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How are new-energy vehicle sales affected by government support? U.S. geospatial evidence*

Abstract. Despite the low crude oil price that has been declining since 2014, the market for electric and hybrid-electric vehicles has grown steadily and reached one million on the road in America in 2015 which itself proves high topicality of research concerning factors affecting new-energy vehicles dissemination in the different states of US. In current paper, we study the effectiveness of government policies on a best-selling hybrid-electric vehicle (HEV) by using proprietary and novel datasets of sales information in 3,000 United States counties while controlling for detailed and unique demographic and governmental factors since 2005, in the initial stage of hybrid car introduction. First, we find that state tax waivers, state income tax credits, and high-occupancy-vehicle lane access are important in HEV sales. Second, HEV tax incentives from the federal government show the negative relationship with HEV sales. These results suggest that the federal government should entrust state governments with promotion policies for HEVs. Third, income level and commuting time do not significantly affect consumers' decision to switch to hybrid vehicles. Fourth, a person who spends a considerable amount of time in a vehicle or is already taking public transportation is unlikely to switch to a new vehicle type: New products should be first marketed to first-time car buyers. Geospatial analyses are followed to study spatial dependencies. We proved that HEV sales in the country is highly connected with proper state support policies at regional level.
Keywords: Hybrid Electric Vehicles; Tax Incentives; Spatial Analysis; Geographically Weighted Regression; U.S. Automotive; Ford; Honda; Nissan; Mazda; Lexus; Toyota; Saturn; Mercury
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Вплив державної підтримки на продажі нових енергоефективних автомобілів у США: геопросторовий аналіз

Анотація. У статті розглядаються питання, пов'язані з ефективністю політики, що проводиться державою стосовно найбільш продаваних гібридних електричних транспортних засобів (ГЕТС). Для вивчення даного аспекту авторами дослідження були використані власні дані, а також офіційна інформація про продажі вищезазначених транспортних засобів у 3000 округах США з 2005 року, тобто з моменту появи гібридних транспортних засобів на ринку США. Автори статті дійшли висновку, що чинники, такі як звільнення від сплати податків, відшкодування податку на прибуток, а також будівництво смуг для пересування транспортних засобів з великою кількістю пасажирів має істотне значення для збільшення продажів ГЕТС. Разом із тим було встановлено, що в даному контексті податкові пільги, що надаються федеральним урядом, є відносно малоефективними та навіть такими, що є шкідливими без додаткових стимулів з боку органів влади на рівні штатів. Це свідчить про те, що федеральний уряд повинен наділити відповідними повноваженнями уряди штатів, тим самим надавши їм можливість самостійно займатися просуванням ГЕТС на ринку. Також слід взяти до уваги той факт, що існує лише мала ймовірність того, що особи, які змушені витрачати значну кількість часу, перебуваючи безпосередньо в транспортному засобі, або особи, які користуються громадським транспортом, погодяться перейти на використання автомобілів нового типу. Під час продажу даного продукту слід орієнтуватися, перш за все, на тих людей, які купують автомобіль уперше. У роботі запропоновано геопросторовий аналіз наданої інформації.
Ключові слова: гібридні електричні транспортні засоби; податкові пільги; просторовий аналіз; просторова регресія.

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Влияние государственной поддержки на продажи новых энергоэффективных автомобилей в США: геопространственный анализ

Аннотация. В статье рассматриваются вопросы, связанные с эффективностью политики, проводимой государством, касающейся наиболее продаваемых гибридных электрических транспортных средств (ГЭТС). Для изучения данного аспекта авторами исследования были использованы собственные данные, а также официальная информация о продажах вышеупомянутых транспортных средств в 3000 округах США с 2005 года, то есть с момента появления гибридных транспортных средств на рынке США. Авторы статьи пришли к выводу, что факторы, такие как освобождение от уплаты налогов, возмещение налога на прибыль, а также строительство полос для передвижения транспортных средств с большим количеством пассажиров имеет существенное значение для увеличения продаж ГЭТС. Вместе с тем было установлено, что в данном контексте налоговые льготы, предоставляемые федеральным правительством, являются относительно малоэффективными и даже такими, что приносят вред без дополнительных стимулов со стороны органов власти на уровне штатов. Это свидетельствует о том, что федеральное правительство должно наделить соответствующими полномочиями правительства штатов, тем самым предоставив им возможность самостоятельно заниматься продвижением ГЭТС на рынке. Также следует принять во внимание тот факт, что существует лишь малая вероятность того, что лица, которые вынуждены тратить значительное количество времени, пребывая непосредственно в транспортном средстве, либо пользующиеся общественным транспортом, согласятся перейти на использование автомобилей нового типа. При продаже данного продукта следует ориентироваться, прежде всего, на тех людей, которые покупают автомобиль впервые. В работе предложен геопространственный анализ предоставленной информации.

Ключевые слова: гибридные электрические транспортные средства; налоговые льготы; пространственный анализ; пространственная регрессия.

Introduction

By September 2015, the total number of plug-in hybrid and electric vehicles has reached one million, faster than the prediction made by Pike Research on their July 2012 study that total sales will reach the one million in 2018. Despite the continual and drastic decline of crude oil price starting from 2014 and continuing in early 2016, based on the report by Lux Research, the total number of new-energy vehicles sold has remained resilient in 2015 and is expected to grow throughout 2016. This coincides with our study such that government incentives are a strong predictor of hybrid sales if each state can tailor its incentives to the local demographics and preferences.

Initially, hybrids 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 U.S., but price premiums of several thousand dollars over equivalent gasoline-only vehicles still deter consumer demand.

By using county level quarterly data for new HEV registrations from R. L. Polk, we consider other factors that could be significant and could thus lead to more accurate results. We are the first researchers to use these county-level data that make it possible to investigate the geographic differences in government policies.

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

Section 1

Literature review

This paper is built on other studies[1] that discuss the demand for hybrid cars or other new vehicles. Kahn (2007) found that communities in California with a higher proportion of Green Party registered voters exhibit higher frequencies of pro-environment behaviors. Diamond (2008) tested the relationship between hybrid adoption and a variety of socioeconomic and policy factors. Using R.L. Polk hybrid vehicle registration data from 2000 to 2006, he found that rising gasoline prices, high income, and vehicle miles traveled were all positively related to market share, albeit disproportionately.

