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Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology

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ABSTRACT

Federal, state, and local governments use a variety of incentives to induce consumer adoption of hybrid-electric vehicles. We study the relative efficacy of state sales tax waivers, income tax credits, and non-tax incentives and find that the type of tax incentive offered is as important as the generosity of the incentive. Conditional on value, sales tax waivers are associated with more than a ten-fold increase in hybrid sales relative to income tax credits. In addition, we examine how adoption varies with fuel prices. Rising gasoline prices are associated with greater hybrid vehicle sales, but this effect operates almost entirely through high fuel-economy vehicles. By comparing consumer response to sales tax waivers and estimated future fuel savings, we estimate an implicit discount rate of 14.6% on future fuel savings.
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1. Introduction

Accelerated domestic adoption of hybrid-vehicle technology plays an important role in both energy and environmental policy debates. Hybrid vehicles consume less gasoline and emit less pollution per mile than traditional engines with similar performance. Beginning in 2000, federal, state, and local governments in the US experimented with a broad set of consumer incentives to stimulate hybrid vehicle adoption, including income tax credits and deductions, sales tax waivers, single-passenger access to carpool lanes, and waivers of emissions testing, registration and parking fees.[1] Many incentives are generous, worth thousands of dollars and substantially reduce the incremental cost of purchasing a hybrid vehicle. Although strong interest exists at the federal, state, and local levels to encourage adoption of hybrid vehicles, relatively little is known about how hybrid buyers respond to different types of government incentives.

In this paper, we study how hybrid vehicle sales responded to the different incentives offered by state governments from 2000 to 2006. We focus on three questions: (1) Is consumer behavior affected by state incentives? (2) Do consumers respond differently to distinct types of tax incentives? and (3) Do consumers respond to rising gasoline prices and, if so, how does the effect of rising gasoline prices compare to that of state incentives? Our context provides an excellent environment in which to distinguish the effect of different types of incentives and the effect of rising gasoline prices.

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[1] The federal government has also supported the research, development, and demonstration of hybrid vehicles for many years. Although this paper does not investigate the impact of government investments into hybrid-vehicle research and development, the federal government has devoted substantial resources to the development of hybrids through the Partnership for a New Generation of Vehicles (PNGV) and its successor, FreedomCAR, as well as through specific hybrid-electric vehicle R&D programs. In fiscal year 2008, for example, the President's budget request to Congress for HEVs was $80 million.

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During this time, eight states offered income tax credits, four waived sales taxes on new hybrid vehicle purchases, and five states allowed hybrid vehicles owners to drive in carpool lanes. State incentives change substantially over the period—we observe states that introduce and drop incentives, states that change incentive generosity over time, and states that target all hybrid vehicles as well as states that target incentives at only a subset of hybrid vehicles. We examine quarterly, state-level sales data for the eleven hybrid models sold from 2000 to 2006 and use time∗model and state∗model fixed effects to allow for flexible national adoption trends and time-invariant state preferences. Thus, we exploit within-state∗model variation in incentives and gasoline prices to estimate the response of sales to different incentives.

Unsurprisingly, we find that state tax incentives are positively correlated with increased hybrid vehicle adoption. When we separately examine coefficients for income tax credits and sales tax waivers, we find that different types of incentives are associated with substantially different changes in hybrid vehicle sales. We estimate that a sales tax waiver of mean value ($1037) is associated with over three times the effect of an income tax credit of mean value ($2011). Conditional on the value of the incentive value, we estimate that sales tax waivers have more than a *ten-fold* greater impact on hybrid vehicle sales. We find less consistent evidence that single-occupancy access to carpool lanes is correlated with adoption—separately estimating carpool access for each state, we only find a positive and significant coefficient for Virginia. Gasoline prices are positively correlated with hybrid vehicle sales, although the effect operates almost entirely through the most fuel-efficient hybrid vehicles. For high fuel-economy hybrids, we estimate that the cross-price elasticity of demand with respect to retail gasoline price is 0.86. We estimate that a $100 increase in annual fuel savings relative to comparable non-hybrid vehicles is associated with a 13% increase in sales.

Our work complements a growing literature examining the relationship between tax incentives, gasoline prices and hybrid vehicle adoption. Sallee [17] studies the incidence of incentives offered to Prius owners using consumer-level purchase data. Using a differences-in-differences approach, he finds evidence that consumers capture the majority of the tax incentive. In addition, he finds evidence that consumers time Prius purchases contemporaneously with generous federal incentives. Chandra et al. [5] examine hybrid vehicle sales in Canadian provinces and finds that provincial tax rebates increase hybrid vehicle sales substantially. The authors also find evidence that the increase in sales comes largely at the expense of other comparable vehicles. While the rebates affect the mix of vehicles sold, they do not affect total vehicle sales. Berensteanu and Li [2] study the effect of gasoline prices and federal tax incentives on MSA-level vehicle sales. The paper finds that both gasoline prices and federal incentives increased hybrid vehicle sales—the authors estimate that hybrid vehicle sales in 2006 would have been 37% lower had gasoline prices remained at 1999 levels and would have been 20% lower absent federal tax incentives. Unlike the previous papers that focus on either federal incentives or provincial incentives that vary by generosity but not form, we examine US state incentives that vary both in generosity and form. Our paper exploits the variation in the type of incentives to better understand how both generosity and form of incentives affect consumer adoption. Our results have clear policy implications—we find suggestive evidence that the form of incentive is as important a factor in consumer adoption as incentive generosity.

Our research also informs the long empirical literature on how consumers incorporate future energy costs into durable goods purchase decisions. Beginning with Hausman [12] and Dubin and McFadden [7], the empirical literature estimates implicit discount rate by examining consumers' relative weights of upfront cost and future energy costs when deciding between more and less energy-efficient durable goods. A more recent literature focuses specifically on automobile purchases—Bento et al. [1], Klier and Linn [16], and West [20] study the relationship between gasoline prices and vehicle purchases using a variety of empirical approaches. Similar to the literature on consumer durable goods, we estimate an implicit discount rate for future fuel costs. By comparing consumer response to changes in gasoline prices and upfront payments, in the form of sales tax waivers, we estimate an implicit discount rate of 14.6%. Although early adopters of hybrid vehicles likely differ in many respects from the typical car buyer, the implied discount rate we estimate is close to estimates in the earlier literature.

Finally, our paper relates to the growing literature examining the structure of tax incentives. Separately estimating quarterly coefficients on income tax credits, we find a seasonal pattern of point estimates consistent with poorly informed consumers rather than one consistent with rational discounting of future income tax benefits. Our point estimates for income tax credits are greatest in the second quarter, when it is most likely that consumers would learn about a tax credit, and then decline monotonically in each subsequent quarter, rather than increasing as consumers gets closer to claiming the credit on their tax returns. We do not find a similar seasonal pattern for sales tax waivers. Consequently, we believe our work complements recent results in Chetty et al. [6] and Finkelstein [8] that find consumer response to taxation varies with the salience of the tax.

We first summarize the federal, state, and local hybrid incentives offered in the US between 2000 and 2006. We then discuss our data and empirical methodology and present our results. We conclude by discussing the policy implications.

2. Hybrid vehicle incentives

Hybrid-electric engines combine a gasoline engine and electric motor to improve fuel efficiency relative to traditional engines.[2] Hybrid vehicles consume less gasoline and emit less pollution per mile than comparable non-hybrid vehicles. With the exception of the Saturn Vue, all hybrids qualify as "super-ultra low-emission vehicles" (SULEVs), and receive

[2] *Fuel efficiency* is defined as the energy at the wheels divided by the energy in the tank whereas *fuel economy* is defined as total miles traveled by a vehicle divided by total fuel use. A large vehicle may be quite fuel efficient while nonetheless achieving low fuel economy.

Table 1
State incentives for hybrid vehicles, 2000–2006.

