true effects.

by the income tax credit program. The key difference between the two types of policies is illustrated by column (2), which presents the changes in total sales of new vehicles under different policies. It shows that the two types of policies have an opposite effect on new vehicle sales: while the tax credit program increases new vehicle sales (by increasing hybrid vehicle sales), a higher gasoline tax would achieve the opposite.

Columns (3) and (4) in Table 12 presents total reductions in gasoline consumption and CO_2 emissions in the U.S. over vehicle lifetime for vehicles sold in 2006.[22] Due to the small number of hybrid models available and the small market share of hybrid vehicles, the reductions in both gasoline consumption and CO_2 emissions from the income tax credit program are inconsequential relative to their total amounts. On the other hand, our results show that an increase in the gasoline tax of only 10 cents would generate much larger reductions. A $1 dollar increase in the gasoline tax would reduce gasoline consumption and CO_2 emissions by over 16 percent. Our analysis shows that to achieve the 20 percent gasoline consumption reduction in 10 years as proposed in the 2007 State of the Union Address, higher gasoline prices (e.g., through a higher gasoline tax) represent a more promising avenue.

We now examine the cost of reducing gasoline consumption and CO_2 emissions in terms of the foregone tax revenue in income tax incentive programs. Based on our model estimates, the total federal income incentives to hybrid buyers in the 22 MSAs were 134.43 million dollars in 2006 while the reductions in gasoline consumption and CO_2 emissions are 1.80 million barrels and 0.76 million tons, respectively. This implies that the cost of gasoline consumption reduction through the income tax credit program is $75 per barrel with a 90 percent confidence interval of [72, 78] while the cost of CO_2 emission reduction is $177 per ton with a 90 percent confidence interval of [170, 184]. By comparison, Metcalf (2008) finds that, in the context of tax credits for ethanol, using tax revenues to achieve energy policy is highly cost ineffective. He estimates that the cost of reducing gasoline consumption through tax credits for ethanol is $85 per barrel in 2006 and the cost of re-

[22] Assume that vehicle lifetime is 15 years and average annual travel is 12,000 miles per vehicle. The combustion of one gallon gasoline generates 19.5 pounds of CO_2 according to the Energy Information Administration.

ducing CO_2 emissions is $1,700 per ton.[23] Our estimates show that the tax credit program for hybrid vehicles, although still costly, is more effective than the tax credit program for ethanol, especially in reducing CO_2 emissions from the point view of government revenue.

It is worthwhile to point out two caveats underlying these results. First, we assume that both vehicle miles traveled and the vehicle lifetime are fixed. Studies have shown that high gasoline prices tend to reduce vehicle miles traveled (see Small and Van Dender (2007) for a recent study). Li et al. (2009) find that higher gasoline prices would prolong the life of fuel-efficient vehicles and shorten that of fuel-inefficient vehicles. Both these results suggest that we may under-estimate the effects of gasoline tax increases on gasoline consumption and CO_2 emissions. Second, our simulations show a decrease in new vehicle sales with a higher gasoline tax due to consumers switching to outside goods. In calculating its effect on gasoline consumption and CO_2 emissions, we assume that outside goods do not use gasoline (e.g., walking or biking). To the extent that outside goods may include other transportation methods that also consume gasoline such as public transportation or used vehicles, we may over-estimate the reductions in gasoline consumption and CO_2 emissions. Alternatively, a lower bound for these estimates could be easily obtained by assuming that outside goods use the same amount of gasoline as an average new vehicle. In this case, the effects of these policies on gasoline consumption and CO_2 emissions would be dictated by those on the average MPG of new vehicle fleet as shown in column (1).