In those studies, the presence or value of monetary incentives at the state level was generally weak or insignificant compared to other factors. Beresteanu and Li (2009) examined the determinants of HEV sales in 22 metropolitan statistical areas from 1999 to 2006. They found that both increasing gasoline prices (e.g., through increased gasoline taxes) and federal income tax incentives expanded the market share of hybrid vehicles. Klier and Linn (2008) got vehicle model sales data from Ward's Automotive Reports (1970–1979) and Ward's AutoInfoBank (1980–2007). The monthly new vehicle sales data allowed them to examine the effect of gasoline prices on new vehicle demand within model-year changes. Their static approach did not consider the endogeneity of vehicle characteristics because gasoline prices and CAFE regulations can affect the characteristics of vehicles.

Another important paper by Berry, Levinsohn, and Pakes (2004) 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. The models allowed characteristics to vary as a function of both observed and unobserved consumer attributes. For that study, they used data 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. BLP's 2004 paper is slightly more complicated than other papers in the field, but it includes important ideas for the future of alternative-fueled vehicle demand.

Section 2

2. 1. Data and methods

2. 1. 1. Overview

The variables and data sources used in this study are obtained from five categories (Table 1):

1. Registration data are from R. L. Polk & Co.

2. Hybrid car characteristics data are from Ward's Automotive Yearbook.

3. State level gasoline prices with taxes from 2005 quarter one to 2007 quarter four from the «Monthly Motor Fuel Reported by States» issued by the Federal Highway Administration (FHWA).

[1] Section 2 is organized and excerpted from various other papers.

4. Government incentives are from fueleconomy.gov[2], Alternative Fuels and Advanced Vehicles Data Center (AFDC)[3], and Hybrid Incentives and Rebates-Region by Region[4].
5. Socioeconomic data are from the 2000 U.S Census.

Tab. 1: **The variable list**

This table represents the five categories of the data: vehicle characteristics, incentives, socioeconomics, Polk's data and gasoline prices. Registration data are from R.L. Polk & Co. Hybrid car characteristics data are from Ward's Automotive Yearbook. State level gasoline prices with taxes from 2005 quarter one to 2007 quarter four from the «Monthly Motor Fuel Reported by States» issued by the Federal Highway Administration (FHWA). Government incentives are from fueleconomy.gov, Alternative Fuels and Advanced Vehicles Data Center (AFDC), and Hybrid Incentives and Rebates-Region by Region. Lastly, socioeconomic data are from the 2000 U.S. Census.

Vehicle characteristics	Incentives	Socioeconomics	Polk's data	Gasoline
Miles per gallon (city/highway)	HOV lane access	Race	State	Gasoline price
Vehicle price (MSRP)	State sales tax	House ownership	County	
	State income tax credit	Vehicle counts	Make	
	Federal income tax credit	Education	Model	
		Family size	Year	
		Travel time	Quarter	
		Commuting mode	Registration number	
		Age		
		Household head age		
2 variables	4 variables	9 variables	7 variables	1 variable

Source: Compiled by the authors

2. 1. 2. Data structure

Table 2 shows the characteristics of geography and time for the datasets. HEV registration data are at the county level and quarterly; gasoline prices are quarterly but at the state level. Government incentive data, including state sales tax waivers, state income tax credits, and HOV lane access, are at the state level and yearly. Note that the federal credit program is by vehicle model but has a different time frame. The socioeconomics variables do not have any time variation but contain county-level data, and car characteristics are yearly data without geographic variations.

Tab. 2: **Datasets structure**

This table shows the characteristics of geography and time for the datasets. Hybrid-energy vehicle (HEV) registration data are at the county level and on a quarterly basis; Gasoline prices are at the state level and quarterly basis. Government incentive data, including state sales tax waivers, state income tax credits, and high-occupancy-vehicle (HOV) lane access, are at the state level and on a yearly basis. Note that the federal credit program is by vehicle model but has a different time frame. The socioeconomics variables do not have any time variation but contain county-level data. Lastly, car characteristics are on a yearly basis without geographic variations.

Data	Geography	Time
HEV registration	County level	Quarterly
Gasoline price	State level	Quarterly
Government incentives	State level	Yearly
Socioeconomics variables	County level	U.S. Census 2000, no time variation
Car characteristics	No geographic variation	Yearly

Source: Compiled by the authors

2. 1. 3. Government incentives

Several incentives to encourage consumers to purchase hybrids have been put in place to address market barriers and overcome the incremental initial purchase costs of hybrids over their gasoline equivalents as shown in Table 3[5]. Still other states, such as Virginia, California, New York, New Jersey, Florida, and Utah, give hybrid owners waivers from HOV lane restrictions on one or more highways in the state (Diamond, 2009) [11].

2. 1. 5. Socioeconomic characteristics

Socioeconomic variables are based on the 2000 Census from the U.S. Census Bureau. We use five categories and twenty-one variables, and all of them are county-based. To distinguish urban and rural differences, we use the Rural-Urban Continuum Codes from the U.S.D.A. Economic Research Service for 2003 (Table 4).

We use the following eleven demographic variables 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 24 minutes, 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, fewer than 2 vehicles per household, and more than 3 vehicles per household.

2. 1. 6. Gasoline prices

For our price data, we use regular grade gasoline calculated as quarterly data using dollars-per-gallon as the unit and including taxes. We obtained the state tax rates on gasoline from Highway Statistics 2010 (Part 8.4.6 State tax rates on motor fuel, Table MF-121T[6]). The study period for state-level gasoline prices with tax data is from 2005 quarter one to 2007 quarter four.

2. 1. 7. Car characteristics

The 2005–2007 Ward's Automotive Yearbook provides car and light truck specifications and prices for the United States. Car characteristics obtained from Ward's Automotive Yearbook include city and highway MPG, and retail price (MSRP) by car class, model, and year (Table 5).

Because vehicle retail prices are not observable at the county level, we use the MSRPs instead. Variations in vehicle retail prices in different counties are captured by an error term. As Beresteanu and Li (2009) explained, the error term also captures local marketing efforts such as advertisements.