Single-occupancy HOV lane access	Income tax credit	Sales tax exemption	Vehicle emissions test exemption	State gov. purchasing requirement	Registration or excise tax exemption	Parking fee reduction or exemptions (cities)
AZ (pilot)	CO	CT+	CO+	MN	DC	Albuquerque, NM
CA+	MD*	DC	MD	NM	IL+	Austin, TX
CO (on hold)	NY+,*	ME*	WA	NY	NM	Baltimore, MD
FL	OR	NM+		WI	PA	Ferndale, MI
GA (on hold)	PA					Huntington, NY
NJ	SC					Los Angeles, CA
NY (pilot)	UT*					New Haven, CT
UT	WV*					Salt Lake City, UT
VA						San Antonio, TX
						San Jose, CA
						Santa Monica, CA
						Vail, CO
						Westchester, NY

Note: +denotes incentive targeted at high fuel-economy hybrid vehicles (e.g. Prius, Insight, Civic), and *denotes expired program. Data sources: State Tax Commissions, http://go.ucsusa.org/hybridcenter/incentives.cfm; http://www.hybridcars.com; http://whybuyhybrid.

ratings of 8 or better on the EPA's air pollution index. As a consequence, policies exist at the federal, state, and local level to encourage consumers to adopt hybrid vehicles.

From 2000 to 2005, the federal government offered a $2000 tax deduction for the purchase of any hybrid vehicle, beginning with the 2000 model-year Honda Insight. Under the Energy Policy Act of 2005, the deduction was converted into a tax credit in January 2006. The tax credit is more generous than the previous tax deduction and varies by model, depending on the emissions and fuel economy. The Toyota Prius qualified for the largest tax credit ($3150) while Accord Hybrids and the Saturn VUE Green Line qualified for the lowest tax credit ($650). After a carmaker's hybrid sales exceed 60,000 units, the credit phases out over the next four quarters. Both Toyota and Honda have exceeded the 60,000 unit threshold. Toyota surpassed the threshold in May 2006 and Honda surpassed the threshold in August 2007.

State and local governments offer a wider variety of incentives than the federal government. Table 1 presents a comprehensive list of state-level incentives offered from 2000 to 2006. Over the period, eight states offered an income tax credit and four states waived sales taxes on hybrid vehicle purchases. Table 2 describes the duration, generosity, and model coverage of the twelve state tax incentives. Generosity varies substantially by state, model, and time. As an example, the tax incentives offered for the Toyota Prius vary from $500 in Maine and Pennsylvania to over $3500 in Colorado and West Virginia. Six of the states only offer incentives for hybrid models achieving the highest fuel economy. Seven of the state programs varied the generosity of the incentive not only by model, but also by model-year. Five of the twelve programs expired by the end of 2006.

Of the eight states offering income tax credits, Colorado, Oregon, Pennsylvania, and South Carolina still offer the incentives. Tax credits vary from $130 (for a Saturn Vue Hybrid in South Carolina) to $4713 (for a 2005 Honda Insight in Colorado). Colorado and West Virginia, the states with the most generous incentives, allow taxpayers to carry-over hybrid credits exceeding their net tax liability for up to five years. Conditional on offering a credit, the mean value of the incentive is $2011.

Four states waived state sales tax on hybrid vehicle purchases. As with tax credits, incentive generosity varies across states—Connecticut and the District of Columbia fully waive sales taxes, while Maine and New Mexico partially waive sales taxes. The value of the waiver varies from $300 (for a Civic in Maine) to $3294 (for a Lexus GS450h in the District of Columbia). Conditional on being eligible for a sales tax waiver, the mean sales tax waiver is worth $1037, about half the value of the mean income tax credit.

A number of states offer other incentives for hybrid ownership. Virginia, California, Utah, New Jersey, and Florida allow single-occupancy hybrid vehicles to drive in high-occupancy vehicle ("HOV") lanes. Virginia allowed all hybrid vehicles to travel in carpool lanes beginning in 2000. In response to increased congestion on I-95/395 HOV-3 lanes (which require 3 passengers per car, rather than 2), Virginia restricted hybrid travel in HOV-3 lanes during rush hour beginning in July 2006. California issued 85,000 HOV lane permits to owners of Prius, Insight, and Civic hybrids in August 2005. Utah allows all hybrid vehicle owners who purchase a special license plate to drive in HOV lanes. Most recently, New Jersey and Florida opened HOV lanes to single-occupancy hybrid vehicles in the second and third quarters of 2006.[3]

A number of other states offer less valuable incentives. Three states reduce or eliminate registration or excise taxes and three states exempt hybrid vehicles from emissions testing. Four states have government purchasing requirements. At the

[3] Currently, pilot programs allowing single occupancy access to HOV lanes run in New York and Arizona. Colorado and Georgia have passed HOV lane exceptions for hybrid vehicles, but are awaiting a federal ruling on HOV access.

Table 2
State tax incentives.

State	Duration	Models covered	Generosity range
Income tax credits			
Colorado	2001–present	All, but VUE, GS450h, and Camry*	\$2265–\$6542
Maryland	2001–2004	Civic, Prius, Insight	\$1000
New York	2000–2006	All	\$2000
Oregon	2003–present	All	\$750–\$1500
Pennsylvania	2006–present	Civic, Prius, Insight, Escape	\$500
South Carolina	2006–present	All	\$130–\$630
Utah	2001–2005	Civic	\$1537–\$1720
West Virginia	2003–2006	All	\$2411–\$3750
Sales tax waivers			
Connecticut	2004–present	Civic, Prius, Insight	\$1217–\$1409
District of Columbia	2005–present	All	\$1226–\$3294
Maine	2000–2005	Civic, Prius, Insight	\$300–\$500
New Mexico	2004–present	Civic, Prius, Insight	\$608–\$704

Colorado income tax credits for the VUE, GS450h, and Camry begin post-2006.Generosity for Sales Tax Waivers in CT, DC, and NM are estimated based on vehicle MSRP.

local level, a number of cities (e.g. San Jose, Baltimore, Albuquerque, and New Haven) reduce or waive public parking fees for hybrid-electric vehicles. Finally, corporations have begun to provide generous private incentives for employee hybrid vehicle purchases. Beginning in 2004, Timberland offered a \$3000 rebate towards hybrid purchases. Google began to offer a \$5000 rebate for hybrid vehicle purchases in March 2005, and Bank of America began to offer a \$3000 rebate for hybrid vehicle purchases in June 2006.

3. Data and methodology

In this paper, we study the extent to which incentives affect consumer purchases of hybrid vehicles. We examine quarterly, state-level hybrid vehicle sales data for the eleven models introduced from the first quarter of 2000 through the fourth quarter of 2006.[4] As a preview of our empirical approach, we allow each model to have a unique national adoption trend and unique attractiveness in each state, and exploit within-state∗model variation to identify the effect of state tax incentives, rising gasoline prices, and single-occupancy access to HOV lanes.

Our data on hybrid sales comes from JD Power and Associates' proprietary Power Information Network. The Power Information Network (PIN) collects real-time transaction-level data from approximately 6000 dealers. Unlike alternative data sources which are based on vehicle registration data, the PIN data is based on the actual date of vehicle purchase. For the analysis, JD Power and Associates aggregated purchases up to quarterly quantities for each model in each state. At our request, JD Power and Associates excluded fleet, corporate, and government sales. The exclusion of these sales ensures that we do not misattribute government purchases to state incentives targeted at consumers. In 2000, when the Honda Insight and Toyota Prius were the only hybrid vehicles available, collective sales are less than 3000 units. Over the next six years manufacturers introduced nine other models and sales grew substantially—over 230,000 hybrid vehicles were sold in 2006.

We constructed our dataset of state incentives by contacting officials in each jurisdiction. Although a large number of incentives exist, we focus specifically on the more valuable state tax incentives and single-occupancy access to HOV lanes. We omit local incentive programs such as parking fee waivers, state vehicle registration fee waivers, and emissions testing exemptions since all are of insufficient magnitude or generosity to affect state-level sales.