5.4 Tax Credit Versus Rebate

As proposed in the Energy Policy Act of 2005, there exist various income tax credits on qualified energy-efficient home improvement appliances, fuel-efficient vehicles, solar energy system, and fuel cell and microturbine power systems. In the case of hybrid vehicles, the income tax credit reduces the regular federal income tax liability of the hybrid vehicle

[23] Although ethanol can substitute for gasoline and hence reduces energy dependence, it still produces a fair amount of CO_2 from combustion.

buyer, but not below zero.[24] Therefore, households whose income tax liability is smaller than the tax credit are not able to enjoy the maximum possible incentive. Nevertheless, these households tend to have low income and be more responsive to the incentives than high-income households. A flat rebate program that offers equal subsidies to all buyers of the same hybrid model, therefore, may result in more hybrid sales than the tax credit program with the same amount of total government subsidy. The better cost-effectiveness of a rebate program should also hold in the income tax credit program for other energy-efficient products aforementioned. To demonstrate this point, we conduct simulations to compare the income tax credit program with a rebate program, which distributes equal subsidy across households who purchase the same hybrid model and are not subject to AMT. For comparison reasons, we assume that the rebate does not reduce AMT as in the tax credit program.

In our simulations, the subsidy varies by model as in the tax credit program. However, we set the difference between the subsidy and the credit to be the same across models. Table 13 shows the differences in total government subsidy between the income tax credit program and the rebate program. Under the current tax credit program, the average MPG of new vehicles sold in 2006 was 23.19. To reach the same average fuel-efficiency, the rebate program would cost 113.60 million dollars in government revenue, comparing to 134.43 million dollars under the tax credit program. This implies a saving of over 15 percent in government subsidy. We also conduct simulations where we set the ratio between the subsidy and the credit to be the same across models. The results, not reported in the table, are very close. For example, the rebate program would cost 114.65 million dollars in government revenue in this setup.

Under the current tax credit program, only families with low income are not able to enjoy full tax incentives due to their low tax liabilities and that the proportion of these households purchasing new vehicles is very small. Therefore, if the tax credit were to be increased or income tax credits for other energy-efficient products are to be considered simultaneously in

[24] The tax credit cannot be carried over to the future. Moreover, the credit will not reduce alternative minimum tax (AMT) when it applies to a hybrid vehicle buyer.

consumers' vehicle purchase decisions, more households would be constrained by their tax liabilities in getting tax benefit from purchasing hybrid vehicles.[25] Therefore, the rebate program would exhibit a stronger advantage over the tax credit program. The difference between a more generous tax credit program and a tax rebate program is shown in the second panel of the table where we assume a doubling of the tax credits. The average fuel-efficiency would increase to 23.31 MPG. To reach the same level of average fuel economy, the rebate program would need 260.61 instead of 346.08 million dollars. This represents almost 25 percent reduction in government subsidy to hybrid vehicle buyers.

5.5 Robustness Analysis

Our counterfactual analysis in previous sections is based on the assumption that multiproduct firms engage in the Bertrand competition. In this section, we investigate the robustness of our previous findings with respect to this assumption. In particular, we now assume that vehicle prices would hold constant in counterfactuals, i.e., vehicle supply curves are flat in the short run. These simulations only rely on the demand side model and provide upper bounds for the effects of gasoline price run-ups and income tax incentives on hybrid sales

Table 14 presents percentage changes in hybrid sales due to gasoline price run-ups and income tax incentives from 2001 to 2006. If gasoline prices in the 22 MSAs had stayed at the 1999 levels, the sales of hybrid vehicles would have been more dramatically reduced compared to the reductions shown in Table 9, which are obtained under the Bertrand competition assumption in the supply side. For example, the sales of hybrid vehicles would have been about 62 percent less than the realized sales in 2006, instead of 37 percent in Table 9. Intuitively, under the Bertrand assumption an increase in the gasoline price would result in higher prices for hybrid vehicles in the new equilibrium. This would dampen the effect of gasoline price increase on hybrid vehicle sales.

