Energy Policy 37 (2009) 972–983

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

The impact of government incentives for hybrid-electric vehicles: Evidence from US states

David Diamond *

LMI Research Institute, 2000 Corporate Ridge, McLean, VA 22102, USA

ARTICLE INFO

Article history:
Received 11 April 2008
Accepted 19 September 2008
Available online 13 December 2008

Keywords:
Hybrid-electric vehicles
Public policy
Technology diffusion

ABSTRACT

This paper examines the impact of government incentives policies designed to promote the adoption of hybrid-electric vehicles (HEVs). As a primary methodology, it employs cross-sectional analysis of hybrid registration data over time from US states to test the relationship between hybrid adoption and a variety of socioeconomic and policy variables. It also compares hybrid adoption patterns over time to the US average for specific states that have changed incentive policies, to examine how differences in incentive schemes influence their efficacy. The results of these analyses suggest a strong relationship between gasoline prices and hybrid adoption, but a much weaker relationship between incentive policies and hybrid adoption. Incentives that provide payments upfront also appear to be the most effective.

1. Introduction

Hybrid-electric vehicles (HEVs) combine a gasoline engine with an electric motor, which is powered by a storage battery charged via regenerative braking.[1] HEV technologies take advantage of the most efficient operational modes of both the engine (high-speed cruising) and motor (low-speed driving and acceleration) and provide a means of recapturing energy normally lost from braking. Despite the additional weight of the electric motor and battery, a typical hybrid is still considerably more fuel efficient than a non-hybrid gasoline vehicle of equivalent size and performance, or more powerful than a conventional vehicle of equivalent engine displacement (How Hybrids Work, 2007). As an energy-efficiency technology, HEVs have the potential to address environmental and resource externalities that are not taken into account by the market (Jaffe and Stavins, 1994), and may help automakers meet new fleet fuel economy requirements recently mandated by the US Congress. However, hybrids also face barriers to adoption that are common to any new technology, such as lack of knowledge by potential adopters, low consumer risk tolerance (Jaffe and Stavins, 1994; Stoneman and Diederen, 1994), and high initial production costs (Argote and Epple, 1990). These factors have been mitigated somewhat by hybrids' established performance and reliability record in the US, but price premiums of several thousand dollars over equivalent gasoline only vehicles still serve as a deterrent to consumer demand.

A number of consumer incentives for purchasing hybrids have been put in place to address these market barriers and to overcome the incremental initial purchase costs of hybrids compared to their gasoline equivalents. Until 2005, the US Federal Government provided a \$2000 tax deduction for all qualifying hybrids, regardless of make and model. Starting in January 2006, however, the Energy Policy Act of 2005 replaced this tax deduction with a tax credit based on an individual model's emissions profile and fuel efficiency compared to equivalent gasoline vehicles. Credits vary from several hundred to several thousand dollars, and phase out over time after the manufacturer sells a total of 60,000 hybrid and lean-burn vehicles (New Energy Tax Credits for Hybrids, 2007).

In addition to the federal tax credit, many states offer additional incentives. As of 2008, the state with the highest effective incentive structures is Colorado, which offers credits of \$2500–\$6000 depending on the model, while several other states offer incentives valued at greater than \$1500 (Hybrid Incentives and Rebates—Region by Region, 2007). Still other states, such as Virginia, California, New York, New Jersey, Florida, and Utah, allow hybrid owners waivers from high occupancy vehicle (HOV) lane restrictions on one or more highways in the state.

Despite the proliferation of these incentives programs, their efficacy in actually promoting adoption of hybrids is unclear. To address that question, this paper examines the significance and strength of government incentives in promoting adoption, how the impact of incentive policies compares to other significant socioeconomic factors, and the implications of those relationships for policymakers. As a primary methodology, cross-sectional

* Tel.: +1 703 477 4101; fax: +1 703 917 7594.
E-mail addresses: ddiamond@lmi.org, Ddiamond71@gmail.com (D. Diamond).

[1] Plug-in hybrids also allow for external recharging of the storage battery, but are not yet available on the mass market.

0301-4215/\$ - see front matter
doi:10.1016/j.enpol.2008.09.094

time-series analysis of HEV registration statistics over time from US states was used to test the relationship between hybrid adoption and a variety of socioeconomic and policy variables. A comparison of hybrid adoption patterns over time to the US average for specific states that have changed incentive policies was also conducted, to examine whether the way in which an incentive is implemented affects its impact. As a primary data source, state hybrid vehicle registration data from 2001 to 2006, provided by RL Polk & Co.,[2] was used to calculate hybrid market share (i.e. new hybrids as a percentage of all new vehicles for a certain time period) for each US state.

The remainder of this paper is organized as follows: Section 2 includes a literature review of previous economic and policy research on hybrids. Section 3 describes the model and methodology used to evaluate state market share data on hybrids. It also provides an overview of hybrid sales over time on a national level, which highlights the limitations of using national aggregated time series registration data to examine policies. In Section 4, the model is used to perform regressions on annual state market share for three hybrid models. In Section 5, additional analysis is conducted on monthly market share in nine individual states that have changed incentive policies, to examine whether the manner in which the incentive was provided (such as a tax credit versus an instant sales tax waiver) had an impact on its efficacy. Section 6 presents conclusions and implications for policymakers.

2. Literature review

Previous research on hybrids has examined the economics and environmental benefits of hybrids, factors influencing adoption, and to a limited extent, the impact of incentives. Several studies comparing the total lifecycle costs of equivalent hybrid and gasoline models found that lifecycle costs for hybrid vehicles would exceed those for equivalent non-hybrid vehicles at past and current gas prices. Canes (2003) examined the first generation Honda Civic Hybrid and Toyota Prius, noting a premium in total ownership cost for hybrids compared to equivalent gasoline models based on vehicle price, fuel cost and maintenance expenses, even if pollution costs and fuel prices well above recent records are included in the analysis. In an early paper on hybrids, Lave and MacLean (2001) noted that gas prices of over $5.00 per gal or a social value of abating tailpipe emissions 14 times greater than 2001 estimated values (as calculated by regulatory agencies) would be required for a Toyota Prius to compare favorably to a conventional Corolla model from a consumer or social benefit standpoint. More recently, Consumer Reports conducted a total ownership cost analysis of 2006 hybrid models based on $3–4 gas prices and including current federal tax credits. The magazine found five-year ownership cost premiums for all hybrid models except the Toyota Prius and Honda Civic Hybrid, which had slight ($406 and $317, respectively) lifetime cost savings over their non-hybrid equivalents (The Dollars and Sense of Hybrids, 2006). Other consumer-oriented analyses have shown similar results, although these types of calculations are extremely sensitive to assumptions about ownership period, discount rates, payback periods, insurance costs and the conventional gasoline model and trim level used for comparison to the hybrid. Ogden et al. (2004) compared theoretical per mile fuel costs and societal lifecycle costs (including environmental externalities) for both conventional and alternative fuel vehicles, as well as for combinations of hybrid-electric technology with internal combustion engines powered by gasoline, natural gas, hydrogen and diesel fuel. The results show the potential for hybrid-electric technology to significantly increase the efficiency of vehicles using a wide variety of alternative fuels. Turrentine et al. (2006) note that the reduction in GHG emissions and oil consumption due to hybrids is largely a function of hybrid market share and the efficiency of the hybrid fleet compared to the larger non-hybrid fleet. However, they estimated that at 1.2% of the national automobile market, hybrids could reduce US oil consumption and GHG emissions by 0.4% compared to baseline scenario with conventional gasoline vehicles.

Looking at factors that influence adoption, Kahn (2007) found that environmentalism (as indicated by Green Party affiliation) was associated with hybrid ownership, based on regression analysis of census track-level data in six California cities. Heffner et al. (2005) conducted detailed interviews with households in Northern California that own HEVs, and determined that both anticipated cost savings and the "green image" of hybrids influence purchase decisions. McManus and Berman (2005) analyzed the results of an online survey taken by 532 hybrid owners and 933 potential owners who visited the HEV information website HybridCars.com. Their report identified the desire to save money on gas and reduce pollution as significant motivating factors for purchasing a hybrid among both sets of respondents. A 2004 marketing survey by ChangeWave Research concluded that hybrid owners tend to be in the highest income demographics and are more sensitive to gas prices than environmental benefits in purchasing their vehicles (Year of the Hybrid, 2004).