To measure consumer response to rising fuel prices, we calculate the average tax-inclusive retail gasoline price for each state in each quarter, based on monthly retail gasoline prices from the Energy Information Administration. For each model, we calculate annual fuel savings as the difference between the annual cost a driver in a particular state would incur by driving the hybrid vehicle and the cost the driver would incur by driving the mean non-hybrid vehicle in the same vehicle class. As an example, to calculate the annual fuel cost savings for a Prius-buyer, we compare the annual fuel cost of driving the Prius with the annual fuel cost of driving the mean non-hybrid compact passenger car. We calculate annual fuel savings (in \$/year) as

$$FuelSavings_{imt} = \left(\frac{1}{MPG_{nh}} - \frac{1}{MPG_m}\right) * Gasprice_{it} * MeanVMT_{it} \quad (1)$$

[4] We first observe sales for each model in: Q1 2000 (Honda Insight), Q3 2000 (Toyota Prius), Q1 2002 (Honda Civic), Q3 2004 (Ford Escape), Q4 2004 (Honda Accord), Q1 2005 (Lexus RX400h), Q2 2005 (Toyota Highlander), Q3 2005 (Mercury Mariner), Q2 2006 (Lexus GS450h, Toyota Camry) and Q4 2006 (Saturn VUE).

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Table 3
Summary statistics.

Variable	N	Mean	Std. Dev.	Min	Max
Sales data					
Vehicle sales	4781	121.1	386.0	1.0	8871.0
Vehicle sales per thousand pop.	4781	0.017	0.025	0.000	0.243
Incentive data					
HOV_lane access	4781	0.055	0.228	0.0	1.0
Federal tax incentive	4300	1073	797	560	3150
State income tax credit	465	2011	1026	130	4713
State sales tax incentive	173	1037	640	300	2722
Total tax incentive	4331	1270	1015	300	6435
Annual fuel savings ($/year)	4630	424.96	131.77	32.03	1009.29
State-level data					
Per-capita income	1228	32.13	5.68	21.01	56.33
Percent of adults graduating high school	1228	0.86	0.04	0.77	0.93
Percent of adults graduating college	1228	0.27	0.06	0.15	0.49
Percent female	1228	0.51	0.01	0.48	0.53
Mean age	1228	36.46	1.45	30.64	39.55
Retail gasoline price, tax inclusive	1228	180.13	47.26	99.43	310.27
Vehicle miles traveled, per capita (0 0 0)	1172	10.43	1.94	6.79	18.34
Sierra club members	1228	13,917	23,222	535	153,619
Sierra club membership, per thousand pop	1228	2.18	1.25	0.38	5.37
Armed forced participation, per capita	1228	0.0094	0.0074	0.0025	0.0383

For tax incentive variables, fuel savings, and vehicle sales, *N* is the number of non-zero observations and the summary statistics are conditional on a non-zero value. For demographics and gasoline prices, *N* reports the number of state∗quarter observations.

where MPG_m is the EPA combined fuel economy rating of hybrid model m, MPG_{nh} is the mean EPA combined fuel economy rating for all non-hybrid vehicles within the same vehicle class, $Gasprice_{it}$ is the average tax-inclusive gasoline price in state i at time t, and $MeanVMT_{it}$ is annual vehicle miles traveled per capita in state i from annual issues of Highway Statistics published by the Federal Highway Administration.[5] To account for inflation, we normalize all nominal dollar values to real terms based on fourth quarter, 2006.

Finally, we include state-level demographic controls from the Current Population Survey. We use the percent of residents with a high school or four-year college diploma, per-capita income, mean age, and the fraction who are women to control for variation in state-level demographic trends.

Table 3 presents the summary statistics for our hybrid sales data, state and federal incentives, gasoline prices, and socioeconomic measures. For state demographics and gasoline prices, we treat each state-quarter as a single observation and report the summary statistics for the balanced panel. Conditional on positive sales, mean quarterly sales by model and state are 121.1, with a high of 8871 Prius sales in California in Q3-2006. Approximately 94% of hybrid sales over the study period are eligible for a federal tax incentive with a mean value of $1073. Twelve percent of hybrid sales are eligible for either a state income tax credit or sales tax waiver, with mean values of $2011 and $1037, respectively.

Rather than increasing fuel economy, automakers often use the hybrid engine to improve performance acceleration or power additional amenities. For example, the combined city-highway EPA fuel economy rating for the ‘‘strong’’ 2007 Civic hybrid (1.3 l engine) was 42 miles per gallon, while the combined fuel-economy rating for the least powerful non-hybrid version of the Civic (1.8 l engine) was 29 miles per gallon. In comparison, the combined fuel-economy rating for the ‘‘mild’’ 2007 Accord hybrid (3.0 l engine) was 27 miles per gallon while the least powerful non-hybrid version (2.4 l engine) was rated at 25 miles per gallon. We classify models as ‘‘high fuel-economy’’ hybrids if the EPA-rated fuel economy is 50% greater than non-hybrid vehicles in the same class and classify all other hybrid vehicles as ‘‘low fuel-economy’’ hybrids.[6] Fig. 1 graphs quarterly domestic sales of high and low fuel-economy hybrids as well as the average quarterly retail price of gasoline reported by the Energy Information Administration (EIA) from Q1 2000 until Q4 2006. Due to earlier introduction of the Prius and Insight, sales of high fuel-economy hybrid models account for the vast majority of hybrid sales through the

[5] As an alternative, we also calculate annual fuel cost savings by comparing each hybrid sedan to the mean passenger car and each hybrid SUV to the mean light truck. Our within-vehicle class comparison is more appropriate if a hybrid owner's most preferred non-hybrid vehicle has similar characteristics to the hybrid vehicle they purchased. Although, to our knowledge, no data exists that can directly verify this assumption, Chandra et al. [5] find some evidence consistent with this assertion—in their study, hybrid vehicle incentives are negatively correlated with sales of *non-hybrid* vehicles with similar characteristics, suggesting that Canadian hybrid vehicle purchasers on the margin choose between hybrid and non-hybrid vehicles with similar characteristics.

[6] Using this criterion, the Honda Insight and Civic, Toyota Prius and Camry and the Ford Escape are high fuel-economy vehicles. The use of an alternative criterion, such as whether EPA-estimated fuel economy exceeds 45 miles per gallon, does not substantively affect any of our empirical conclusions.

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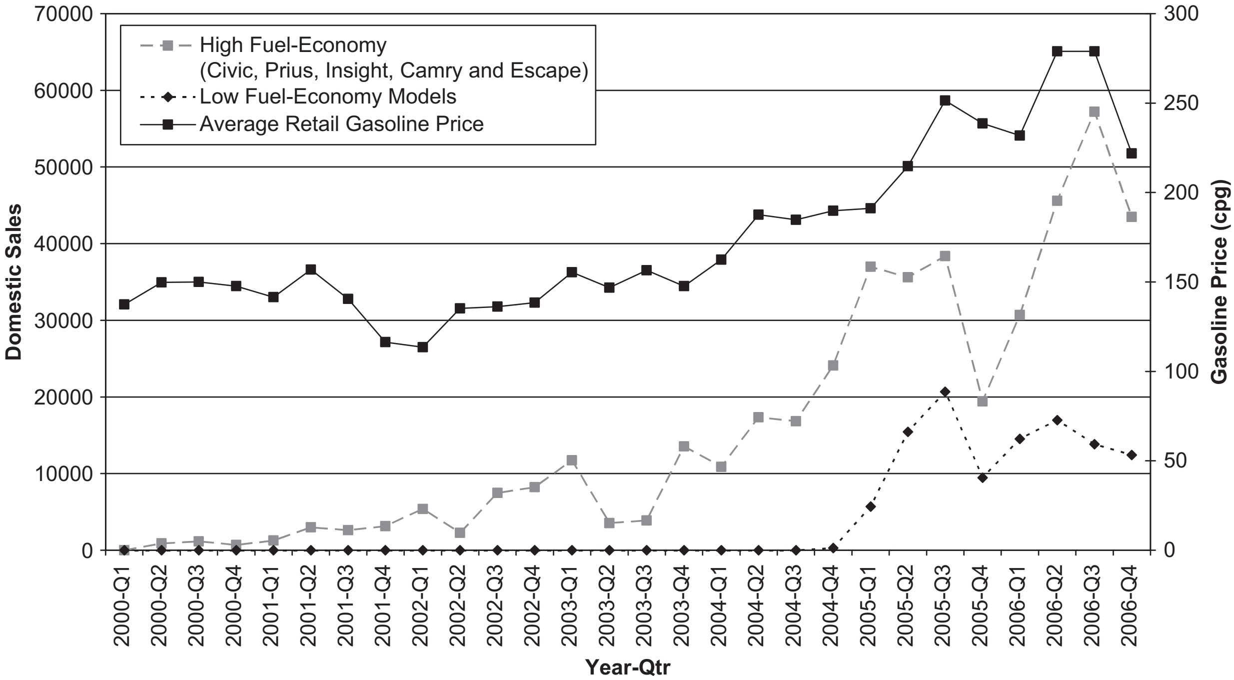