The simulated effects of gasoline price changes on hybrid vehicle sales hinge on the

[25] The Energy Policy Act of 2005 includes tax credits for many types of energy-efficient products. The maximum amount of credit for qualified home improvements combined is $500 during the two year period of 2006 and 2007. Moreover, a tax credit, up to $2,000, is available for qualified solar energy systems.

estimated demand responses to gasoline prices from the demand model. Therefore, it is helpful to compare our estimates to several recent studies. Using U.S. monthly sales data of new vehicles from 1980 to 2006, Linn and Klier (2007) find that a one-dollar increase in the gasoline price raises the average fuel economy of new vehicles in 2006 by 0.5 MPG, compared to our estimate of 1.01 MPG with a 90 percent confidence interval of [0.92, 1.08] under the Bertrand assumption and 1.78 MPG with a 90 percent confidence interval of [1.54, 2.02] with vehicle prices fixed.

Using a similar data set to ours but a different empirical method, Li et al. (2009) estimate the elasticity of the average MPG of new vehicles with respect to the gasoline price to be 0.204 in 2005. Small and Van Dender (2007) obtain a similar estimate of 0.21 for 1997-2001 using U.S. level time-series data on vehicle fuel efficiency and gasoline prices. Our simulation suggests that the elasticity in 2005 to be 0.096 with a 90 percent confidence interval of [0.087, 0.106] with the Bertrand assumption, and 0.169 with a 90 percent confidence interval of [0.151, 0.189] assuming fixed vehicle prices. Therefore, our estimate of consumer sensitivity to gasoline prices lies within the range of these recent studies.

Column (3) in Table 14 gives the simulated percentage changes of hybrid vehicle sales in the absence of federal income tax incentives during the period. Compared to the results in Table 11 under the Bertrand competition assumption, these changes are again larger in magnitude. The predicted sales of hybrid vehicles without incentives in 2006 would have been about 31 percent less, holding vehicle prices fixed, compared to about 20 percent under the Bertrand competition assumption. These simulated changes largely depend on consumer price sensitivities. Our estimates of price elasticities from the demand side as well as price-cost margins obtained under the Bertrand competition assumption are close to those in some recent studies as discussed in Section 4.2.

6 Conclusion

With rising gasoline prices, unstable petroleum supplies, and growing concern about global climate change and pollution, support for curbing U.S. fuel consumption has increased dramatically in recent years. The hybrid technology is considered as one promising solution to energy security and environmental protection. To promote consumer adoption of hybrid vehicles, the U.S. government has been providing hybrid vehicle buyers with income tax incentives to offset the significantly higher cost of hybrid vehicles relative to their non-hybrid counterparts.

Our empirical analysis shows that both recent increases in gasoline prices and federal income tax incentives contribute significantly to the growing market share of hybrid vehicles. If the gasoline price in 2006 had stayed at the 1999 level ($1.53 instead of $2.60 on average), hybrid vehicle sales in 2006 would have been about 37 percent less in the 22 MSAs under study. In terms of government programs, federal income tax deductions explained less than 5 percent of hybrid vehicle sales from 2001 to 2005 while more generous income tax credits in 2006 accounted for about 20 percent of hybrid vehicles sales. However, due to the small market share of hybrid vehicles, the reduction in both gasoline consumption and CO_2 emissions resulting from government support has been inconsequential. Taken together, these findings suggest that it may take both high gasoline prices (e.g., through increased gasoline taxes) and continued government incentives to enable the hybrid technology to play a significant role in solving U.S. energy and environmental problems.

We estimate that the reduction of gasoline consumption costed $75 of government revenue per barrel while the reduction of CO_2 emissions costed about $177 per ton through the federal income tax credit program in 2006. In light of the recent analysis of the tax credit for ethanol by Metcalf (2008), these cost estimates suggest that the income tax credit program on hybrid vehicles is more effective than the tax credit on ethanol from the perspective of government expenditures. Nevertheless, the regressive nature of the income tax credit program on hybrid vehicles hinders its cost-effectiveness. We find that a flat rebate program that achieves the same fuel-efficiency for new vehicles as in the current tax credit program would cost over 15 percent less in government revenue. Although current government support for consumers to adopt energy-efficient products mainly takes the form of income tax credits, this finding calls for wider adoption of the flat rebate scheme instead of the income tax-based scheme in future legislations that aim to promote energy conservation and environmental protection.

