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Incentivizing Alternative Fuel Vehicle Transactions: Analysis of Cash-for-Clunkers Transactions for New Alternative Fuel Vehicles

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Abstract

Monetary incentives to accelerate the transition of private vehicle fleets to zero emissions promote sustainability in the transportation sector. Clean Cars for America to incentivize transactions for new battery power vehicles is a program in furtherance of sustainable transportation goals in the United States. Unfortunately, data on transactions for new alternative fuel vehicles (AFVs) are scarce so empirical research to explore the costs and/or the benefits of such programs is also scarce. Analysis of transactions for new AFVs from a past, national vehicle retirement program known as Cash for Clunkers provides a rare glimpse into the economic costs and into the environmental benefits of monetary incentives. Analysis of transactions for new AFVs also provides an empirical context for a future, national retirement program such as Clean Cars for America. To that end, the analysis estimates Greenhouse Gas (GHG) emission reduction from a subsample of Cash-for-Clunkers transactions for new AFVs. Overall, incentivizing AFV transactions effectively decreases GHG emissions though regional differences may necessitate dynamic, rather than static, voucher amounts so as to harmonize such differences.

Keywords
Private vehicle retirement; alternative fuel vehicles; greenhouse gas emissions; private vehicle usage; rebound effect; multilevel model

1. Introduction

One manifestation of the macroeconomic shock from the COVID-19 pandemic is low private vehicle sales. Total sales[1] in April of 2020 (9.1 million) equal the low in the United States since January of 1976 [1] (Figure 1). Year-over-year sales in April of 2020 are also low worldwide [2]. Contraction in an industry so vital to past, present, and future economic growth is the impetus for calls to reintroduce programs to incentivize private vehicle transactions. In the United States, Senator Chuck Schumer (D-NY), Senator Debbie Stabenow (D-MI), Senator Sherrod Brown (D-OH), and Senator Jeff Merkley (D-OR) propose a program to incentivize private vehicle transactions from gasoline power to zero emission known as Clean Cars for America [3]. Such a program is reminiscent of the private vehicle retirement program in the United States known as Cash for Clunkers. In the short term, the goals of the programs are the same; that is, to incentivize transactions so as to decrease greenhouse gas (GHG) emissions from the private vehicle fleet. In the long term, however, the goal of the latter program is different than the goal of the former program; that is, to incentivize transactions so as to accelerate the transition of the private vehicle fleet from internal combustion engine power to battery power.

[1]. Seasonally-adjusted, annual rate of total vehicle sales—domestic and foreign. Total vehicles are: automobiles (passenger cars as well as station wagons); and light trucks (minivans and sport utility vehicles). Domestic sales are sales in the United States where assembly is in the United States, Canada, or Mexico. Foreign sales are sales in the United States where production is elsewhere.

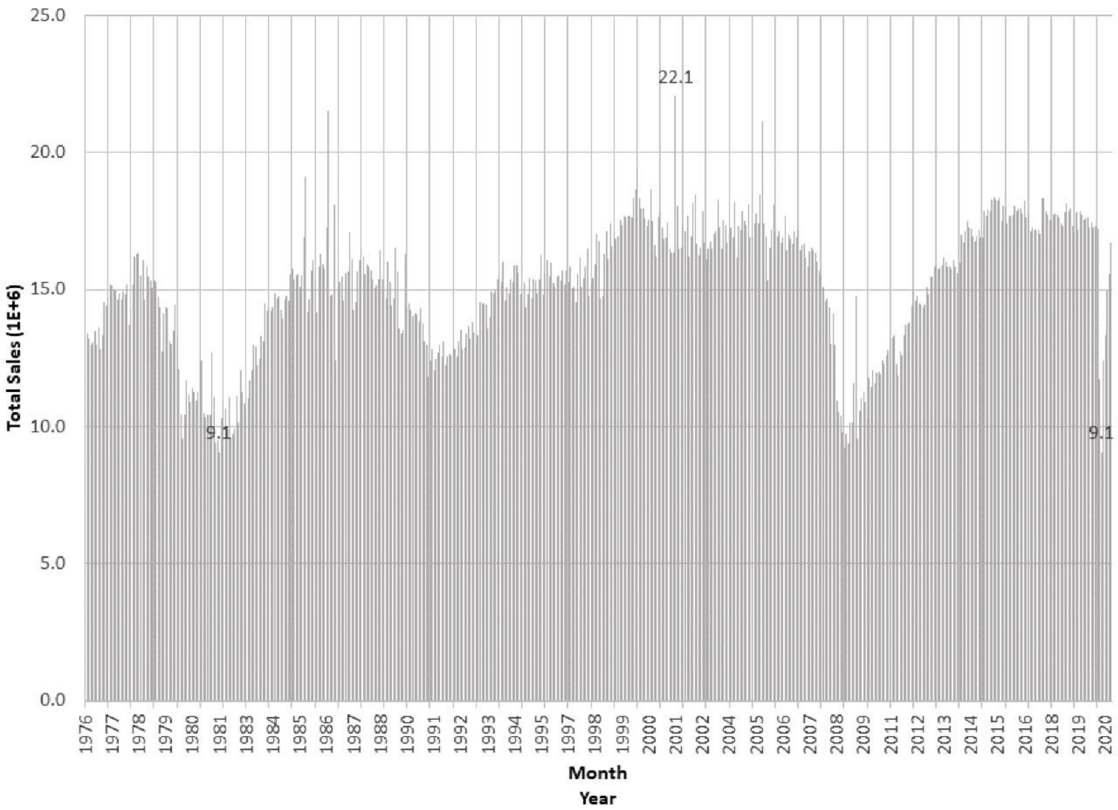

Figure 1 Total sales (1E+6) by month from January of 1976 to October of 2020 in the United States with lowest-sales (9.1) months (December of 1981 and April of 2020) and with highest-sales (22.1) month (October of 2001).