Fig. 1. Domestic hybrid sales. *Note*: National Vehicle Sales are reported on the primary axis. Average US retail gasoline price is reported on the secondary axis.

fourth quarter of 2006.[7] Over 2005 and 2006, sales of low-economy hybrids increase substantially, accounting for 28% of the 182,000 hybrid sales in 2005 and 25% of the 235,000 hybrid sales in 2006.

Fig. 1 also graphs the average tax-inclusive retail gasoline price in the US. Gasoline prices rise substantially during the period, from \$1.49 per gallon over 2000–2003 to \$1.89 per gallon in 2004, \$2.31 per gallon in 2005 and \$2.61 per gallon in 2006. The mean gasoline price from 2000 to 2006 is \$1.80 gallon with a low of \$0.994 a gallon (Georgia, Q4-2001) and a high of \$3.10 a gallon (Hawaii, Q3-2006). Variation in fuel economy across different models, states, and time generates annual fuel savings that average \$425 per year, with a standard deviation of \$132 per year.

To estimate the relationship between hybrid sales, incentives, and gasoline prices, we regress the log of per-capita sales on state hybrid vehicle incentives, annual fuel savings, state demographics, state∗model fixed effects, and time∗model fixed effects. Indexing state, model and time as *i*, *m*, and *t*, respectively, our base specification is given by

$$Log(Sales\ Per\ Capita_{imt}) = \alpha_{im} + \beta Fuel\ Savings_{imt} + \lambda\ Incentives_{imt} + \theta Demographics_{it} + \eta_{mt} + \varepsilon_{imt} \tag{2}$$

where α_{im} denotes the state∗model fixed effects, η_{mt} denotes the time∗model fixed effects and ε_{imt} denotes the stochastic error term. The time∗model fixed effects flexibly control state-invariant trends in sales, national production constraints, and the timing of each model's introduction. The state∗model fixed effects allow each state to have unique time-invariant preferences for each hybrid vehicle model. Consequently, we identify our coefficients off of cross-state variation in model-level sales trends.[8]

Several sources of potential bias exist. First, policy selection is endogenous—a state may choose the most effective incentive for the local environment. For example, California and Virginia may choose to allow hybrid vehicles to drive in HOV lanes because traffic congestion is significant—in these states, consumers may have a strong incentive to purchase a hybrid vehicle to avoid traffic congestion. Other states, where traffic congestion is less severe, may choose to use tax incentives instead. Endogenous policy selection would lead our point estimates to be upper bounds on the efficacy of government incentives. In contrast, state gasoline prices are plausibly exogenous to hybrid sales. Although high

[7] Total hybrid sales in the JD Power data total 554,657 units from Q1 2000 until Q4 2006. Sales of high efficiency models total 445,342 units over the period.

[8] Our fixed effects explain approximately 97% of the variation in state gasoline prices and 77% of the variation in tax incentives. The 10th and 90th percentiles of the residual variation of gasoline prices are −4.5 cents per gallon and 5.0 cents per gallon, corresponding to approximately 3% of the average tax-inclusive gasoline price during the period. Three significant sources of the remaining variation are: (1) state-specific supply shocks, due to pipeline or refinery outages, (2) changes in state gasoline taxes, and (3) changes in gasoline formulation requirements. Restricting the sample to models and states for which an income tax credit was offered between 2000 and 2006, the 10th and 90th percentiles of the residual variation of income tax credit values are −\$746 and \$798. Similarly restricting the sample for states and models for which consumers were eligible for a sales tax waiver between 2000 and 2006, the 10th and 90th percentiles of the residual variation of sales tax waiver values are −\$435 and \$799.

fuel-economy hybrids are substantially more fuel efficient than comparable non-hybrid vehicles, hybrid market penetration is fairly low during the study period. Hybrid vehicles account for a small share of total gasoline consumption and are unlikely to affect state gasoline prices.

In several quarters in 2002 and 2003, production constraints limited sales of the Toyota Prius and Honda Civic hybrid. If production constraints affected all states equally, our time∗model fixed effects would control for state-invariant scarcity. If during periods of scarcity automakers allocated a greater proportion of vehicles to states with more generous incentives, we may inappropriately attribute the effect of production constraints to the government incentives. We do not believe that this concern substantively biases our results. Our conversations with Toyota indicate that the firm allocated scarce production to equalize the delivery delays in different markets. If sales during these periods were proportional to existing demand, time∗model fixed effects will control for the effect of production constraints. As a check, we test the robustness of our estimates to the exclusion of periods with documented production constraints. We find the exclusion of these quarters does not substantively change our conclusions.

A final source of bias may arise because we observe model-level sales, but do not observe the negotiated price between the dealer and the consumer. We cannot observe dealer incentives, nor can we observe how the dealer and consumer split the tax incentive. Although Sallee [17] finds strong evidence that consumers retain the vast majority of the hybrid tax incentives, if the benefits of state incentives are partially captured by dealers, either from negotiation or through endogenous dealer incentives, we would expect the coefficients for the state incentives to be biased conservatively.

4. Results

Table 4 presents our initial regression results. In our base specification (column 1), we regress the log of per-capita sales on the value of tax incentives, a dummy variable for single-occupant access to HOV lanes, annual fuel savings, and state demographics. Specifications (2) and (3) consider alternative measures of the tax incentives—the specifications use the value of tax incentives as a proportion of model-year MSRP and a dummy variable for any tax incentive as alternatives to the value of the tax incentive. Specification (4) separately estimates the dummy variable for HOV access by state. In specification (5), we estimate the regression using the log of the tax-inclusive retail gasoline price rather than the estimate of annual fuel savings. In specification (6), we separately estimate the coefficient on the log of gasoline price for high and low fuel-economy hybrids. In all specifications, we include state∗model and time∗model fixed effects and estimate our coefficients off within-state∗model variation.

The coefficient on the value of state tax incentives is positive and significant.[9] We estimate that offering a tax incentive of $1000 is associated with a 5% increase in hybrid sales. When measured relative to model MSRP, increasing a tax incentive by 1% of a vehicle's MSRP is associated with a 1.2% increase in sales. Offering a tax incentive of mean value is associated with a .20 increase in log sales per-capita equivalent to a 22% increase in sales.[10]

We find little evidence that allowing single occupancy travel HOV lane access has a significant impact on hybrid vehicle sales. When we separately estimate coefficients for each state's HOV program, we find that the effects of HOV access vary significantly by state. Virginia is the only state for which the coefficient on HOV access is significant and of the expected sign. Allowing the coefficient in Virginia to vary before and after rush hour HOV-3 lane restrictions, we find a statistically significant difference. Prior to the HOV-3 restriction, HOV access in Virginia is associated with a 92% increase in hybrid sales. This is consistent with anecdotal evidence that hybrid vehicle owners in Virginia used carpool lanes to travel to and from Washington DC extensively. The Washington Post reported that by October 2003, hybrid vehicles accounted for roughly 25–30% of traffic in HOV-3 lanes, or roughly 1700 cars per day. This is equivalent to approximately one-third of hybrid sales in Virginia from 2000 through third quarter 2003.[11] We find that the HOV-3 rush hour lane restriction is associated with a significant reduction in this effect. Our point estimate for the effect of the HOV lane restriction falls to 49% following the HOV-3 restriction.