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Table 1: History of Hybrid Vehicles

Year	No. of hybrid models offered	Hybrid sales	New vehicle sales in mil.	Percent of hybrid
2000	2	9,367	17.41	0.054
2001	2	20,287	17.18	0.118
2002	3	35,961	16.85	0.213
2003	3	47,525	16.68	0.285
2004	4	83,153	16.91	0.492
2005	8	209,711	17.00	1.234
2006	10	251,864	16.56	1.521
2007	15	345,920	16.09	2.150

Table 2: New vehicle Sales and Characteristics

	Mean	Median	Std. Dev.	Min	Max
Quantity ('000)	78.9	45.3	104.5	2.1	939.5
Price (in '000 $)	30.1	26.4	14.2	10.3	98.9
Size(in '000 inch^2)	13.5	13.4	1.6	8.3	18.9
Horsepower	195	190	59	55	405
MPG	22.4	22.0	5.2	13.2	64.7

Note: Data are from various issues of Automotive News Market Data Book (1999-2006) and the EPA's fuel economy database.

Table 3: Hybrid Sales and Local Incentives in 2006

MSA	Number of households	Hybrid sales	Percent in total vehicle sales	Local incentive (start date)	Gasoline price $
Albany, NY	360,273	737	1.62	Income tax (03/04)	2.70
Albuquerque, NM	319,922	763	2.37	Excise tax (07/04)	2.58
Atlanta, GA	1,994,938	2,775	1.34	No	2.52
Cleveland, OH	1,167,916	1,643	1.16	No	2.51
Denver, CO	1,132,085	3,561	3.51	Income tax (01/01)	2.45
Des Moines, IA	209,297	438	1.96	No	2.32
Hartford, CT	704,130	1,535	2.00	Sales tax (10/04)	2.80
Houston, TX	2,197,010	3,132	1.22	No	2.49
Lancaster, PA	197,929	318	1.80	No	2.53
Las Vegas, NV	713,397	1,340	1.32	No	2.62
Little Rock, AR	250,142	436	1.50	No	2.48
Madison, WI	185,657	917	4.88	No	2.55
Miami, FL	1,706,995	2,322	0.87	HOV (07/03)	2.64
Milwaukee, WI	682,896	1,340	1.99	No	2.59
Nashville, TN	548,192	752	1.47	No	2.43
Phoenix, AZ	1,585,544	3,254	1.53	No	2.51
St. Louis, MO	1,100,071	1,526	1.30	No	2.40
San Antonio, TX	739,674	1,022	1.25	No	2.41
San Diego, CA	1,177,384	4,946	3.40	HOV (08/05)	2.85
San Francisco,CA	2,871,199	20,162	7.02	HOV (08/05)	2.87
Seattle, WA	1,529,146	5,732	3.82	Sales tax (01/05)	2.70
Syracuse, NY	292,717	408	1.15	Income tax (03/04)	2.69

Table 4: Household Demographics and Vehicle Choice

	All	Households who purchase				
		New	Car	Van	SUV	Pickup
	(1)	(2)	(3)	(4)	(5)	(6)
Household size	2.55	2.88	2.67	3.81	3.02	2.84
Renter	0.364	0.211	0.266	0.090	0.147	0.163
Children dummy	0.336	0.402	0.328	0.696	0.499	0.352
Time to work (minutes)	17.90	20.92	20.49	19.75	19.73	24.00

Income ('000)	New vehicle purchase probability
< 15	0.0020
[15, 25)	0.0440
[25, 50)	0.1125
[50, 75)	0.1728
[75, 100)	0.1972
≥ 100	0.2574
All households	0.1304

Note: Summary statistics are based on households in MSAs from the 2001 National Household Travel Survey.