Other studies have used diffusion and consumer choice models to forecast hybrid demand in future years. Cao and Mokhtarian (2004) used a new technology diffusion model based on Bass (1969) to predict the adoption rate curves for a variety of alternative energy and energy efficiency automobile technologies. For hybrids, they used national-level hybrid sales data in a study that found lagged gasoline prices to be significant in explaining aggregate diffusion patterns. However, the authors also note that the Bass model can be unreliable in its peak prediction ability using only data from early in the adoption process (as is likely the case with hybrids) and that it is highly dependent on the initial assumption for the size of the potential market.[3] Greene et al. (2004) used a nested logit model to predict market penetration through 2012, and concluded that hybrids could achieve market shares of 10–15% based on anticipated model introductions.

Several studies examining the impact of government incentives on hybrid vehicle adoption have been conducted using sales and registration data for US states. Diamond (2008b), on which this paper is partially based, and Diamond (2008a) examined hybrid market share at the county level in Virginia using cross-sectional regression. The research concluded that HOV lane incentives, along with income and environmentalism, were significant predictors of market share, but that the HOV lane effect was highly dependent on local conditions. Gallagher and Muehlegger (2008) analyzed state market share using sales transaction data provided by JD Power and found that state incentives, average income and social preferences were all significant in explaining state market share. The study also noted that sales tax waivers tended to be more significant than income tax credits, and that Virginia's HOV incentive appeared to have significantly impacted market share. This paper complements Gallagher and Muehlegger's work and uses a different data source, R.L. Polk data, which is based on actual vehicle registrations vice dealer reported sales. The use of R.L. Polk data addresses one

[2] The analyses and results expressed herein are those of the author and do not reflect conclusions derived by R. L. Polk & Co.

[3] For HEVs, the authors assumed the potential market to be 10% of the total automobile sales market.

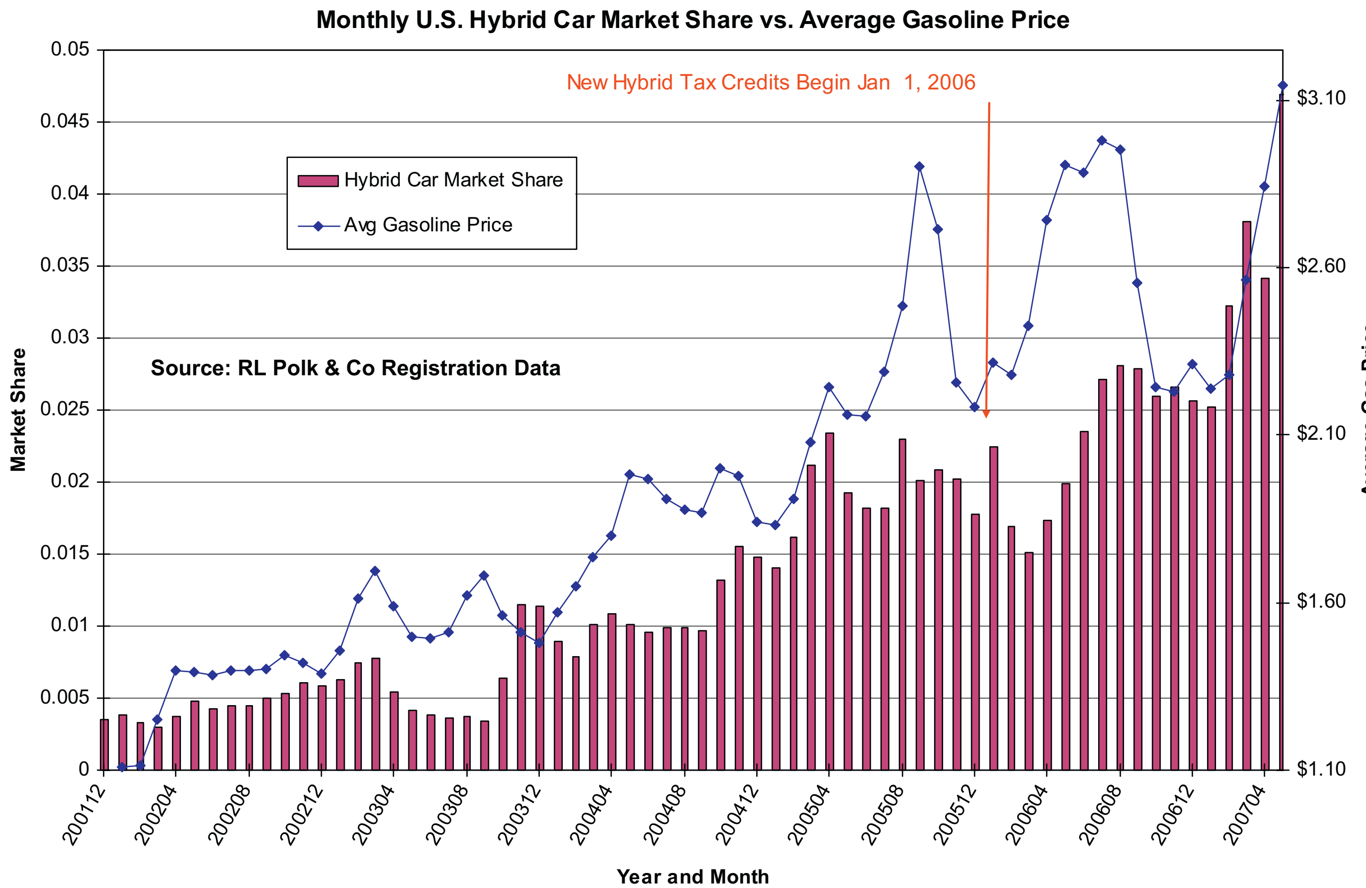

Fig. 1. Monthly US Hybrid Car Market Share and Average Monthly Gasoline Prices.

shortcoming of JD Power data, in that Power data reports only the location of the sale, which may be different from the actual jurisdiction in which the vehicle is registered. The latter would determine the actual state incentive received for the purchase.

3. Methodology

3.1. *Limitations of national time-series data*

One significant difficulty in analyzing hybrid adoption using time series data is isolating the specific effects of a number of predictor variables that have all generally increased over time. Figs. 1 and 2 illustrate monthly market share (new hybrid cars or trucks as a percentage of all new cars or trucks registered) for all hybrids in the US, based on R.L. Polk & Co. registration data, and one of the anticipated significant predictor variables, corresponding monthly gasoline prices.[4]

Although the market share curves for hybrid cars and light trucks appear to follow roughly the gasoline price curve, gas prices exhibit seasonality and are subject to sharp short-term fluctuations. Market share, although corrected for seasonality, is also an unreliable indicator on a monthly basis due to short term constrained supply issues that led to long waiting lists (up to six months in some cases) during several periods of high demand. Attempts to regress market share with gasoline prices (including a variety of annual and monthly lags and differences) failed to note a significant relationship. On an annual basis, both variables have increased steadily year after year.

Figs. 1 and 2 also illustrate the difficulty in isolating the effects of individual factors such as gasoline prices, incentive policies, or other events—such as Hurricane Katrina—that could potentially influence hybrid sales. Likewise, is difficult to draw conclusions about the impact of federal incentive policies. Market share increased over time both before and after the transition from the original federal hybrid tax deduction to the follow-on federal tax credit incentive scheme in January 2006. Figs. 1 and 2 do show a short-term drop in the month before the tax credit scheme went into effect on January 1, 2006, followed by a spike in sales in the following month. However, market share dropped again in February, suggesting that the temporary spike in January may have been due to consumers simply postponing purchases at the end of 2005 to take advantage of the increased value of the tax credit versus the original tax deduction.

Absent other factors, hybrid market share might also be expected to increase over time naturally, following the classical pattern of new technology diffusion noted by Griliches (1957), Bass (1969) and Rogers (1995). Diffusion is an important factor in increased market share, but diffusion is simply an observed phenomenon based on many observed and unobserved factors that lead to increased adoption over time, such as increases in manufacturing capacity, the greater number of hybrid models available, publicity and growing visibility of hybrids by the general public. Most of these factors contributing to diffusion are correlated with other socioeconomic predictor variables over time, so it is difficult to isolate the effect of a specific variable on

[4] Because the market share represents hybrids as a fraction of sales, as opposed to the actual number of vehicles sold, Figs. 1 and 2 account for seasonality in vehicle sales. While this does not rule out the possibility that seasonality affects hybrids differently than other vehicles, there is no clear evidence or logical cause for a seasonal trend in hybrid market share.