The combined MPG is calculated as:

$$MPG \equiv \frac{1}{(0.55/City\ MPG)+(0.45/Highway\ MPG)}$$

to evaluate a car's fuel efficiency. Higher MPG means a HEV is more fuel efficient. In our dataset (2005–2007), the Honda Insight has the highest city-MPG at 63. The lowest MPG for a hybrid vehicle is the 2005 Lexus RX400h, a mid-size SUV with an MPG of 17. We use a 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 2005 Honda Insight has the highest ratio (0.32), and the 2005 Lexus RX400h has the lowest ratio (0.06).

<u>Section 3</u>

3. 1. Methodology and empirical model specifications

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

$$\begin{aligned} &\mathrm{Log}((Sales+1)/population)_{imt} = \alpha_i + \beta_1(dollars-per-mile)_{it} + \\ &+ \beta_2 log(Vehicle\ Prices)_{mt} + \beta_3(Incentives)_{imt} + \\ &+ \beta_4(Socioeconomics)_i + \mu_m + \theta_t + \varepsilon_{imt}\ , \end{aligned} \quad (1)$$

where the subscripts indicate a vehicle model sale m or 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 DPM is $(Gasoline\ Prices)_t/(Miles\ Per\ Gallon)_{mt}$.

<u>Section 4</u>

4. Empirical results

4. 1. Overview

Using the fixed effect model described in the previous section, 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. We also include the county-level socioeconomic factors from the Census

[2] http://www.fueleconomy.gov/Feg/tax_hybrid.shtml
[3] http://www.afdc.energy.gov/afdc/vehicles/hybrid_electric_laws.html
[4] http://www.hybridcars.com/local-incentives/region-by-region.html
[5] http://www.fueleconomy.gov/feg/taxevb.shtml
[6] https://www.fhwa.dot.gov/policyinformation/statistics/2010/mf121t.cfm

2000 datasets and use those data to control for variation in county-level demographic trends. In summary, this section reports parameter estimates from the fixed effects model at the county level for the sales of HEVs and then examines the effects of subsidy policies on the diffusion of hybrid vehicles.

4. 2. Regression results

$Log((hybrid\ sales + 1)/population)$ is the dependent variable, and the explanatory variables are DPM, $Log(vehicle\ Price)$, 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 6. The fixed effect model has three different specifications. For all of them, the dependent variable is $Log((hybrid\ sales + 1)/population)$, and the independent variables are DPM, $Log(vehicle\ Price)$, a dummy variable for HOV lanes, county demographic variables, and the one of the specifications.

In specification (1), the three monetary incentives (state sales tax incentives, state income tax incentives, and federal credit incentive) are scaled by $1,000 to be a single explanatory variable. In specification (2), the same three monetary incentives are divided by vehicle price. In specification (3), a dummy variable for the sales tax waiver incentive and a dummy variable for an income tax credit incentive are used as alternative ways to represent the monetary incentives. Table 6 shows an analysis of the seasonal pattern of tax incentives by type and quarter of year, and the estimates for states that offer tax incentives. State income tax policy occurs in Colorado, Louisiana, South Carolina, and West Virginia, and state sales tax policy occurs only in Connecticut, Maine, and New York. Table 7 shows the post-estimation analysis of the effects of different subsidies.

Following the conventional practice, we begin the analysis with a fixed effects model of panel data at the county level. As shown in Table 6, for the non-monetary policy (single-occupant access to the HOV lane), all the estimation results for 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 for the three specifications, indicating that little evidence in this analysis supports the claim that federal credit incentives have a significant effect on HEV sales. The estimation result also suggests that college graduates have a greater propensity to purchase HEVs. For the interaction term of transportation mode and travel time to work, the estimation result showed that travel time has no effect on HEV purchasing decisions. However, people in counties with more commuters driving alone purchased more HEVs. Interestingly, counties with a large number of people who commute using public transit with a travel time of more than 40 minutes have lower HEV sales than other counties. Furthermore, a household with 2 or fewer cars has a higher tendency to buy a HEV than a household with more than three cars. We recognize that this point is trivial, but it serves as a control variable. Consumers' mean age is positively correlated with HEV sales, which is inconsistent with the result of Gallagher and Muehlegger (2011). Of all the independent variables, the DPM variable is the most important determinant of hybrid sales.

Table 7 shows the effects of different forms of state tax incentives on HEV sales. In specifications (1) and (2), the models examine the effects of state income tax credits and state sales tax waivers, respectively. In those two specifications, all the government supports, including the HOV access dummy, sales tax incentive, and income tax incentive, are positive, but the sales tax waivers results are not significant. Furthermore, we estimate the effects of income tax policy and sales tax policy in different states. For the income tax credit, only West Virginia shows

Tab. 3: **State incentives**

This table shows the list of state incentives. Several incentives address market barriers and overcome the incremental initial purchase costs of hybrids over their gasoline equivalents. Until 2005, the U.S. federal government provided a $2,000 tax deduction for all qualifying hybrids, regardless of make and model. Starting in January 2006, however, the Energy Policy Act of 2005 replaced that tax deduction with a tax credit based on an individual model's emissions profile and fuel efficiency compared to equivalent gasoline vehicles. Credits varied from several hundred to several thousand dollars and phased out over time after the manufacturer sold a total of 60,000 hybrid and lean-burn vehicles. The federal credit was completely phased out on April 1, 2010. Toyota sales reached the 60,000 unit threshold in May 2006, and Honda reached the threshold in August 2007. In addition to the federal tax credit, many states offer additional incentives. As of 2008, the state with the highest effective incentive structures was Colorado, which offers credits of $2,500–$6,000 depending on the model. Several other states offer incentives valued at greater than $1,500 (Hybrid Incentives and Rebates-Region by Region, 2007). Still other states, such as Virginia, California, New York, New Jersey, Florida, and Utah, give hybrid owners waivers from HOV lane restrictions on one or more highways in the state (Diamond, 2009). The source is the AFDC at http://www.afdc.energy.gov/laws/state

Panel A. High-occupancy-vehicle (HOV) lane			
State Incentives	Vehicle	Time	Value
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.	
Panel B. Sales tax exemption			
State Incentives	Vehicle	Time	Value
Connecticut	Civic, Prius, Insight	2004-2010	6% savings ($1,217-1,409)
Maine	All HEVs	2005 only	50% credit of 5% tax.($300-$500)
New York	All HEVs	1/2004-2/2005	$3,000 credit.
Panel B. Income tax credit			
State Incentives	Vehicle	Time	Value
Colorado	Certain HEVs	2001-2010	Varying value ($2,265- $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, ($1,537-$3,000)
Oregon	Certain HEVs	2005-2010	$750 or $1,500 residential and Business tax credit
West Virginia	All HEVs	Pre 2005-6/2006	$3,750

Source: Compiled by the authors

Tab. 4: **2003 Rural-urban continuum codes**

This table provides the 2003 rural-urban continuum codes in order to distinguish urban and rural differences. The source is the U.S.D.A.'s (2003) Economic Research Survey.