Table 5: Parameter Estimates of the Random Coefficient Model

	DPM exogenous		DPM endogenous	
	Para.	S.E.	Para.	S.E.
Parameters in mean utility				
Dollars per mile (DPM)	-2.934	1.241	-8.618	1.181
Local support dummy	0.523	0.581	0.720	0.466
MSA dummy * hybrid (21)	Yes		Yes	
MSA dummy * segment (84)	Yes		Yes	
Product dummies (1619)	Yes		Yes	
Heterogenous preference parameters				
Price/Income if income $\leq$ 50,000	-72.196	7.755	-65.576	5.147
Price/Income if income $\in$ (50,000, 100,000]	-35.884	3.851	-32.679	3.184
Price/Income if income > 100,000	-11.981	5 2.335	-9.927	1.613
Household size * vehicle size	0.501	0.080	0.820	0.092
Renter dummy * vehicle size	-2.288	0.312	-3.106	0.297
Children dummy * vehicle size	5.069	0.602	4.686	0.480
Travel time * vehicle size	-0.015	0.004	-0.016	0.003
Random coefficients				
Car dummy	70.013	7.727	66.215	4.662
Van dummy	7.404	1.099	8.414	0.573
SUV dummy	31.868	3.464	30.272	2.829
Pickup dummy	78.111	8.453	74.687	6.398
Size	9.364	1.127	8.768	0.751
Horsepower	7.573	0.765	5.734	0.335
Dollars per mile	2.105	0.478	5.768	1.237

Household demographics are drawn from 2000 Census and are adjusted in different years based on Census data as well as American Community Survey 2000-2006. The unobserved household attributes are standard normal draws from Halton sequences. Within each parameter iteration, the contraction mapping algorithm has to be carried out for each market in each year (172 in total). In addition, the large dimension of the contraction mapping (over 200) dramatically adds to the computation intensity. Because of the computational concern, we limit the number of random draws to 250 in each MSA. The convergence criterion for the simulated GMM is 10e-8 while that for the contraction mapping is set up to 10e-14. Following Nevo (2000), the convergence criterion for the contraction mapping starts low and increases as the search goes on in order to expedite the estimation.

Table 6: A Sample of Own- and Cross-price Elasticities and Price-cost Margins

Products in 2006	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	Price	Margin(%)
Toyota Corolla (1)	-11.14	1.31	0.01	0.00	0.00	0.02	0.00	0.00	1.77	0.46	0.00	15,485	17.25
Toyota Camry (2)	1.61	-9.00	0.08	0.00	0.00	0.03	0.00	0.00	1.06	0.92	0.00	19,855	18.28
Mercedes E Calss (3)	0.00	0.03	-3.65	0.00	0.00	0.00	0.00	0.00	0.01	0.12	0.00	51,825	33.66
Kia Sedona (4)	0.00	0.00	0.00	-7.00	0.46	0.00	0.01	0.00	0.00	0.00	0.00	23,665	15.67
Toyota Sienna (5)	0.00	0.00	0.00	1.72	-3.84	0.01	0.01	0.01	0.00	0.00	0.00	24,380	28.12
Honda CR-V (6)	0.01	0.02	0.00	0.02	0.01	-8.88	0.56	0.01	0.00	0.00	0.36	22,145	15.78
Jeep Grand Cherokee (7)	0.00	0.00	0.00	0.02	0.01	0.36	-9.43	0.04	0.00	0.00	0.12	28,010	13.47
Cadillac Escalade (8)	0.00	0.00	0.00	0.01	0.01	0.01	0.05	-4.45	0.00	0.00	0.06	57,280	33.67
Toyota Prius (9)	0.90	0.44	0.01	0.00	0.00	0.00	0.00	0.00	-6.17	0.37	0.00	22,305	27.57
Toyota Camry Hybrid (10)	0.07	0.12	0.04	0.00	0.00	0.00	0.00	0.00	0.11	-7.77	0.00	25,900	22.34
Toyota Highlander Hybrid (11)	0.00	0.00	0.00	0.00	0.00	0.12	0.07	0.02	0.00	0.00	-4.08	34,430	38.55