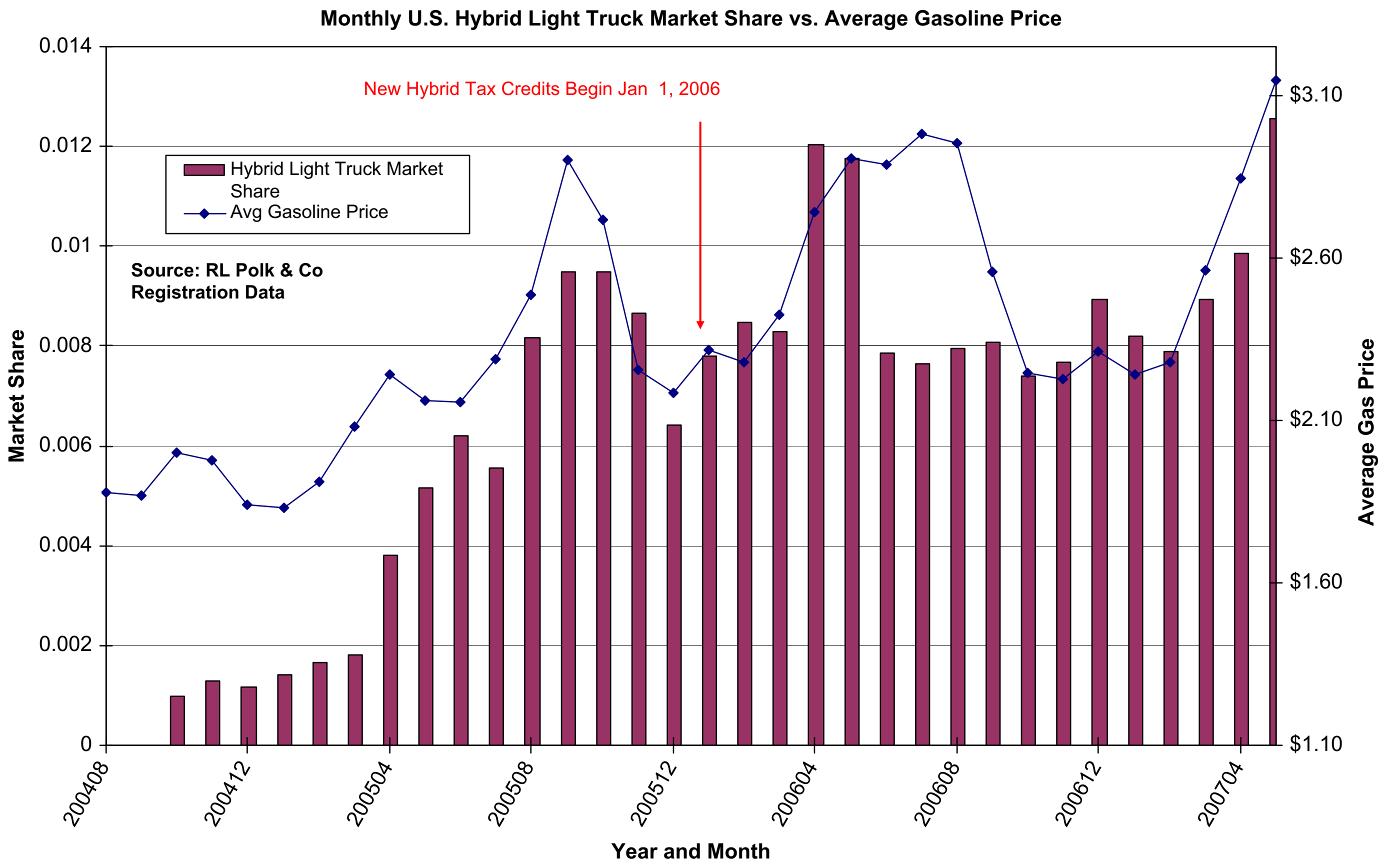

Fig. 2. Monthly US Hybrid Light Truck Market Share and Average Monthly Gasoline Prices.

hybrid adoption if all predictors have exhibited similar trends. While it might be theoretically possible to regress the effects of predictor variables using time series data and a parameterized diffusion curve, for hybrids this would likely require a much longer market history so that the true shape of the diffusion curve becomes evident. Absent this long time history, diffusion models used to predict early adoption of new technologies rely on significant assumptions about the potential market size and current place in time on a theoretical adoption curve (Santini and Vyas, 2005). Deviations from these assumptions would lead to significant errors both in forecasting and comparing the effects of predictors.

3.2. Cross-sectional model for market share

The variance in hybrid adoption at the state level was used to help overcome the inherent limitations of using national level time-series data. Looking at the variation between states—in addition to the variation over time—helped isolate and separate the policy and economic determinants of adoption that vary across space but are highly correlated in time.

The basic premise of this methodology is to compare the market share or rate of adoption among jurisdictions over any given time interval, to test how variations in different socio-economic factors, on average, affect the tendency of consumers to purchase HEVs. This methodology is in keeping with other studies that have used cross-sectional sales and registration data from different countries and regions to examine factors influencing automobile adoption. These include Button et al. (1993), which used cross-sectional data on car adoption in low income countries; Cao et al. (2004), which looked at car ownership in California neighborhoods, and Kahn (2007), which used census track data on hybrid registrations in California cities.

The basic cross-sectional model for hybrid vehicle market share is derived from a behavioral utility function for automobile demand given by Berry et al. (1995). The model specification reduces to a cross-sectional objective function, state market share, which is a function of a number of independent socioeconomic and policy variables that are assumed to be significantly related to variations in market share between states. Over a given time period, the indirect utility of consumer i for any vehicle j can be expressed as

$$U_{i_j} = f(p_j, x_j, \xi_j, \zeta_i; \theta) \tag{1}$$

where, p_j is the price of vehicle j; x_j is the observed product characteristics of vehicle j (size, features, power, etc.); ξ_j is the unobserved product characteristics (quality, styling, brand reputation, etc.); ζ_i is the consumer preferences and socioeconomic characteristics of consumer i and θ is a vector of parameters to be estimated.

Consumer i will choose to purchase vehicle j if and only if:

$$U_{i_j}(p_j, x_j, \xi_j, \zeta_j; \theta) \geqslant U_{ir}(p_r, x_r, \xi_r, \zeta_r; \theta) \text{ for } r = 0, 1, 2, \ldots, J;\ r \neq j$$

where the choice $r = 0$ corresponds to the outside alternative of not purchasing any vehicle. For a given population, the aggregate demand A_j for vehicle j is given by

$$A_j = \{\zeta : U_{i_j}(p_j, x_j, \xi_j, \zeta_j; \theta) \geqslant U_{ir}(p_r, x_r, \xi_r, \zeta_r; \theta)\}$$
$$\text{for } r = 0, 1, 2, \ldots, J;\ r \neq j$$

The market share s_j of a given model is now a function of

$$s_j = f(p_j, x_j, \xi_j, \zeta; \theta) \tag{2}$$

It is important to note that in Eq. (2), the market share is now a function of the price and characteristics of an *individual* product *j*, but of the characteristics of the *overall* population, so that average consumer preferences and characteristics can be assumed for any market share data point.

For the cross-sectional analysis, it is assumed that observed and unobserved product characteristic vectors x and ξ do not vary among states or other jurisdictions, because automakers sell the same car models with nearly equivalent prices and specifications in each US state.[5] This reduces Eq. (2) to

$$s_{s_j} = f(p_{sj}, \zeta_s; \theta) \tag{3}$$

where the subscript *s* denotes an observation for model *j* (taken to be a specific hybrid model) for an individual state *s*.

On an individual level, consumers' preferences for different auto characteristics, ζ, are affected by a number of predictor variables that vary, on average, by state and either influence the effective total ownership cost of the vehicle or provided a non-monetary benefit that affects consumer utility. Monetary considerations include the value of government incentives (Incentive variable), gas prices (Gas variable) and annual miles traveled (VMT variable, which is related to the annual cost of fuel). Non-monetary factors include HOV-lane privileges (HOV variable), which provide a benefit to the consumer via convenience, and average consumer environmentalism (GPC variable that is defined in the following section), which would be make hybrids attractive due to their image as "green" technology (Heffner et al., 2005). Income is also included as a predictor variable, under the assumption that income relates to effective consumer discount rate for future energy cost savings, and risk tolerance for new technologies.

