DETERMINANTS OF U.S. HYBRID ELECTRIC VEHICLE SATURATION LEVELS AND THE IMPLICATIONS FOR POLICY

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DETERMINANTS OF U.S. HYBRID ELECTRIC VEHICLE SATURATION LEVELS AND THE IMPLICATIONS FOR POLICY

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Abstract: The hybrid electric vehicle (HEV), a $30 billion per annum industry, has long been treated as another commodity where only its price and fuel efficiency matter. In fact, its growth has deep socioeconomic roots, and auto manufacturers have long practiced concentrated and localized marketing when rolling out new models through their branches, dealers and wholesalers. However, no previous study has investigated this effect for HEVs down to the county level. This thesis analyzes a new and previously inaccessible data set to provide a detailed view of the saturation rate of HEVs for 3000 counties in the U.S. Utilizing the U.S. county-level registration data for HEVs, our results show that the dollars-per-mile cost is the most important factor for consumers purchasing HEVs. State tax waivers, state income tax credits and HOV lane access are shown to be important for promoting HEV sales. On the other hand, the HEV tax incentives from the Federal government are relatively ineffective without these additional incentives from state governments. These results suggest that the federal government should allow state governments to decide their own policies for promoting HEVs. Lastly, a Geographic Information System (GIS) analysis of the sales of Toyota Prius shows that they have a spatial clustering feature indicating that, contrary to popular opinion, state government incentives have a greater effect on consumers in the Midwest than they do in the East and West Coast

BIOGRAPHICAL SKETCH

Kuming Chang was born and raised in Taiwan. Before beginning his Ph.D. study in Regional Science Program at Cornell University. He earn a B.S. degree in the field of Applied Economics from National Chung-Hsing University, Taichung City, Taiwan. He also received a M.S. degree in the same field with thesis work in efficiency and productivity analysis by using the nonparametric Data Envelopment Analysis (DEA) and Malmquist Index. After that, he served as a Second lieutenant in the Coast Guard Administration, Taiwan for around two years. His main research activities at Cornell University is the investigation the determinants of the large-scale sales data of hybrid electric vehicles in the U.S.. He completed his Ph.D. in Regional Science in 2015.

To my parents

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Chapter 1

Introduction

The transportation sector accounts for 33 percent of the America's carbon dioxide emissions (EIA 2005), with over half of that coming from cars and trucks. In addition, highway petroleum consumption increased 62 percent between 1973 and 2005, from 110.5 to 179 billion gallons. Until recently, the source of petroleum depended largely on imported oil, and such dependence raised national security concerns. The U.S. Department of Energy states that about 45% of the petroleum was imported making the US economy sensitive to price spikes and supply disruptions[1]. One way to resolve such concerns is to adopt a non-petroleum technology for transportation. For many years, scientists and policy makers have discussed using electric motors in vehicles because they are cleaner and more efficient than the internal combustion engine and they can gradually reach oil independence and improve air quality. In addition, in the 1980s, the Federal government adopted the Corporate Average Fuel Economy (CAFE) standard to push the auto manufacturers to build higher fuel economy vehicles in response to the strategic goal of promoting the environment responsibility. The first hybrid model, Honda Insight, was introduced in 1999 which sold only 17 units[2] in that calendar year. But the number of hybrid electric vehicle (HEV) models and sales volume steadily grew, and the number of hybrids is expected to increase from about 20 models today to more than 40 models by the end of 2014[3]. However, compared with the conventional vehicles, the high purchase price is one of the barriers to adopt HEVs. For example, a Nissan

[1] See http://www.afdc.energy.gov/fuels/electricity_benefits.html#savings
[2] See http://www.afdc.energy.gov/afdc/data/vehicles.html
[3] See http://www.hybridcars.com/news/new-study-hybrid-cars-rise-especially-europe-25267.html

Altima hybrid is $6,750 more than its counterpart[4]. Therefore, in order to enhance the market penetration of HEVs, the Federal government provided income tax credits of 2,000 dollars until the end of 2005 and began more generous income tax credit in January 2006. State and local governments also offered incentives such as state income tax credit, state sales tax exemption, High-Occupancy-Vehicle (HOV) lane access privileges and free parking.

Most of previous studies have examined the relationships among gasoline prices, different government policies and vehicle sales. However, few papers included other related factors such as characteristics of vehicles and geographic characteristics[5]. In other words, they considered the effects of rising gasoline prices on HEV sales but they did not examine whether other factors also induce consumers to buy HEVs. By using county level quarterly data for new HEV registrations from *R.L. Polk*, this paper considers other factors that could be significant and lead to more accurate results. Furthermore, this is the first paper that utilizes these county-level data, and makes it possible to investigate the geographic differences in government policies.

This study is organized as the follows. The remainder of Chapter 1 contains a history of the hybrid electric vehicle and a literature review. Chapter 2 discusses the data sources and analysis of the datasets. Chapter 3 introduces the methodology and empirical model specification. Chapter 4 discusses the parameter estimates and the policy analysis. Chapter 5 uses the Toyota Prius as an example to analyze the spatial effects of state government incentives using GIS techniques. Chapter 6 summarizes the conclusions.

[4] Nissan Altima 2.5 is MSRP $19,900 while Nissan Altima Hybrid is MSRP $26,650, see http://www.nissanusa.com/altima/

[5] West (2007) suggested that these variables should be included in order to get more insights on the effect of gasoline prices on the demand for sport-utility vehicles (SUV).

1.1 History of the Hybrid Electric Vehicle

Hybrid electric vehicles (HEVs) combine a gasoline engine with an electric motor, which is powered by a storage battery charged via regenerative braking. 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). Hybrid electric vehicles have demonstrated significant potential to reduce fuel consumption and exhaust emissions. Especially, advances in battery, power electronics technologies have made huge commercialization. Performance is generally as good as or better than conventional vehicles. Hybrid electric vehicles use both internal combustion engine and electric motor and breaking is used to recharge a battery. Much of hybrid technology falls into one of two classes: full hybrid vehicles and mild hybrid vehicles. Full hybrids propel vehicles without using any gasoline. An example would be a fully electric vehicle (EV) that generates power from nickel metal hydride batteries. As an energy-efficiency technology, HEVs have the potential to address environmental and resource externalities that are not taken into account by the market 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 and high initial production costs. 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. Recognizing consumer demand for better fuel economy and reduced emissions, both Toyota and Honda have introduced hybrid vehicles to the American market. Toyota introduced the Prius to the U.S. in 2000. Honda began selling the hybrid two-seater Insight in the U.S. in 1999.

1.2 Literature Review

This paper is built on other studies[6] that discuss the demand of hybrid cars or new vehicles. *Kahn (2007)* finds that communities in California with a higher proportion of Green Party registered voters exhibiting higher frequencies of pro-environment behaviors. The conclusion of his study is that the environmentalists are more likely to commute by public transit, purchase hybrid vehicles, and consume less gasoline than non-environmentalists. *Gallagher and Muehlegger (2008)* analyzed quarterly state-level HEV sales data provided by *JD Power* from 2000Q1 to 2006Q4 and found that the state tax incentives, rising gasoline prices, and social preferences (e.g. environmental quality and energy security) are all important on hybrid vehicle sales and increased sales 6, 27 and 36 percent, respectively. However, their reduced form methodology does not distinguish total sales effects from timing effects or geographic diversion. *Diamond (2008)* tested the relationship between hybrid adoption and a variety of socioeconomic and policy factors. Using *R.L. Polk* hybrid vehicles registration data from 2000 to 2006, he found that rising gasoline prices, high income, vehicle miles traveled were all positively related to market share, albeit disproportionately. However, the presence or values of monetary incentives at the state level was generally weak or insignificant compared to these other factors. *Beresteanu and Li (2009)* examined the determinants in the sales for HEVs in 22 Metropolitan Statistical Areas (MSAs) from 1999 to 2006. They found that both the increase in gasoline prices (e.g., through increased gasoline taxes) and federal income tax incentives expand the market share of hybrid vehicles. *Klier and Linn (2008)* got the vehicle model sales data from Ward's Automotive Reports (1970-1979) and Ward's AutoInfoBank (1980-2007). Their monthly new vehicle sales data allows them to examine

[6] Section 1.2 are organized and excerpted from other various papers.

the impact of gasoline prices on the new vehicle demand within model-year change. They concluded that by using gasoline tax to reduce fuel consumption, an increase in the Federal gasoline tax that raises the gasoline price by one dollar would raise the average fuel efficiency of new vehicles by about 0.5 to 1 mile per gallon (MPG). However, their static approach did not consider the endogeneity of vehicle characteristics because gasoline prices and CAFE regulations may affect the characteristics of vehicles.

Turrentine and Kurani (2007) did a limited survey of early HEV adopters in California. Many of the interviewees stated that they were primarily motivated by non-economic considerations, such as being a pioneer, an environmentalist, or just ‘‘living lighter.’’ They mentioned that almost none of these sample households track gasoline costs over time or consider them explicitly in household budgets. These households may know the cost of their last tank of gasoline and the unit price of gasoline on that day, but this accurate information is rapidly forgotten and replaced by typical information. In other words, they were not particularly concerned about the specific price difference that they had paid for their HEV. *Gallagher and Muehlegger(2008)* differentiate between tax credits and sales tax incentives and find that the latter are associated with a greater increase in hybrid sales, consistent with the results in *Chetty, Kroft and Looney (2007)* and *Finkelstein (2007)* who find consumer response to taxation varies with the salience of the tax.*Sallee(2008)*studies the incidence of tax credits for the Toyota Prius and shows that consumers, rather than producers, capture the significant majority of the benefit from tax subsidies.

Some of the related papers in consumer choices of the automotive use discrete choice model to measure the differentiated products demand while some studies use reduce-form methodology.

One of the most influential methods by using the discrete choice methodology in demand estimation is proposed by *Berry, Levinsohn, and Pakes (BLP) (1995)*[7]. BLP allows for endogenous prices, random coefficients and consistent estimation of the model parameters even if the market is imperfect (oligopolistic) competition. They emphasized estimation strategies based on changes across markets and across time in the choice set facing consumers. The major contribution of this classic paper is not only on the analysis of the demand in the U.S. automobile market, but, most importantly, provide a framework to utilize the existing aggregate consumer-level data and estimate the cost and demand parameters. BLP offered a useful method to deal with endogeneity and move it out of nonlinear choice models into linear regression, such as generalized method of moments (GMM). In BLP's utility form, they included a specific unobservable term, which is known to the market participants but not the econometricians. For example, the term may include the aspects of style, prestige, reputation, advertisement and consumer's past purchase experience. BLP approach is able to perform regression based on market data (revealed preference), not survey data (stated preference). The product attributes in their logit demand model are ratio of horsepower to weight (HP/WT), air conditioning dummy variable, MP$ (miles per dollar), vehicle size, and price (in 1983 dollars). The automobile market data is collected in a 20-year period from 1971 to 1990 from Automotive News Market Data Book. The substitution behavior of moving from vehicle purchase to outside good, when price increased, is compared under standard logit and BLP's random coefficient logit model. Their another important paper is *Berry, Levinsohn, and Pakes (2004)*, which discusses an algorithm for estimating characteristic based demand models from alternative data sources and applies it to new data on the market for passenger vehicles. They have found that provided that the data is rich enough, the model can rationalize existing results

[7] The other demand estimation methods could be hedonic approach by Bajari and Benkard(2005), control function approach by Petrin and Train(2009) or maximum likelihood approach by Gupta and Park(2008).

and provide realistic out of sample predictions for future purchases. An essential part to this study is that they utilize not only a consumer's first choice car (the one purchased), but also the second choice car that the consumer might have purchased. This information proved helpful in determining just how important each characteristic or factor was for each consumer. The study compares the results of using a logit model where only the first choice data is used and one where both the first and second choice data are used. The models used also allow for characteristics to vary as a function of both the observed and unobserved consumer attributes, data was acquired from the 1993 CAMIP Sample by General Motors, which included about 37,500 completed surveys (34,500 of which also reported their second choice), and the Current Population Survey was used. This paper is slightly more complicated than the other papers, but it seems to include important ideas for the future of alternative-fueled vehicle demand. *Petrin (2002)* thinks the previous studies have ambiguous prediction about new products. He modified BLP approach to allow for combination of average demographic data (from consumer expenditure survey, CEX),the characteristics of the products, and market share data, making the estimates of demand and supply curves more precise, attempting to measure the benefits of a new vehicle, the minivan. The micro data he used can give information about how substitution patterns vary with demographic groups and can release the model from a heavy dependence on the idiosyncratic logit taste error. The estimator in his study is essentially BLP with additional moments on purchases conditional on demography. *Train and Wilson (2007)* employed mixed logit demand model to study the relation between the consumer choice behavior and market share drops of the U.S. automakers in the past decade. It showed that the loss of U.S. automaker market shares can be explained by the vehicle attributes, such as retail price, power, weight, fuel consumption, body type, transmission type and reliability, where Japanese and European manufacturers have more improvements on attributes than U.S. manufacturers.

However, the BLP methodology needs to find instruments for a set of unobserved supply shifters, (e.g. change in costs). It raised the problems that there are too few instruments and they may be weak. And the weak instruments will cause the incorrect standard errors and larger bias. Recent work has critiqued the robustness of BLP's GMM estimator. Using these same data, Knittel and Metaxoglou (2008) found that many solvers stopped at different points and that these points were often sensitive to start values. Nevo's (2000b) "Researcher's Guide" reported estimates that were not a local optimum because of the use of a loose outer loop tolerance. I therefore use multilevel regression model in this study. It is a common specification and is adopted here as it provides a good fit to the data.

Chapter 2

Data Sources and Data Analysis

2.1 Introduction

This chapter introduces the five main datasets and analyze the characteristics of these datasets. The variables and data sources used in this study are obtained from the following five categories.

(1) **New HEVs registration data from *R. L. Polk & Co.*:** This data contains state, county, vehicle make, vehicle model, year, and quarter.

(2) **Car characteristics:** Hybrid car characteristics data obtained from *Ward's Automotive Yearbook* include (a)body style;(b) drive type;(c) wheelbase;(d) length;(e) width(f) height;(g) curb weight;(h) net horsepower;(i)revolutions per minute(RPM);(j) city and highway miles per gallon(MPG);(k) manufacturer suggested retail price(MSRP).

(3) **Gasoline prices:** State level gasoline prices with taxes from 2005 quarter one to 2007 quarter four are obtained from "Monthly Motor Fuel Reported by States" issued by the Federal Highway Administration (*FHWA*).

(4) **Government Incentives**: In this study, four main policies (a)HOV lane access; (b)State sales tax;(c)State income tax credit;(d)Federal income credit will be used. Most of the incentives information can be obtained from fueleconomy.gov[8], Alternative Fuels and Advanced Vehicles Data Center (AFDC)[9], and Hybrid Incentives and Rebates-Region by Region[10].