Note: Columns labeled (1) to (11), corresponding to the 11 products, present the matrix of own- and cross-price elasticities. The last column in the table gives the price-cost margins. These numbers are based on parameter estimates in Table 5 with the endogenous DPM assumption. The sales-weighted average of own-price elasticities and price-cost margins among all 1,619 products are -8.40 and 17.72%, respectively.

Table 7: Robust Analysis: Estimation without Product Dummies

	DPM exogenous		DPM endogenous	
	Para.	S.E.	Para.	S.E.
Parameters in mean utility				
Dollars per mile (DPM)	-14.914	0.138	-16.445	0.152
Local support dummy	0.202	0.159	0.066	0.172
Size	0.616	0.350	0.897	0.382
Horsepower	2.381	0.157	2.424	0.171
Vehicle class dummy (15)	Yes		Yes	
MSA dummy * hybrid (21)	Yes		Yes	
MSA dummy * segment (84)	Yes		Yes	
Heterogenous preference parameters				
Price/Income if income $\leq$ 50,000	-61.214	1.496	-66.556	1.750
Price/Income if income $\in$ (50,000, 100,000]	-39.086	0.750	-42.019	0.901
Price/Income if income $>$ 100,000	-11.911	0.601	-11.026	0.728
Household size * vehicle size	0.005	0.029	-0.024	0.039
Renter dummy * vehicle size	-3.234	0.148	-3.453	0.169
Children dummy * vehicle size	6.328	0.240	6.951	0.278
Travel time * vehicle size	-0.044	0.003	-0.048	0.003
Random coefficients				
Car dummy	53.630	1.256	59.112	1.824
Van dummy	4.533	0.849	4.875	0.851
SUV dummy	29.451	0.939	31.745	1.064
Pickup dummy	57.828	2.328	62.176	2.224
Size	8.597	0.319	9.352	0.323
Horsepower	6.642	0.202	7.227	0.230
Dollars per mile	11.967	0.379	12.802	0.438

Table 8: The Effect of Gasoline Price Run-ups from 1999 on Vehicle Prices and Sales

Models in 2006	Price in 2006 $ (1)	Price change in % & 90% C.I. (2)	Sales in 22 MSAs (3)	Sales change in % & 90% C.I. (4)
Hybrid Models				
Ford Escape Hybrid	29,140	-6.09 [-6.67, -5.33]	3,862	-34.21 [-36.00, -31.82]
Honda Civic Hybrid	22,400	-5.59 [-6.34, -4.70]	7,232	-36.82 [-38.55, -33.09]
Honda Accord Hybrid	31,540	-4.19 [-4.95, -3.56]	1,210	-21.78 [-22.25, -20.09]
Toyota Highlander Hybrid	34,430	-9.56 [-11.14, -8.05]	7,594	-32.13 [-35.21, -28.35]
Toyota Prius	22,305	-7.01 [-7.73, -6.08]	26,625	-37.44 [-39.35, -32.71]
Non-hybrid Models				
Ford Escape	21,745	2.95 [2.39, 3.83]	17,276	25.11 [22.40, 30.36]
Honda Civic	17,660	-1.83 [-2.10, -1.46]	60,112	-14.11 [-14.68, -12.24]
Honda Accord	21,725	-0.18 [-0.27,-0.07]	69,852	-0.90 [0.20, 1.54]
Toyota Highlander	26,535	1.00 [0.74, 1.12]	15,684	2.01 [1.03, 2.92]
Toyota Corolla	15,485	-1.43 [-1.56, -1.11]	74,928	-8.03 [-8.78, -6.38]

Note: The table presents the percentage changes in vehicle prices and sales if the gasoline prices had stayed at the 1999 level. The vehicle sales-weighted average annual gasoline price in the 22 MSAs was $2.60 in 2006 compared to $1.53 in 1999, both in 2006 dollars. The brackets give 90% confidence intervals based on parametric bootstrapping.