The final model specification is given as

$$\log s_{it} = \alpha + \beta_1 \log \text{Incentive}_{it} + \beta_2 \log \text{Income}_{it} + \beta_3 \log \text{HOV}_{it} + \beta_4 \log \text{Gas}_{it} + \beta_5 \log \text{VMT}_{it} + \beta_6 \log \text{GPC}_{it} + \varepsilon_{it} \tag{4}$$

where the subscripts indicate an observation for an individual state *i* at time *t*.

The choice of the log–log specification was purely empirical, and generally provided a better fit to the data than an OLS specification, as indicated by the adjusted R^2 values, as well as an absence of heteroskedasticty as indicated by graphical and numerical analysis.[6] The log–log form was also useful because it allowed the interpretation of the regression coefficient for each variable as the elasticity of market share with respect to that predictor. Lastly, the log–log form was consistent with Box-Cox transformations of the data for each year and model, as suggested by Bajic (1988)[7] in his work on automobile demand.

Constrained short-term supply was addressed through the use of annual market share observations. It was assumed that a one-year time period for each market share observation was long enough to smooth out the effects of waiting lists and backlogs that may have occurred on a monthly or even quarterly basis. This time period was also assumed to be long enough for manufacturers to adjust the distribution of hybrids between states in order to maximize profits, even if the nationwide supply of hybrids was limited. Manufacturers would likely send more hybrids to areas where the market was willing to bear higher prices due to differences in socioeconomic factors that affected demand or state government incentives that offset price premiums (effectively transferring the incentive from consumer to dealer).

While models sold in each state may look and perform identically, regulations in California, New York and six New England states require vehicles with stricter emissions standards than in the rest of the US (EPA Green Vehicle Guide, 2008). While this would limit manufacturers short-term ability to shift cars from states with more lenient emissions standards to meet demand in states with stricter standards, there does not appear to be a legal barrier to manufacturers selling the lower emissions automobiles in states that do not require them (Blanco, 2007). Over the year-long time periods, it was assumed that manufacturers could vary their mix of higher and lower emissions automobiles to the demand patterns from each state.

4. Data and results

4.1. Description of data

Table 1 provides a description of the variables and data sources.

The dependent variable in the analysis was annual state market share, which represented new registrations of a particular hybrid model as a percentage of all new car or light truck registrations in the state for that same time period. Market share observations were derived for three models, the Honda Civic Hybrid, Toyota Prius and Ford Escape from the year of their initial model introduction in the US through 2006, using RL Polk and Co. registration data.[8] These three models were chosen because they represented the top selling hybrid sedans and the top selling hybrid SUV (through 2006) and because they each had three or more years of price data. Additionally, each of these HEVs is in the median price range for their vehicle class (approximately $20,000–25,000), so they represent a reasonable substitute to conventional gasoline sedans for most consumers purchasing new cars. Other hybrid models with several years of sales history (such as the two-seater Honda Insight or Lexus luxury hybrids) tended to be limited to a much smaller segment of the market.

The HOV dummy variable was used to represent HOV lane privileges on one or more major highways. Although the HOV effect would likely be on a local, rather than statewide, basis, it was included as a control due to its demonstrated effect in Virginia (Diamond, 2008a).

As a measure of state environmentalism, the Research Renewal Institute's Green Planning Capacity (GPC) index was used. This index is an aggregate of four separate variables measuring each state's environmental management framework, level of environmental policy innovation, fiscal and program commitment to green planning and the quality of environmental governance, (Siy et al., 2001). It serves as a proxy for the relative value placed by residents from each state—as reflected by government actions—on conserving energy and protecting the environment.

The incentive variable included the combined value of federal and state monetary incentives, and ranged from $560 to $5618

[5] In reality, there are differences in emissions standards from state to state, but, it was assumed that these differences were transparent to consumers and did not factor into buying decisions or increase vehicle cost significantly.

[6] Breusch–Pagan/Cook–Weisberg tests for heteroskedasticity were performed in SATA for log–log regression results for each year and hybrid model. All tests failed to reject the null hypothesis of constant variance in the residuals. Plots of residuals versus fitted values of the dependent variable for each model and year also failed to show evidence of heteroskedasticity. Similar tests for the linear specification, on the other hand, showed evidence of heteroskedasticity.

[7] Box-Cox transformations for each data panel failed to reject the null hypothesis of $\lambda = 0$, and generally returned λ values between -0.5 and 0.5.

[8] The registration data indicated the number of new registrations for a given time period of a particular model, but did not take into account the model year of the vehicle. Therefore, it was not possible to address the impact of changes in vehicles from one model year to another.

Table 1
List of variables and data sources.

Variable	Data	Source
s_h	Market share of hybrids as a percentage of all new car registrations (for car models) or hybrids as a percentage of all new light truck registrations (for SUV models) during a particular time period)	RL Polk and Co (2007). Polk provided a dataset of total registrations of particular hybrid models for each state from 2001 to 2006, as well as a separate dataset of total new car and new light truck registrations for each year. These datasets were combined and manipulated to create the market share ratio variable[a]
VMT	Vehicle Miles Traveled per capita (annual data were available only through 2005, so 2005 data was substituted for 2006)[b]	US Department of Transportation Annual Highway Statistics (2001–2005)
Gas	Yearly average gasoline price per state for 2001–2006 (average of monthly fuel price for each state, all gasoline blends, including Federal and Local taxes)	Federal Highway Administration, Monthly Motor Fuels Report (2007)
Incentive	Combined value of all federal and state-wide tax incentives, rebates and other benefits based on a 28% tax rate and base model purchase prices	Incentive data from the Department of Energy, Energy Efficiency and Renewable Energy Division (DOE EERE) and hybridcars.com. Base model prices from Edmunds.Com
HOV	Dummy variable for HOV restriction exemptions for hybrids on one or more major highways in a state	DOE EERE and hybridcars.com
Income	State per capita income	US Census Bureau
GPC	Green planning capacity index	Resource Renewal Institute

[a] Disclaimer: Statistics based on R.L. Polk & Co. data for new hybrid vehicle registrations. The analyses and results expressed herein are those of the author and do not reflect conclusions derived by R.L. Polk & Co.

[b] In a cross-sectional regression, the significance of the variable is determined by the variance or relative value of the variable between states rather than the actual magnitude of the value. Therefore, a significant error is not anticipated in using 2005 values for 2006.

depending on the state, year and model. The inclusion of federal incentives would not have been necessary for an OLS regression. However, it was useful for the log–log specifications because it provided a non-zero value for each state observation. It also provided an indication of the relative magnitude of the federal to state incentives.

State incentive schemes varied widely, and included rebates, tax credits and tax deductions, whose value was sometimes tailored to a specific model or offered as a percentage of the purchase price. Other state incentives were in the form of reductions or waivers for registration and inspection fees for a number of years. In calculating state and federal tax incentive values for each model, the highest value of the incentive at any time during the year was used as the incentive value for that year. The value of the Federal tax deduction for each state was calculated at a 28% rate, and state income tax rate rates were not included due to the wide variance in state tax schemes. The value of annual fee waivers was based on the Net Present Value of the incentive stream for a 10 year ownership period at 5% annual interest rate. While consumers' effective discount rate may actually be much higher, this NPV calculation likely represented the upper bound of the incentive's value to a consumer. Vehicle prices used to calculate the incentive values were for the base model Prius and Civic Hybrid with an automatic transmission, and the average of the base price for the 4-wheel drive and 2-wheel drive versions of the Escape. Changes to these assumptions had a negligible impact in the overall significance and magnitude of the regression coefficients in the results.

4.2. Market share overview and observations

The geographic plot in Fig. 3 illustrates the relative market shares for all hybrid cars during 2006.

State market share rankings among states remained relatively stable from 2001 to 2006, so the plots for other years are similar. Individual plots for the three vehicle models analyzed, the Prius, Civic and Escape, are also similar. The geographic plot shows a significant variance in market share between states. Many states typically associated with environmental awareness, such as California, Washington, Oregon, Maine, Vermont and Massachusetts, were among the highest ranking states in market share. The geographic plots also suggest some degree of spatial relationship, with large clusters of neighboring states having similar market share values. However, several of the predictor variables, including gas prices, income, and dealer locations exhibited a similar spatial trend. Gasoline, in particular, has been more expensive on the US West Coast than in the rest of the country due to high demand coupled with limited refinery and pipeline capacity (Washington State Gasoline Report, 2007).