(5) **Socioeconomic variables**: County-level socioeconomic characteristics such as (a)race; (b)income;(c)house ownership;(d)vehicle counts;(e)education;(f)family size;(g)travel time;(h)

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[8] See http://www.fueleconomy.gov/Feg/tax_hybrid.shtml
[9] See http://www.afdc.energy.gov/afdc/vehicles/hybrid_electric_laws.html
[10] See http://www.hybridcars.com/local-incentives/region-by-region.html

commuting mode;(i) age; (j)household head age are collected from the U.S Census 2000.

Table 1 The variable list

Vehicle Characteristics	Incentives	Socioeconomics	Polk's data	Gasoline
body style	HOV lane access	race	State	Gasoline price
drive type	State sales tax	house ownership	County	
wheelbase	State income tax credit	vehicle counts	Make	
length	Federal income tax credit	education	Model	
width		family size	Year	
height		travel time	Quarter	
curb weight		commuting mode	Registration number	
horsepower		age		
RPM		household head age		
MPG(City/Highway)				
Vehicle price(MSRP)				
11 variables	4 variables	9 variables	7 variables	1 variable

There are 5 categories of the data; vehicle characteristics, incentives, socioeconomics, Polk's data and gasoline prices.

2.2 Unit of Study and Datasets Structure

Counties are an important part of the nation's territory and local government apparatus. Billions of public dollars are spending every year to provide public services to millions of residents (Dewees et al. 2003). Lobao and Kraybill (2005) found a positive and significant correlation between social economics activities and economic development within counties, which implied that counties are a promising level and also the fastest growing of all general-purpose local governments (Lobao and Kraybill, 2005). Meanwhile, county areas are relatively more stable boundaries than other jurisdictions Therefore, counties are good units to analyze changes over time (Lichter and Johnson 2007; Lobao and Hooks 2003). Therefore, county is the main unit of analysis in the current study.

This study contains 48 states in the United States except Alaska, Hawaii and Washington, D.C. Meanwhile, there are 3113 counties are included. The five boroughs in New York City are counted as one county area by the definition from the Census of Government. Therefore, socioeconomic variables for New York City needed to be aggregated from its five administrative divisions. Moreover, the independent cities in Virginia are counted as counties. However, Clifton Forge city in Virginia is no longer an independent city (a county equivalent) after July 1, 2001, so there is no sales data but the 2000 census data exists. It is also excluded from the dataset[11]. In addition, **Broomfield County,** Colorado was created on November 15, 2001. Therefore, no demographic data is in this county because the census data source was in 2000 and the next version will be in 2010. This county had 47 units HEV in 2005, 78 units HEV in 2006 and 118 units HEV in 2007.

[11] See http://www.census.gov/epcd/nonemployer/changes02.html

In sum, 243 units were deleted in these three years.

However, not all the datasets are collated by county level due to the budget constraint and data insufficiency. Therefore, the geography and time structures of current dataset in this study was showed in the following table.

Table 2 Datasets Structure

	Data	Geography	Time
1	HEV Registration Data	County level data	Quarterly data
2	Gasoline Price	State level data	Quarterly data
3	Government Incentives	State level data	Yearly data
4	Socioeconomics Variables	County level data	Census 2000, no time variation
5	Car characteristics	No Geographic variation	Yearly data

Table 2 shows the characteristics of geography and time for the datasets. First, for the Hybrid Electric Vehicle (HEV) registration data, it is county level and quarterly data. Second, the gasoline price is quarterly data as well, but it's at the state level. Third, government incentives, which include the state sales tax waiver, state income tax credit and HOV lanes access. Note that the federal credit program is by vehicle models but has a different time frame. Fourth, Socioeconomics variables are from US census bureau 2000, which doesn't have any time variation but it contains a county-level data. Finally, car characteristics are yearly data but naturally have no geographic variations.

2.3 Registration Number of Hybrid Electric Vehicles

This section used several tables to explore the data of new hybrid electric vehicle‘s registration numbers. This dataset obtained from the R. L. Polk & Co contains information of registration number of HEV of various make and model in each state and county from year 2005 quarter one to 2007 quarter four. In other words, Polk's data contains state name, county name, hybrid vehicle make, hybrid vehicle model, year, quarter and registration number of hybrid electric vehicle.

In the hybrid electric vehicles registration data, some vehicles sales have to be removed from the dataset because of insufficient data. In the sample year from 2005 to 2007, Ford Focus sold only three units in Florida and one unit in Miami in the third quarter, 2005; total four units sold in twelve quarters. Due to such insignificant volume, Ford Focus was excluded from the final dataset. Honda FCX, which is fuel cell vehicle, sold only one unit in Los Angeles, CA in the first quarter of 2007 during the study period. Therefore, due to the data completeness, six vehicle models, which are Ford Escape, Honda Accord, Honda Civic, Toyota Prius, Lexus RX, and Toyota Highlander, are chosen into the final dataset. In the segment of the vehicle, Ford Escape and Honda Civic belong to small car; Honda Accord and Toyota Prius are in the segment of midsize car, and Lexus RX and Toyota Highlander are in the car class of midsize SUV.

In summary of the following tables in this section, Table 5 is the registration numbers of Hybrid Electric Vehicle of make and model from 2005 to 2007. From this table you can see how many models were sold in the particular year and which vehicle make and model are the most popular. Table 6 is the percentage change of hybrid electric vehicles by car classes and models. The trend will be seen in this table. Table 7 shows the top ten best sell state in last research period, i.e. 2007.

The next Table 8 indicated the top 5 states for each vehicle segments and models for these three years. Table 9 shows the growth rate for each vehicle classes and models. And Table 10 is the growth rate by different make and model. Table 11 shows the market share by car classes. And Table 12 is much more succinct information about share by car classes, by car make and by car model.

Table 3 Registration numbers of Hybrid Electric Vehicle of make and model

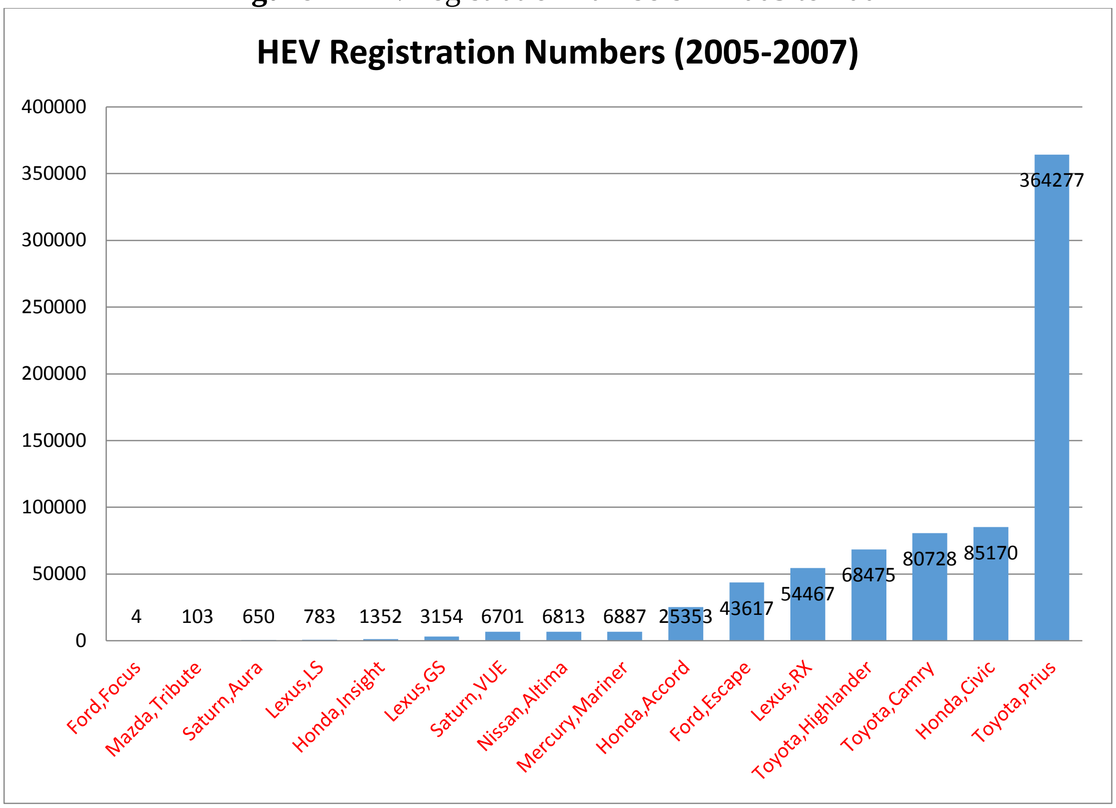
Make	Model	2005	2006	2007	Total
Ford	Escape	12,855	15,681	15,081	43,617
	Focus	4	-	-	4
Honda	Accord	16,616	5,450	3,287	25,353
	Civic	24,252	29,960	30,958	85,170
	Insight	631	711	10	1,352
Lexus	RX400h	18,823	19,209	16,435	54,467
	GS450h	-	1,560	1,594	3,154
	LS600hL	-	-	783	783
Mercury	Mariner	250	3,036	3,601	6,887
Toyota	Highlander	16,514	30,901	21,060	68,475
	Prius	99,878	104,100	160,299	364,277
	Camry	-	29,617	51,111	80,728
Saturn	VUE	-	1,404	5,297	6,701
	Aura	-	-	650	650
Mazda	Tribute	-	-	103	103
Nissan	Altima	-	-	6,813	6,813
		189,823	241,629	317,082	748,534
8 Makes	16 Models	9 Models	11 Models	15 Models	

Source: R. L. Polk & Co.

Table 3 shows the hybrid electric vehicles registration data from 2005Q1 to 2007Q4 purchased from *R. L. Polk & Co.*, an automotive analysis company. This registration data is organized by county and by quarter. Polk's data includes 3141 counties, 8 vehicle makes, and 16 models in the U.S market. In 2005, there were nine models available. In 2006, three new models (Lexus GS450h, Toyota Camry Hybrid and Saturn VUE Green Line) were introduced into the market but the Ford Focus was retired during the year, so there were eleven hybrid models available in 2006. In 2007, there were additional four new models introduced (Lexus LS600hL, Saturn Aura, Mazda Tribute and Nissan Altima hybrid). Combined with the eleven models in 2006, there were 15 models available in 2007. In other words, due to the different distribution years of the hybrid vehicles, the hybrid vehicles market had 5 makers and 9 models in 2005, 6 makers and 11 models in 2006 and 8 makers and 15 models in 2007.

In Figure 1, we can see that Toyota Prius totally dominated the market.

Figure 1 HEV registration numbers in 2005 to 2007



Source: R. L. Polk & Co.

Table 4 percentage change of Hybrid Electric Vehicle by car classes

Car Classes	Model	%Change 2005-2006	%Change 2006-2007	%Change 2005-2007
Small Car				
	Ford Focus			
	Honda Civic	19%	3%	22%
Midsize Car				
	Honda Accord	-205%	-66%	-406%
	Honda Insight	11%	-7010%	-6210%
	Nissan Altima			
	Saturn Aura			
	Toyota Camry	100%	42%	100%
	Toyota Prius	4%	35%	38%
Compact SUV				
	Ford Escape	18%	-4%	15%
	Mazda Tribute			
	Mercury Mariner	92%	16%	93%
	Saturn VUE		73%	
Midsize SUV				
	Lexus RX	2%	-17%	-15%
	Toyota Highlander	47%	-47%	22%
Large Luxury				
	Lexus GS		2%	
Super Luxury				
	Lexus LS			

Source: R. L. Polk & Co.

Table 4 shows the growth rates of HEVs by car classes and by model. Excluding the Toyota Camry, which was just introduced in 2006 Q2, Mercury Mariner’s growth increased the most (by 92%) and the Honda Accord Hybrid dropped the most (by 205%) in 2005. From 2006 to 2007, the Saturn VUE Green Line increased by 73% and the Honda Insight dropped extensively (by 7010%). In these three years, Mercury Mariner increased the most (by 93%) and Honda Insight dropped 6210% because of Honda Insight gradually leaves the market. The Honda Insight was totally removed from the HEV market in 2007 Q2 (5 units in 2007Q1 and 2007 Q2).

Table 5 Top 10 States of Hybrid Sales (2007 Calendar Year)

Rank	**State**	**Total New Hybrid Registration**	**Share of US Hybrid Vol. (%)**	**Vol. Increase from 2006 (%)**
1	California	91,417	26.1	35.4
2	Florida	19,283	5.5	49.5
3	New York	17,385	5	49.4
4	Texas	17,196	4.9	37
5	Washington	13,107	3.7	51.5
6	Illinois	13,094	3.7	37.9
7	Virginia	11,952	3.4	14.6
8	Pennsylvania	11,089	3.2	31.9
9	Massachusetts	9,982	2.8	35.5
10	New Jersey	9,645	2.8	36.1

Source: R. L. Polk & Co.

From Polk's data, Table 5 shows that in 2007, the top 10 states for new HEV registrations are the following: California, Florida, New York, Texas, Washington, Illinois, Virginia, Pennsylvania, Massachusetts, and New Jersey.

Table 6 Top 5 HEV registration numbers by state

Segment	Model	Top 5 HEV Sales by state					5 states total	51 states total
Small Car	**Ford Focus**	**FL**	**MI**	-	-	-		
		3	1	-	-	-	4	4
		75%	25%	-	-	-	100%	
	Honda Civic	**CA**	**TX**	**VA**	**FL**	**NY**		
		23044	4695	4116	4109	3309	39273	85170
		27.10%	5.50%	4.80%	4.80%	3.90%	46.10%	
Midsize Car	**Honda Accord**	**CA**	**TX**	**FL**	**NC**	**VA**		
		5238	1740	1441	1071	1070	10560	25353
		20.70%	6.90%	5.70%	4.20%	4.20%	41.70%	
	Honda Insight	**CA**	**FL**	**TX**	**WA**	**PA**		
		281	94	87	74	54	590	1352
		20.80%	7.00%	6.40%	5.50%	4.00%	43.60%	
	Nissan Altima	**CA**	**NY**	**MA**	**NJ**	**PA**		
		4203	852	486	307	142	5990	6813
		61.70%	12.50%	7.10%	4.50%	2.10%	87.90%	
	Saturn Aura	**CA**	**TX**	**MI**	**IL**	**FL**		
		58	46	41	38	37	220	650
		8.90%	7.10%	6.30%	5.80%	5.70%	33.80%	
	Toyota Camry	**CA**	**FL**	**TX**	**NY**	**IL**		
		18670	4854	4788	3403	3360	35075	80728
		23.10%	6.00%	5.90%	4.20%	4.20%	43.40%	
	Toyota Prius	**CA**	**FL**	**TX**	**NY**	**VA**		
		102409	17818	16131	15647	13629	165634	364277
		28.10%	4.90%	4.40%	4.30%	3.70%	45.50%	
Compact SUV	**Ford Escape**	**CA**	**VA**	**NY**	**IL**	**TX**		
		11408	2373	2098	2038	1978	19895	43617
		26.20%	5.40%	4.80%	4.70%	4.50%	45.60%	
	Mazda Tribute	**CA**	**OR**	**TX**	-	-		
		99	2	1	-	-	102	102
		97.10%	2.00%	1.00%	0.00%	0.00%	100.00%	
		CA	**MI**	**IL**	**NY**	**VA**		
	Mercury Mariner	914	422	390	374	372	2472	6887
		13.30%	6.10%	5.70%	5.40%	5.40%	35.90%	
		CA	**FL**	**TX**	**MI**	**IL**		
	Saturn VUE	1134	428	409	359	310	2640	6701
		16.90%	6.40%	6.10%	5.40%	4.60%	39.40%	
Midsize SUV	**Lexus RX450h**	**CA**	**FL**	**NY**	**TX**	**NJ**		

		14244	3956	3643	3502	2404	27749	54467
		26.20%	7.30%	6.70%	6.40%	4.40%	50.90%	
	Toyota Highlander	**CA**	**NY**	**FL**	**TX**	**VA**		
		14595	3567	3514	3115	3070	27861	68475
		21.30%	5.20%	5.10%	4.50%	4.50%	40.70%	
Large Luxury	**Lexus GS450h**	**CA**	**FL**	**TX**	**NY**	**IL**		
		1032	307	286	123	110	1858	3154
		32.70%	9.70%	9.10%	3.90%	3.50%	58.90%	
Super Luxury	**Lexus LS600h L**	**CA**	**TX**	**NY**	**FL**	**IL**		
		181	67	64	62	50	424	783
		23.10%	8.60%	8.20%	7.90%	6.40%	54.20%	

Source: R. L. Polk & Co.