Table 9: Total Hybrid Sales in 22 MSAs under Different Gasoline Price Scenarios

Year	Gas price in 2006 $ (1)	Sales in 22 MSAs (2)	Sales change in % with 90% C.I. 1999 level (3)	$4.00 (4)	$6.00 (5)
2001	1.75	5,461	-11.47 [-11.67, 11.12]	207.06 [192.63, 238.38]	456.26 [414.02, 540.77]
2002	1.54	8,231	2.20 [2.03, 2.38]	205.77 [187.36, 233.10]	430.07 [391.72, 499.63]
2003	1.76	9,117	-9.51 [-9.77, 9.31]	157.18 [143.98, 177.60]	364.30 [332.25, 419.95]
2004	2.01	17,732	-18.62 [-19.94, -16.17]	110.16 [101.65, 131.61]	268.39 [239.08, 304.60]
2005	2.41	43,658	-23.69 [-26.64, -20.99]	64.59 [60.69, 73.18]	165.47 [147.15, 189.71]
2006	2.60	59,059	-36.60 [-38.04, -32.41]	64.55 [56.55, 76.02]	183.24 [159.10, 216.30]

Note: Column (1) lists vehicle sales-weighted average annual gasoline prices in the 22 MSAs. Column (3) presents the percentage changes in total hybrid vehicle sales with 90% confidence intervals when gas prices were assumed to be at the 1999 level in each of the MSAs. The sales-weighted average gasoline price in the 22 MSAs was $1.53 in 1999.

Table 10: The Effect of Tax Incentives on Selected Hybrid Models

	Observed Incentives			Without Incentives	
	Price (in 2006 $)	Sales in 22 MSAs	Subsidy in 2006$	Price change in % with 90% C.I.	Sales change in % with 90% C.I.
	(1)	(2)	(3)	(4)	(5)
2005 Hybrid					
Ford Escape	28,330	2,918	371	-0.67 [-0.69, -0.66]	-0.62 [-1.00, -0.26]
Honda Civic	20,815	4,836	471	-0.82 [-0.84, -0.79]	-3.86 [-4.19, -3.39]
Honda Accord	31,489	3,146	527	-0.69 [-0.70, -0.68]	-1.55 [-1.91, -1.09]
Toyota Highlander	33,476	3,366	450	-0.65 [-0.66, -0.65]	-0.38 [-0.74, 0.11]
Toyota Prius	22,106	25,528	522	-0.89 [-0.92, -0.86]	-2.27 [-2.44, -2.01]
2006 Hybrid					
Ford Escape	29,140	3,862	1,960	-3.25 [-3.38, -3.16]	-17.48 [-18.69, -15.98]
Honda Civic	22,400	7,232	1,947	-3.11 [-3.20, -3.07]	-22.31 [-23.89, -20.51]
Honda Accord	31,540	1,210	624	-0.86 [-0.88, -0.85]	-4.41 [-4.99, -3.79]
Toyota Highlander	34,430	7,594	2,172	-2.94 [-2.97, -2.93]	-10.68 [-12.38, -8.72]
Toyota Prius	22,305	26,625	2,617	-4.36 [-4.52, -4.29]	-24.60 [-25.56, -23.17]

Note: Column (3) presents the average tax benefit received by the buyers of each hybrid model in the 22 MSAs. The 90% confidence intervals for simulation results in brackets are obtained using parametric bootstrapping.