Support from stakeholders worldwide for Clean Cars for America speaks to the potential of battery power. However, the diffusion of new technology is typically not even spatially or temporally, especially new technology for private vehicles. Further, such programs may not accelerate the transition of the private vehicle fleet because the target of the policy is wrong. The argument relates to the paradox of a policy to economically incentivize transactions when social behavior at the point of sale renders such incentives irrelevant to consumers. Indeed, first adopters already possess the resources to absorb any potential financial losses due to the inherently uncertain viability of new technology [4]. The shift of the policy target from the vehicle to the consumer harkens to past efforts by social scientists to refocus attention on how individuals behave economically and socially [5]. Regarding the latter, such programs to accelerate the retirement of older private vehicles engender resistance from individuals who object to government efforts to enforce the obsolescence of classics worthy of preservation, not clunkers worthy of retirement [6].

To test the viability of a national retirement program to transition the private vehicle fleet from fossil fuels to alternative fuels[2], the study analyzes a national retirement program to incentivize private vehicle transactions from 2009. Analysis of the national retirement program highlights the transactions where the trade-in vehicle uses fossil fuels and the new vehicle uses alternative fuels. Analysis of the national retirement program also highlights who adopts the new technology and

[2]. Flexible-Fuel Vehicles (FFVs) use flex fuel (E85 = Ethanol 85% + Gasoline 15%) as an alternative fuel. Hybrid Electric Vehicles (HEVs) use electric motors for alternative power. Natural Gas Vehicles (NGVs) use Compressed Natural Gas (CNG) as an alternative fuel.

where the new technology is popular. The questions the analysis answers are as follows. First, what are the economic costs as well as the environmental benefits of the monetary incentives for new alternative fuel vehicles (AFVs) in the national retirement program? Second, how effective are vouchers to incentivize transactions for new AFVs in each state?

The following section reviews the empirical literature on vehicle retirement programs.

2. Background

2.1 Clean Air Act Amendments of 1990

The Clean Air Act Amendments of 1990 (Public Law 101-549) identify a "program to encourage the voluntary removal from use and the marketplace of pre-1980 model year light duty vehicles and pre-1980 model light duty trucks" (p. 2466) as one of sixteen control measures to mitigate emissions. Guidance from the United States Environmental Protection Agency [7] highlights the generation of mobile-source emission reduction credits (MERCs) from a market-based, control measure to accelerate the retirement of vehicles. Such guidance encourages potential public sponsors and/or potential private sponsors to target high-emitter vehicles and to target vehicles with obsolete emission-control technology so as to maximize cost effectiveness. However, the objective is to assist program sponsors in the design of flexible retirement programs to best suit the sponsors' goals within the context of sound policy. To that end, sponsors can design emission-limiting programs or market-response programs. In the former, a sponsor retires vehicles until the program achieves a specific emission reduction target. In the latter, a sponsor incentivizes retirements without a specific emission reduction target. Either way, public sponsors and/or private sponsors incentivize retirements so as to generate an emission credit equivalent to the emission difference between the new vehicle and the old vehicle.

2.2 Consumer Assistance to Recycle and Save Act of 2009

The Car Allowance Rebate System (CARS), also known as Cash for Clunkers, is an example of a market-response, retirement program in the United States. The enactment of the Consumer Assistance to Recycle and Save Act of 2009 (Public Law 101-549) on June 24th, 2009 directs the Secretary of Transportation to establish and to administer CARS thru the National Highway Traffic Safety Administration (NHTSA). CARS incentivizes purchase transactions or lease transactions via vouchers dependent on the fuel economy difference from the new vehicle to the trade-in vehicle. The total appropriation for CARS transactions was three billion dollars. A total of 677,842 voucher applications were paid from July 1st, 2009 to August 25th, 2009. The sum of the paid voucher applications was $2.9 billion. The mean paid voucher was $4,209.00.

Total (purchase plus lease) transactions from CARS was 677,842:401,274 automobiles; 274,602 light trucks; and 1,966 heavy trucks. Mean combined fuel economy of new vehicles was 24.9 miles per gallon. Mean combined fuel economy of trade-in vehicles was 15.8 miles per gallon. The mean combined fuel economy difference (from the new vehicle to the trade-in vehicle) per transaction was 9.2 miles per gallon. NHTSA estimates CARS decreases annual fuel consumption by approximately thirty-three million gallons. NHTSA also estimates CARS decreases quarter-century carbon dioxide (CO_2) emissions by nine million metric tons.

2.3 Literature Review

Table 1 lists analyses on the effectiveness of vehicle retirement programs. The list is long, but not exhaustive. Rather, the list represents a sample of analyses on the effectiveness of vehicle retirement programs: prospective [8-12]; and retrospective [13-18]. Analyses on the optimal subsidy for vehicle retirement programs [19, 20] are not on the list. A review of the analyses in Table 1 reveals the following. First, variation in program design is evident. Nonetheless, the majority are market-response programs without a specific emission reduction target. Second, the majority of programs are local in scale or regional in scale [18]. To that end, *Retiring Old Cars: Programs To Save Gasoline and Reduce Emissions* from the Office of Technology Assessment [8] is a rare example of a prospective analysis to estimate the effectiveness of a national program to retire one million vehicles in the United States. Third, cost-benefit analyses of vehicle retirement programs are rare [9-12, 18].

Table 1 Analyses of vehicle retirement programs.