From Table 6, the top 5 HEV registration states per vehicle accounted for the following amounts for each respective vehicle: a minimum of 34% for the Saturn Aura and a maximum of 88% for the Nissan Altima. When computing these extreme values the Ford Focus and the Mazda Tribute were excluded because Ford Focus was retired from the market in 2005 and Mazda Tribute had just entered the market in 2007. Since the above five states welcome hybrid cars so much, it is especially important to pay attention to these specific states to see what kind of incentives or other factors affect their high sales of hybrid cars.

Table 7 growth rate by car classes and by car models

Car Classes	Share	growth rate 2005-2007	Model	share	growth rate 2005-2006	growth rate 2006-2007	growth rate 2005-2007
Small Car	11.38%	**27.63%**	Ford Focus	0.00%	-100.00%		
			Honda Civic	11.38%	23.54%	3.33%	27.65%
Midsize Car	64.01%	**89.69%**	Honda Accord	3.39%	-67.20%	-39.69%	-80.22%
			Honda Insight	0.18%	12.68%	-98.59%	-98.42%
			Nissan Altima	0.91%			
			Saturn Aura	0.09%			
			Toyota Camry	10.78%		72.57%	
			Toyota Prius	48.67%	4.23%	53.99%	60.49%
Compact SUV	7.66%	**83.76%**	Ford Escape	5.83%	21.98%	-3.83%	17.32%
			Mazda Tribute	0.01%			
			Mercury Mariner	0.92%	1114.40%	18.61%	1340.40%
			Saturn VUE	0.90%		277.28%	
Midsize SUV	16.42%	**6.11%**	Lexus RX	7.28%	2.05%	-14.44%	-12.69%
			Toyota Highlander	9.15%	87.12%	-31.85%	27.53%
Large Luxury	0.42%	**2.18%(06-07)**	Lexus GS	0.42%		2.18%	
Super Luxury	0.10%	**N/A(2007)**	Lexus LS	0.10%			
Total	100.00%			**100.00%**	**27.29%**	**31.23%**	**67.04%**

The definition of vehicle size classes is based on U.S. News[12] and U.S. Department of Energy[13]. Two main categories of size classes are cars and trucks. The definition of the size class for cars is based on cargo volumes and interior passenger as showed in Table 8, while the size class for trucks is defined by the gross vehicle weight rating (GVWR), which is the vehicle weight and its carrying capacity. However, fuel economy regulations are not applicable to heavy duty vehicles (see Frequently Asked Questions in Fuel Economy Estimates at fueleconomy.gov).

[12] See http://usnews.rankingsandreviews.com/cars-trucks/
[13] See http://www.fueleconomy.gov/feg/info.shtml

Table 8 Vehicle Size Classes Used in the Fuel Economy Guide

Cars		
Class	**Passenger & Cargo Volume (Cu. Ft.)**	
Two-Seaters	Any (cars designed to seat only two adults)	
Sedans		
Mini-compact	Less than 85	
Subcompact	85 to 99	
Compact	100 to 109	
Mid-Size	110 to 119	
Large	120 or more	
Station Wagons		
Small	Less than 130	
Mid-Size	130 to 159	
Large	160 or more	

Trucks		
Class	**Gross Vehicle Weight Rating (GVWR)***	
Pickup Trucks	**Through 2007**	**Beginning 2008**
Small	Less than 4,500 lbs.	Less than 6,000 lbs.
Standard	4,500 to 8,500 lbs.	6,000 to 8,500 lbs.
Vans	**Through 2010**	**Beginning 2011**
Passenger	Less than 8,500 lbs.	Less than 10,000 lbs.
Cargo	Less than 8,500 lbs.	
Minivans	Less than 8,500 lbs.	
Sport Utility Vehicles		
	Through 2010	**2011–2012**
All	Less than 8,500 lbs.	Less than 10,000 lbs.
	Beginning 2013	
Small	Less than 6,000 lbs.	
Standard	6,000 to 9,999 lbs.	
Special Purpose Vehicles	**Through 2010**	**Beginning 2011**
	Less than 8,500 lbs.	Less than 8,500 lbs. or less than 10,000,depending on configuration

*Gross Vehicle Weight Rating (GVWR) is calculated as truck weight plus carrying capacity.
Data source: http://www.fueleconomy.gov/feg/info.shtml

There are six car classes in Polk's data. In the class of small car, there are two models, Ford Focus and Honda Civic, account for 11.38% for the share of the data. Midsize cars, which contained six models, dominated the HEV market with 64.01% of market share. Midsize SUVs have the second largest HEV share but far less than midsize car by approximately a factor of four. Midsize cars plus midsize SUVs make up 80% of total market share. Within the class of midsize car, Toyota Prius has 49% of market share, and the Honda Civic (which belongs to the small car category) ranks second. Both of these vehicles make up 60.05% the total HEV market. The top three HEV shares are Toyota Prius, Honda Civic and Toyota Camry. Each of the remaining 13 models does not individually exceed 10%. HEV sales grew continually over time with the following growth rates: from 2005-2006, a 27.29% increase and from 2006-2007, a 31.23% increase and from 2005 to 2007 and a total growth rate of 67.04%.

Table 9 Growth rate by make

Make	share	growth rate 2005-2007 by make	Model	share	growth rate 2005-2006 by model	growth rate 2006-2007 by model	growth rate 2005-2007 by model
Ford	5.83%	17.28%	Escape	5.83%	21.98%	-3.83%	17.32%
			Focus	0.00%	-100.00%		
Honda	14.95%	-17.46%	Accord	3.39%	-67.20%	-39.69%	-80.22%
			Civic	11.38%	23.54%	3.33%	27.65%
			Insight	0.18%	12.68%	-98.59%	-98.42%
Lexus	7.80%	-0.06%	RX400h	7.28%	2.05%	-14.44%	-12.69%
			GS450h	0.42%		2.18%	
			LS600hL	0.10%			
Mercury	0.92%	1340.40%	Mariner	0.92%	1114.40%	18.61%	1340.40%
Toyota	68.60%	99.73%	Highlander	9.15%	87.12%	-31.85%	27.53%
			Prius	48.67%	4.23%	53.99%	60.49%
			Camry	10.78%		72.57%	
Saturn	0.98%	277.28% (2006-2007)	VUE	0.90%		277.28%	
			Aura	0.09%			
Mazda	0.01%	N/A(2007)	Tribute	0.01%			
Nissan	0.91%	N/A(2007)	Altima	0.91%			
	100.00%		Total growth	100.00%	27.29%	31.23%	67.04%

On Table 9, growth rate by make, the three models (Accord, Civic, and Insight) made by Honda have about 15% market share almost entirely through the hybrid Civics. The market share of Honda Accord Hybrids declined and the growth rate of this vehicle dropped 80.22% from 2005 to 2007 because the Accord hybrid has been gradually discontinued and inventory is being cleared out. Honda insight has the same situation where its growth rate is down 98.42%. Nissan distributed the Altima hybrid in 2007 and limited sales to just eight states. The Altima Hybrid was available only in California, New York, Massachusetts, Connecticut, Vermont, Oregon, Rhode Island, Maine, and New Jersey. Service of hybrid components outside those states was limited and could have involved large delays in service. Nissan used Toyota's hybrid synergy drive (HSD) system but if they could have expanded their inventory and built their hybrids using their own technology, they could increase their sales by regions. Toyota's market share is the highest of any company with 68.6% and in these three years the company's sales of HEVs grew 99.73%.

Table 10 market share by car classes

Car Classes	2005 share	2006 share	2007 share	growth rate 2005-006	growth rate 2006-2007	growth rate 2005-2007	Model	2005 share	2006 share	2007 share	05-07 share
Small Car	12.78%	12.40%	9.76%	23.52%	3.33%	27.63%	Ford Focus	0.00%			0.00%
							Honda Civic	12.78%	12.40%	9.76%	11.38%
Midsize Car	61.70%	57.89%	70.06%	19.43%	58.83%	89.69%	Honda Accord	8.75%	2.26%	1.04%	3.39%
							Honda Insight	0.33%	0.29%	0.00%	0.18%
							Nissan Altima			2.15%	0.91%
							Saturn Aura			0.20%	0.09%
							Toyota Camry		12.26%	16.12%	10.78%
							Toyota Prius	52.62%	43.08%	50.55%	48.67%
Compact SUV	6.90%	8.33%	7.60%	53.54%	19.69%	83.76%	Ford Escape	6.77%	6.49%	4.76%	5.83%
							Mazda Tribute			0.03%	0.01%
							Mercury Mariner	0.13%	1.26%	1.14%	0.92%
							Saturn VUE		0.58%	1.67%	0.90%
Midsize SUV	18.62%	20.74%	11.82%	41.81%	-25.17%	6.11%	Lexus RX400h	9.92%	7.95%	5.18%	7.28%
							Toyota Highlander	8.70%	12.79%	6.64%	9.15%
Large Luxury		0.65%	0.50%		2.18%		Lexus GS450h		0.65%	0.50%	0.42%
Super Luxury			0.25%				Lexus LS600h L			0.25%	0.10%
	100.00%	100.00%	100.00%	27.29%	31.23%	67.04%		100.00%	100.00%	100.00%	100.00%

Table 9 shows that midsize cars comprised 62%, 58% and 70% of all hybrid vehicle sales in 2005, 2006 and 2007, respectively. Midsize SUV's market share in all sample HEV registration data was roughly 19%, 21% and 12% in 2005, 2006 and 2007, respectively. Although Compact SUV sales grew quickly but their market share did not rise above 9%.

Table 11 share by car classes, by make and by model

Car Classes	Share	Make	Share	Model	Share
Midsize Car	64.01%	**Toyota**	68.60%	**Toyota Prius**	48.67%
				Honda Civic	11.38%
Midsize SUV	16.42%	**Honda**	14.95%	**Toyota Camry**	10.78%
				Toyota Highlander	9.15%
Small Car	11.38%	**Lexus**	7.80%	**Lexus RX400h**	7.28%
				Ford Escape	5.83%
Compact SUV	7.66%	**Ford**	5.83%	**Honda Accord**	3.39%
				Mercury Mariner	0.92%
Large Luxury	0.42%	**Saturn**	0.98%	**Nissan Altima**	0.91%
				Saturn VUE	0.90%
Super Luxury	0.10%	**Mercury**	0.92%	**Lexus GS450h**	0.42%
				Honda Insight	0.18%
		Nissan	0.91%	**Lexus LS600h L**	0.10%
				Saturn Aura	0.09%
		Mazda	0.01%	**Mazda Tribute**	0.01%
6 Classes	100.00%	**8 Makes**	**100.00%**	**15 Models**	100.00%

Table 11 shows that the share by different car classes, by make and by model. Midsize car dominated the other car class, which is around four times of the second largest car class, midsize SUV. Meanwhile, super luxury owns the lowest share, 0.1%.

For the different make, there are eight makes in the current data, they are Toyota, Honda, Lexus, Ford, Saturn Mercury Nissan and Mazda. Toyota ranks number one in these eight makes, which is 4.6 times the second largest make, Honda. Moreover, Mazda is the lowest share which is 0.01%. Finally, for different model, there are total 15 models in these three years, and the Toyota Prius is the best-selling vehicle, around four times more than the second largest hybrid, Honda Civic. The lowest share of the model is Mazda Tribute, which is 0.01.

2.4 Government Incentives

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. As showed in Table 11[14], 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. In addition to the federal tax credit, many states offer additional incentives as showed in Table 12. 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[15].

[14] Tax Incentives Information Center - Fuel Economy (http://www.fueleconomy.gov/feg/taxevb.shtml)

[15] See Diamond(2009)

Table 12 Federal credit support

Company	Vehicle Make & Model		Full Credit	Phase Out 50%	Phase Out 25%	No Credit
			Jan.1, 06	**Apr. 1–Sep. 30, 09**	**Oct. 1, 09 – Mar. 31, 10**	**Apr. 1, 10**
Ford	2005-07 Ford Escape Hybrid	2WD	$2,600	1,300	$650	$0
		4WD	$1,300	$975	$487.50	$0
	2006-07 Mercury Mariner Hybrid	4WD	$1,950	$975	$487.50	$0
			Jan.1–Sep. 30, 06	**Oct. 1, 06 – Mar. 31, 07**	**Apr. 1 – Sep. 30, 07**	**Oct. 1, 07**
Toyota	2005-08 Prius		$3,150	$1,575	$787.50	$0
	2006-08 Highlander Hybrid (2WD & 4WD)		$2,600	$1,300	$650	$0
	2006-08 Lexus RX400h (2WD & 4WD)		$2,200	$1,100	$550	$0
	2007-08 Camry Hybrid		$2,600	$1,300	$650	$0
	2007 Lexus GS 450h		$1,550	$775	$387.50	$0
	2008 Lexus LS 600h		-	-	$450	$0
			Jan.1, 06-Dec.31, 07	**Jan. 1 – Jun. 30, 08**	**July 1 – Dec. 31, 08**	**Jan. 1, 09**
Honda	2005-06 Insight CVT		$1,450	$725	$362.50	$0
	2005 Accord Hybrid AT &Navi AT		$650	$325	$162.50	$0
	2006-07 Accord Hybrid AT &Navi AT		$1,300	$650	$325	$0
	2005 Civic Hybrid (SULEV) MT & CVT		$1,700	$850	$425	$0
	2006-09 Civic Hybrid CVT		$2,100	$1,050	$525	$0
			Jan. 1, 06	**TBD**	**TBD**	**TBD**
GM	2007-08 Saturn Aura Hybrid		$1,300	-	-	-
	2007 Saturn Vue Hybrid		$650	-	-	-
Nissan	2007-09 Altima Hybrid		$2,350	-	-	-
Mazda	2008 Mazda Tribute Hybrid	2WD	$3,000	-	-	-
		4WD	$2,200	-	-	-

Table 12 shows that the Federal government offers a 2,000 dollar tax deduction from 2000 to 2005 for buying hybrid electric vehicle. However, the deduction was converted to tax credit in January 2006 based on the Energy Policy Act of 2005. The tax credit varies by car model and the Toyota Prius qualified for the largest tax credit at $3150. The 2005 Accord Hybrid model and the 2007 Saturn VUE Green Line hybrid qualified for the lowest tax credit at $650. The federal credit phases out over the next four quarters when auto manufacturer's hybrid sales exceed 60,000 units. The federal credit was completely phased out on April 1st, 2010. Toyota sales have reached the 60.000 unit threshold in May 2006 while Honda reached the threshold in August, 2007.