Panel A. Metro counties	
Code	Definition
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
Panel B. Nonmetropolitan counties:	
Code	Definition
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: Compiled by the authors

Tab. 5: **MPG and MSRP**

This table provides the miles per gallon (MPG) and manufacturer's suggested retail prices (MSRP) of competing hybrid-energy vehicles (HEVs) in USD. Car and light truck specifications and prices for the U.S. are sourced from the 2005–2007 Ward's Automotive Yearbook.

		2005		2006		2007		2005	2006	2007
Car Classes	Model	Combined MPG	MSRP	Combined MPG	MSRP	Combined MPG	MSRP	MPG/MSRP (×100)		
Small car	Ford Focus	29								
	Honda Civic	48	20,165	50	22,400	50	23,195	0.24	0.22	0.22
Midsize car	Honda Accord	33	30,505	32	31,540	32	31,685	0.11	0.1	0.1
	Honda Insight	64	19,695	63	19,880	63	19,880	0.32	0.31	0.31
	Nissan Altima					27	18,565			0.14
	Saturn Aura					23	20,595			0.11
	Toyota Camry			27	18,985	39	26,480		0.14	0.15
	Toyota Prius	56	21,415	56	22,305	56	22,305	0.26	0.25	0.25
Compact SUV	Ford Escape	34	26,970	34	27,515	34	26,320	0.12	0.12	0.13
	Mazda Tribute					30	20,705			0.14
	Mercury Mariner	24	21,995	31	29,840	31	28,615	0.11	0.1	0.11
	Saturn VUE			25	17,990	29	22,995		0.14	0.13
Midsize SUV	Lexus RX400h	17	36,400	29	49,060	30	41,895	0.05	0.06	0.07
	Toyota Highlander	24	24,645	31	33,595	31	33,095	0.1	0.09	0.09
Large luxury	Lexus GS 450h			25	43,800	26	44,865		0.06	0.06
Super luxury	Lexus LS600h L					21	30,970			0.07

Source: Compiled by the authors

Tab. 6: **Panel regression results with fixed effects**

This table provides the panel regression results with fixed effects which are analyses of the seasonal pattern of tax incentives by type and quarter of year (Table 6), and parameter estimates for states that offer tax incentives (Table 6, continued). State income tax policy occurs in Colorado, Louisiana, South Carolina, and West Virginia, and state sales tax policy occurs only in Connecticut, Maine, and New York. The dependent variable is Log((Sales+1)/population). The explanatory variables are dollars-per-mile (DollarsPerMile), the log of retail vehicle price (LogRetailPrice), a dummy variable for high-occupancy-vehicle (HOV) lanes (HovAcess), state and federal incentives, and demographic variables. In Model 1, the three monetary incentives (state sales tax incentives, state income tax incentives, and federal credit incentive) are scaled by $1,000. In Model 2, the same three monetary incentives are divided by the vehicle price. In Model 3, a dummy variable for the sales tax waiver incentive (SalesTax) and a dummy variable for an income tax credit incentive (IncomeTax) are used as alternative ways to represent the monetary incentives. Standard errors under the estimated coefficients.

Variable	Model 1	Model 2	Model 3
DollarsPerMile	-5.8998***	-6.1614***	-6.2049***
	-0.12	-0.1195	-0.1174
LogRetailPrice	-0.3201***	-0.3300***	-0.2512***
	-0.012	-0.0137	-0.0112
HovAccess	0.6432***	0.6322***	0.6402***
	-0.0153	-0.0153	-0.0152
Incentives:			
SalesTaxIncentive ($'000s)	0.6007***		
	-0.0447		
IncomeTaxIncentive ($'000s)	0.0473***		
	-0.0129		
FederalCreditIncentive ($'000s)	-0.0800***		
	-0.0031		
SalesTaxPolicyPerVehiclePrice		15.4596***	
		-0.9103	
IncomeTaxPolicyPerVehiclePrice		-0.0872	
		-0.2695	
FederalCreditPolicyVehiclePrice		-1.3385***	
		-0.0821	
SalesTax			1.0460***
			-0.0646
IncomeTax			-0.3488***
			-0.0587
FederalCredit			-0.3789***
			-0.0112

Source: Compiled by the authors

Tab. 7: **Form of state tax incentives**

This table shows the effects of different forms of state tax incentives on hybrid-energy vehicle (HEV) sales. The dependent variable is Log((HEV sales+1)/population). Models 1 and 2 examine the effects of state income tax credits and state sales tax waivers, respectively. Standard errors are within parentheses, * $p<0.05$ ** $p<0.01$ *** $p<0.001$. All specifications contain socioeconomics variables and vehicle price.

Variable	Model 1	Model 2
DollarsPerMile	-16.7617***	-16.2782***
	-2.1156	-2.1153
HovAccess	0.1997***	0.2021***
	-0.0148	-0.0148
SalesTaxIncentive ($'000s)	0.0675***	
	-0.0188	
IncomeTaxIncentive ($'000s)		0.0251
		-0.0128
IncomeTaxPolicyColorado	0.1233***	
	-0.0319	
IncomeTaxPolicyLouisiana	0.7545***	
	-0.1605	
IncomeTaxPolicySouthCarolina	0.03	
	-0.0427	
IncomeTaxPolicyWestVirginia	-0.0023	
	-0.0149	
IncomeTaxPolicyConnecticut		0.4380***
		-0.0516
IncomeTaxPolicyMaine		-0.1530**
		-0.0548
IncomeTaxPolicyNewYork		0.0385
		-0.0217
No. of observations	69,449	69,449
R^2	0.6626	0.6627

Source: Compiled by the authors

a negative relationship, but it is not significant. State income tax credit policy is most effective in Colorado and Louisiana. The sales tax waiver policy is most effective in Connecticut.