Reference	Where	When	Results
[8]	United States		Prospective analysis of a program to retire one million vehicles in nonattainment areas for carbon monoxide and for ozone. For pre-1970 vehicles, the program saves: 63,000 tons of hydrocarbons per year; 343,000 tons of carbon dioxide per year; 13,500 tons of nitrogen oxides per year; and 171 million gallons of gasoline per year.
[9]	Sacramento, California	1961 to 1978	Cost-benefit analysis of prospective regional retirement program known as the Sacramento Area Scrappage Program (SASP). Estimates regional vehicles available for retirement from national data. Analyses of scenarios to retire, at the least, 8,000 vehicles and to retire, at the most, 12,000 vehicles show SASP is not economically justifiable.
[10]	Los Angeles County, California	1957 to 1992	Estimates vehicle supply curve to prospectively analyze costs-benefits of local vehicle retirement program. Base case of $1,000 subsidy (with transfer payments) retires 653,000 vehicles and reduces total emissions from 2% to 6% for hydrocarbons and for nitrogen oxides.
[11]	Los Angeles County, California Orange County, California Riverside County, California San Bernadino County, California	1999 to 2010	Prospective simulation of household-level response to a regional accelerated vehicle retirement program (AVRP) for light-duty vehicles 10 years old and older as well as vehicles 20 years old and older with a vehicle choice-demand-usage model known as CALCARS (California Conventional and Alternative Fuel Response Simulator). Analyses show latter program is more cost effective.
[13]	Greece	January 1, 1991 to March 31, 1993	Retrospective analysis of retirement/replacement policy shows pollutant emission reduction and lower fleet age are consistent with theoretical model of optimal vehicle replacement.
[12]	Israel	2003 to 2007	Prospective cost-benefit analysis of accelerated vehicle-retirement (AVR) program. AVR with 6,309 New Israeli Shekel (NIS) incentive maximizes net benefit for private vehicles. AVR retires 97,108 private vehicles to decrease total air pollution from private

			vehicles by approximately 17% every year over a five-year span. Net benefit over time span of AVR is 237,974,000 NIS.
[14]	United States	June 24, 2009 to August 25, 2009	Retrospective analysis of net new vehicle sales and employment from Consumer Assistance to Recycle and Save (CARS). CARS induces 395,000 new vehicle sales and induces 40,200 full-time equivalent jobs.
[15]	United States	June 24, 2009 to August 25, 2009	Retrospective vehicle life cycle analysis of greenhouse gas (GHG) emission reduction from CARS. Results show CARS prevents 3.9 million metric tons of CO_2-equivalent emissions at a 10% rebound effect.
[16]	United States	June 24, 2009 to August 25, 2009	Retrospective analysis of new vehicle sales and environmental effects of CARS. CARS increases new vehicle sales by 370,000. CARS decreases carbon dioxide emissions from 9.0 million tons to 28.2 million tons. CARS costs from $92 to $288 to decrease carbon dioxide emissions by one ton. CARS costs from $0.89 to $2.80 to decrease gasoline consumption by one gallon.
[17]	United States	June 24, 2009 to August 25, 2009	Retrospective economic impact of CARS. CARS increases vehicle sales +43% from June of 2009 to August of 2009. CARS also decreases fuel consumption −33 million gallons per year for 25 years.
[18]	Beijing-Tianjin-Hebei, China	2008 to 2015	Retrospective, cost-benefit analysis of retirement subsidy policy on 1.362 million yellow-label vehicles (YLV). YLV are light-duty vehicles unable to achieve China I emission standards or heavy-duty vehicles unable to achieve China III emission standards. Net benefits of 16.43 Chinese yuan, 2.71 Chinese yuan, and 1.20 billion Chinese yuan in Beijing, Tianjin, and Hebei, respectively.

In light of the above on the effectiveness of vehicle retirement programs, *Lessons Learned Cash for Clunkers Program* [21] and *Subsidizing Replacement of Motor Vehicles: An Analysis of Cash for Clunkers Program* [22] audit the performance of a national vehicle retirement program in the United States. Explicit program objectives are not evident in the Consumer Assistance to Recycle and Save Act of 2009, but implicit program objectives are: to stimulate private vehicle sales; and to increase private-vehicle fuel economy. The performance audits suggest Cash for Clunkers was somewhat successful with regard to the former implicit program objective. Higher monthly, private vehicle sales in July of 2009 and in August of 2009 than in January of 2009, in February of 2009, in March of 2009, in April of 2009, in May of 2009, or in June of 2009 are testament to the economic benefit of the incentive program. The program audit also suggests Cash for Clunkers was successful with regard to the latter implicit program objective. The mean combined fuel economy difference per transaction (9.2 miles per gallon) is testament to the environmental benefit of the incentive program.

3. Methodology and Data

3.1 Methodology

The methodology to explore CO_2 emission reduction and CO_2 emission reduction cost from CARS transactions for new AFVs is known as a multilevel model. The advantages of a multilevel methodology for such an exploration are as follows. First, a multilevel model nests micro-level events within macro-level units of analysis. Second, a two-level model, such as in the study, estimates two sets of parameters. The first set of parameters summarizes the average relationship between CO_2 emission reduction or CO_2 emission reduction cost and the state-level independent variables known to affect CARS transactions for new AFVs. The second set of parameters summarize the variation in the average relationship between CO_2 emission reduction or CO_2 emission reduction cost and the state-level independent variables known to affect CARS transactions for new AFVs.