Table 13 State Incentives

State Incentives	Vehicle	Time	Value
HOV lane			
Arizona	Insight, Civic, Prius	2/2007-2010	
California	Insight, Civic, Prius	1/2005-2010	
Florida	All HEVs	Q3, 2006-2010	
Utah	All HEVs	2005-2010	
New Jersey	Certain HEVs*	5/2006-2010	
New York	Insight, Civic, Prius	3/2006-2010	
Virginia	Certain HEVs*	Prior to 7/2006-all lanes open.	
		7/2007-2010: no access on I-95/395.	
Sales Tax Exemption			
Connecticut	Civic, Prius, Insight	2004-2010.	6% savings($1217-1409)
Maine	All HEVs	2005 only	50% credit of 5% tax.($300-$500)
New York	All HEVs	1/2004-2/2005	$3000 credit.
Income Tax Credit			
Colorado	Certain HEVs*	2001-2010	Varying value ($2265- $4,713).
Louisiana	All HEVs	2002-2010	2% of value of vehicle
South Carolina	All HEVs	6/2006-2010	State income tax credit=20% of federal credit ($130-$630)
Utah	Civic only	2005 only	50% of incremental cost, ($1537-$3000)
Oregon	Certain HEVs*	2005-2010	$750 or $1500 residential and Business tax credit
West Virginia	All HEVs	Pre 2005-6/2006	$3,750

*Toyota Prius, Honda Insight, Honda Civic, 2005 Ford Escape, 2006 Ford Escape, 2006 Toyota Highlander, 2006 Lexus RX400, 2006 Mercury Mariner, 2006 Honda Accord, 2007 Toyota Camry, 2007 Lexus GS450h, 2007 Ford Escape, 2007 Mercury Mariner, 2007 Honda Accord and 2007 Toyota Highlander.
http://www.afdc.energy.gov/laws/state

Table 13 shows that the state incentives include the high-occupancy-vehicle (HOV) lane access, Sales tax exemption and income tax credit. There are 7 states that allowed single-occupancy hybrid vehicles have the HOV lane access: Arizona, California, Florida, Utah, New Jersey, New York and Virginia. This policy is also implemented for different car models and starting periods. In Arizona, the HOV access started from 2007 Q1 for Insight, Civic and Prius. California issued 85,000 permits for HOV lane starts from 2005Q1 for Insight, Civic and Prius. The HOV policy in Florida applied for all HEV models since 2006Q3. Starting from 2005, Utah also provided HOV lane access for all HEVs. New Jersey offers HOV lane access starting from 2005 for the following HEVs: Toyota Prius, Honda Insight, Honda Civic, 2005 Ford Escape, 2006 Ford Escape, 2006 Toyota Highlander, 2006 Lexus RX400, 2006 Mercury Mariner, 2006 Honda Accord, 2007 Toyota Camry, 2007 Lexus GS450h, 2007 Ford Escape, 2007 Mercury Mariner, 2007 Honda Accord and 2007 Toyota Highlander. New York offers HOV lane access for Insight, Civic and Prius starting from 2006Q1.

The sales tax exemption applied to three states; Connecticut, Maine and New York. In 2004, Connecticut provided a 6% saving through the sales tax exemption, which applied to HEVs whose MPGs were greater than 40. Maine offered a 50% credit of 5% tax for all HEVs but for 2005 only. New York offered a 3000-dollar credit for all HEVs from January 2004 to February 2005.

Six states offered income tax credit: Colorado, Louisiana, South Carolina, Utah, Oregon and West Virginia. Colorado offered an income tax credit since 2001 and this credit was valid up to 4713 dollars for certain HEVs. Louisiana offered a 2% credit for all HEV models from 2002 to 2010. South Carolina gave a 205-dollar federal credit for all HEVs starting from 2006 Q2. Utah offered a 50% credit of incremental cost, up to $3000 for Honda Civic since 2005. Oregon started this policy from 2005 to 2010 for certain HEVs. West Virginia offered a flat credit of 3750 dollars from 2005 for all HEVs.

2.5 Socioeconomic Characteristics

Socioeconomic variables are based on the "Census 2000" from the U.S. Census Bureau. There are five categories and twenty-one variables in the data, and all of them are county-based. However, in Polk's data, there is "Broomfield County, Colorado" which is not included in the Census 2000. It is because Broomfield County combines parts of four adjacent counties-Adams, Boulder, Jefferson and Weld; on November 15, 2001, Broomfield County became the 64th county of Colorado. Thus, it is not included in the census 2000 data. In addition, the interaction-term data also included in this study.

In order to distinguish the urban and rural difference, the Rural-Urban Continuum Codes from the U.S.D.A. Economic Research Service for 2003 are used as Table 14 described.

Table 14 2003 Rural- Urban Continuum Codes

2003 Rural-Urban Continuum Codes

Code	Definition
Metro counties:	
1	Counties in metro areas of 1 million population or more
2	Counties in metro areas of 250,000 to 1 million population
3	Counties in metro areas of fewer than 250,000 population
Nonmetropolitan counties:	
4	Urban population of 20,000 or more, adjacent to a metro area
5	Urban population of 20,000 or more, not adjacent to a metro area
6	Urban population of 2,500 to 19,999, adjacent to a metro area
7	Urban population of 2,500 to 19,999, not adjacent to a metro area
8	Completely rural or less than 2,500 urban population, adjacent to a metro area
9	Completely rural or less than 2,500 urban population, not adjacent to a metro area

Source: U.S.D.A., 2003 Economic Research Survey

The following eleven demographic variables are used in this study: Mean Age, College degree per capita, High school degree per capita, Drive alone and travel time greater than 40 minutes, Drive alone and travel time less than 24minutes, Public transport and travel time greater than 40 minutes, Public transport and travel time less than 24 minutes, High Income household in urban area, Low income household in urban area, Household vehicle amount less than 2 cars, and Household vehicle amount greater than 3 cars.

2.6 Gasoline Prices

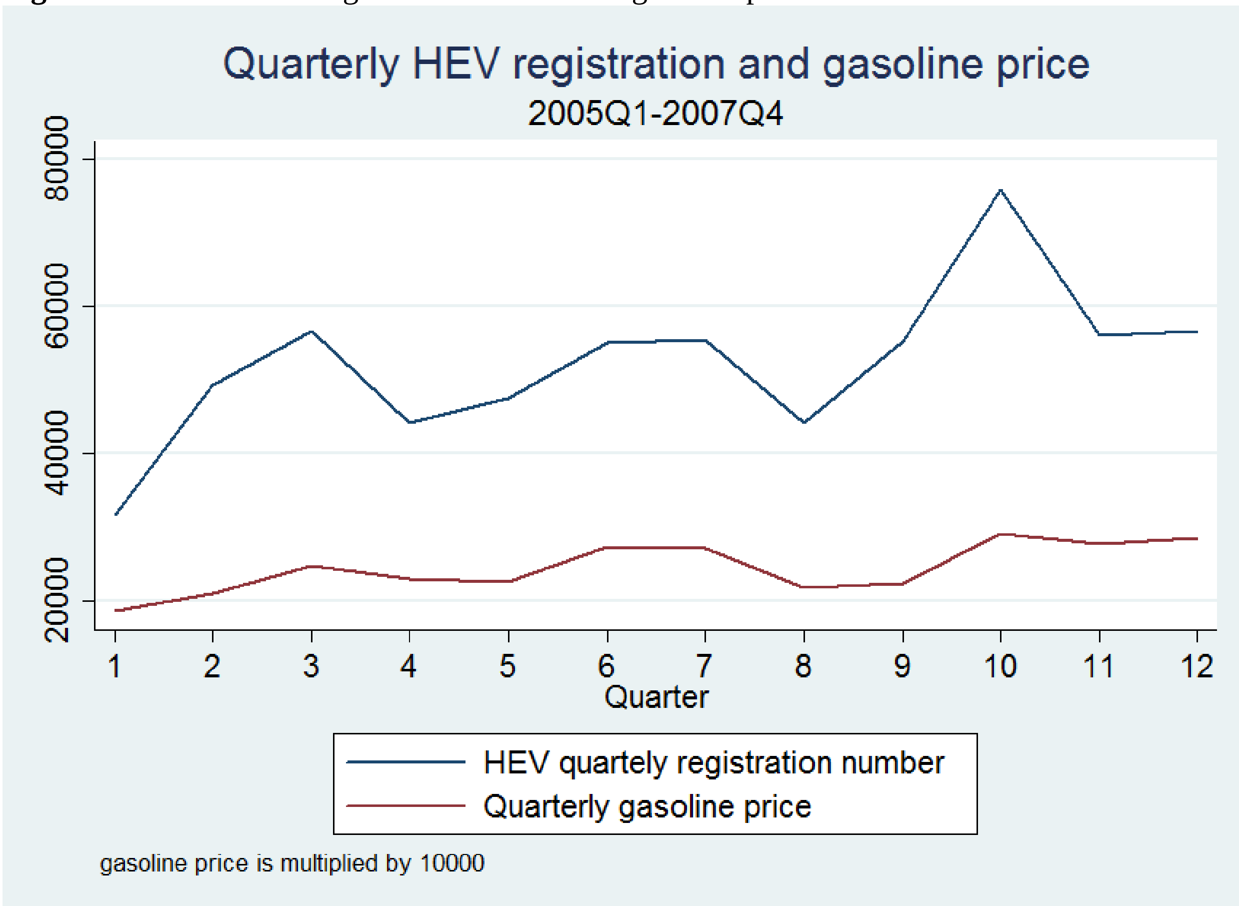
State-level gasoline price data is acquired from "Monthly Motor Fuel Reported by States" issued by the Federal Highway Administration (*FHWA*), which details the retail prices of motor fuel sale to the end users through retail outlets. Gasoline prices in this report are taken from the U.S. Department of Energy, Energy Info Admin's Petroleum Marketing Monthly Report, Table 31 - Motor Gasoline Prices by Grade, Sales Type, PAD District (Cents per Gallon Excluding Taxes)[16]. The motor fuel report contains three grades of motor fuels — Regular, Midgrade and Premium. I choose the regular grade gasoline price into my data, and its price is recorded monthly at the state level. Since the report is by month, I calculated the gasoline prices as a quarterly data. The unit of the gasoline price in the dataset is dollars-per-gallon. Noting that taxes have been included. The state taxes rate on gasoline are obtained from Highway Statistics 2010 (Part 8.4.6 State tax rates on motor fuel, Table MF-121T[17]). The study period of state-level gasoline price with taxes data is from 2005 quarter one to 2007 quarter four.

Meanwhile, for lacking of the historical gasoline price data in Washington DC because of no disclosure, hybrid electric vehicle sales data (650 units in year 2005, 801 units in year 2006, and 982 units in year 2007) in District of Columbia has been removed. The gasoline price excluding taxes in District of Columbia are only available in year 2000, year 2002, and year 2010 from the source of U.S. Energy Information Administration (EIA) (Prices, Sales Volumes & Stocks by State)[18].

[16] See https://www.fhwa.dot.gov/policyinformation/motorfuelhwy_trustfund.cfm
[17] See https://www.fhwa.dot.gov/policyinformation/statistics/2010/mf121t.cfm
[18] See http://www.eia.gov/dnav/pet/pet_sum_mkt_dcu_nus_m.htm

Figure 2 shows the HEV registration number and gasoline price from 2005 quarter 1 to 2007 quarter 4. Gasoline price rose from 1.73 per gallon in 2005 Q1 to 3.16 per gallon in 2007 Q2. The quarterly gasoline price is multiplied by 10000 for better demonstration. The blue line is the HEV quarterly registration number while the brown line is the quarterly gasoline price. The two lines showed the same trend. In other words, when gasoline price goes up, the registration of the HEV rises.

Figure 2 Trend of HEV registration number and gasoline price



2.7 Car Characteristics

The 2005-2007 *Ward's Automotive Yearbook* provides car and light truck U.S. specifications and prices. Car characteristics obtained from *Ward's Automotive Yearbook* include body style, drive type, wheelbase, length, width, height, curb weight, net horsepower, revolutions per minute(RPM), and city and highway miles per gallon(MPG), and retail price. All of above vehicle attributes are by make, model, and year.

However, not all of the hybrid electric vehicles characteristics are provided in *Wards*. For those not in *Wards*, we utilize the market information provided by *InternetAutoguide.com*. Specifically, there are four models that do not have the corresponding specifications in 2005: Ford Focus, Lexus RX400h, Mercury Mariner and Toyota Highlander. In 2006, three models, Lexus GS450H, Toyota Camry Hybrid, and Saturn VUE Green Line, are not provided in *Wards*. In 2007, four models which are Honda Insight, Lexus LS600H, Saturn Aura, and Nissan Altima Hybrid are not in *Wards*.

Table 15 MPG and MSRP

Car Classes	Model	2005 Combined MPG	2005 MSRP	2006 Combined MPG	2006 MSRP	2007 Combined MPG	2007 MSRP	Ratio of MPG and MSRP(*100) 2005	2006	2007
Small Car	Ford Focus	29								
	Honda Civic	48	20165	50	22400	50	23195	0.24	0.22	0.22
Midsize Car	Honda Accord	33	30505	32	31540	32	31685	0.11	0.10	0.10
	Honda Insight	64	19695	63	19880	63	19880	0.32	0.31	0.31
	Nissan Altima					27	18565			0.14
	Saturn Aura					23	20595			0.11
	Toyota Camry			27	18985	39	26480		0.14	0.15
	Toyota Prius	56	21415	56	22305	56	22305	0.26	0.25	0.25
Compact SUV	Ford Escape	34	26970	34	27515	34	26320	0.12	0.12	0.13
	Mazda Tribute					30	20705			0.14
	Mercury Mariner	24	21995	31	29840	31	28615	0.11	0.10	0.11
	Saturn VUE			25	17990	29	22995		0.14	0.13
Midsize SUV	Lexus RX400h	17	36400	29	49060	30	41895	0.05	0.06	0.07
	Toyota Highlander	24	24645	31	33595	31	33095	0.10	0.09	0.09
Large Luxury	Lexus GS 450h			25	43800	26	44865		0.06	0.06
Super Luxury	Lexus LS600h L					21	30970			0.07

Table 15 shows the Miles-per-Gallon (MPG) and vehicle price (MSRP) for different car models. Newer vehicles are based on the base price of the vehicle, so a 1990 car is based on its value in 1990. The MSRP and Plate Fee Charts are available at the website of Michigan Secretary of State's Office[19]. Since the vehicle retail prices at the county level are not observable, we use the MSRPs instead. The variations in vehicle retail prices in different counties are captured by the error term. As Beresteanu and Li (2009) mentioned, the error term also captures marketing efforts at the local level such as advertisement.