We find strong evidence that hybrid adoption is positively correlated with higher gasoline prices. In our base specification, we estimate that a $100 increase in annual fuel savings is associated with a 13% increase in sales. Moreover, in specifications (5) and (6), we find that the correlation operates predominately through sales of high fuel-economy hybrid vehicles. Separately estimating gasoline cross-price elasticities for high and low fuel-economy vehicles as defined in Fig. 1, we estimate that a 10% increase in gasoline price leads to an 8.6% increase in per-capita sales of high fuel-economy hybrid vehicles. Our point estimate for the cross-price elasticity of low fuel-economy hybrids is statistically indistinguishable from zero (0.027).

[9] We omit federal tax incentives from our regressions—federal tax incentives do not vary by state and are subsumed by our set of model∗time fixed effects. Aggregating federal incentives with state incentives change the magnitude of the estimated coefficient, but do not change the significance or our conclusions.

[10] To verify that a single state was not driving our tax incentive results, we ran the regressions excluding each incentive state in turn. The coefficient on the value of state tax incentives varies from a low of 0.0386 (excluding Connecticut, p-value=0.054) to a high of 0.0956 (excluding West Virginia, p-value=0.010).

[11] See "As Hybrid Cars Multiply, So Do Carpooling Gripes", Steven Ginsberg and Carol Morello, Washington Post, Friday, January 7, 2005.

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Table 4
Hybrid incentives. Dependent variable: log per-capita sales.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
State tax incentive ($000)	0.0485* (0.0292)			0.0486* (0.0291)	0.0431 (0.0282)	0.0435 (0.0282)
State tax incentive/MSRP		1.186* (0.678)				
State tax incentive dummy			0.201*** (0.0681)			
HOV access dummy	−0.0692 (0.0595)	−0.0690 (0.0594)	−0.0622 (0.0587)		−0.0821 (0.0596)	−0.0798 (0.0603)
UT HOV access				−0.107*** (0.0375)		
CA HOV access				−0.0691 (0.157)		
VA HOV access				0.651*** (0.228)		
VA HOV access*post-7/1/06				−0.250*** (0.0730)		
FL HOV access				−0.175** (0.0864)		
NJ HOV access				0.0110 (0.0729)		
Annual fuel savings ($/year)	0.00132** (0.000580)	0.00133** (0.000580)	0.00146** (0.000576)	0.00132** (0.000581)		
Log (retail gasoline price)					0.706** (0.309)	
Log (retail gasoline price)*low FE hybrid						0.0263 (0.805)
Log (retail gasoline price)*high FE hybrid						0.855** (0.333)
Log (per-capita income)	2.016*** (0.725)	2.021*** (0.726)	2.017*** (0.723)	2.015*** (0.727)	2.109*** (0.666)	2.109*** (0.666)
Log (mean age)	−16.88*** (5.147)	−16.95*** (5.144)	−16.77*** (5.150)	−17.16*** (5.140)	−15.35*** (5.141)	−15.16*** (5.161)
Log (percent female)	0.256 (19.64)	0.108 (19.68)	2.140 (19.43)	−0.343 (19.69)	−0.892 (18.51)	−0.986 (18.47)
Log (percent HS graduate)	1.090 (1.003)	1.080 (1.003)	0.969 (1.003)	1.069 (0.993)	1.074 (0.984)	1.084 (0.982)
Log (percent college graduate)	−0.158 (0.256)	−0.156 (0.256)	−0.140 (0.251)	−0.151 (0.256)	−0.157 (0.254)	−0.156 (0.254)
Observations	4630	4630	4630	4630	4781	4781
R^2	0.935	0.935	0.935	0.935	0.933	0.933

Standard errors, in parentheses, are clustered by state*model. All specifications include state*model and time*model fixed effects. *, **, and ***denote significance at 10%, 5%, and 1%, respectively.

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Table 5
Tax incentives, by type. Dependent variable: log per-capita sales.

Variables	Specification		
	(1)	(2)	(3)
Annual fuel savings ($/year)	0.00145** (0.000584)	0.00146** (0.000584)	0.00152*** (0.000579)
HOV access dummy	−0.0606 (0.0588)	−0.0603 (0.0587)	−0.0600 (0.0583)
State income tax credit ($000)	0.0239 (0.0246)		
State sales tax waiver ($000)	0.374*** (0.141)		
State income tax credit/MSRP		0.578 (0.532)	
State sales tax waiver/MSRP		8.343*** (3.143)	
State income tax credit dummy			0.138** (0.0649)
State sales tax waiver dummy			0.420** (0.171)
P-value for the null hypothesis equating the sales tax and income tax coefficients	0.014	0.014	0.124
Observations	4630	4630	4630
R^2	0.935	0.935	0.935

All specifications include state∗model and time∗model fixed effects, and the full set of demographic controls. Standard errors, in parentheses, are clustered by state∗model. *, **, and ***denote significance at 10%, 5%, and 1%, respectively.

Our estimated coefficients for the demographic variables tend to be relatively robust across the different specifications. We find that per-capita income is significantly correlated with hybrid sales. We estimate that the point estimate for income elasticity is approximately 2.0—a one-standard deviation increase in per-capita income is associated with a 32% increase in hybrid sales. In addition, we find that hybrid sales are negatively correlated with the mean age. Coefficients on gender and educational attainment are not distinguishable from zero.

4.1. Sales tax waivers and income tax credits

In addition to examining tax incentive generosity, we test whether the form of state tax incentives affects hybrid vehicle sales. Conditional on value, there are several reasons to expect consumers to be more sensitive to a sales tax waiver than an income tax credit. First, a sales tax waiver is automatic. An income tax credit requires both foresight and additional effort—a buyer must understand the credit prior to buying a hybrid and apply for it the following year. Second, a sales tax waiver is immediate—a buyer may discount the value of an income tax incentive claimed on a future return. Finally, the value of a sales tax waiver is easy to understand, whereas the value of an income tax credit may vary with a hybrid purchaser's tax burden. If the value of the credit exceeds a buyer's state tax burden, she may be ineligible to claim the full value in the first tax year. Interaction of federal and state tax rules further complicate the value—since state income taxes are deductable on federal returns, the value of a state tax credit depends on a taxpayer's marginal federal tax rate.[12]

We separately estimate coefficients for sales tax waivers and income tax credits and present the results in Table 5. All specifications continue to include state∗model fixed effects, time∗model fixed effects, and the full set of demographic controls. Conditional on value, a sales tax waiver is associated with more than a ten-fold greater increase in hybrid vehicle sales than a comparable income tax credit. We estimate that a one thousand dollar tax waiver is associated with a 45% increase in hybrid vehicle sales, whereas a one thousand dollar income tax credit is associated with a 3% increase in hybrid vehicle sales. When incentives are measured relative to vehicle MSRP, we again find that a sales tax waiver is associated with a greater increase in hybrid vehicle sales than an income tax credit. A sales tax waiver equal to 1% of the retail price is associated with an 8.3% increase in sales—a comparable income tax credit is associated with a 0.6% increase in retail sales. Although in both specifications, we cannot distinguish the coefficient on income tax credits from zero, we are able to reject the equality of the sales tax waiver and income tax credit coefficients with *p*-values of less than 2%. [13]

We also estimate a specification using dummy variables corresponding to whether a particular state offers an income tax credit or a sales tax waiver. We estimate that eligibility for a sales tax waiver is associated with a 52% increase in sales whereas eligibility for an income tax credit is associated with a 15% increase in sales. Estimates from this specification understate the true relative effect—state income tax incentives are twice as generous (Mean value=$2011) on average than sales tax waivers (Mean value=$1037).

[12] Exceptions are filers subject to the Alternative Minimum Tax. For these filers, state taxes are not deductable—a $1000 state income tax credit is worth $1000.