The multilevel models in the study nest micro-level transactions (*t*) within macro-level states (*s*) [23]. In each macro-level unit of analysis, the micro-level dependent variable (Y_{ts}) is a function of micro-level independent variables as well as a micro-level error term (r_{ts})

$$Y_{ts} = \beta_{0s} + \beta_{1s}X_{1ts} + \beta_{2s}X_{2ts} + \cdots + \beta_{\mathrm{P}s}X_{\mathrm{P}ts} + r_{ts} \tag{1}$$

where: Y_{ts} is CO_2 emission reduction or CO_2 emission reduction cost for transaction *t* in state *s*; $\beta_{\mathrm{P}s}$ are (p = 0, 1, 2, …, P) transaction-level coefficients; $X_{\mathrm{P}ts}$ is the transaction-level independent variable P for transaction *t* in state *s*; and r_{ts} is the transaction-level error term. The variance of the transaction-level error term (r_{ts}) is σ^2. In a two-level model, such as in the study, the y-intercept and the coefficients at the micro-level are fixed (invariant at the macro-level) or random (variant at the macro-level). The two-level model in the study is known as a random-intercept model—the y-intercept is random, but the coefficients are fixed. The model for variation in CO_2 emission reduction or in CO_2 emission reduction cost between states is as follows

$$\beta_{0s} = \gamma_{00} + \gamma_{01}W_{1s} + \gamma_{02}W_{2s} + \cdots + \gamma_{0\mathrm{Q}}W_{\mathrm{Q}s} + u_{0s} \tag{2}$$

where: γ_{00} is the y-intercept for the transaction effect β_{0s}; γ_{0Q} are (q = 1, 2, 3, …, Q) state-level coefficients; W_{Qs} is the state-level independent variable Q in state *s*; and u_{0s} is the state-level error term. The variance of the state-level error term (u_{0s}) is τ_{00}.

The multilevel models in the study are fit with HLM software, Version 8.2.1.13 of HLM for Windows [24].

3.2 Data

The transaction-level dependent variables and the transaction-level independent variables in the multilevel models are from CARS.

The transaction-level dependent variables are as follows. CO_2 Emission Reduction and CO_2 Emission Reduction Cost represent the CO_2 emissions decrease and the cost of the CO_2 emissions decrease from the trade-in vehicle to the new vehicle where the trade-in vehicle uses fossil fuels and the new vehicle uses alternative fuels.[3]

The transaction-level independent variables are as follows. Hybrid is 1 if the new vehicle is a Hybrid Electric Vehicle (HEV), 0 otherwise. Invoice Amount is a voucher of $3,500.00 or a voucher of $4,500.00. New Vehicle MSRP (Manufacturer Suggested Retail Price) is the base MSRP for the new vehicle up to the price limit of $45,000.00. New Vehicle MSRP tests if price is a barrier to emission reduction—if price is higher, then emission reduction is greater. Trade-in Vehicle Category-New Vehicle Category are retirement-eligible, vehicle-category pairs. Vehicles (trade-in or new) are Passenger Cars, Category 1 Trucks, or Category 2 Trucks.[4] Passenger Cars excludes vehicles whose manufacture is not primarily for the transport of persons and vehicles capable of off-highway operation. Category 1 Trucks includes sport utility vehicles, small pickup trucks, medium pickup trucks, small passenger vans, medium passenger vans, small cargo vans, and medium cargo vans. Category 2 Trucks includes large pickup trucks and large vans.

The state-level independent variables in the multilevel model are as follows. CO_2 Emissions are total CO_2 emissions from the transportation sector in 2009 [29].[5] CO_2 Emissions test if CARS is more effective in higher-emission states where the marginal benefits of retirement are presumably greater [10]. Gasoline Price is the mean of the retail prices of regular gasoline in June of 2009 [30], in July of 2009 [31], and in August of 2009 [32]. Gasoline Tax is the mean of the tax on gasoline in

[3]. CO_2 emissions per gallon of gasoline are 19.38 pounds [25]. Total annual gasoline in gallons is the quotient of total annual distance in miles and fuel economy in miles per gallon. The formula to estimate total annual distance in miles for trade-in vehicles is Trade-in Vehicle Miles = Trade-in Vehicle Odometer Reading/(2009 − Trade-in Vehicle Year) where: Trade-in Vehicle Miles is the total annual distance in miles for the trade-in vehicle; Trade-in Vehicle Odometer Reading is the mean odometer reading by model year and by vehicle type from the 2009 National Household Travel Survey (NHTS); 2009 is the year of CARS; and Trade-in Vehicle Year is the model year of the trade-in vehicle. Assume total annual distance in miles for the new vehicle is ten percent more than total annual distance in miles for the trade-in vehicle due to the rebound effect. The rebound effect is "the interaction of energy use with the efficiency of energy use: lower the energy required to do something, and you will do a bit more of that thing" [26]. Jevons [27] was the first to describe the rebound effect on the use of coal. A ten percent rebound effect on the use of gasoline represents a survey of the literature by Greening et al. [28].

[4]. Category 3 Trucks (very large pickup trucks and very large vans) are also a retirement-eligible, vehicle category for CARS transactions. However, no Category 3 Trucks (trade-in or new) are in the subsample of CARS transactions for new AFVs.

[5]. Carbon dioxide (CO_2) was approximately 94.45% of direct emissions from the transportation sector in 2009 [29]. Nitrogen dioxide (N_2O), hydrofluorocarbons (HFCs), and methane (CH_4) were: approximately 4.20%; approximately 1.44%; and approximately 0.13%, respectively, of direct emissions from the transportation sector in 2009.

June of 2009 [30], in July of 2009 [31], and in August of 2009 [32].[6] Gasoline Price and Gasoline Tax test if CARS is less effective in lower-gasoline price states where the benefits of retirement are presumably lower [33]. Vehicle Registrations is the sum of the number of private vehicle registrations in 2009 plus the number of commercial vehicle registrations in 2009 [34].[7] Vehicle Registrations controls for the number of retirement-eligible vehicles in each state. Vehicle Type is the location quotient for Passenger Cars, for Category 1 Trucks, and for Category 2 Trucks.[8] If the location quotient equals 1.00, then the incidence of a vehicle type is the same in the state as in the United States. Vehicle Type, therefore, controls for the incidence of different types of retirement-eligible vehicles in each state.