The combined MPG is calculated as $\frac{1}{(0.55/City\ MPG)+(0.45/Hightway\ MPG)}$ to evaluate car's fuel efficiency. Higher MPG means a HEV is more efficient in fuel consumption. From my dataset in 2005-2007, the highest city-MPG is Honda Insight at 63 miles-per-gallon. The lowest MPG for hybrid vehicle is the 2005 Lexus RX400h, which belongs to midsize SUV and the MPG at 17 MPG. I use ratio of MPG and MSRP multiplied by 100 to demonstrate the basic cost/performance. When MSRP is lower and MPG is higher, the ratio is higher. Therefore, the highest ratio is the 2005 Honda Insight which is 0.32 and the lowest ratio is the 2005 Lexus RX400h.

[19] See http://www.michigan.gov/sos/0,1607,7-127-49534_50300_50310-30109--,00.html

Table 16 Model status and hybrid system by car classes

Car Classes	Model	Status Full/ Mild	Hybrid System	Year Introduced
Small Car				
	Ford Focus	Retired Full	Ford Hybrid System	2004
	Honda Civic	Current Full	IMA	2002
Midsize Car				
	Toyota Prius	Current Full	HSD	2000 in US
	Honda Accord	Retired Full	IMA	2004
	Nissan Altima	Current Full	HSD	2007
	Saturn Aura	Current Mild	BAS	2007
	Toyota Camry	Current Full	HSD	2006
Compact SUV				
	Ford Escape	Current Full	Ford Hybrid System	2004
	Mercury Mariner	Current Full	Ford Hybrid System	2005
	Mazda Tribute	Current Full	Ford Hybrid System	2007
	Saturn VUE	Current Mild	BAS	2006
Midsize SUV				
	Lexus RX400h	Current Full	HSD	2005
	Toyota Highlander	Current Full	HSD	2005
Large Luxury				
	Lexus GS 450h	Current Full	HSD	2006
Super Luxury				
	Lexus LS600h L	Current Full	HSD	2007

(Note: IMA-Honda's Integrated Motor Assist (IMA) system; HSD: Toyota's Hybrid Synergy Drive; BAS: Belt Alternator Starter)

Table 16 mentioned about the different hybrid car model, Fuel-Efficient System Design (either mild or full hybrids)[20] and the year introduced. Despite its name, a mild hybrid vehicle is more closely to a standard gasoline-powered vehicle than the gasoline-electric hybrid vehicle. Meanwhile, the different degrees of hybridization happens between mild and full hybrid vehicles. A full hybrid vehicle is largely powered by its battery for the entire time when the car is running. Therefore, a full hybrid vehicle can be powered by only the

[20] See http://www.afdc.energy.gov/vehicles/electric_basics_hev.html

combustion engine, the electric motor, or by both. Therefore, the full hybrid system is more sophisticated. On the other hand, a mild hybrid is still using a combination of gas and electric power sources, so that the electric motor doesn't be capable of powering the car on its own; it uses the electric motor to supplement the engine during acceleration. Only Saturn Aura and Saturn VUE during our study period use the mild hybrid system. In this table, the drive train technology has different name by its brands. For example, Honda uses Integrated Motor Assist (IMA) and Toyota uses Hybrid Synergy Drive (HSD). General Motors used belt alternator starter (or BAS) for a mild hybrid system so that only two mild hybrids, Saturn Aura and Saturn VUE, use BAS system.

Toyota Prius enters the US market in 2000 while after two years, Honda Civic introduced. Additional three hybrid models (Ford Focus, Honda Accord and Ford Escape) was sold in 2004. In 2005, the three SUV hybrids (Lexus RX400h, Toyota Highlander and Mercury Mariner) enter the market while in 2006, three additional hybrids (Lexus GS 450h, Toyota Camry and Saturn VUE) introduced into the market. Four hybrid models introduced in 2007, which is Nissan Altima, Saturn Aura, Mazda Tribute and the Super Luxury model, Lexus LS600h L.

2.8 Descriptive Statistics

The following table presents the summary statistics for the hybrid vehicle registration data, state and federal incentives, HOV lane access privilege, gasoline prices, car characteristics and socioeconomic variables. 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

Table 17 Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Geographic Data					
State	48	27.24171	14.048	1	48
County	3059	1586.179	898.4134	1	3059
Sales Data					
Make	8	4.382353	2.57836	1	8
Model	16	8.558824	4.833657	1	16
New vehicle count	3113	1.743165	18.435	0	3275
year	3	2.205882	0.7962943	1	3
Quarter	12	7.323529	3.375701	1	12
Car Characteristics Data					
body style	4	1.823529	0.8214269	1	4
drive type	4	1.323529	0.8303301	1	4
wheelbase	16	105.5412	4.247023	94.5	112.3
length	16	179.7238	9.862594	155.1	191.1
width	16	70.36769	1.801797	66.7	72.6
height	16	61.67652	5.944047	53.3	70.4
curb weight	16	3325.325	604.9633	1850	4365
net hp	16	160.384	63.34906	67	303
Revolutions per minute(rpm)	16	5441.134	1165.188	1200	6600
mpg(city)	16	35.44139	13.80783	19	61
mpg(highway)	16	36.82332	12.80517	15	68
retail price(MSRP)	16	27379.19	8067.44	17990	49060
gasoline(taxes included)	51	2.499134	0.3379046	1.73	3.16
Incentives Data					
HOV lane	51	0.0498897	0.2177174	0	1
State Sales Tax Incentives	51	6.041129	117.7083	0	3000
State Income Tax credit	51	97.43227	496.4919	0	3906
Fed credit	51	1609.876	796.904	0	3400

Table 18 Summary Statistics (continued): Socioeconomics Data

Variable	Obs	Mean	Std. Dev.	Min	Max
Socioeconomics Data					
total county population	3113	89799.5	293431	67	9519338
Income more than 150 thousand	3113	1536.07	7111.1	0	196753
Income between 149 and 50 thousand	3113	12591.2	41529.7	14	1154043
income less than 49 thousand	3113	19559.1	57793.7	16	1785483
Sum of owner and renter households with 0 vehicles	3113	3444.06	20227.7	0	572094
Sum of owner and renter households with 1 vehicles	3113	11519.2	38804	9	1158027
Sum of owner and renter households with 2 vehicles	3113	12936.7	37188.4	10	1079792
Sum of owner and renter households with 3 vehicles	3113	4203.33	11218.8	6	353452
Sum of owner and renter households with 4 vehicles	3113	1135.45	3130.56	3	105580
Sum of owner and renter households with 5 vehicles	3113	428.736	1227.72	0	43614
College/ masters/ professional/ PhD	3113	14164.2	52712.6	3	1462389
HS/ Associates degree/ Some (incomplete) college	3113	32562.7	93068.1	41	2650035
travel time takes less than 25 min	3113	23644.4	64662.5	32	1850266
travel time takes 25 to 40 min	3113	8540.55	31549.4	3	941527
travel time takes 40 min or more	3113	7409.76	31782.2	3	932314
Use car/truck, drive alone	3113	31042	92070.4	26	2714944
Carpool	3113	4973.6	17057.7	4	582020
Use public transport including taxi	3113	1912.01	18757.5	0	517635
Use other method (e.g. motorcycle)	3113	1667.11	6673.23	7	177494
Work at home	3113	1333.14	4232.01	0	134643
approximate mean age	3113	38.614	3.06563	24.2889	50.4116

Table 17 and 18 represents the summary statistics which included hybrid registration data, car characteristics, federal and state incentives, gasoline prices, and socioeconomics variables.

Chapter 3

Methodology

3.1 Introduction

The purpose of this chapter is to present the econometric model used to analyze the panel data described in the previous chapter. The method chosen is a regression with fixed effects (also called Least Squares Dummy Variable Regression (LSDV)) that can control for the fixed factors the researchers cannot directly observe. By using a fixed effects model, it is possible to analyze the impact of variables that vary over time and investigate the relationship between independent variables and the dependent variable within an entity (county or vehicle model in this study). It is assumed that each entity's error term and the fixed constant (which controls for the unobserved characteristics) are not correlated. Therefore, in this chapter, the basic specification of a fixed effects model is described, and in the next chapter, the specific form of the model used for the analysis is estimated.

3.2 Empirical Model Specification

The fixed effects regression model is constructed to estimate the relationship between sales of the hybrid cars, government incentives, gasoline prices and socioeconomic factors. This methodology usually includes the dummy variables to control for unobserved heterogeneity without using any instruments. Therefore, it is also called least squares dummy variable (LSDV) model. I regress log of hybrid sales plus one divided by population on dollars-per-miles, vehicle price (MSRP), government incentives, socioeconomics variables, geographic fixed effects, vehicle model fixed effects, and time fixed effects.

The base model specification is given by

$$Log((Sales+1)/population)_{imt} = \alpha_i + \beta_1 (dollars-per-mile)_{it} + \beta_2 \log(Vehicle\ Prices)_{mt}$$
$$+\beta_3 (Incentives)_{imt} + \beta_4 (Socioeconomics)_i + \mu_m + \theta_t + \varepsilon_{imt} \qquad (3.1)$$

where the subscripts indicate a vehicle model sale m for a county i at time t. The α_i denotes the county fixed effects, μ_m denotes the vehicle model fixed effects, θ_t denotes the time fixed effects, and ε_{imt} denotes the stochastic error terms. The definition of dollars-per-mile (DPM) is $(Gasoline\ Prices)_t / (Miles\ Per\ Gallon)_{mt}$.

As Gallaghera and Muehlegger (2011) indicated that there are some potential bias exist. First of all, endogeneity problem exists due to the incentive policy selection, in other words, a state may choose the most effective incentive based on the local environment. For instance, because of the significant traffic congestion, allowing hybrid cars to dive in HOV lanes may happen in California and Virginia. Therefore, in these states, potential consumers may have a stronger incentive to buy hybrid cars to avoid the traffic congestion and save some time. The point estimates would go upper bounds on the efficiency of government incentives due to the endogenous policy selection.

Another possible bias may happen because we do not observe the negotiated price between dealer and the consumer. They might be able to split the tax incentive but that's what we cannot observe directly. Thus, the coefficients for the incentives would be expected to be biased conservatively (Gallaghera and Muehlegger, 2011).

3.3 Fixed Effects Model of Panel Data and Least Squares Dummy Variable (LSDV) Estimation

Consider the general panel data framework with fixed effects α_i

$$y_{it} = x_{it}'\beta + \alpha_i + \varepsilon_{it} \tag{3.2}$$

where $i = 1,\dots,n$ (units), $t = 1,\dots,T$ (time period) and α_i is the unobserved fixed effects. The fixed effect component α_i captures unobserved heterogeneity across individuals that is fixed over time. The endodeneity due to unobserved heterogeneity (i.e., $E\left[x_{it}\alpha_i \neq 0\right]$) can be eliminated by using first differenced data without the use of instruments.

Now, we stack the observations over *t* giving

$$\underset{(T\times1)}{Y_i} = \underset{(T\times L)}{X_i}\,\underset{(L\times1)}{\beta} + \underset{(1\times1)}{\alpha_i}\,\underset{(T\times1)}{1_T} + \underset{(T\times1)}{\varepsilon_i} \tag{3.3}$$

Next, create the giant regression

$$\begin{bmatrix} Y_1 \\ \vdots \\ Y_n \end{bmatrix} = \begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix}\beta + \begin{bmatrix} 1_T & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & 1_T \end{bmatrix}\begin{bmatrix} \alpha_1 \\ \vdots \\ \alpha_n \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \vdots \\ \varepsilon_n \end{bmatrix} \tag{3.4}$$

or

$$\underset{(T_n\times1)}{Y} = \underset{(T_n\times L)}{X}\,\underset{(L\times1)}{\beta} + \underset{(T_n\times n)}{D}\,\underset{(n\times1)}{\alpha} + \underset{(T_n\times1)}{\varepsilon} = X\beta + \left(I_n \otimes 1_T\right)\alpha + \varepsilon \tag{3.5}$$

where $D = I_n \otimes 1_T$

Now we need to use the technique of Partitioned Regression

Consider the following simple partitioned regression equation

$$\underset{(n\times1)}{Y} = \underset{(n\times k_1)}{X_1}\,\underset{(k_1\times1)}{\beta_1} + \underset{(n\times k_2)}{X_2}\,\underset{(k_2\times2)}{\beta_2} + \varepsilon \tag{3.6}$$

The Least Squared estimators for β_1 and β_2 can be expressed as

$$\hat{\beta}_1 = \left(X_1'Q_2X_1\right)^{-1} X_1'Q_2y \text{, } Q_2 = I_n - P_{X_2} \quad \textbf{(3.7)}$$

$$\hat{\beta}_2 = \left(X_2'Q_1X_2\right)^{-1} X_2'Q_1y \text{, } Q_1 = I_n - P_{X_1} \quad (3.8)$$

where

$$P_{X_1} = X_1\left(X_1'X_1\right)^{-1} X_1' \quad \textbf{(3.9)}$$

$$P_{X_2} = X_2\left(X_2'X_2\right)^{-1} X_2' \quad (3.10)$$

So the fixed effect estimator is the partitioned OLS estimator of β in the giant regression

$$\hat{\beta}_{FE} = \left(X'Q_DX\right)^{-1} X_1'Q_Dy \quad \textbf{(3.11)}$$

where $Q_D = I_{T_n} - P_D$, $P_D = D(D'D)^{-1}D'$, $D = I_n \otimes 1_T$

Now,

$$P_D = \left(I_n \otimes 1_T\right)\left[\left(I_n \otimes 1_T\right)'\left(I_n \otimes 1_T\right)\right]^{-1}\left(I_n \otimes 1_T\right)'$$

$$= \left(I_n \otimes 1_T\right)\left[I_n \otimes 1_T'1_T\right]^{-1}\left(I_n \otimes 1_T\right)'$$

$$= \left(I_n \otimes 1_T\right)\left[I_n \otimes \left(1_T'1_T\right)^{-1}\right]\left(I_n \otimes 1_T\right)'$$

$$= I_n \otimes P_T \quad (3.12)$$

Therefore,

$$Q_D = I_{T_n} - P_D$$

$$= I_{T_n} - \left(I_n \otimes P_T\right)$$

$$= I_n \otimes Q_T \quad (3.13)$$

As a result,

$$\hat{\beta}_{FE} = \left(X'Q_DX\right)^{-1} X'Q_Dy$$

$$= \left(X'\left(I_n \otimes Q_T\right)X\right)^{-1} X'\left(I_n \otimes Q_T\right)y$$

$$= \left(\sum_{i=1}^{n} \bar{X}_i'\bar{X}_i\right)^{-1} \sum_{i=1}^{n} \bar{X}_i'\bar{y}_i \quad (3.14)$$

That is the least squares dummy variable (LSDV) estimator of β in the fixed effects model.