Although market share observations for Washington, DC were available, the city was not included in the regression due to the omission of DC gas prices in the Federal Highway Administration's Monthly Motor Fuels Report. Gas prices also were not available for Connecticut in 2003.

4.3. Regression results

Tables 2–4 show regression results for the three vehicle models—the Honda Civic Hybrid, Toyota Prius and Ford Escape—from 2001 to 2006, for the years each model was available.

In addition to the cross-sectional regression results for individual years, panel results are shown using three different types of effects: fixed, random and between effects. The fixed effects specification controled for cross-sectional variance, and indicates the strength and significance of each variable over time, averaged across all of the states (Stock and Watson, 2003). Because the national market share of hybrids increased significantly each year due to diffusion-related effects discussed earlier, the significance and strength of the coefficients in the fixed effects regression results was based on the degree to which they increase over time in concert with average (i.e. national) market share. Average gasoline price increased at a faster rate than any of the other predictors, which resulted in large significant coefficients for the gas price variable for each hybrid model in the fixed effects specification. Coefficients for other variables that increased in magnitude more slowly, such as income and VMT, were smaller or insignificant. GPC was dropped entirely from the fixed effect regression because the same values were used each year. The apparent inverse relationship between incentives and market

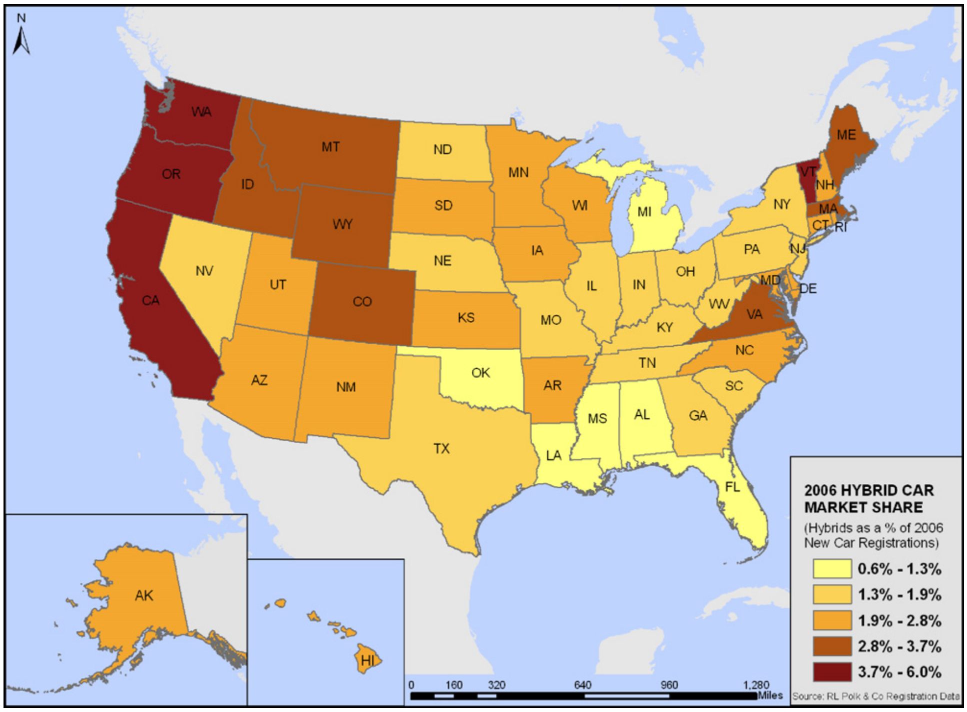

Fig. 3. Hybrid Car Market Share 2006.

share using fixed effects was likely a spurious correlation, based on the phase out of certain state incentives over time even as market share increased.[9]

The between effects regression, on the other hand, measured only the impact of the cross-sectional (i.e. among states) variance on market share. It essentially calculated the average market share for each state over the time periods of interest and ran a single multivariate regression on the set of state averages against the set of average values of each independent variable, over time, for each state (Panel Data, 2006). While this method resulted in a loss of information about the impact of time-dependent variables on market share, it prevented the time effects from masking the impact of the cross-sectional variance, and actually gets at the phenomenon of greatest interest—the relationship between market share and the unique incentives and socioeconomic characteristics of a particular state. The random effects regression allowed for both state and time effects, and essentially averaged the results from the fixed and between effects models (Gould, 2001). As a result, the coefficients for each variable fell somewhere between those of the other two models.[10]

Looking at the coefficients from the between effects regressions, which represent the impact of changes in factors between states, results are fairly consistent between the Prius, Civic and Escape with regard to the significance and effect of the independent predictor variables. Gas price was significant and had the strongest effect on market share, with regression coefficients (which can be interpreted as elasticities for a log–log specification) of 9.3 for the Prius, 7.2 for the Civic and 8.9 for the escape. In other words, a 10% increase in average gas prices would result in, on average, a 72–93% increase in state hybrid market share, depending on the vehicle. Possible reasons for this result are discussed in detail later.

Average vehicle miles traveled (VMT) per capita was also significant with coefficients between 0.8 and 1.5, meaning that a 10% increase in average per-capita miles traveled would result in an 8–15% increase in state hybrid market share, depending on the hybrid model.

The significance and effect of per-capita income was mixed. It was significant for the Ford Escape with a coefficient of 2.8%, indicating that state market share for the Escape was highly elastic with respect to income. The coefficient was significant but less than unity for the Prius, and insignificant for the Civic. This result might have been an indication of the higher demand and longer waiting lists for the Escape and Prius, which would have resulted in higher price premiums. Ford, in particular, developed a large nationwide waiting list for the Escape starting over a year before its introduction. It may also indicate that the Prius and Escape project a more substantial environmental image, and would therefore have attracted higher income consumers who were willing and able to pay a premium purely for the image factor.

The GPC Index variable was also significant, but the effect, as measured by the regression coefficients with values less than 0.5 in all cases, was fairly weak. This may be due to the moderate correlation between the GPC Index and both income ($r = 0.43$) and average gas price ($r = 0.46$).

The presence of an HOV lane incentive was significant with near unity coefficients for all three vehicles. Looking at regressions for individual years, however, it appears that it was most significant from 2001 to 2004, during which time Virginia was the only state offering an HOV lane incentive. Starting in 2005, when other states began to implement HOV incentives, the effect diminishes, indicating that the HOV incentive likely had a greater impact in Virginia than in other states.

The most surprising result was the lack, over the six-year average, of a significant positive relationship between market share and non-HOV incentives for any of the vehicles. On a yearly

[9] In fact, this inverse relationship over time would be observed for any incentive that was phased out over time as it was no longer needed to overcome initial barriers to adoption, highlighting the danger in making conclusions about relationships based on time-series data.

[10] Hausman tests for all three vehicle model regressions indicated that the fixed effects model was inefficient compared to the random effects model.

Table 2
Regression results for Toyota Prius.

Indep. variable	Prius panel regressions (2001–2006)				Prius individual year regressions					
	Fixed effects	Between effects	Random effects		2001	2002	2003	2004	2005	2006
	Coef. (Std. err.)	Coef. (Std. err.)	Coef. (Std. err.)		Coef. (Std. err.)	Coef. (Std. err.)	Coef. (Std. err.)	Coef. (Std. err.)	Coef. (Std. err.)	Coef. (Std. err.)
log_Incentive	−0.260 (0.037)***	0.105 (0.137)	−0.237 (0.036)***		0.093 (0.196)	0.086 (0.152)	0.167 (0.124)	0.110 (0.119)	0.176 (0.113)+	0.211 (0.348)
HOV	−0.129 (0.119)	0.953 (0.383)**	−0.062 (0.118)		1.209 (0.690)*	1.257 (0.547)	1.146 (0.431)**	0.967 (0.417)**	0.176 (0.237)	0.136 (0.180)
log_Income	2.299 (0.878)***	0.778 (0.533)+	1.456 (0.457)***		0.661 (0.883)	1.073 (0.708)+	1.071 (0.598)*	1.334 (0.535)**	1.130 (0.480)**	0.372 (0.524)
log_vmt	1.574 (0.613)**	0.823 (0.474)***	0.961 (0.327)**		1.723 (0.706)**	1.113 (0.525)**	1.892 (0.467)***	1.911 (0.464)***	1.446 (0.443)***	1.352 (0.498)***
log_gas	3.266 (0.255)***	9.338 (1.536)***	3.48 (0.161)***		5.730 (1.827)***	8.446 (1.727)***	8.399 (1.268)***	10.197 (1.423)***	9.026 (1.883)***	9.490 (2.098)***
log_gpc	Dropped	0.319 (0.130)*	0.191 (0.130)+		0.451 (0.225)*	0.404 (0.171)**	0.200 (0.133)+	0.105 (0.127)	0.224 (0.122)*	0.294 (0.129)**
N	297	297	297	N	48	50	49	50	50	50
R^2 (within)	0.908	0.872	0.907	R^2	0.310	0.501	0.577	0.6089	0.469	0.408
R^2 (between)	0.1657	0.548	0.266	Adj R^2	0.209	0.431	0.517	0.5543	0.395	0.325
R^2 (overall)	0.666	0.697	0.703							