The code for the variables in the study is in SAS software, Version 9.4 of the SAS System for Windows.[9]

4. Results

4.1 CO_2 Emission Reduction versus CO_2 Emission Reduction Cost

Table 2 ranks mean CO_2 emission reduction in each state (from highest to lowest) and ranks mean CO_2 emission reduction cost in each state (from lowest to highest). Table 2 also highlights the top ten states as well as the bottom ten states. The five left columns in Table 2 rank mean CO_2 emission reduction in each state and the five right columns in Table 2 rank mean CO_2 emission reduction cost in each state. The last row provides column sums (Pounds (1E+3) in the second column, Transactions in the third column, Dollars in the seventh column, and Transactions in the eighth column) or column means (Pounds (1E+3) per Transactions in the fourth column and Dollars per Transaction in the ninth column) where appropriate.

[6]. Alaska did not tax regular gasoline from September 1st of 2008 to August 31st of 2009 [32].
[7]. Includes taxicabs.
[8]. Data on the number of Passenger Cars, the number of Category 1 Trucks, and the number of Category 2 Trucks are from the 2009 NHTS.
[9]. Copyright © 2013 SAS Institute Incorporated. SAS and all other SAS Institute Incorporated product names or service names are registered trademarks or trademarks of SAS Institute Incorporated Cary, NC, USA.

Table 2 Ranks of CO_2 emission reduction in each state (highest to lowest) and ranks of CO_2 emission reduction cost in each state (lowest to highest).

State	Pounds (1E+3)	Transactions	Pounds (1E+3) per Transaction	Rank	State	Dollars	Transactions	Dollars per Transaction	Rank
Hawaii	**185,829.57**	**38**	**4,890.25**	**1**	**Hawaii**	**$50.21**	**38**	**$1.32**	**1**
Connecticut	**1,404,017.74**	**322**	**4,360.30**	**2**	**Oregon**	**$557.37**	**390**	**$1.43**	**2**
Oregon	**1,675,506.20**	**390**	**4,296.17**	**3**	**Connecticut**	**$462.84**	**322**	**$1.44**	**3**
California	**11,403,798.50**	**2,655**	**4,295.22**	**4**	**Massachusetts**	**$682.48**	**471**	**$1.45**	**4**
Massachusetts	**1,976,316.50**	**471**	**4,196.00**	**5**	**California**	**$3,898.66**	**2,655**	**$1.47**	**5**
Rhode Island	**282,834.06**	**70**	**4,040.49**	**6**	**New Jersey**	**$1,201.13**	**808**	**$1.49**	**6**
Washington	**2,095,587.72**	**521**	**4,022.24**	**7**	**Rhode Island**	**$107.54**	**70**	**$1.54**	**7**
New Jersey	**3,224,751.19**	**808**	**3,991.03**	**8**	**Washington**	**$813.21**	**521**	**$1.56**	**8**
Nevada	**440,715.99**	**112**	**3,934.96**	**9**	**New York**	**$2,237.85**	**1,413**	**$1.58**	**9**
New York	**5,320,057.58**	**1,413**	**3,765.08**	**10**	**Arizona**	**$581.36**	**358**	**$1.62**	**10**
Alaska	345,403.61	93	3,714.02	11	Alaska	$154.84	93	$1.66	11
Arizona	1,308,308.06	358	3,654.49	12	Ohio	$2,963.54	1,748	$1.70	12
Colorado	1,350,796.44	373	3,621.44	13	Illinois	$3,198.86	1,879	$1.70	12
Montana	329,413.98	93	3,542.09	14	Maryland	$989.60	579	$1.71	13
Virginia	3,003,140.39	849	3,537.27	15	Florida	$2,012.30	1,174	$1.71	13
New Hampshire	579,913.05	165	3,514.62	16	Nevada	$192.42	112	$1.72	14
Florida	4,120,999.57	1,174	3,510.22	17	Colorado	$643.23	373	$1.72	14
North Carolina	2,736,428.88	805	3,399.29	18	Virginia	$1,467.10	849	$1.73	15
Ohio	5,925,788.56	1,748	3,390.04	19	New Hampshire	$286.63	165	$1.74	16
Maryland	1,961,169.06	579	3,387.17	20	Michigan	$5,791.04	3,293	$1.76	17
Illinois	6,341,795.17	1,879	3,375.09	21	Indiana	$1,971.96	1,106	$1.78	18
Texas	6,717,394.75	2,025	3,317.23	22	Tennessee	$1,082.38	597	$1.81	19
Utah	757,815.35	229	3,309.24	23	Montana	$169.03	93	$1.82	20
Maine	588,531.89	178	3,306.36	24	Maine	$324.75	178	$1.82	20