[13] We verify that a single state does not drive our sales tax waiver results by rerunning the regressions, excluding each state in turn. The point estimates for the coefficient on the value of sales tax waivers vary from a low of 0.328 (excluding Connecticut) to a high of 0.400 (excluding Maine). In all cases, the *p*-value on the null hypothesis that the coefficient on the value of sales tax waiver is equal to the coefficient on the value of income tax credits is less than 0.10.

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Table 6
Tax incentives, by type and quarter of year. Dependent variable: log per-capita sales.

Variables	Specification			
	(1)		(2)	
	Income tax credit ($000)	Sales tax waiver ($000)	Income tax credit/MSRP	Sales tax waiver/MSRP
Second quarter coefficient	0.0355 (0.0293)	0.373*** (0.137)	0.848 (0.641)	8.484*** (3.077)
Third quarter coefficient	0.0327(0.0305)	0.473 (0.305)	0.751 (0.652)	10.58 (6.797)
Fourth quarter coefficient	0.0239 (0.0304)	0.325*** (0.0692)	0.392 (0.677)	7.013*** (1.493)
First quarter coefficient	0.00957 (0.0260)	0.333** (0.155)	0.301 (0.601)	7.450** (3.473)
Observations	4630		4630	
R^2	0.935		0.935	

All specifications include state*model and time*model fixed effects, annual fuel savings, a dummy variable for HOV access, and the full set of demographic controls. Standard errors, in parentheses, are clustered by state*model. *, **, and ***denote significance at 10%, 5%, and 1%, respectively.

To better understand why consumers respond more to sales tax waivers than income tax credits, we estimate the coefficients seasonally in Table 6. If the observed difference is entirely attributable to discounting, we would expect the effect of the tax credit to be monotonically increasing over the course of the year. The coefficient on the tax credit should be smallest in the first quarter and greatest in the fourth quarter, when a purchaser is closest to being able to claim the credit on their subsequent tax return. If buyers are poorly informed or poorly understand income tax credits at the time of vehicle purchase, we would expect a different seasonal pattern. In this case, we might expect the greatest effect to occur in the second quarter, when consumers are most likely to learn about a tax credit. The seasonal coefficients would likely decline monotonically in subsequent quarters as "knowledgeable" consumers make their purchases and other consumers forget about the tax credits.

We organize Table 6 so as to highlight the seasonal pattern associated with poor buyer information as clearly as possible—the first row contains the coefficient for the second quarter, followed by the third, fourth and first quarters, respectively. Although we lack the power to statistically distinguish the quarterly coefficients from each other, we find an intertemporal pattern consistent with what we would expect if consumers were poorly informed or poorly understood the tax credit—the point estimates for the quarterly income tax coefficients are greatest in the second quarter and decline monotonically in each successive quarter. Under the null hypothesis that no quarterly pattern exists, the probability of seeing this exact monotonically decreasing series of quarterly point estimates is approximately 4%.[14] As a falsification text, we also estimate quarterly coefficients on sales tax waivers. We do not see a similar seasonal pattern in the quarterly coefficients.

We further consider four possible sources of bias that may lead us to over- or under-estimate consumer response to sales tax waivers or income tax credits. First, poor knowledge of the income tax credits could lead to less than full take-up. In the three states for which data is available, Colorado, Pennsylvania and Utah, income tax credits were only claimed on a subset of eligible vehicles. Comparing the total number of tax credits claimed to the total number of credit-eligible vehicles sold, we find that consumers claimed credits for approximately 70%, 65%, and 85% of the credit-eligible vehicles sold in Colorado, Pennsylvania, and Utah from 2000 to 2006. Second, as we mention above, tax filers not subject to the Alternative Minimum Tax can deduct state taxes from their federal returns. For these filers, and income tax credit increases federal tax liability—consequently, it is appropriate to scale the value of the tax credit by the filer's federal marginal tax rate.

These two sources of bias would lead us to overestimate the benefit a consumer derives from an income tax credit—and thus, underestimate the coefficient on income tax credits. As a test of our results in Table 5, we replicate the regression in column (1) using the most conservative assumptions—that only 65% of all eligible hybrid vehicle owners in income tax credit states were aware of the tax credit and that all of them faced the maximum federal marginal tax rate of 35%. Even after scaling the income tax credits appropriately, we still find a statistically significant difference between the coefficient on income tax credits and sales tax waivers at a p-value of 0.035. Even in this extreme case, a sales tax waiver is associated with a seven-fold greater increase in hybrid sales than an income tax credit of comparable magnitude.

The remaining sources of bias would cause us to underestimate the relative effect of income tax credits and sales tax waivers. Sales taxes are calculated based on the sale price of the vehicle less any trade-in or rebate. To the extent that a consumer is trading in a vehicle, we would overestimate the sales tax waiver. In a similar vein, if a vehicle is financed by a loan, a consumer only receives the benefit of a sales tax waiver gradually. Again, this would lead us to overestimate the benefit of the sales tax waiver to the consumer.

Finally, the incidence of sales tax waivers and income tax credits may differ. Although we do not observe the transaction price associated with vehicle purchases and cannot observe how the consumers and dealers share tax incentives, we

[14] If the quarterly coefficients are drawn from the same sampling distribution, the probability that the coefficient in the second quarter would be the greatest would be 25% and the probability of seeing the exact monotonic relationship we observe is 1/24.

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believe the omission of bargaining conservatively biases our results. Busse et al. [4] find that information asymmetries play an important role in the incidence of dealer and consumer vehicle incentives. In our context, the value of a sales tax waiver is clearly known to both parties at the time of negotiation, while the value of an income tax credit depends the consumer's tax status, federal marginal tax rate and expected state tax liability all of which are private information. Moreover, if a consumer's objective is to pay less than or equal to a particular price for a vehicle, the consumer might bargain less aggressively if they know they will receive the sales tax waiver. Both of these explanations would lead us to underestimate the coefficient on the value of the sales tax waiver by more than that coefficient on the income tax credit and, thus, understate, the true relative effect of the tax incentives.

4.2. Estimating implicit discount rates on future fuel savings

A number of empirical papers estimate implicit discount rates for durable goods by examining how consumers weigh the upfront price and future energy costs in their purchase decisions. While reasonable for durable goods for which the primary tradeoff is immediate versus future costs, this approach does not work well for hybrid vehicles. Consumers value hybrid vehicles for many reasons, only one of which is a lower cost of operation. If, for example, an environmentally minded consumer places a premium on driving a hybrid vehicle, a more appropriate calculation of the implicit discount rate would compare the incremental price less the consumer's environmental premium with the stream of future fuel savings. A simple comparison of the incremental price of a hybrid vehicle and the annual fuel savings biases the implicit discount rate downward.

With a few assumptions, our estimates in Table 5 allow us to avoid this source of bias and more accurately calculate an implicit discount rate for future fuel costs. To do so, we compare consumer response to sales tax waivers and to annual fuel cost savings. We calculate the annual fuel cost savings required to generate a similar demand response to a one thousand dollar sales tax waiver. The implicit discount rate equates the net present value of this stream of future savings with the $1000 value of the waiver. Unlike tax credits that are received at a later point and may require additional effort to claim, sales tax incentives are immediate and offer the best comparison to the present discounted value of the stream of future fuel savings.

To calculate the implicit discount rate, we need to make two assumptions about consumer beliefs: (1) consumer expectations of future gasoline prices and (2) the vehicle lifespan over which a consumer will internalize the fuel cost savings. For the first, we assume that consumers believe that gasoline prices follow a random walk—current gasoline prices provide the best prediction of gasoline prices in the future. Second, although a vehicle's true lifespan is longer, we assume that consumers only internalize the fuel savings associated with first five years of ownership. Our five-year benchmark comes from industry estimates of the average length of vehicle ownership.[15] There are two interpretations for the limited, five-year horizon. First, internalizing only five years of fuel savings may be appropriate if consumers do not anticipate recouping the value of subsequent fuel cost savings when selling or trading in a vehicle. Alternatively, the limited horizon may also be interpreted as consumer myopia—Fischer et al. [9] considers a similar interpretation when examining the welfare effects of CAFE standards.