In this chapter, I have presented the basic econometric method used to analyze the panel data described in Chapter 2. In the following chapter, I will estimate different fixed effects models, analyze the data and offer some policy suggestions.

Chapter 4

Estimation Results

4.1 Introduction

In this chapter, I study the factors that determine the sales of the hybrid electric vehicles and the effect of government incentives using quarterly, county-level data for sixteen vehicle models introduced from the first quarter of 2005 through the fourth quarter of 2007. Taking advantage of this rich data set of new hybrid vehicle registrations in 3,000 U.S. counties, I can analyze more detailed information about purchases than state level data would allow.

Using the fixed effect model described in the previous chapter, the Log((hybrid sales+1)/population) is the dependent variable and the explanatory variables include the state tax incentives, federal credit policy, driving cost, vehicle price, and single-occupancy access to HOV lanes. Finally, I include the county-level socioeconomic factors from the Census 2000 datasets, and use the percent of residents with college degree or high school degree, mean age, drive alone or take public transport, high income or low income household, travel time, and household vehicle amount to control for variation in county-level demographic trends.

In summary, this chapter reports the parameter estimates from the fixed effects model at the county level for the sales of hybrid electric vehicles, and then examines the effects of subsidy policies on the diffusion of hybrid vehicles.

4.2 Parameter Estimates

This section shows the estimation results. The dependent variable is Log((hybrid sales+1)/population), and the explanatory variables are dollars-per-mile, Log(vehicle price), a dummy variable for HOV lanes, monetary policy for the state and federal incentives, and the demographic variables.

The estimation results are shown in Table 19 and Table 20. There are three different specifications for the fixed effect model. For all of these three specifications, the dependent variable is Log((hybrid sales+1)/population) and the independent variables are dollars-per-mile, Log(vehicle price), a dummy variable for HOV lanes, county demographic variables and the one of the following different specifications.

In specification (1), the three monetary incentives (state sales Tax Incentive, state income Tax Incentive, and Federal Credit Incentive) are scaled by $1000 dollars to be a single explanatory variable. In specification (2), the three monetary incentives (state sales Tax Incentive, state income Tax Incentive, and Federal Credit Incentive) are divided by vehicle price. In specification (3), a dummy variable for the sales tax waiver incentive and for an income tax credit incentive are used as alternative ways to represent the monetary incentives.

Furthermore, in Table 21, the seasonal pattern of tax incentives by type and quarter of are year are analyzed, and Table 22 shows the estimates for the states which offer the tax incentives. In other words, state income tax policy occurs in Colorado, Louisiana, South

Carolina and West Virginia while state sales tax policy only occurs in Connecticut, Maine, and New York. Finally, Table 23 shows the post-estimation analysis of the effects of different subsidies.

Following the conventional practice, I begin the analysis with a fixed effects model of panel data in the county level. As showed in Table 19, for the non-monetary policy which is the single-occupant access to the HOV lane, all the estimation results of the three specifications are robust and show positive and significant results. On the other hand, interestingly, the federal support policy coefficients are all negative and significant in these three specifications, indicating that there is little evidence in this analysis to support the claim that federal credit incentives have a significant impact on the sales of HEVs. A possible explanation is that federal incentives were reduced over time when the sales of hybrids were increasing. As expected, the dollars-per-miles and the vehicle price in three specifications are all negative related to the HEV sales. The estimation result also suggested that counties that have more college graduates have greater propensity to purchase HEVs. For the interaction term of transportation mode and travel time to work, the estimation result showed that the travel time has no impact in HEV purchasing decisions. However, counties that have more commuters driving alone would purchase more HEVs. Interestingly, when a county has more people who commute through public transit (train, bus, and so on.) and travel time is over 40 minutes, it will have lower HEV sales. Furthermore, a household that owns fewer than or equal to two cars will have higher tendency to buy a HEV. On the other hand, when a household has more than three cars, it is less likely to buy a HEV. I recognize that this point is trivial, but it serves as a control variable. The mean age is positively correlated with HEV sales which is inconsistent with the result of Gallagher and Muehlegger (2011). For all of these independent variables, the variable of dollars-per-mile has the most important factor for determinant of the hybrid sales.

Table 19 Parameter Estimates of the Fixed Effects Model

Dependent Variable: Log((Sales+1)/pop)

Variable	(1)	(2)	(3)
dollars-per-mile(DPM)	-5.8998***	-6.1614***	-6.2049***
	(0.1200)	(0.1195)	(0.1174)
log(retail price)	-0.3201***	-0.3300***	-0.2512***
	(0.0120)	(0.0137)	(0.0112)
Incentives:			
HOV access dummy	0.6432***	0.6322***	0.6402***
	(0.0153)	(0.0153)	(0.0152)
Sales Tax Incentive($000)	0.6007***		
	(0.0447)		
Income Tax Incentive($000)	0.0473***		
	(0.0129)		
Federal Credit Incentive($000)	-0.0800***		
	(0.0031)		
Sales Tax policy/vehicle price		15.4596***	
		(0.9103)	
Income tax policy/vehicle price		-0.0872	
		(0.2695)	
Federal credit policy/vehicle price		-1.3385***	
		(0.0821)	
Sales Tax dummy			1.0460***
			(0.0646)
Income Tax dummy			-0.3488***
			(0.0587)
Federal Credit dummies			-0.3789***
			(0.0112)

Table 20 (continued) Parameter Estimates of the Fixed Effects Model
Dependent Variable: Log((Sales+1)/pop)

Variable	(1)	(2)	(3)
Socioeconomics:			
Mean Age	0.0893***	0.0893***	0.0893***
	(0.0007)	(0.0007)	(0.0007)
College degree per capita	0.0082	0.0083	0.0082
	(0.0389)	(0.0389)	(0.0388)
High school degree per capita	-1.9124***	-1.9124***	-1.9124***
	(0.0424)	(0.0425)	(0.0424)
Drive alone and travel time greater than 40 minutes	-3.3793***	-3.3793***	-3.3792***
	(0.0505)	(0.0505)	(0.0504)
Drive alone and travel time less than 24minutes	-3.9283***	-3.9283***	-3.9283***
	(0.0314)	(0.0314)	(0.0314)
Public transport and travel time greater than 40 minutes	-4.4622***	-4.4621***	-4.4621***
	(0.2666)	(0.2668)	(0.2662)
Public transport and travel time less than 24 minutes	-8.8456***	-8.8462***	-8.8458***
	(0.2955)	(0.2957)	(0.2951)
High Income household in urban area	-0.0000***	-0.0000***	-0.0000***
	(0.0000)	(0.0000)	(0.0000)
Low income household in urban area	-0.0000***	-0.0000***	-0.0000***
	(0.0000)	(0.0000)	(0.0000)
Household vehicle amount less than 2 cars	0.0755	0.0754	0.0756
	(0.0831)	(0.0831)	(0.0829)
Household vehicle amount greater than 3 cars	4.1376***	4.1375***	4.1376***
	(0.0779)	(0.0780)	(0.0778)
Constant	-6.6940***	-6.6250***	-7.1285***
	(0.1381)	(0.1543)	(0.1308)
Observations	218088	218088	218088
R-Squared	0.498	0.498	0.500

Standard errors in parentheses.
All specifications include state and quarter fixed effects and all socioeconomics controls.
Data Source: Polk's HEV data and Census 2000
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The following Table 21 is to investigate whether the seasonal pattern exists. The fourth rows contains the coefficient for the second quarter, followed by the third, fourth and first quarters, respectively. The seasonal pattern are the same for state income tax credit and state sales waiver. Although I lack the power to statistically distinguish the quarterly coefficients from each other for state income tax credit, I found the seasonal pattern that the both of the state government incentives increase monotonically in the subsequent quarters starting from the second quarter. Although the quarterly coefficient for the first quarter in these three types of incentives are the greatest, the federal credit incentive showed the different seasonal pattern---it decreased monotonically from the first quarter. I would expect that consumers were fully informed or fully understood the state government incentives during the study period.

Table 21 Tax incentives, by type and quarter of year.
Dependent Variable: Log((Sales+1)/population)

	Specification		
	(1) State Income Tax Credit ($000)	(2) State Sales Tax Waiver ($000)	(3) Federal Credit ($000)
dollars-per-miles	-5.8990***	-5.9009***	-5.8313***
	(0.1200)	(0.1200)	(0.1200)
Log(retail price)	-0.3201***	-0.3200***	-0.3155***
	(0.0120)	(0.0120)	(0.0120)
HOV access dummy	0.6432***	0.6432***	0.6437***
	(0.0153)	(0.0153)	(0.0152)
Quarter 2	0.0205	0.4899***	-0.0334***
	(0.0266)	(0.0893)	(0.0059)
Quarter 3	0.0342	0.5180***	-0.0781***
	(0.0254)	(0.0893)	(0.0063)
Quarter 4	0.0601*	0.5522***	-0.1583***
	(0.0237)	(0.0893)	(0.0048)
Quarter 1	0.0743**	0.8427***	0.0374***
	(0.0276)	(0.0893)	(0.0073)
Constant	-6.6935***	-6.6959***	-6.7965***
	(0.1381)	(0.1381)	(0.1381)
Observations	218088	218088	218088
r2	0.4982	0.4983	0.4997

Standard errors in parentheses.
All specifications include state and quarter fixed effects and all socioeconomics controls.
Data Source: Polk's HEV data and Census 2000
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 22 shows the effects of different forms of state tax incentives on HEV sales. In specification (1) and (2), the models examine the effects of state income tax credit on sales and state sales tax waiver, respectively. In these two specifications, all the government supports, which include HOV access dummy, sales tax incentive and income tax incentive, are positive but the sales tax waiver not shows the signification result. Furthermore, I estimate the income tax policy and sales tax policy by different states and their effects on the HEV sales. The estimation result shows that for income tax credit, only West Virginia shows negative relationship, but it is not significant. Moreover, state income tax credit policy is more effective in Colorado and Louisiana. For the sales tax waiver policy, the result indicates that this policy is much more effective in Connecticut.

Table 22 Form of State tax incentives

Dependent Variable: Log((HEV sales+1)/population)

	(1)	(2)
	State Income tax policy	State Sales tax policy
dollars-per-mile	-16.7617***	-16.2782***
	(2.1156)	(2.1153)
HOV access dummy	0.1997***	0.2021***
	(0.0148)	(0.0148)
Sales Tax Incentive($000)	0.0675***	
	(0.0188)	
Income Tax Incentive($000)		0.0251
		(0.0128)
Income tax policy in Colorado	0.1233***	
	(0.0319)	
Income tax policy in Louisiana	0.7545***	
	(0.1605)	
Income tax policy South Carolina	0.0300	
	(0.0427)	
Income tax policy in West Virginia	-0.0023	
	(0.0149)	
Sales Tax policy in Connecticut		0.4380***
		(0.0516)
Sales Tax policy in Maine		-0.1530**
		(0.0548)
Sales Tax policy in New York		0.0385
		(0.0217)
Observations	69449	69449
r2	0.6626	0.6627

Standard errors in parentheses,* p<0.05 ** p<0.01 *** p<0.001

All specifications contain socioeconomics variables and vehicle price

4.3 Post-Estimation Analysis---Effects of Different Subsides

In this section, I analyze the effects of different subsidies, including no incentives and doubled incentives, what the hybrids sales changes.

Effects of Different Subsides

This section describes the effect of no incentives and doubled incentives after the estimation. As showing in Table 23, we can see that if without government financial incentives, all the hybrid sales will goes down in the three years; sales in 2005 goes down to 0.78%, 2006 slides down 2.93% and decrease 3.41 % in 2007.

However, when we double the incentives, we can see that all the sales increase in these three years, 0.81% increase in 2005, 3.67% increase in 2006 and 4.52% increase in 2007.

Table 23 Effect of Incentives

	Observed Incentives		Without Incentives	Doubled Incentives
	hybrid sales	subsidy	Sales Change in %	Sales Change in %
year	(1)	(2)	(3)	(4)
2005	189,823	2,341	-0.78	0.81
2006	241,629	9,320	-2.93	3.67
2007	317,082	13,346	-3.41	4.52

Chapter 5

Geographic Information System (GIS) Analysis---Case of Toyota Prius

5.1 Introduction

This chapter utilizes one of the most useful spatial regression models, Geographically Weighted Regression (GWR), to analyze the panel data for the following three purposes. First of all, to correct spatial autocorrelations of spatial dependence that similar values in space tend to cluster together and solve the spatial heterogeneity problem that non-uniform distribution of observations over space makes spatial regimes or spatial structure not homogeneous and stationary. Secondly, to better understand the diverse impacts of factors by allowing relationships to vary across space and provide results, which are location specific through spatial disaggregation of global models. Finally, to test performance of different models across geographic locations.

In order to avoid the missing values problem, Toyota Prius was taken as a case study due to its high market share and more complete data. In the chapter 5.2, spatial autocorrelation tests are conducted. Then chapter 5.3 introduces the Geographically Weighted Regression (GWR) methodology. Finally chapter 5.4 uses Geographically Weighted Regression (GWR) to test the efficiency of the government policy for promoting the hybrid electric vehicle.

5.2 Spatial Autocorrelation Analysis

Spatial autocorrelation is a measure of the degree to which a set of spatial features and their associated data values tend to be clustered together in space (positive spatial autocorrelation) or dispersed (negative spatial autocorrelation). Spatial autocorrelation of local effort is expected. First, the HEV sales intensity of one place is likely to be affected by the surrounding counties. This spatial dependence of sales is reflected in the Figure 3 of Prius sales distribution in which clusters can be found easily across county areas. Second, if looking at these clusters carefully, they tend to be in the boundary of states. The counties as individuals are nested within states and influenced by higher-level government, the state. States have differences. In terms of their county-nested structure, in the U.S. due to factors or policy choices regarding gasoline prices or state incentives, the effects between counties need to be corrected by models.

In order to test the spatial autocorrelation, Patrick Alfred Pierce Moran developed *Moran's I* to measure whether the spatial pattern expressed is clustered, dispersed, or random. In other words, the index values to capture the spatial autocorrelation are from −1 (indicating perfect dispersion) to +1 (perfect correlation), while zero value means a random spatial pattern. Global Moran's I investigates the overall clustering of the data. However, if homogeneity assumption in the global analysis does not hold, then having the statistic should be different over space. We can still use local spatial autocorrelation to find clusters when there is no global autocorrelation or no clustering. Therefore, "Local indicators of spatial association" (LISA) are used to capture the clustering for the spatial unit.