New Mexico	443,032.13	135	3,281.72	25	West Virginia	$318.19	174	$1.83	21
Tennessee	1,953,072.64	597	3,271.48	26	North Carolina	$1,475.23	805	$1.83	21
Indiana	3,609,908.94	1,106	3,263.93	27	Missouri	$1,859.84	1,004	$1.85	22
West Virginia	558,581.23	174	3,210.24	28	New Mexico	$251.63	135	$1.86	23
Georgia	2,244,738.09	701	3,202.19	29	Wisconsin	$2,454.59	1,306	$1.88	24
Michigan	10,535,713.60	3,293	3,199.43	30	Delaware	$178.64	95	$1.88	24
Delaware	301,655.35	95	3,175.32	31	Kentucky	$967.52	506	$1.91	25
Missouri	3,178,788.55	1,004	3,166.12	32	Minnesota	$2,821.40	1,463	$1.93	26
Wyoming	177,110.20	56	3,162.68	33	Pennsylvania	$2,505.74	1,295	$1.93	26
Minnesota	4,624,422.56	1,463	3,160.92	34	Utah	$444.27	229	$1.94	27
Pennsylvania	4,067,965.35	1,295	3,141.29	35	Georgia	$1,398.11	701	$1.99	28
Kentucky	1,558,732.84	506	3,080.50	36	Texas	$4,094.98	2,025	$2.02	29
Idaho	457,202.45	149	3,068.47	37	Idaho	$301.35	149	$2.02	29
Wisconsin	3,995,225.45	1,306	3,059.13	38	Wyoming	$113.74	56	$2.03	30
Mississippi	632,718.38	209	3,027.36	39	South Carolina	$741.03	359	$2.06	31
Oklahoma	1,876,805.29	627	2,993.31	40	Oklahoma	$1,307.21	627	$2.08	32
Vermont	**274,741.39**	**92**	**2,986.32**	**41**	**Vermont**	**$192.42**	**92**	**$2.09**	**33**
Alabama	**1,313,877.11**	**444**	**2,959.18**	**42**	**Iowa**	**$1,876.75**	**895**	**$2.10**	**34**
South Carolina	**1,057,330.04**	**359**	**2,945.21**	**43**	**Alabama**	**$943.46**	**444**	**$2.12**	**35**
Louisiana	**1,209,455.91**	**413**	**2,928.46**	**44**	**Arkansas**	**$900.53**	**423**	**$2.13**	**36**
Arkansas	**1,234,526.20**	**423**	**2,918.50**	**45**	**Kansas**	**$1,180.38**	**528**	**$2.24**	**37**
Kansas	**1,481,161.40**	**528**	**2,805.23**	**46**	**Mississippi**	**$470.47**	**209**	**$2.25**	**38**
Iowa	**2,498,721.92**	**895**	**2,791.87**	**47**	**South Dakota**	**$757.86**	**336**	**$2.26**	**39**
South Dakota	**879,552.63**	**336**	**2,617.72**	**48**	**Louisiana**	**$952.97**	**413**	**$2.31**	**40**
North Dakota	**719,805.62**	**294**	**2,448.32**	**49**	**Nebraska**	**$1,077.48**	**457**	**$2.36**	**41**
Nebraska	**1,109,319.78**	**457**	**2,427.40**	**50**	**North Dakota**	**$703.45**	**294**	**$2.39**	**42**
	116,070,478.85	34,305	3,383.49			$62,129.60	34,305	$1.81	

The geographic distributions of top-rank states versus the geographic distribution of bottom-rank states on CO_2 emission reduction and on CO_2 emission reduction cost are clearly different. The top-rank states are mostly on the periphery (Hawaii, Connecticut, and Oregon) and more populous (California and New York), while the bottom-rank states are mostly in the core (Nebraska and North Dakota) and less populous (Vermont and South Dakota). The top-rank state (Hawaii) is also clearly different from the bottom-rank states (Nebraska and North Dakota). First, the majority of new vehicles in Hawaii transactions are HEVs (52.63%), while the minority of new vehicles in Nebraska transactions are HEVs (2.63%) and the minority of new vehicles in North Dakota transactions are HEVs (2.72%). Second, most of the Hawaii transactions (31.58%) are Category 1 Truck-Passenger Car, while most of the Nebraska transactions (64.55%) and most of the North Dakota transactions (62.93%) are Category 2 Truck-Category 2 Truck. Third, invoice amounts are higher for Hawaii transactions ($4,342.66) than for Nebraska transactions ($4,189.28) or for North Dakota transactions ($4,180.27) which follows from the fact that the majority of new vehicles in Hawaii transactions are Passenger Cars.

4.2 Multilevel Models

Table 3 presents descriptive statistics for the transaction-level dependent variables and the transaction-level independent variables as well as the state-level independent variables. Table 4 presents results from a multilevel model with CO_2 Emission Reduction as the dependent variable (left column) and a multilevel model with CO_2 Emission Reduction Cost as the dependent variable (right column). The left column of Table 4 lists the coefficient estimates and the y-intercept estimate for the CO_2 Emission Reduction multilevel model. The right column of Table 4 lists the coefficient estimates and the y-intercept estimate for the CO_2 Emission Reduction Cost multilevel model. At the transaction level, if the new vehicle is a HEV, then CO_2 emissions decrease by 1,249.30 thousand pounds or by 6.90%[10]. A one standard deviation increase in Invoice Amount ($449.81) decreases CO_2 emissions by 805.16 thousand pounds. Transactions in the Category 2 Truck-Passenger Car category decrease CO_2 emissions by 3,386.49 thousand more pounds and cost $2.60 less per thousand pounds than transactions in the Category 2 Truck-Category 2 Truck category. Transactions in the Category 1 Truck-Passenger Car category decrease CO_2 emissions by 3,091.98 thousand more pounds and cost $2.59 less per thousand pounds than transactions in the Category 2 Truck-Category 2 Truck category. Transactions in the Passenger Car-Passenger Car category decrease CO_2 emissions by 1,153.44 thousand more pounds and cost $2.08 less per thousand pounds than transactions in the Category 2 Truck-Category 2 Truck category. At the state-level, a one standard deviation increase in CO_2 Emissions (88.29 billion pounds) decreases CO_2 emissions by 17.66 thousand pounds. CO_2 emissions decrease by 5,105.22 thousand pounds in states if the location quotient for passenger cars increases by one unit.