*** $P<0.01$.
** $P<0.05$.
* $P<0.10$.
+ $P<0.15$.

basis, incentives were marginally significant for the three vehicles in 2005, but with regression coefficients less than 0.2. For the Ford Escape, the regression coefficient of 0.18 indicates that doubling the average monetary incentive value (federal plus state) of $830 would have resulted in only an 18% increase in average state market share. For a state whose residents purchased 1000 Ford Escape Hybrids in 2005, this would translate to additional incentive payments of approximately $1.13 Million for 180 additional vehicles, or $6271 per additional vehicle. Based on EPA fuel economy estimates (available from www.fueleconomy.gov) for the hybrid and non-hybrid Escape and average state VMT for that year, those additional 180 vehicles would only reduce statewide oil consumption by 576 barrels and CO_2 emissions by 306 tons, at a cost of approximately $1962 per barrel of oil or $3693 per ton of CO_2. On the other hand, that same 18% increase in market share would be associated with only a 3.1% increase in state average gas price, which translates to $.071 per gal for a state with the average national price of $2.30 per gal in 2005. A 10% increase in average gas price (from $2.30 to $2.53) would have been associated with a 58% increase in market share, although the increased fuel price would have cost a driver of a non-hybrid Escape $186 extra in fuel per year with a $498 difference in annual fuel costs between the hybrid and non-hybrid models.[11]

4.4. Trends over time

The explanatory power of the model, as indicated by the adjusted R^2 values for individual year regressions, peaked for the Toyota Prius and Honda Civic Hybrid in 2003 and 2004, and for the Ford Escape Hybrid in 2004 and 2005. For each of those years and vehicle models, the specification accounted for over 50% of the variance in the dependent variable, state market share. The adjusted R^2 values drop-off sharply in later years, falling to less than 0.45 for the Ford Escape Hybrid in 2006, less than 0.4 for the Toyota Prius in 2005 and 2006, and less than 0.3 for the Honda Civic Hybrid in 2005 and 2006. This result could have been due to several reasons. A key change in 2005 was the introduction of HOV lane incentives in additional states besides Virginia. The dramatic drop-off in the significance and magnitude of effect for the HOV dummy variable in 2005 and 2006 indicate that these incentives generally had a less significant impact on market share than in Virginia. In turn, the reduction in explanatory power of the HOV dummy variable may have reduced the explanatory power of the entire model. When the HOV dummy variable was removed from the regressions for the Honda Civic Hybrid in 2003 and 2004, adjusted R^2 values dropped to 0.32 and 0.31, respectively, very close to the values in 2005 and 2006 when HOV incentives were insignificant. Similar results occurred for the Toyota Prius, and there was also a slight drop-off for the Ford Escape Hybrid.

Another possibility is the proliferation and differentiation of hybrid models in later years, which may have resulted in a more complex behavioral choice for consumers. Instead of simply deciding to purchase a hybrid car and choosing between several models with nearly identical size and performance (the Civic and first generation Prius), consumers in 2005 and 2006 had several performance and luxury hybrids available. Likewise for hybrid SUV buyers in 2006, who could choose between the Ford Escape, Lexus Rx400 h, and Toyota Highlander. However, additional regressions (not shown) using total car and truck market share rather than individual models yielded similar results.

Factors at the national level, such as effect of Hurricane Katrina on gas prices and the introduction of more lucrative federal tax

[11] Based on EPA combined fuel economy ratings of 21 mpg for the non-hybrid 2-wheel drive Escape and 29 mpg for the hybrid (www.fueleconomy.gov).

Table 3
Regression results for Honda Civic Hybrid.

Indep. Variable	Civic panel regressions (2002–2006)				Civic individual year regressions				
	Fixed effects	Between effects	Random effects		2002	2003	2004	2005	2006
	Coef. (Std. err.)	Coef. (Std. err.)	Coef. (Std. err.)		Coef. (Std. err.)	Coef. (Std. err.)	Coef. (Std. err.)	Coef. (Std. err.)	Coef. (Std. err.)
log_Incentive	−0.085 (0.039)**	0.076 (0.113)	−0.070 (0.037)*		0.065 (0.112)	0.154 (0.103)+	0.090 (0.100)	0.164 (0.112)+	0.012 (0.239)
HOV	−0.047 (0.097)	0.889 (0.297)***	0.023 (0.097)		1.040 (0.392)**	1.632 (0.357)***	1.481 (0.363)***	0.288 (0.226)	0.138 (0.153)
log_Income	0.899 (0.897)	0.424 (0.431)	0.679 (0.399)*		0.727 (0.507)	0.585 (0.495)	0.688 (0.464)+	0.789 (0.457)*	0.178 (0.445)
log_vmt	1.018 (0.721)	1.475 (0.376)***	0.514 (0.294)*		1.392 (0.377)***	1.386 (0.391)***	1.630 (0.406)***	1.329 (0.426)***	0.843 (0.424)*
log_gas	1.120 (0.240)***	7.208 (1.312)***	1.169 (0.135)***		5.124 (1.234)***	6.093 (1.051)***	7.169 (1.238)***	7.568 (1.791)***	7.154 (1.784)***
log_gpc	Dropped	0.226 (0.105)**	0.150 (0.108)		0.287 (0.123)**	0.284 (0.111)**	0.184 (0.112)+	0.123 (0.118)	0.192 (0.109)*
N	249	249	249	N	50	49	50	50	50
R^2 (within)	0.675	0.655	0.673	R^2	0.449	0.593	0.5564	0.375	0.336
R^2 (between)	0.071	0.507	0.185	Adj R^2	0.372	0.535	0.4945	0.288	0.243
R^2 (overall)	0.295	0.348	0.362						

*** $P<0.01$.
** $P<0.05$.
* $P<0.10$.
+ $P<0.15$.

Table 4
Regression results for Ford Escape Hybrid.

Indep. variable	Escape panel regressions (2004–2006)				Escape individual year regressions		
	Fixed effects	Between effects	Random effects		2004	2005	2006
	Coef. (Std. err.)	Coef. (Std. err.)	Coef. (Std. err.)		Coef. (Std. err.)	Coef. (Std. err.)	Coef. (Std. err.)
log_Incentive	−0.82 (0.1828)***	0.270 (0.199)	−0.453 (0.1332)***		0.435 (0.332)	0.179 (0.104)*	0.177 (0.280)
HOV	0.002 (0.423)	0.668 (0.374)*	0.350 (0.299)		2.581 (1.179)**	0.313 (0.202)+	0.121 (0.169)
log_Income	−6.014 (5.112)	2.827 (0.656)***	2.62 (0.722)***		7.230 (1.918)***	1.474 (0.411)***	1.082 (0.493)**
log_vmt	−4.522 (9.936)	1.135 (0.518)**	1.024 (0.556)*		2.935 (1.744)+	0.406 (0.379)	−0.124 (0.468)
log_gas	14.950 (1.341)***	8.903 (1.883)***	10.939 (0.745)***		12.237 (4.242)***	5.814 (1.603)***	5.280 (1.961)***
log_gpc	Dropped	0.407 (0.168)**	0.378 (0.176)**		0.649 (0.417)+	0.326 (0.104)***	0.239 (0.120)*
N	143	143	143	N	43	50	50
R^2 (within)	0.826	0.694	0.795	R^2	0.592	0.615	0.503
R^2 (between)	0.004	0.598	0.476	Adj R^2	0.524	0.561	0.434
R^2 (overall)	0.386	0.674	0.725				

*** $P<0.01$.
** $P<0.05$.
* $P<0.10$.
+ $P<0.15$.

incentives, may have also contributed to the change in explanatory power. If these factors increased the tendency of all consumers to purchase hybrids, the additional affect of state-level factors may have been muted.