In Figure 4, the results of global Moran's I by both "polygon contiguity 1st order" and “inverse distance” conceptualization of spatial relationship indicate the distribution of Prius sales is severely clustered. The Moran’s I values of 2005, 2006, 2007 are 0.43, 0.41 and 0.43, respectively. This positive value suggested clusters of Prius sales in these three years. The z- score is large as well and the p value is almost 0. The test is statistically significant to reject the null hypothesis that the distribution is similar with random distribution.

Figure 3 Distribution of Toyota Prius

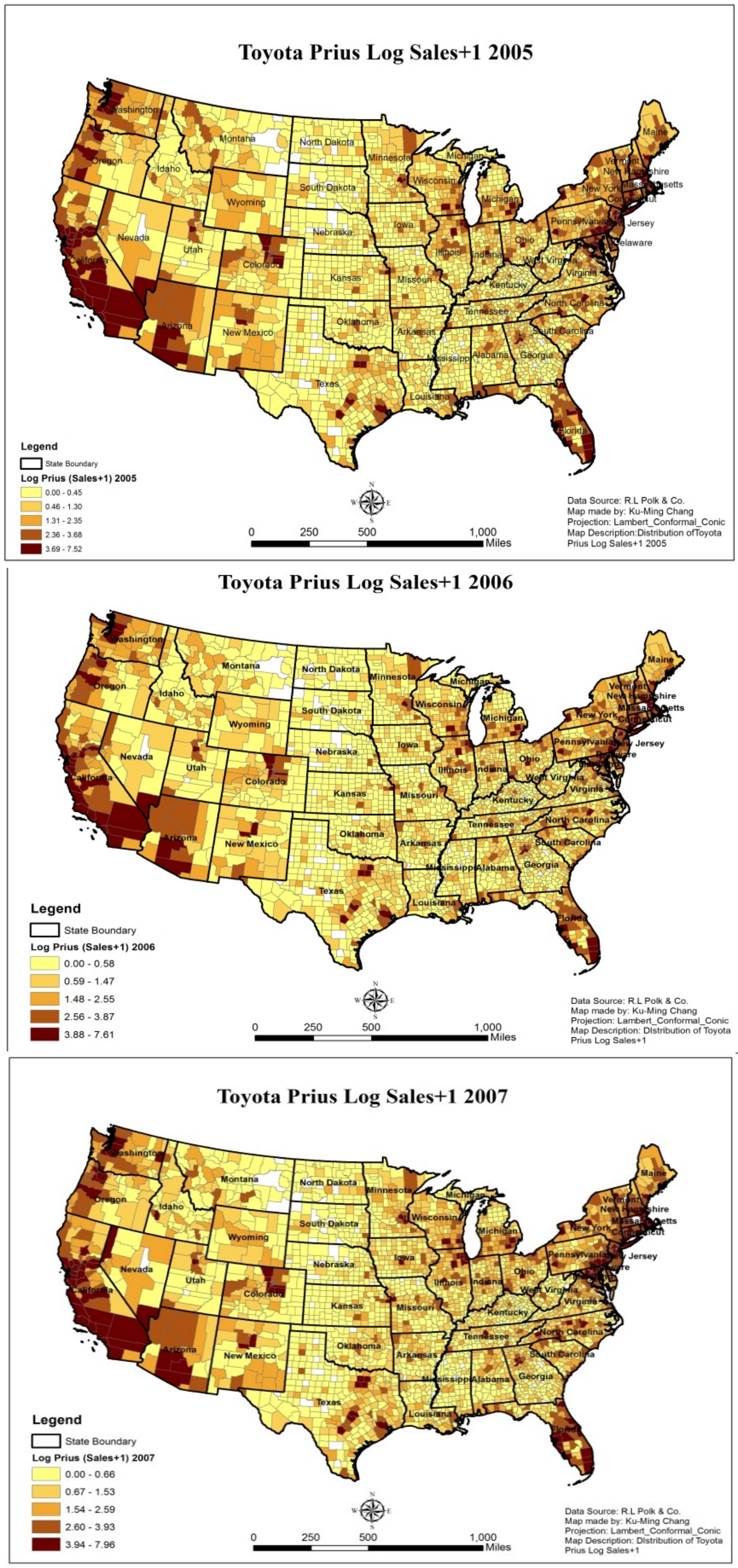
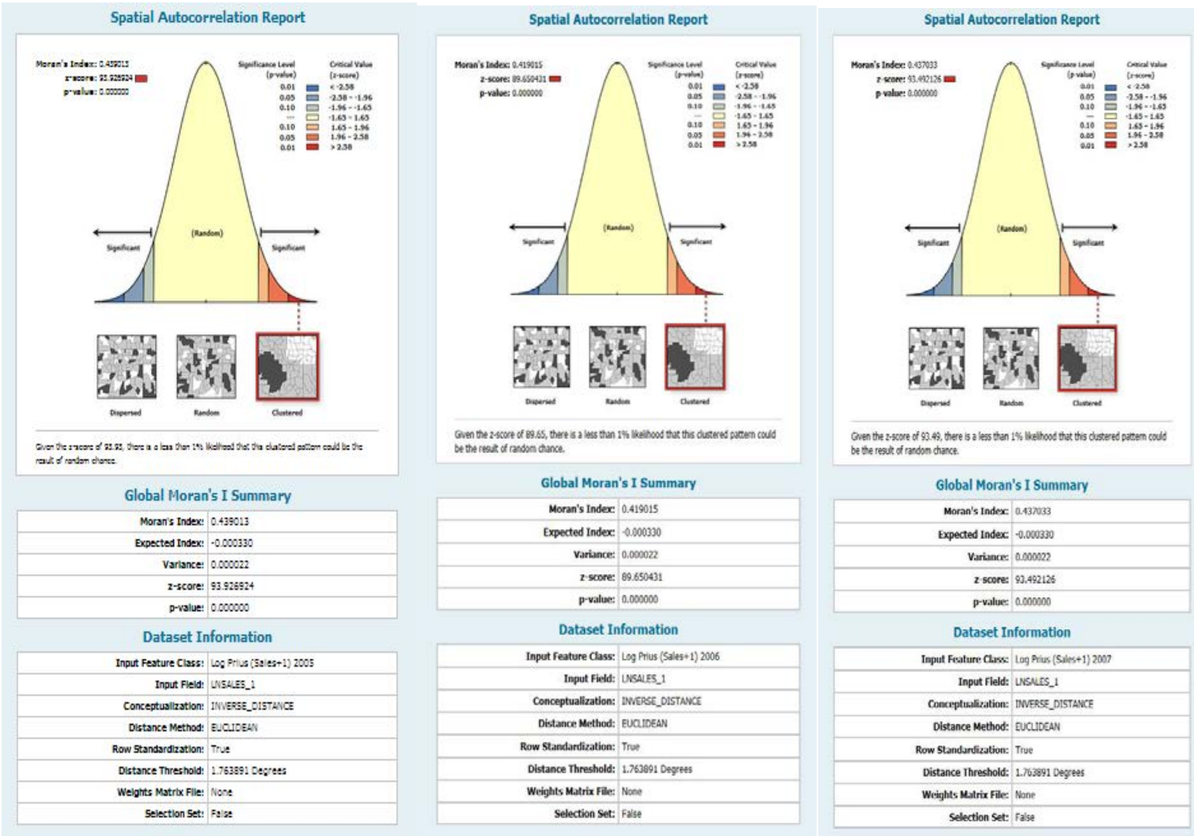
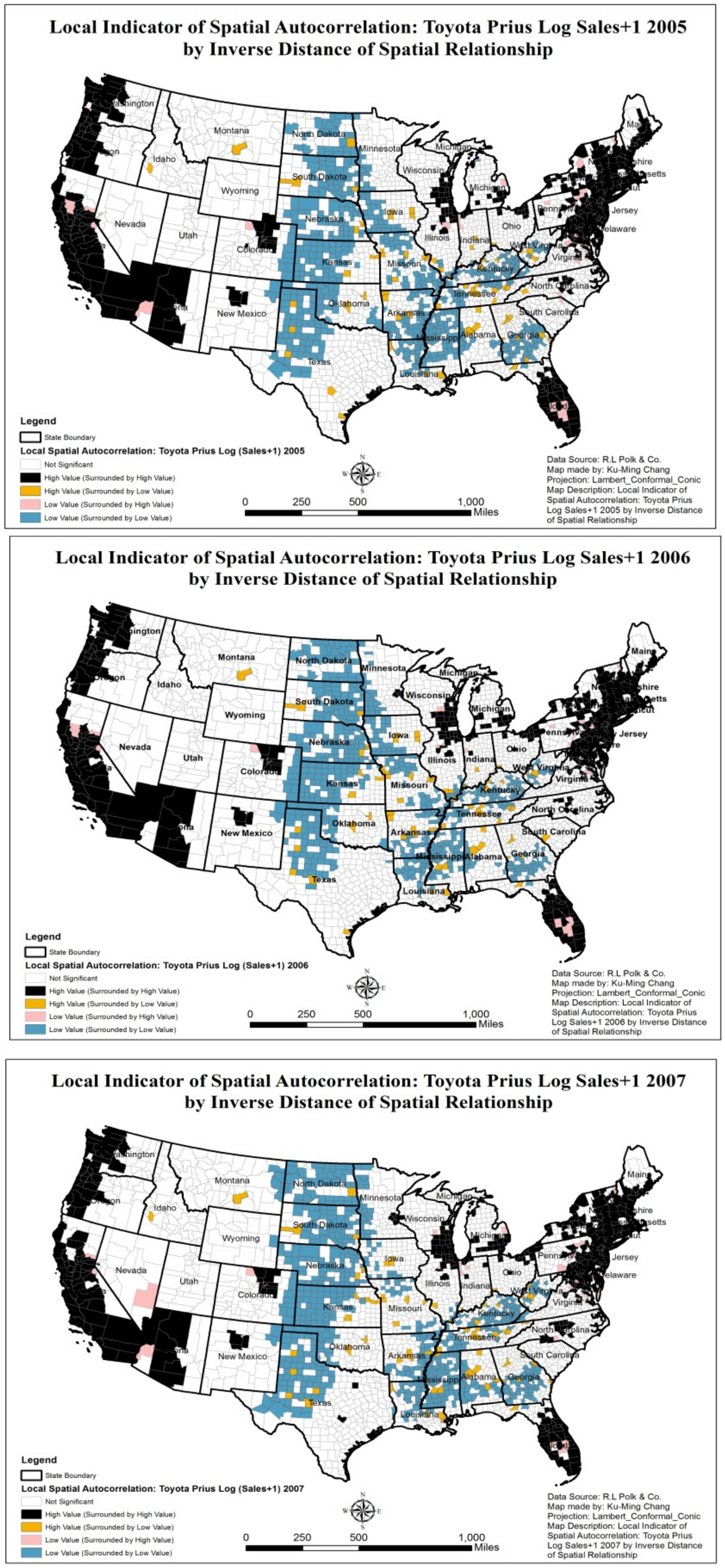


Figure 4 Global Moran’s I



Figures 5 demonstrate the *local indicator of spatial autocorrelation* (LISA) by 5 categories: Not significant, high value surrounded by high value, high value surrounded by low value, low value surrounded by high value, and low value surrounded by low value. The counties in grey have no local spatial autocorrelation. However, counties in black have high Prius sales and are surrounded by high Prius sales counties as well, while counties in blue have low Prius sales and are surrounded by low Prius sales counties. Counties in these two categories suffer from the local spatial autocorrelation problem since they are surrounded by counties with similar local situations. In contrast, counties in orange and pink are outliers in terms of local spatial autocorrelation in that they are surrounded by counties with opposite local situations.

Figure 5 Local Spatial Autocorrelation



Standardized Residuals Distribution

The following figures from figure 6 to figure 8 demonstrate the comparison between the residuals distribution of OLS and GWR. Some improved examples that can be found by eye are highlighted in black circles.

From the residual comparison, the clusters of standardized residuals are reduced apparently by the GWR model. In general, the distribution of standardized residuals in GWR is more similar to a random pattern with significant elimination of clusters. Some improved examples that can be found by eye are highlighted in red circles.

Figure 6 Distribution of Standardized Residuals of OLS and GWR in 2005

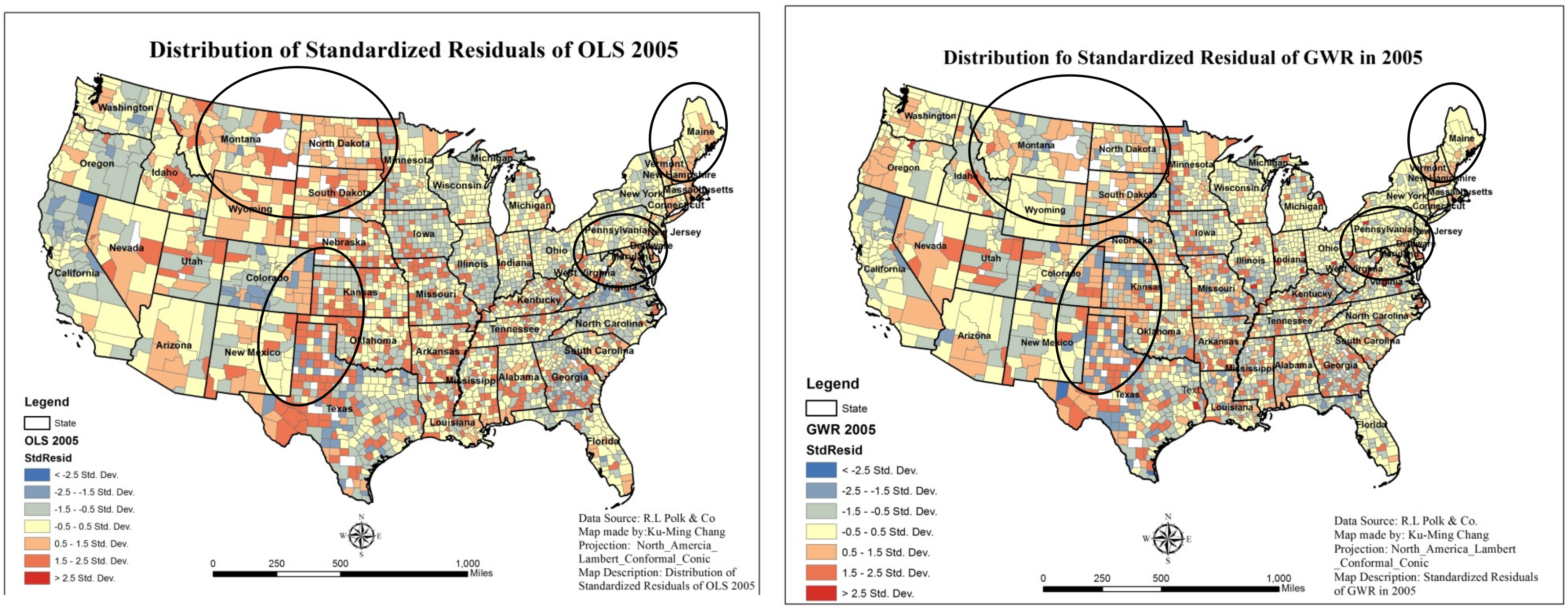
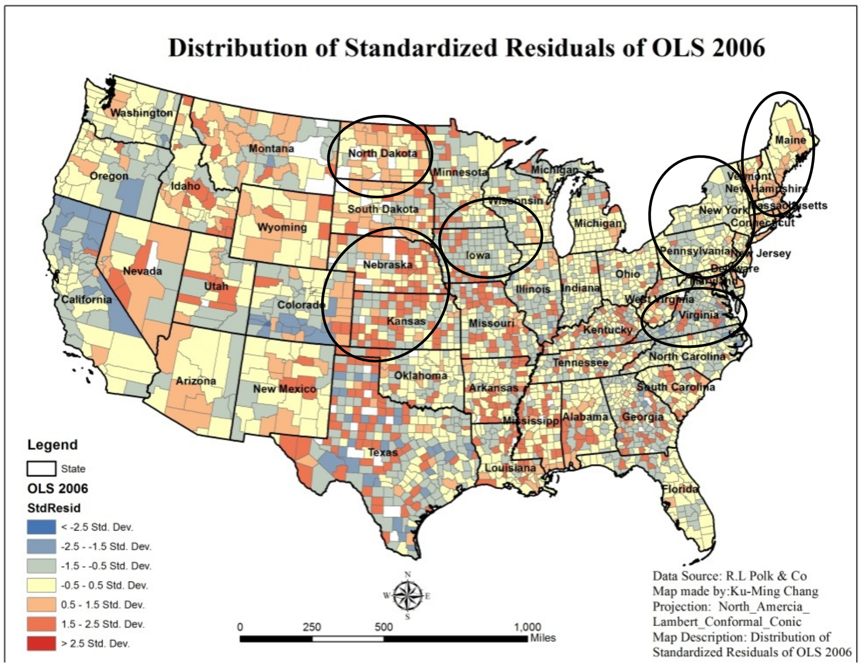