[10]. If the dependent variable is the natural log of CO_2 Emission Reduction.

Table 3 Descriptive statistics for the transaction-level variables and for the state-level variables.

Level (n)	Variable Category	Mean	SD	Min	Max
Transaction (34,305)					
	Dependent				
	Carbon Dioxide (CO_2) Emission Reduction (Pounds) (1E+3)	3,383.49	2,002.65	406.38	13,330.74
	Carbon Dioxide (CO_2) Emission Reduction Cost (Dollars per (1E+3) Pounds)	1.81	1.23	0.34	8.61
	Independent				
	Hybrid (%)				
	Yes	13.45			
	No	86.55			
	Invoice Amount (Dollars)	4,218.35	449.81	3,500.00	4,500.00
	New Vehicle MSRP (Dollars)	27,108.82	6,207.78	17,930.00	43,250.00
	Trade-in Vehicle Category-New Vehicle Category (%)				
	Passenger Car-Passenger Car	8.92			
	Passenger Car-Category 1 Truck	3.86			
	Passenger Car-Category 2 Truck	0.01			
	Category 1 Truck-Passenger Car	16.77			
	Category 1 Truck-Category 1 Truck	28.24			
	Category 1 Truck-Category 2 Truck	0.06			
	Category 2 Truck-Passenger Car	4.41			
	Category 2 Truck-Category 1 Truck	6.56			
	Category 2 Truck-Category 2 Truck	31.16			
State (50)					
	Independent				
	Carbon Dioxide (CO_2) Emissions (Pounds) (1E+9)	80.90	88.29	7.85	472.07
	Gasoline Price (Dollars per Gallon)	2.530	0.124	2.307	2.916
	Gasoline Tax (Dollars per Gallon)	0.215	0.064	0.000	0.375
	Vehicle Registrations (1E+6)	0.21	3.27	0.16	19.76
	Vehicle Type (Location Quotient)				
	Passenger Cars	0.97	0.12	0.68	1.24
	Category 1 Trucks	0.98	0.10	0.70	1.21
	Category 2 Trucks	1.10	0.35	0.40	1.92

SD = Standard Deviation.

MSRP = Manufacturer Suggested Retail Price.

Table 4 Results from multilevel models for CO_2 emission reduction and for CO_2 emission reduction cost.

Level (n)	Variable	Category	CO_2 Emission Reduction Pounds (1E+3) Coefficient (SE)	CO_2 Emission Reduction Cost Dollars per (1E+3) Pounds Coefficient (SE)
Transaction (34,305)				
	Hybrid (Yes = 1/No = 0)		+1,294.30*** (105.02)	+0.44*** (0.02)
	Invoice Amount (Dollars)		+1.79*** (0.03)	−0.001*** (0.00003)
	New Vehicle MSRP (Dollars)		−0.01 (0.01)	−0.00001*** (0.000001)
	Trade-in Vehicle Category-New Vehicle Category			
		Passenger Car-Passenger Car	+1,153.44*** (41.18)	−2.08*** (0.03)
		Passenger Car-Category 1 Truck	+159.62* (88.73)	−0.84*** (0.04)
		Passenger Car-Category 2 Truck	−273.10** (110.17)	+0.66 (0.87)
		Category 1 Truck-Passenger Car	+3,091.98*** (98.62)	−2.59*** (0.03)
		Category 1 Truck-Category 1 Truck	+1,827.09*** (68.79)	−1.66*** (0.03)
		Category 1 Truck-Category 2 Truck	+870.21*** (266.77)	−0.89*** (0.34)
		Category 2 Truck-Passenger Car	+3,386.49*** (86.44)	−2.60*** (0.04)
		Category 2 Truck-Category 1 Truck	+2,281.53*** (82.60)	−1.73*** (0.03)
		Category 2 Truck-Category 2 Truck	Referent	Referent
State (50)				
	Y-Intercept		+1,748.42*** (41.40)	+3.11*** (0.02)
	Carbon Dioxide (CO_2) Emissions (Pounds) (1E+9)		+0.20** (0.09)	+0.0001** (0.00005)
	Gasoline Price (Dollars per Gallon)		−0.17 (1.33)	−0.002** (0.001)
	Gasoline Tax (Dollars per Gallon)		−0.27 (1.50)	+0.001 (0.001)
	Vehicle Registrations (1E+6)		−4.25 (2.56)	+0.004** (0.002)
	Vehicle Type (Location Quotient)			
		Passenger Cars	+5,105.22** (2,407.56)	−0.53 (2.02)

	Category 1 Trucks	+2,369.72* (1,216.84)	−0.25 (0.99)
	Category 2 Trucks	+1,883.18* (947.09)	−0.11 (0.79)

SE = Standard Error.

*** significant at the 99% confidence level.

** significant at the 95% confidence level.

* significant at the 90% confidence level.

Choropleth maps of residuals from the multilevel model with CO_2 Emission Reduction as the dependent variable (Figure 2) and from the multilevel model with CO_2 Emission Reduction Cost as the dependent variable (Figure 3) test if spatial autocorrelation is evident in the respective model specifications.[11] The maps display standard deviation classification schemes where observed thousands of pounds (Figure 2) or observed dollars per thousand pounds (Figure 3) are lower than expected (blue) or higher than expected (red). Results suggest that clusters of residuals are evident. Moran's *I* for the residuals from the thousands-of-pounds model is +0.18 (Z = +2.28, p = 0.02), while Moran's *I* for the residuals from the dollars-per-thousand-pounds model is +0.24 (Z = +3.00; p = 0.003).