4.5. Alternate specifications

The strong effect of gas price variable and relatively week effect of incentives raised some concerns that the results were being skewed by outliers or problems with disaggregating the data to specific years and models. To account for the presence of outliers, the log–log specification was also run using a robust regression algorithm in STATA, without major changes in the significance or strength of effect for either the gasoline or monetary incentive variables.

One alternative specification used a single variable for fuel costs—the product of gas price and VMT—in place of those two separate variables. This single gas*VMT variable was significant for all years and models with coefficients closer to unity, but with substantially (approximately two thirds of the original) lower R^2 values.

Another specification used total hybrid car market share and total hybrid light truck market share as the dependent variable. Because tax incentives and rebates varied by model, a dummy variable for each year indicating the presence or absence of a monetary incentive greater than $100 was used in place of the variable for specific incentive values. The results of the regression analysis for both cars and light trucks were similar to the regressions for the individual models. Likewise, similar results were obtained when the average value of incentives among models were used. Lastly, alternate specifications for the Prius and Civic included variable a variable that indicated the ratio of the number of Toyota or Honda dealerships in a particular state to the total number of new car dealerships. This variable was intended to account for the relative popularity and availability of cars from particular manufacturers. This variable was marginally significant (at the 0.06 level) only for the Prius in the yearly regression for 2004, but its effect was relatively small ($\beta = 0.23$) and its inclusion only minimally improved the adjusted R^2 value for the analysis (from 0.55 to 0.58). The significance in 2004 could have due to the waiting lists for the Prius that year, and an indication that Toyota rationed their inventory evenly among dealerships.

Table 5
Individual state responses to policy changes.

State	Change in incentive policy	Date	Months of data before incentive change	Months of data after incentive change	Change in differential between state and US average market share
California	Implemented HOV incentive	August 10, 2005	45	16	Insignificant
	HOV permits issued reach 85,000 vehicle limit	February 2007	16	4	Insignificant
Connecticut	Implemented sales tax exemption	October 1, 2004	32	34	−9% to+13%↑
Florida	Implemented HOV incentive	October 1, 2005	46	20	−54% to −44%↑
Maryland	Ended 5% excise tax waiver	June 30, 2004	31	35	+14% to +4%↓
New Mexico	Implemented 3% excise tax exemption	July 1, 2004	31	35	+23% to +34%↑ (insignificant when six months before and after are excluded)
New York	Ended waiver for sales tax on incremental cost of hybrid	February 28, 2004	26	24	Insignificant
	Implemented HOV incentive on Long Island Expressway	March 1, 2006	24	8	Insignificant
	Ended $2000 incremental cost tax credit	December 31, 2006	8	5	Insignificant
Utah	Ended incremental cost credit on Civic	December 31, 2005	49	17	Insignificant
	Implemented HOV incentive	September 1, 2006	9	9	Insignificant
Virginia	Adjusted HOV incentive	June 30, 2006	55	11	+50% to +10%↓
West Virginia	Ended incremental cost credit	June 30, 2006	55	11	Insignificant

5. Implementation of incentives

On aggregate, the regression results failed to show a significant impact from monetary incentives. One aspect not captured in this analysis is whether differences in how states implement incentives—as rebates, tax credits, fee waivers, etc.—has had any impact on effectiveness. To get at this issue, individual state monthly time-series data were examined from nine individual states that either started or ended significant incentive policies during the past few years, to determine if adoption patterns changed significantly in response to the policy change. As a metric for comparison, the percentage differential between state market share and average national market share for each month was used. The results for each state are shown in Table 5.

In Connecticut, Florida, Maryland and Virginia, changes in policy incentives were consistent with sustained significant changes in market share compared to the US monthly average, even when the six months before and after the changes were excluded from the analysis (to account for people timing purchases to coincide with the most favorable incentive offerings). In the other states, the results were less clear. New Mexico appeared to experience an 11% increase in market share compared to the national average, but the change became insignificant when data from the six months before and after the incentive change were excluded. New York and California and Utah each experienced more than one incentive policy change during the period of analysis, making it difficult to isolate the effects of each change. However, in neither of those states was a statistically significant difference in market share associated with any single change in incentive policy. It should be noted that the effect of Utah's HOV incentive was expected to be much weaker than in other states offering HOV privileges for hybrids, since the same privilege is available to owners of any vehicle in Utah willing to pay a $50 monthly fee ($600 per year total) (Cutchin and Benko, 2007). This relatively modest annual cost likely provides a significant disincentive for residents to buy hybrids solely for HOV access.

While the small sample size and unique circumstances for each state made it difficult to draw broad conclusions from the analysis of individual states, a few trends emerged. Overall, changes to incentives in the form of sales or excise tax waivers appear to have had a more noticeable effect than changes in incentive in the form of rebates or tax credits. This is not surprising, since sales and excise tax waivers affect the up-front price that the consumer pays for the vehicle (or at least are realized immediately after purchase when titling the vehicle), while other tax credits and rebates take much longer to receive.

Another observation is related to the overall state trend in market share compared to the national average. In most cases, the statistically significant changes in market share only changed the degree to which the state exceeded or lagged the national average. Except for Connecticut (whose market share rose from below to above the national average after), states who exceeded or lagged the national average before the policy change also did so afterwards. It is notable that the exception—the state of Connecticut—implemented a sales tax waiver that was applied at the time of purchase.

Even when policy changes resulted in a statistically significant change in market share compared to the national average, over the long term the trends from month to month still mirrored those at the national level. This suggests that while state incentives may have had an effect at the margin, it would be very difficult for a state to create a profound change in its HEV adoption curve without influencing other key determinants of adoption such as gas prices, state driving patterns or environmentalism.

Finally, this individual state analysis—like the cross-sectional analysis—does not fully capture the effect of Federal Government incentives over time. The expiration of many of the state incentives in 2005 and 2006 coincided with the passage and implementation of the new—more generous—federal tax credit scheme for hybrids. This analysis assumed that policy changes at the national level affected state adoption patterns uniformly, but there may have been complex behavioral interactions between federal and state incentives that led to state-specific effects on consumer purchase decisions.

6. Conclusions and implications for policymakers

Specific recommendations for policy changes are beyond the scope of this paper, but it is hoped that policy makers will benefit from the its basic insights. While several factors—monetary incentives, gas prices and vehicle miles traveled—have a direct impact on total ownership cost of a hybrid, the results of the regressions suggest that consumers react to each of these factors to varying degrees. The significance of state average gasoline price was expected, but the magnitude of its affect was much larger than anticipated. However, the disproportionate strength of gasoline price as a predictor of market share may actually be consistent with earlier survey and interview findings that consumers buy hybrids based on general notions of perceived savings or vehicle image rather than a detailed benefit-cost or lifecycle cost analysis (Sperling et al., 2004). Gasoline prices serve as the most visible signal for consumers to think about fuel savings and fuel economy, so it is reasonable that relatively minor variations in gasoline prices could lead to significant changes in adoption patterns, particularly for people in the market for a new car as gas prices rise or fall. As an example, the rise in US gas prices to the symbolic $4.00 mark nationwide in the spring and summer of 2008 appears to have prompted a significant change in driving habits and preference for fuel efficient vehicles. In particular, prices and waiting lists for hybrid vehicles rose dramatically (Benton, 2008). Even if consumers did try to explicitly calculate the lifecycle costs of hybrid ownership, recent volatility and uncertainty in future gas prices over time would make this calculation difficult. Fuel prices are largely beyond consumers' control, which might make a hybrid attractive simply as an insurance policy or hedge against future volatility and price spikes.

Other researchers have found relatively small gasoline price elasticities for fuel consumption and miles traveled, on the order of -0.5 or lower (Litman, 2008). However, it is important to note that because current hybrid sales are relatively small (less than 5% of the national automobile market), even large increases in hybrid market share from current levels would correspond to only minor changes in overall national fuel consumption (Turrentine et al., 2006).

The weak relationship between monetary incentive values and state market share also has significant policy implications. One plausible explanation for this finding is that dealers factor state incentives into their pricing structure and charge consumers more for the vehicles. If this is the case, then the monetary incentives effectively serve as a subsidy to automobile dealers without significantly increasing HEV adoption, which almost certainly runs contrary to policymakers' objectives. Another factor could be the delay in receiving the incentive payment in some states. In particular, incentives that reduce or waive registration and inspection fees provide a value stream over many years, which may be highly discounted by consumers in their up-front cost calculations. This explantion is consistent with the analysis of individual state market share trends in Section 5, which suggested that up-front excise or sales tax waivers are more effective than delayed rebates or tax credits in influencing adoption. If the decision is made to offer incentives, providing them to consumers up-front might be the most efficient use of government funds.