Figure 7 Distribution of Standardized Residuals of OLS and GWR in 2006



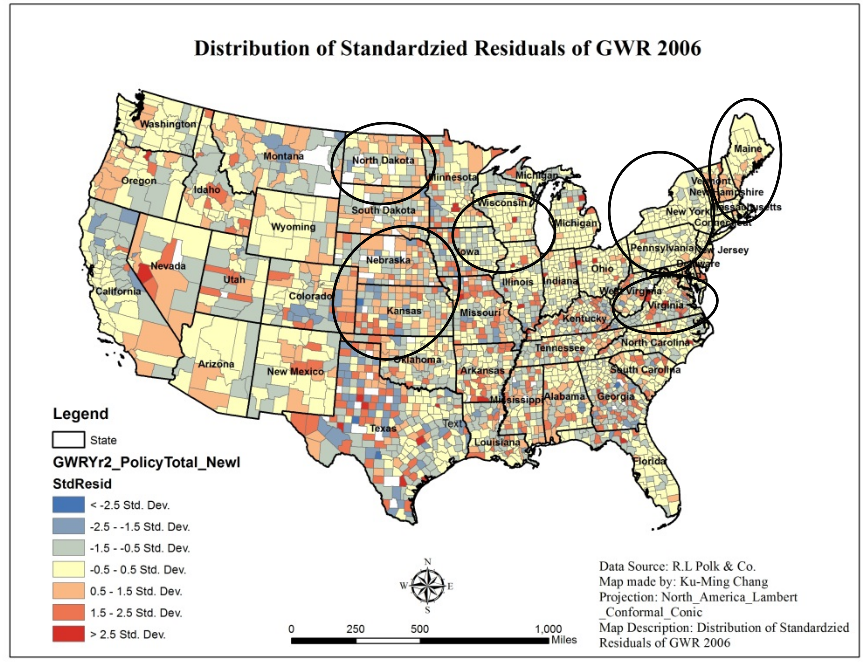
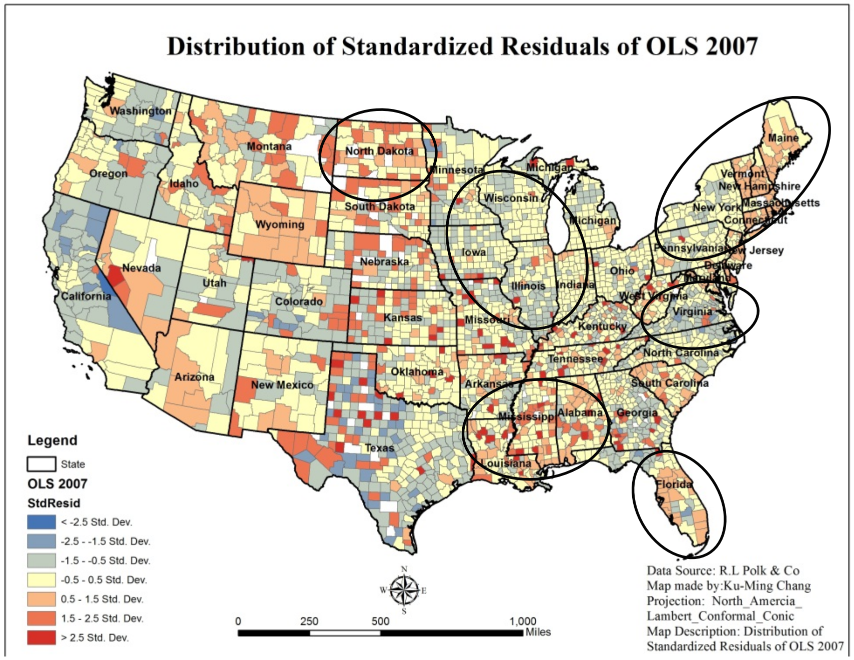
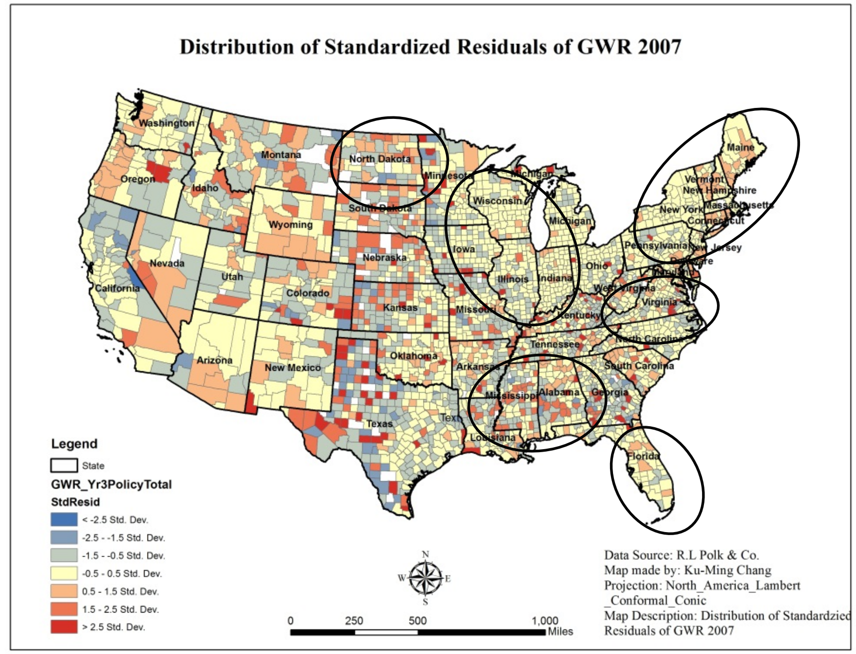


Figure 8 Distribution of Standardized Residuals of OLS and GWR in 2007





5.3 Geographically Weighted Regression (GWR)

To deal with the non-stationary problem that the goodness of fit varies across space, we disaggregate the global models to better understand virtuous and vicious cycles. We run the geographically weighted regression model of the standardized dataset of the same variables as we ran with fixed effect regression.

The Geographically Weighted Regression (GWR) divides the whole study region into different neighborhoods based on their characteristics and this methodology is fully described by Fotheringham et al. (2002). The global models are disaggregated to allow the variance of models across space to overcome the non-stationarity problem. Each local model is the best fit model compared with the global model and the performance varies across region. It is helpful to examine the distribution of local R Squared to have an understanding of which part of the study region the model fits best as well as which fit worst. Figures 3 demonstrated the variance of the local models' performance.

The equation for a typical GWR version of the OLS regression model would be:

$$Y_i(u) = \beta_{0i}(u) + \beta_{1i}(u) X_{1i} + \beta_{2i}(u) X_{2i} + \ldots + b(u) X_{mi} \qquad (5.1)$$

The notation $\beta_{0i}(u)$ indicates that the parameter describes a relationship around location u and is specific to that location.

The estimator for this model is similar to the WLS (weighted least squares) global model above except that the weights are conditioned on the location u relative to the other observations in the dataset and hence change for each location.

The estimator takes the form:

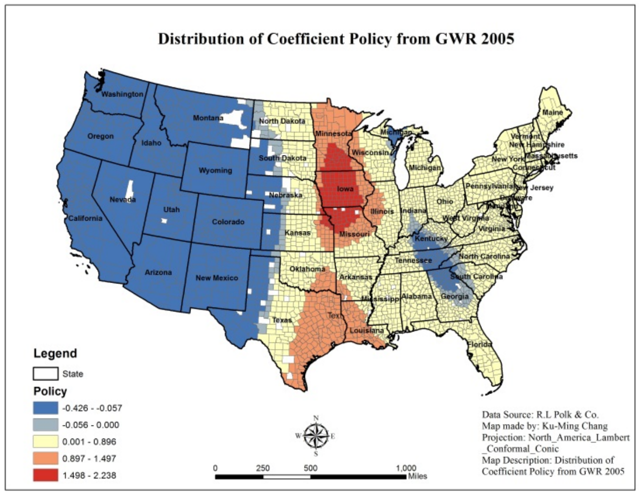
$$\hat{\beta}(u) = \left(X^T W(u) X \right)^{-1} X^T W(u) Y \qquad (5.2)$$

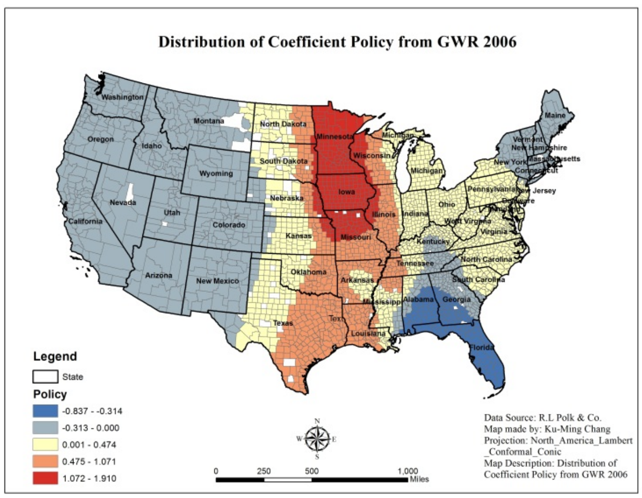
$W(u)$ is a square matrix of weights relative to the position of u in the study area; $X^T W(u) X$ is the geographically weighted variance-covariance matrix (the estimation requires its inverse to be obtained), and Y is the vector of the values of the dependent variable.

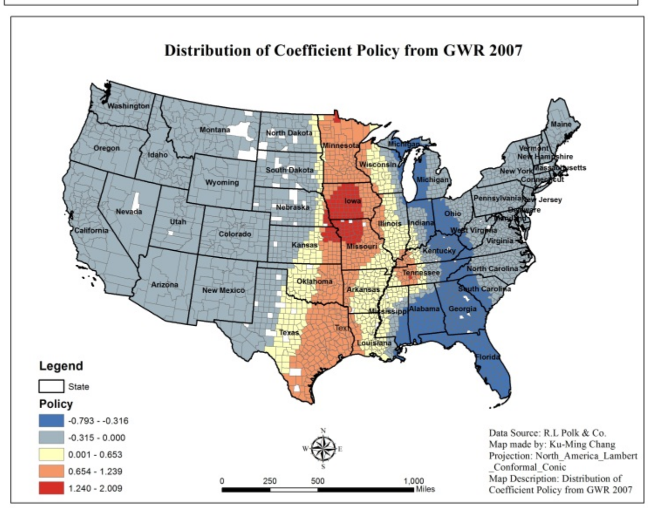
5.4 Analysis of the Government Policy

The following figure 9 is the result of the coefficients distribution for the policy variable after running GWR in GIS. Counties in red, orange and yellow have positive coefficients of HEV sales, while blue and light blue showed that negative relationship of HEV sales. From 2005 to 2007, the graph of the coefficients showed that the total government policy in the west coast is negative. The sign in the east coast changed from positive to negative from 2005 to 2007 and gradually has more negative sign in the east-coast in 2007. I would expect this trend is the government support is gradually phasing out to the market. However, in the middle US, the government policy is the effective policy comparing to the east coast and the west coast.

Figure 9 Policy Coefficients from Geographically Weighted Regression







Chapter 6

Conclusion

In this study, I examined how hybrid sales respond to federal tax incentives, state tax incentives, rising gasoline prices and perks such as HOV lane access. I also took the Toyota Prius as a case study to examine the spatial autocorrelations of spatial dependence in order to analyze a policy's effect when considering geographic differences. My empirical results suggest some important points for policy makers to consider when attempting to introduce a new product into the market.

First, my estimation results show that state tax incentives are important for consumers' adoption of hybrid vehicles. Furthermore, non-monetary policies, such as the privilege to access HOV lanes, are positively correlated to HEV sales. There is also evidence that federal incentives are not effective. Finally, Dollars-per-mile (DPM) was found to be the most important factor in the adoption of the HEV, which means that consumers primarily consider how much they can save immediately when buying a HEV.

Secondly, in terms of socioeconomic factors, I found that counties with more college graduates see more HEV purchases. For the interaction terms of transportation mode and travel time to work, the estimation results show that travel time is not important if it is less than 24 minutes or greater than 40 minutes; a county that has more commuters driving alone is more likely to buy more HEVs. When a county has more people who commute through public transit (train, bus, and so on), and the travel time to work is over 40 minutes, HEV sales are lower.

Finally, I considered the geographic patterns of HEV sales, which has not been done before in literature with respect to HEV sales. The GIS analysis showed that from 2005 to 2007, the coefficients of total government policy variables on the West coast is negative. The sign of the variables for the East coast changed from positive to negative from 2005 to 2007, and then became more negative throughout 2007. These negative signs indicate that the government policies in these areas were ineffective. I suspect this trend is the result of government support gradually being phased out of the market. However, in the Midwestern U.S., government policy is shown to be effective compared to the East and West coasts.

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