Table 11: The Effect of Tax Incentives on Hybrid Adoption from 2001 to 2006

	Observed Incentives		Without Incentives	Doubled Incentives	
Year	Hybrid Sales in 22 MSAs	Subsidy in 2006 $	Sales change in % with 90% C.I	Subsidy in 2006 $	Sales change in % with 90% C.I
	(1)	(2)	(3)	(4)	(5)
2001	5,461	611	-4.51 [-4.92, -4.12]	1,233	4.96 [4.54, 5.41]
2002	8,231	572	-4.79 [-5.15, -4.39]	1,154	4.89 [4.54, 5.28]
2003	9,117	529	-4.32 [-4.63, -4.02]	1,048	4.01 [3.73, 4.35]
2004	17,732	521	-4.49 [-4.71, -4.11]	1,030	4.24 [3.86, 4.49]
2005	43,658	473	-3.58 [-3.78, -3.23]	943	3.46 [3.15, 3.68]
2006	59,059	2,276	-19.75 [-20.91, -18.08]	4,754	22.94 [20.55, 24.45]

Table 12: Policy Effects on Gasoline Consumption and CO_2 Emissions

	New Vehicle MPG (1)	New Vehicle Sales in '000 (2)	Gas Consumption in mil. barrels (3)	CO_2 Emissions in mil. tons (4)
Observed	23.19	2467.92	456.04	191.54
Changes under Different Policies				
Income Tax Credit				
Without	-0.10 [-0.10, -0.09]	-0.65 [-0.78 -0.48]	1.80 [1.73, 1.88]	0.76 [0.73, 0.79]
Doubled	0.12 [0.11, 0.13]	0.81 [0.71, 1.02]	-2.15 [-2.28, -1.98]	-0.90 [-0.96, -0.03]
Gasoline Tax Increase				
$0.10	0.10 [0.09, 0.11]	-37.36 [-39.31 -36.27]	-8.83 [-9.31 -8.50]	-3.70 [-3.91 -3.57]
$0.25	0.29 [0.27, 0.30]	-98.23 [-103.44, -96.05]	-23.51 [-24.44 -22.88]	-9.87 [-10.27, -9.61]
$1.00	1.01 [0.92, 1.08]	-309.54 [-323.27, -297.15]	-73.84 [-76.83, -70.64]	-31.01 [-32.27, -29.67]

Note: The numbers in the table are for 2006 cohort of new vehicles sold in the 22 MSAs. Both total gasoline consumption and CO_2 emissions are calculated for the lifetime of these vehicles (15 years with 12,000 miles traveled per year).

Table 13: Comparison of the Tax Credit Program with a Rebate Program

	Average MPG in 22 MSAs	Total Subsidy in 2006 $million with 90% C.I.
Baseline: Current Tax Credits		
Tax Credit Program	23.19	134.43 [134.13, 134.72]
Rebate Program	23.19	113.60 [112.50, 115.91]
Difference	0	-20.83 [-21.87, -18.59] (-15.5%)
Baseline: Doubling Tax Credits		
Tax Credit Program	23.31	346.08 [336.99, 352.52]
Rebate Program	23.31	260.21 [255.14 264.93]
Difference	0	-85.87 [-89.90 -80.01] (-24.8%)

Table 14: Robustness Analysis: Vehicle Prices Constant

Year	Hybrid Sales in 22 MSAs	Sale Change in % with 90% C.I.	
		Gas Price at 1999 Level	Without Incentives
	(1)	(2)	(3)
2001	5,461	-23.04 [-23.40, -22.40]	-8.54 [-9.30, -7.77]
2002	8,231	4.47 [4.10, 4.85]	-8.96 [-9.71, -8.17]
2003	9,117	-19.12 [-19.69, -18.64]	-8.08 [-8.68, -7.46]
2004	17,732	-35.62 [-38.09, -31.14]	-8.49 [-8.94, -7.81]
2005	43,658	-44.63 [-50.22, -39.59]	-7.03 [-7.45, -6.32]
2006	59,059	-61.96 [-65.05, -56.13]	-31.40 [-33.05, -29.28]

Note: Vehicle prices are held constant in the simulations.