There are several reasons to expect that our baseline may provide a lower-bound estimate of the true implicit discount rate. First, the five-year mean length of vehicle ownership is based on a fleet-wide average—industry studies do not distinguish between the mean length of hybrid vehicle and conventional vehicle ownership. If hybrid vehicles are owned from a longer period of time than conventional vehicles, the five-year time frame may be inappropriately short. Alternatively, if the seller obtains a fuel economy premium when selling the vehicle or is less myopic, our estimate of the implicit discount rate will be conservatively biased towards zero. As a robustness check, we alternatively calculate the implicit discount rates implied by six-year and eight-year vehicle life-spans—if a consumer anticipates keeping a new hybrid vehicle for more than five years or expects to obtain a fuel economy premium when selling the car, the discount rate implied by a longer lifespan may be more appropriate.

In addition, there are several ways in which our estimate of the implicit discount rate may be biased upwardly. If consumers believe that gasoline prices exhibit some degree of mean reversion, rather than being a random walk, we would tend to overestimate the true discount rate. Alternatively, we would overestimate the true discount rate if consumers respond more to a sales tax waiver than any other reduction in the purchase price of similar magnitude. As a check, our estimates in the second column of Table 5 imply an average own-price elasticity of -8.3 for models on which sales tax waivers were offered. Although slightly higher, this estimate is comparable to other own-price elasticity estimates from the literature on automobile demand. For example, Berry et al. [3] report own-price elasticities of -6.4, -6.5, -6.0, and -4.8 for the model-year 1990 Mazda 323, Nissan Sentra, Ford Escort, and Honda Accord, respectively.

Table 7 presents the discount rates implied by our regression results in column (1) of Table 5. For each specification, we report the discount rates implied by five-year, six-year, and eight-year vehicle lifespans. Column (1) presents our base results, obtained by within-vehicle class comparisons (e.g. comparing the Prius to non-hybrid compact passenger cars) to

[15] A recent survey of 700 vehicle owners conducted by R.L. Polk estimates that consumers own a vehicle for 56 months on average. http://usa.polk.com/News/LatestNews/2009_0323_auto_purchase_plans.htm.

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Table 7
Implied discount rate robustness tests. Dependent variable: log per-capita sales.

Variables	Within-vehicle class comparison (base case) (1)	Within-vehicle type comparison (2)	Comparison to mean fuel economy for all light vehicles (3)	Within-class comparison using EPA-highway fuel economy for hybrids (4)	Within-class comparison using EPA-city fuel economy for hybrids (5)
Annual fuel savings ($/year)	0.00145**	0.00136***	0.00120***	0.00149**	0.00140**
	(0.000584)	(0.000502)	(0.000436)	(0.000594)	(0.000571)
HOV access dummy	−0.0606	−0.0594	−0.0587	−0.0603	−0.0613
	(0.0588)	(0.0592)	(0.0593)	(0.0589)	(0.0588)
State income tax credit ($000)	0.0239	0.0239	0.0241	0.0239	0.0238
	(0.0246)	(0.0246)	(0.0245)	(0.0246)	(0.0246)
State sales tax waiver ($000)	0.374***	0.376***	0.377***	0.375***	0.374***
	(0.141)	(0.140)	(0.141)	(0.141)	(0.140)
Observations	4630	4630	4630	4630	4630
R^2	0.935	0.935	0.935	0.935	0.935
Implied discount rates					
Five-year vehicle lifespan	14.6%	19.4%	29.5%	13.0%	17.0%
Six-year vehicle lifespan	21.8%	26.3%	35.9%	20.2%	24.0%
Eight-year vehicle lifespan	28.9%	33.0%	41.8%	27.4%	30.9%

All specifications include demographic variables, state∗model fixed effects and time∗model fixed effects. Robust standard errors are clustered at the state∗model level. ***denotes significance at the 1% level. Within-type comparisons compare each hybrid vehicle to the mean non-hybrid light truck or passenger car. Within-class comparisons compare each hybrid vehicle to the mean non-hybrid vehicle in the same vehicle class (e.g. comparing the Toyota Prius to non-hybrid compact passenger cars).

calculate annual fuel cost savings. The point estimates in column (1) imply that annual fuel savings of $257 generate an equivalent increase in sales to a $1000 sales tax waiver. This flow of future savings implies a discount rate of 14.6% using a five-year vehicle lifespan, 21.8% using a six-year vehicle lifespan, and 28.9% using an eight-year vehicle lifespan. Interestingly, our benchmark estimates are close to previous estimates of implicit discount rates for consumer durable goods—Hausman [12] and Dubin and McFadden [7] estimated discount rates of 20% and 20.5% at the mean income level, respectively. The similarity in estimates is surprising since our sample focuses on early adopters of hybrid vehicles who may differ in many respects from purchasers of established durable goods.

In columns (2) through (5), we calculate the discount rates implied by several alternative methods for calculating fuel savings. In column (2), we calculate the discount rate implied by a comparison of hybrid fuel costs and mean fuel costs for light trucks or passenger cars. Unsurprisingly, the discount rate implied by this comparison is greater than the discount rate implied by the within-class comparison. Early hybrid models tend to be smaller than the average conventional vehicle—consequently, a comparison to all passenger cars or light trucks tend to increase the perceived annual fuel savings and consequently, increase the implied discount rate. In column (3), we calculate the implied discount rate when we use the stock of all light vehicles (both passenger cars and light trucks) as the comparison group for calculating annual fuel savings. Although the effect of this change is theoretically ambiguous as it increases annual fuel savings for hybrid sedans while decreasing annual fuel savings for hybrid SUVs, we find that this further increases the implied discount rate. Finally, in columns (4) and (5), we calculate the discount rates implied if consumers use the city-ratings and highway-ratings for hybrid vehicles rather than the combined fuel economy rating. We find little evidence that changing the source of the fuel economy rating for the hybrid vehicles substantively affects our implied discount rates.

4.3. *Sensitivity tests*

Table 8 reports coefficients for a number of sensitivity tests of our base econometric specification. In our first sensitivity test, we restrict the sample to twelve states offering a tax incentive between 2000 and 2006—we estimate the effect of the incentives purely off of variation within the twelve tax incentive states. Next, we restrict our analysis to quarters in which a model is sold in all states—this test effectively excludes the first quarter of each model's introduction, in which only 70% of states have sales on average. In our third sensitivity test, we omit quarters in which we document production constraints for the Civic Hybrid and Toyota Prius. Finally, we run a sensitivity test excluding the three lowest volume models, the Honda Insight, Saturn VUE, and Lexus GS450h, each of which sold less than 5000 units over the sample period.

The sensitivity tests do not substantially affect our point estimates although in some cases, we are no longer able to estimate coefficients precisely. The point estimate for the coefficient on the value of state tax incentives is essentially unchanged across the four sensitivity tests. The coefficient on fuel savings is unchanged in three of the four sensitivity

Table 8
Sensitivity analyses. Dependent variable: log per-capita sales.

Variables	Base results (1)	Restrict sample to states offering a tax incentive (2)	Restrict sample to quarters with positive sales in all states (3)	Drop months with Prius and Civic production constraints (4)	Drop low volume models (insight, VUE, GS450h) (5)
Annual fuel savings ($/year)	0.00132**	0.000794	0.00159***	0.00130**	0.00166**
	(0.000580)	(0.00128)	(0.000560)	(0.000584)	(0.000644)
HOV access dummy	−0.0692	−0.137	−0.0975*	−0.0687	0.0196
	(0.0595)	(0.105)	(0.0577)	(0.0600)	(0.0482)
State tax incentive ($000)	0.0485*	0.0501	0.0498*	0.0474	0.0491
	(0.0292)	(0.0337)	(0.0290)	(0.0289)	(0.0389)
Observations	4630	1056	4319	4514	3594
R^2	0.935	0.939	0.935	0.935	0.912

All specifications include state∗model and time∗model fixed effects, and the full set of demographic controls. Standard errors, in parentheses, are clustered by state∗model. *, **, and ***denote significance at 10%, 5%, and 1%, respectively.

tests. When we restrict the sample to the states offering a hybrid incentive, we no longer estimate a significant coefficient on annual fuel savings. Finally, the point estimate on the coefficient on HOV access is negative for three of the four sensitivity tests and imprecisely estimated in three of the four.