Regardless of the type of incentive, the disproportionate influence of gas prices on market share suggests that market-driven spikes in gasoline prices are likely to crowd out any modest effects from incentives or gasoline taxes at current US levels. Higher gas prices are also likely encourage consumers to purchase more fuel efficient cars in general, and to induce the innovation of new energy efficiency technologies by manufacturers (Newell et al., 1999), all without the need for government tax expenditures. Induced innovation also leaves the door open for other types of government policy instruments, such as direct funding of research and development and action to reduce regulatory barriers to new technologies.

From an equity standpoint, the positive relationship between income and hybrid adoption for the Escape and Prius also suggests that financial incentives may disproportionately benefit higher income consumers who are more likely to purchase hybrids in the first place. Lower income consumers are less able to afford the higher up-front premium for a hybrid and more likely to discount future fuel cost savings from a hybrid purchase. Given the apparent weak or negligible effect of monetary incentives, this could result in incentive payments effectively creating a subsidy for the highest income consumers without significantly affecting their purchase decisions. In other words—current monetary incentives for hybrids may be rewarding those who need the incentive the least for a purchase they were likely to have made anyway.

Finally, while this analysis provides interesting insights into the determinants of HEV adoption and the impact of government incentives, it also highlights the need for additional research on the topic. Additional years of adoption data would provide a better indication of the shape and characteristics of the diffusion curve for hybrids, and allow the application of more sophisticated modeling techniques. The widespread introduction of plug-in hybrid, clean diesel, fuel cell and all-electric vehicles to the US market in the next decade may also allow for a broader analysis of how consumers respond to government incentives and choose among different types of energy efficient vehicles.

Acknowledgements

This paper, based on part of the author's Ph.D. Dissertation at the George Mason University School of Public Policy, was supported by funding from the LMI Research Institute. The author would like to thank dissertation committee chair Phil Auerswald; committee members David Hart, Chris Hill, Allison Macfarlane, and Peter Blair; two anonymous reviewers and numerous colleagues from LMI for their valuable advise and assistance.

References

Argote, L., Epple, D., 1990. Learning curves in manufacturing. Science 247, 920–924.
Bajic, V., 1988. Market shares and price-quality relationships: an econometric investigation of the US automobile market. Southern Economic Journal 54, 888–900.
Bass, F., 1969. A new product growth model for consumer durables. Management Science 15, 215–227.
Benton, J., 2008. Hybrid Sales and Prices Climb in Lockstep with Gas Prices, Consumeraffairs.com.
Berry, S., Levinsohn, J., Pakes, A., 1995. Automobile prices in market equilibrium. Econometrica 63, 841–890.
Blanco, S., 2007. Can this be True, Does the Clean Air Act Stop Most of us From Buying Clean Cars? Autobloggreen.com.

Button, K., Ngoe, N., Hine, J., 1993. Modelling vehicle ownership and use in low income countries. Journal of Transport Economics and Policy.
Canes, M.E., 2003. Economics of hybrid electric vehicles. IAEE Newsletter, 13–17.
Cao, X., Mokhtarian, P., 2004. Future demand for alternative fuel passenger vehicles: a diffusion of innovation approach. UC Davis-Caltrans Air Quality Project.
Cao, X., Mokhtarian, P., Handy, S., 2004. Cross-Sectional and Quasi-Panel Explorations of the Connection between the Built Environment and Auto Ownership. University of California (Dave).
Cutchin, C., Benko, M., 2007. Congestion Pricing, ITS Decision: A Gateway to Applying and Understanding Intelligent Transportation Systems. California Center for Innovative Transportation at the University of California, Berkeley and Caltrans.
Diamond, D., 2008a. The impact of HOV lane incentives for hybrids in Virginia. Journal of Public Transportation 11 (4), 57–76.
Diamond, D., 2008b. Ph.D. Dissertation: Public Policies for Hybrid Electric Vehicles–The Impact of Government Incentives on Consumer Adoption, School of Public Policy. George Mason University, Fairfax, VA.
EPA Green Vehicle Guide, 2008. US Environmental Protection Agency.
Gallagher, K.S., Muehlegger, E., 2008. Giving Green to Get Green: Incentives and Consumer Adoption of Hybrid Vehicle Technology, John F. Kennedy School of Government Faculty Research Working Paper Series. Harvard University, Cambridge.
Gould, W., 2001. What is the between estimator? Stata Corporation.
Greene, D.L., Duleep, K.G., McManus, W.S., 2004. Future Potential of Hybrid and Diesel Powertrains in the US Light-Duty Vehicle Market. Oak Ridge National Laboratory.
Griliches, Z., 1957. Hybrid corn: an exploration in the economics of technological change. Econometrica 25, 501–522.
Heffner, R.R., Kurani, K.S., Turrentine, T.S., 2005. Effects of Vehicle Image in Gasonline-Hybrid Electric Vehicles. UC Davis Institute for Transportation Studies, Davis.
Highway Statistics, 2001–2005. Federal Highway Administration, Washington, DC.
How Hybrids Work, 2007. US Department of Energy.
Hybrid Incentives and Rebates—Region by Region, 2007. HybridCars.com.
Jaffe, A.B., Stavins, R.N., 1994. The energy efficiency gap: what does it mean? Energy Policy 22, 804–810.
Kahn, M., 2007. Do greens drive hybirds or hummers? Environmental ideology as a determinant of consumer choice. Journal of Environmental Economics and Management 54, 129–145.
Lave, L.B., MacLean, H., 2001. Are hybrid vehicles worth it? IEEE Spectrum 38, 47–50.
Litman, T., 2008. Transportation elasticities: how prices and other factors affect travel behavior. Victoria Transport Policy Institute.
McManus, W.S., Berman, B., 2005. 2005 O.S.A.T.–HybridCars.com Survey of Owners and Shoppers. University of Michigan Transportation Research Institute.
Monthly Motor Fuels Report, 2007. Federal Highway Administration, Washington, DC.
New Energy Tax Credits for Hybrids, 2007. Department of Energy.
Newell, R.G., Jaffe, A.B., Stavins, R.N., 1999. The induced innovation hypothesis and energy saving technological change. The Quarterly Journal of Economics 114, 941–975.
Ogden, J.M., Williams, Robert H., Larson, Eric D., 2004. Societal lifecycle costs of cars with alternative fuels/engines. Energy Policy 32, 7–27.
Panel Data, Data and Statistical Services, 2006. Princeton University Library, Princeton.
RL Polk & Co., 2007. Dataset of Hybrid Vehicle Registrations per State 2001–2006. RL Polk & Co.
Rogers, E.M., 1995. Diffusion of Innovations, Forth ed. The Free Press, New York.
Santini, D.J., Vyas, A.D., 2005. Suggestions for a New Vehicle Choice Model Simulating Advanced Vehicles Introduction Decisions (AVID): Structure and Coefficients. Center for Transportation Research, Argonne National Laboratory, Argonne, IL.
Siy, E., Koziol, L., Rollins, D., 2001. State of the States: Assessing the Capacity of States to Achieve Sustainable Development Through Green Planning. Resource Renewal Institute, San Francisco.
Sperling, D., Bunch, D., Burke, A., 2004. Analysis of Auto Industry and Consumer Response to Regulations and Technological Change, and Customization of Consumer Response Models in Support of AB 1493 Rulemaking. Institute of Transportation Studies, University of California, Davis, Davis, CA.
Stock, J.H., Watson, M.W., 2003. Introduction to Econometrics. Addison Wesley, Boston.
Stoneman, P., Diederen, P., 1994. Technology diffusion and public policy. The Economic Journal 104, 918–930.
The Dollars and Sense of Hybrids, 2006. Consumer Reports, April ed, 18–21.
Turrentine, T.S., Delucchi, M., Heffner, R.R., Kurani, K.S., Sun, Y., 2006. Quantifying the Benefits of Hybrids Vehicles. Institute for Transportation Studies. University of California, Davis.
Washington State Gasoline Report, 2007. Washington State Office of the Attorney General.
Year of the Hybrid, 2004. ChangeWave Research, Rockville.