Section 5

5. Geographic information system analysis

5. 1. Overview

This section uses a spatial regression model, geographically weighted regression (GWR), to analyze the panel data for the following purposes. First, we use GWR to correct spatial autocorrelations of spatial dependence that similar values in space tend to cluster together. We can solve the spatial heterogeneity problem that non-uniform distribution of observations over space makes spatial regimes non-homogeneous. GWR also helps to better understand the diverse effects of factors: it allows the relationships to vary across space and provides results that are location specific through spatial disaggregation of global models. Lastly, we can test the performance of different models across geographic locations.

Section 5. 2 describes spatial autocorrelation tests. Section 5.3 introduces the GWR methodology, and Section 5.4 uses GWR to test the efficiency of government policies in promoting HEVs.

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. Figure 1 shows the HEV registration numbers from 2005 until 2007. Toyota Prius appears to have led the market.

Figure 2 reflects the spatial dependence of sales, which shows that clusters in Prius sales distribution can easily be

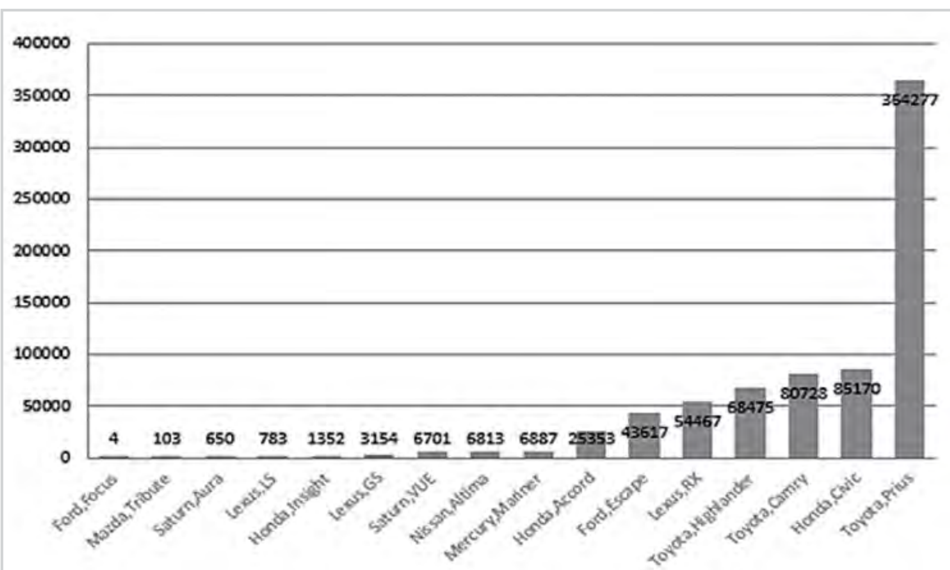


Fig. 1: **Number of HEV registrations, 2005-2007**
Source: Made by the authors based on the data from R. L. Polk & Co.