4.4. Social preferences

As a final analysis, we examine whether hybrid vehicle adoption correlates with preferences for environmentalism or energy security. We test for evidence consistent with hybrid vehicle adoption on ideological, rather than economic grounds.[16] Conditional on purchasing a hybrid, we expect that groups with strong preferences for environmentalism or energy security to prefer high fuel-economy hybrids, which have substantial environmental or energy security benefits, relative to low fuel-economy hybrids. To test for evidence, we decompose the state∗model fixed effects into a state fixed-effect common for all hybrid vehicles, and a dummy variable for high fuel-economy models which we interact with proxies for environmentalism or energy security salience. That is, we consider the equation:

$$Log(SalesPerCapita_{imt}) = \phi_i + \gamma HighEff_m * proxies_{it} + \beta FuelSavings_{imt} + \lambda Incentives_{imt} + \theta Demographics_{it} + \eta_{mt} + \varepsilon_{imt} \quad (3)$$

As a proxy for environmental preferences, we use state-level per-capita Sierra Club membership. For preferences for energy security, we use per-capita active and reserve military participation, which is likely correlated with concern about the wars in Iraq and Afghanistan and plausibly correlated with preferences for enhanced energy security. We present our estimates in Table 9. Since we no longer include state∗model fixed effects, we interpret the coefficients on the interaction terms as the correlation between sales of high fuel-economy hybrids and our demographic proxies. In specification (1), we interact the proxies with the dummy variable for high fuel-economy models. In specification (2), we interact the proxies with each model's fuel economy rating. In both cases, the point estimates for the interaction terms are positive. We estimate that one standard deviation increases in Sierra Club membership per capita and per-capita military participation are associated with 17% and 11% increases in sales of high fuel-economy hybrid vehicles.

In specifications (3) and (4), we additionally interact our proxies with dummy variables for the Prius and Insight. We estimate a positive and significant coefficient for the Prius, suggesting that consumers in states with high Sierra Club Membership have an additional preference for the Prius relative to other high fuel-economy hybrid vehicles. Interestingly, we find that a negative and significant coefficient for the Insight, suggesting that states with high Sierra Club membership have a lower preference for the Insight than other hybrid vehicles. We find a similarly low preference for the Prius in states with high military participation.[17] Although certainly not conclusive, these results suggest that consumers in states with high Sierra Club membership have an idiosyncratic preference for the Prius beyond their preference for fuel economy, consistent with what we would expect to see if consumers had a desire to purchase a conspicuously "green" vehicle.

5. Conclusion

In this paper, we estimate how hybrid sales respond to state tax incentives, rising gasoline prices, and access to carpool lanes. Our empirical results have several important implications for the design of incentives meant to foster consumer

[16] See, for example, Kahn [15] and Turrentine and Kurani [19].

[17] We omit regressions in which we use higher-order fuel economy terms—our conclusions are robust to the parameterization of the fuel economy interaction term.

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Table 9
Determinants of demand for high efficiency hybrids. Dependent variable: log per-capita sales.

Variables	Specification			
	(1)	(2)	(3)	(4)
Annual fuel savings ($/year)	0.00162*** (0.000526)	0.00173*** (0.000558)	0.00164*** (0.000563)	0.00170*** (0.000583)
HOV lane access	0.00971 (0.0830)	0.0211 (0.0775)	0.00643 (0.0842)	0.0148 (0.0775)
State tax incentive ($000)	0.0352 (0.0388)	0.0347 (0.0388)	0.0388 (0.0344)	0.0381 (0.0324)
Sierra club membership per capita∗high FE hybrid	0.131*** (0.0235)		0.126*** (0.0257)	
Military participation per capita∗high FE hybrid	14.49** (6.093)		18.96*** (6.297)	
Sierra club membership per capita∗fuel economy rating		0.00220*** (0.000800)		0.00169 (0.00118)
Military participation per capita∗fuel economy rating		0.303 (0.207)		0.839*** (0.261)
Sierra club per capita∗Prius			0.0896*** (0.0181)	0.120*** (0.0223)
Sierra club per capita∗Insight			−0.0970*** (0.0348)	−0.0733* (0.0420)
Military participation∗Prius			−9.510*** (2.885)	−15.21*** (3.999)
Military participation∗Insight			−8.611 (11.48)	−17.71 (14.25)
Observations	4630	4630	4630	4630
R^2	0.889	0.887	0.892	0.891

All specifications include state fixed effects, time∗model fixed effects, and the full set of demographic controls. Standard errors, in parentheses, are clustered by state∗model. *, **, and ***denote significance at 10%, 5%, and 1%, respectively.

adoption of energy-efficient technology. First, we find evidence that both the generosity and type of tax incentive affects consumer behavior. Even though state sales tax waivers tend to be less generous than state income tax credits, we find that the mean sales tax waiver (value $1077) is associated with over three times the increase in sales of the mean income tax credit (value $2011). Although the result is somewhat imprecisely estimated, due to the fact that only four states chose to waive sales taxes, the results provide suggestive evidence that consumers respond to both the generosity and form of tax incentives. In particular, the results suggest that immediacy, transparency, and ease may be important attributes when designing incentives meant to affect consumer behavior. This provocative result should encourage policy-makers to carefully consider both the nature of incentives and incentive generosity as well as motivate future research in this area. In particular, these results suggest that "feebate" programs, where consumers pay a fuel-economy based fee at the time of purchase may be more effective at encouraging the purchase high fuel-economy vehicles than fuel-economy based registration or emissions testing fees. Moreover, unlike a sales tax waiver, a feebate could be designed to be revenue neutral.

We find inconsistent evidence that consumers respond to single-occupancy HOV access. Only the HOV program offered by Virginia is estimated to be positively correlated with hybrid sales. Although we find the estimated effect to be quite large, the magnitude of the effect decreases after Virginia limited access to HOV-3 lanes during rush hour.

We find evidence that hybrid vehicle adoption is positively correlated with gasoline prices. In particular, we find compelling evidence that demand for the highest fuel-economy vehicles rises most with gasoline prices. In addition, we estimate that a $100 increase in annual fuel savings is associates with a 13% increase in hybrid vehicles sales. Comparing the demand response to sales taxes waivers and demand response to fuel savings, we estimate that early hybrid vehicle adopters place an implicit discount rate of 14.6% on future fuel savings. Although the US government has not used higher gasoline taxes as a policy instrument to motivate consumer adoption of more fuel-efficient vehicles, this is a policy tool that has been employed to varying degrees in Europe and Japan. While hybrid vehicle adoption is correlated with gasoline prices, our results suggest that even under conservative assumptions early adopters discount future fuel savings substantially. Based on our estimates, increasing the average gasoline price in a state by 20% over 2000–2006 (equivalent to increasing a state's gasoline tax by 36 cents per gallon and increasing average fuel economy savings from driving a hybrid vehicle by $85 per year) would increase hybrid vehicle sales an equivalent amount to a $330 sales tax wavier.

Although we do not directly address it in this paper, it is important to consider the larger impacts of state policies on national adoption of hybrid vehicles. Our results suggest that state policies can substantially affect hybrid vehicle purchases at the state-level. If, in response, automakers reallocate production from jurisdictions without incentives to jurisdictions with incentives, the national impact of state and local incentives may be blunted. Similarly, if hybrid sales in a state create positive spillovers in neighboring jurisdictions, local incentives may have additional benefits. Better understanding interjurisdictional spillovers is important for the design of policy to encourage vehicle adoption and a direction for further research.

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