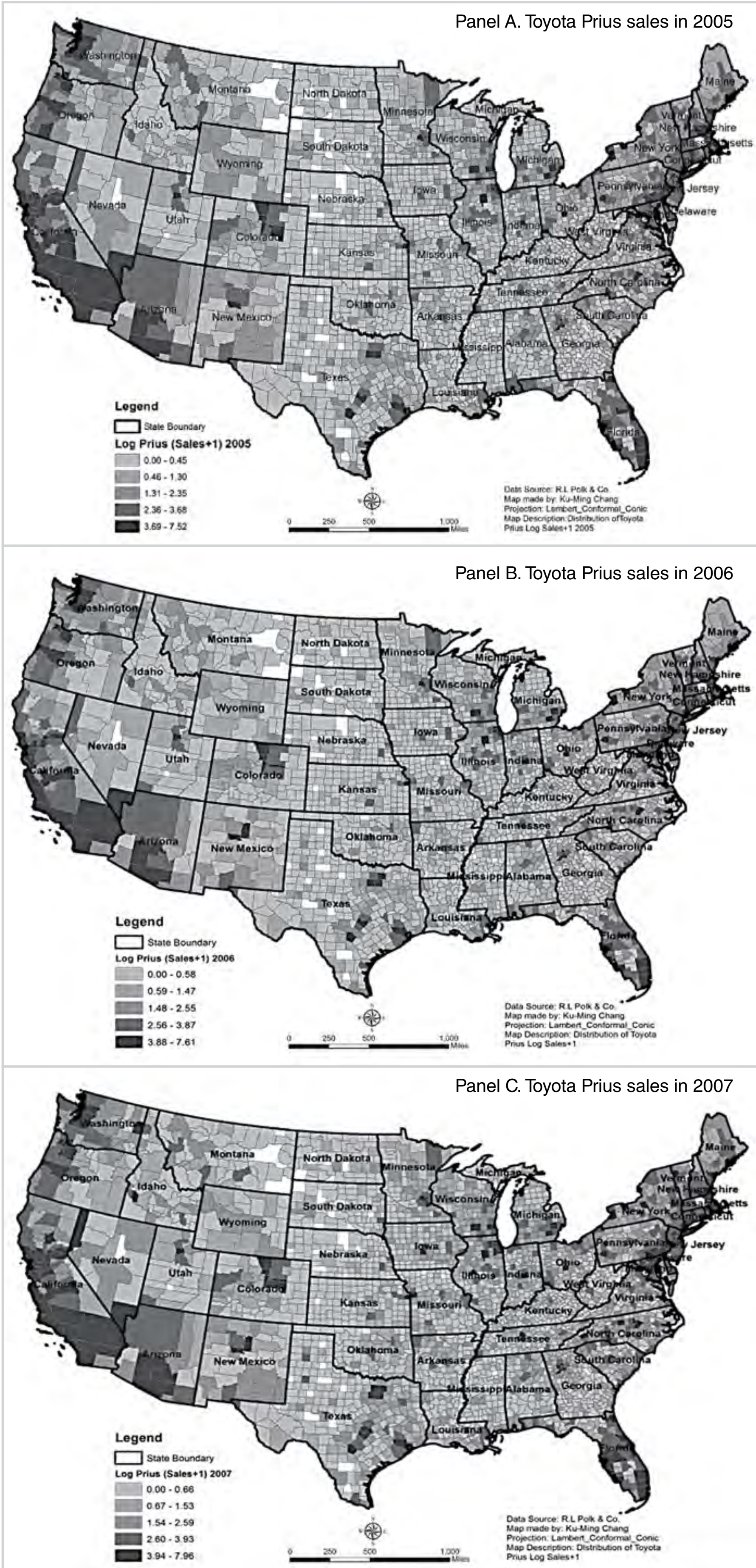


Fig. 2: **Distribution of Toyota Prius**
Source: Made by the authors based on the data from R. L. Polk & Co.

found across county areas. Such clusters tend to be within state boundaries. The counties act as individuals nested within states that are influenced by the higher-level state government. But not all states are the same in terms of their county-nested structure. Due to factors or policy choices regarding gasoline prices and state incentives, the effects between counties need to be corrected by models.

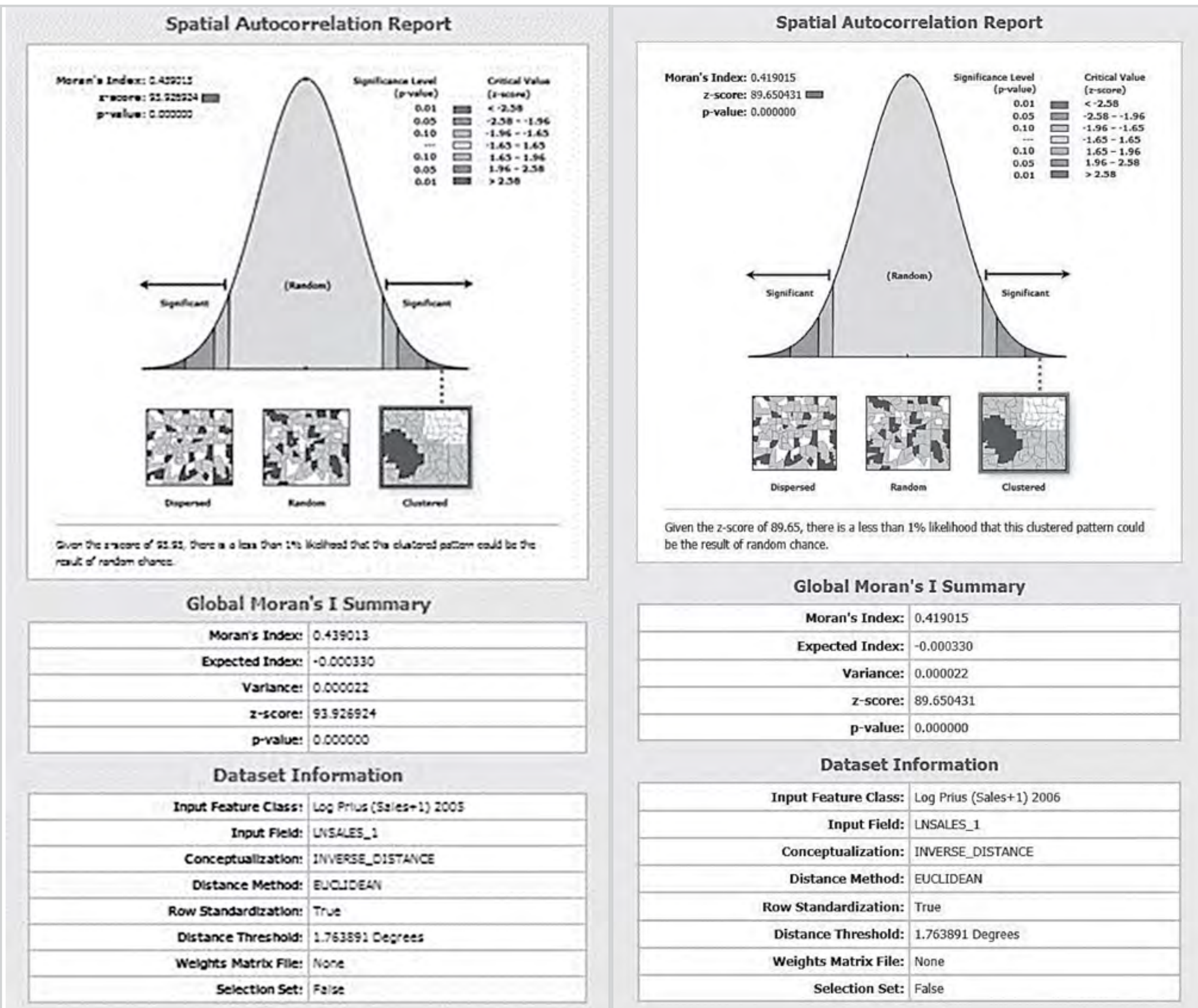
To test for spatial autocorrelation, the Australian statistician Patrick Alfred Pierce Moran (1917–1988) developed Moran's I to measure whether the spatial pattern expressed is clustered, dispersed, or random. The index values that capture spatial autocorrelation are from -1 (indicating perfect dispersion) to +1 (perfect correlation) with a zero value indicating a random spatial pattern. Global Moran's I investigates the overall clustering of the data. However, if the homogeneity assumption in the global analysis does not hold, then the statistic should be different over space. Local spatial autocorrelation can still find clusters in the absence of global autocorrelation. Therefore, we use Local Indicators of Spatial Autocorrelation (LISA) to capture the clustering for the spatial unit (see Figure 3).

Figure 4 shows the results of the global Moran's I using both the «polygon contiguity 1st order» and «inverse distance» conceptualizations of spatial relationships. As shown in the figure, the distribution of Prius sales is severely clustered. The Moran's I values for 2005, 2006, and 2007 are 0.43, 0.41, and 0.43, respectively. This positive value suggests 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 random. Furthermore, Figure 4 demonstrates 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, the counties in black have high Prius sales and are surrounded by other counties with high Prius sales, and the counties in blue have low Prius sales and are surrounded by other counties with low Prius sales. Counties in the latter two categories suffer from the local spatial autocorrelation problem because they are surrounded by counties with similar local situations. In contrast, counties in orange and pink are outliers in terms of local spatial autocorrelation because they are surrounded by counties with opposite local situations.

5. 3. Geographically weighted regressions

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

The GWR model divides the whole study region into different neighborhoods based on their characteristics, as described by Fotheringham et al. (2002) [12]. The global models are disaggregated to allow their variance across space



Panel A. Toyota Prius sales in 2005 Panel B. Toyota Prius sales in 2006

Fig. 3: **Global Moran's I spatial autocorrelations**

Source: Made by the authors based at the data from R. L. Polk & Co.

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 understand which part of the study region the model fits best and which it fits worst. Figure 3 demonstrates the variance of the local models' performances.

5. 4. Analysis of government policy

Figure 5 illustrates the results of the coefficients distribution for the policy variables after running the geographically weighted regression (GWR) model in GIS. Counties in red, orange, and yellow have positive coefficients of HEV sales, whereas those in blue and light blue show a negative relationship with HEV sales. From 2005 to 2007, the graph of the coefficients shows that the total government policy effect on the West Coast is negative. The sign on the East Coast changed from positive to negative between 2005 and 2007 and gradually became more negative as 2007 progressed. We explain that trend as a reflection of government support gradually phasing out. However, in the middle of the US, government policies are more effective than on either coast.

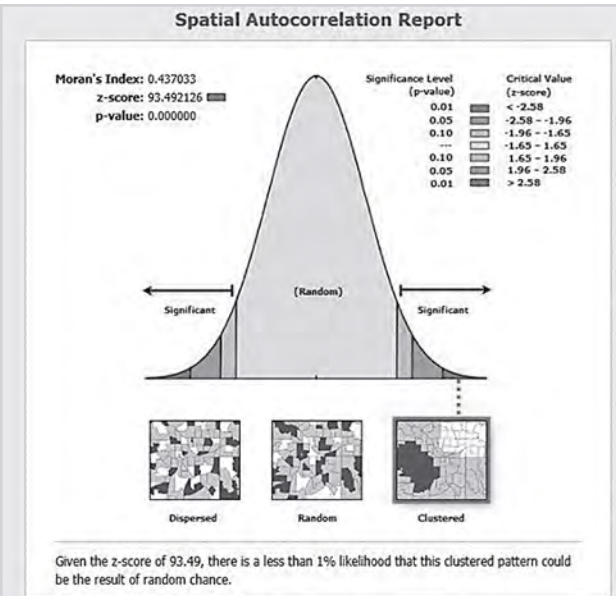
6. Conclusion

Despite the low crude oil price that has been declining since 2014, the market for electric and hybrid-electric vehicles has grown steadily and reached one million on the road in America in 2015. To study this successful introduction of such «new-energy vehicles», we examined how hybrid sales responded to federal tax incentives, state tax incentives, rising gasoline prices, and perks such as HOV lane access. We also took the Toyota Prius as a case study to examine the spatial autocorrelations of spatial dependence and analyze each policy's effect when considering geographic differences. Our empirical results suggest some important points for policymakers to consider when attempting to introduce a new product into the market.

First, our estimation results show that state tax incentives are important for consumers' adoption of hybrid vehicles. Furthermore, non-monetary policies, such as privileged access to HOV lanes, are positively correlated with HEV sales. We also found evidence that federal incentives are negative relationship with HEV sales. Finally, we found DPM, which is the operation cost for a vehicle, to be the most important factor in the adoption of HEVs, which means that consumers primarily consider how much they can save immediately when buying a HEV.

Second, in terms of socioeconomic factors, we found that counties with more college graduates saw more HEV purchases. For the interaction terms of transportation mode and travel time to work, our estimation results show that travel time is unimportant if it is less than 24 minutes or greater than 40 minutes; a county with more commuters driving alone is more likely than other counties to see more HEV sales. In counties with more people who commute through public transit with a travel time to work of over 40 minutes, HEV sales are lower.

Finally, we considered the geographic patterns of HEV sales, which has not been done before in the literature. The GIS analysis showed that from 2005 to 2007, the coefficients for all government policy variables on the West Coast are negative. The sign for the variables on the East Coast changed from positive to negative from 2005 to 2007 and then became more negative throughout 2007. Those negative signs indicate that government policies in those areas were ineffective. We suspect this trend to be the result of government support gradually being phased out.



Moran's Index:	0.437033
Expected Index:	-0.000330
Variance:	0.000022
z-score:	93.492126
p-value:	0.000000

Input Feature Class:	Log Prius (Sales+1) 2007
Input Field:	LNSALES_1
Conceptualization:	INVERSE_DISTANCE
Distance Method:	EUCLIDEAN
Row Standardization:	True
Distance Threshold:	1.763891 Degrees
Weights Matrix File:	None
Selection Set:	False

Panel C. Toyota Prius sales in 2007

Fig. 3: **Global Moran's I spatial autocorrelations**

Source: Made by the authors based at the data from R. L. Polk & Co.

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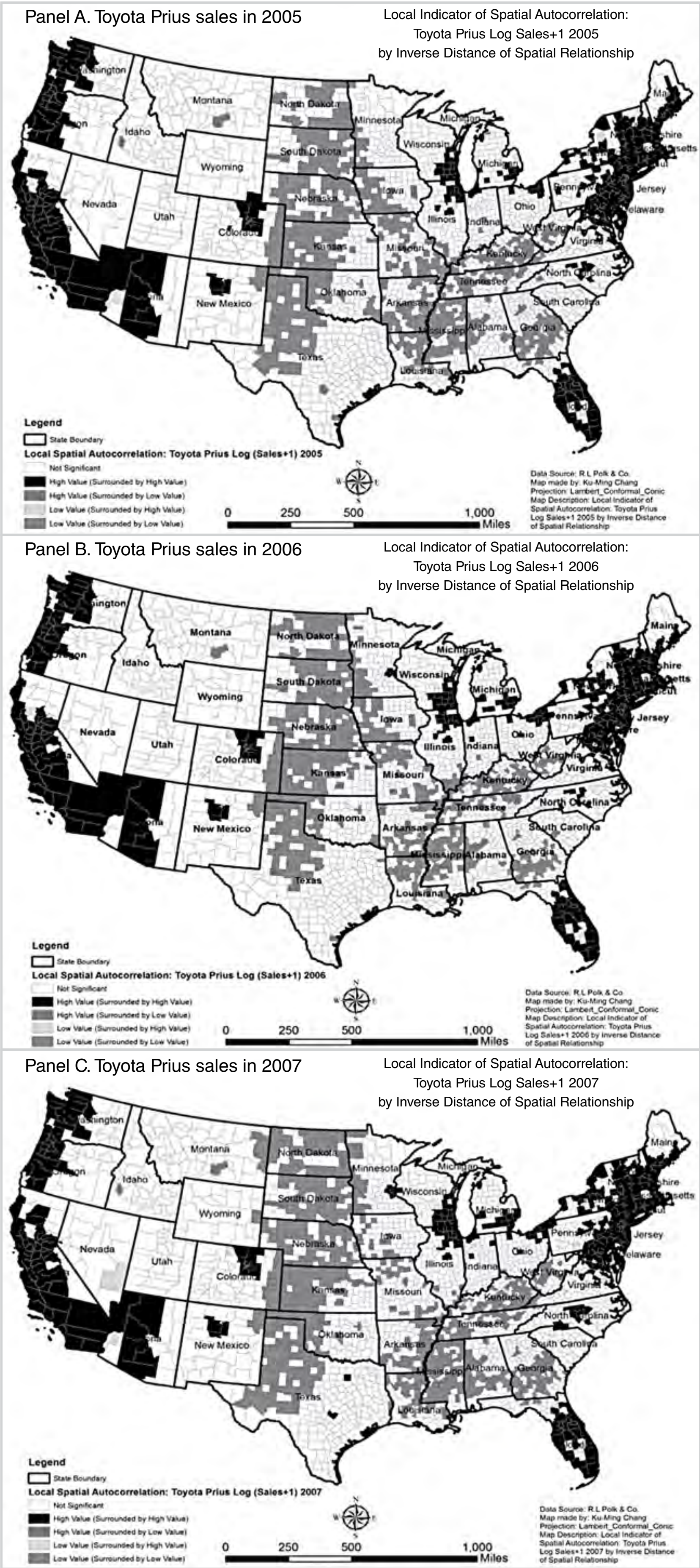

Fig. 4: **Local indicators of spatial autocorrelation**
Source: Made by the authors based at the data from R. L. Polk & Co.

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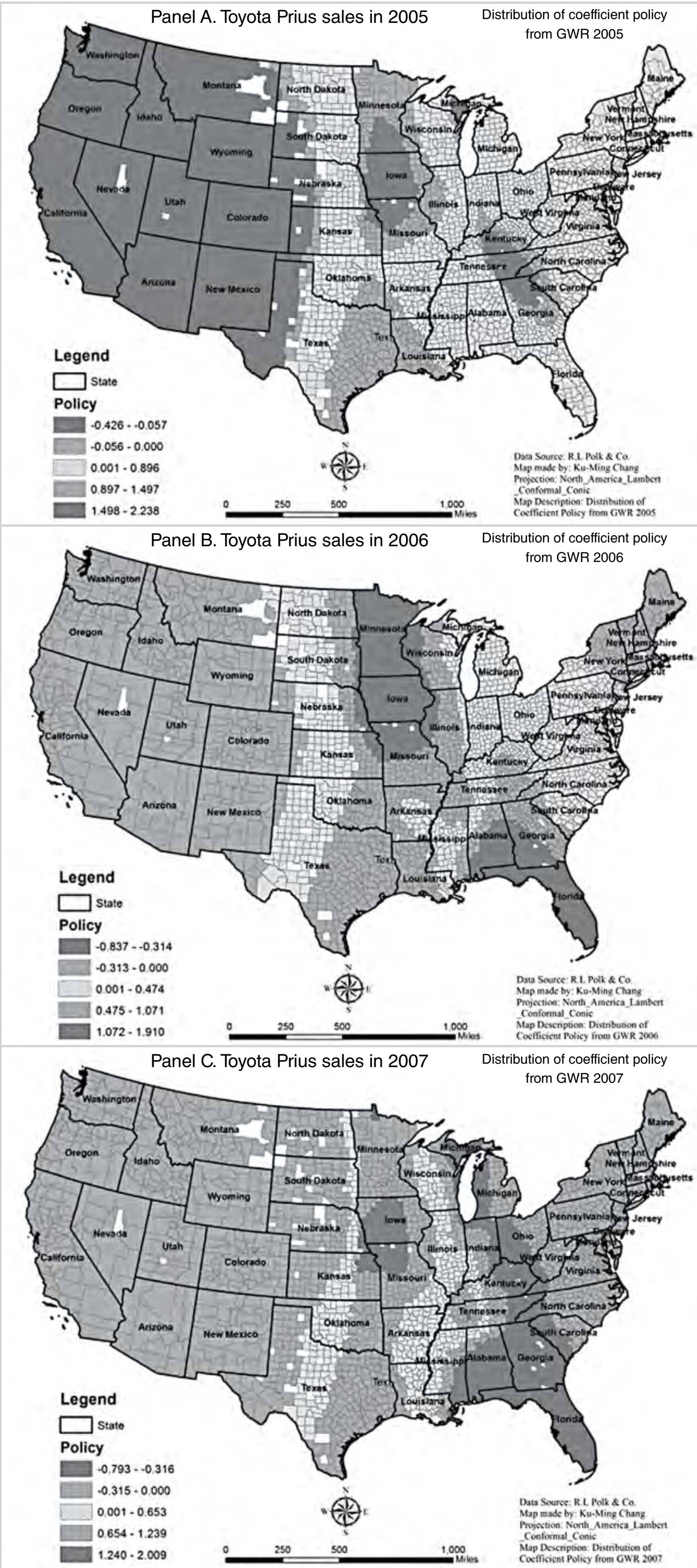

Fig. 4: **Policy effects based on geographically weighted regressions**
Source: Made by the authors based at the data from R. L. Polk & Co.

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