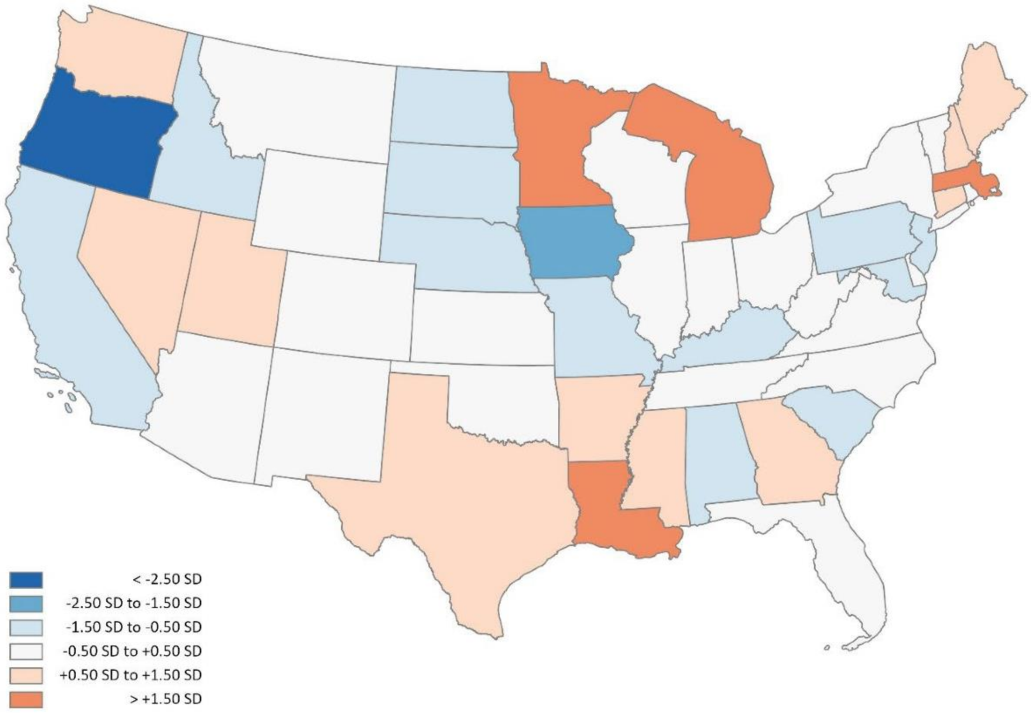

Figure 2 Choropleth map of residuals from multilevel model with CO_2 emission reduction as the dependent variable.

[11]. Contiguity is the spatial operator for the tests of spatial autocorrelation so Figure 2 and Figure 3 include only the contiguous states/state equivalents (except the District of Columbia).

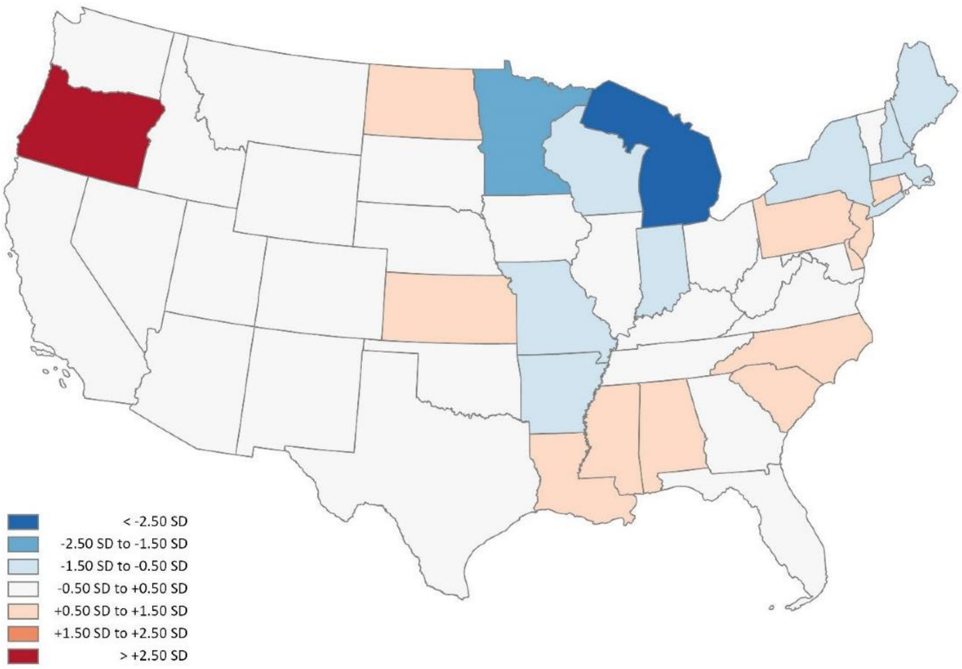

Figure 3 Choropleth map of residuals from multilevel model with CO_2 emission reduction cost as the dependent variable.

Local Indicators of Spatial Association (LISA) maps [35] of residuals from the multilevel model with CO_2 Emission Reduction as the dependent variable (Figure 4) and from the multilevel model with CO_2 Emission Reduction Cost as the dependent variable (Figure 5) test if local spatial association is evident in the respective model specifications.[12] The maps display High-High Cluster states and High-Low Outlier states (red) as well as Low-Low Cluster states and Low-High Outlier states (blue). Results suggest that clusters with similar values (High-High or Low-Low) and outliers with dissimilar High-Low values are evident. However, outliers with dissimilar Low-High values are not evident. In the thousands-of-pounds LISA map, High-High Cluster states are evident in the New England region (New Hampshire, Rhode Island, and Vermont) and in the South region (Arkansas and Louisiana). In the dollars-per-thousand-pounds LISA map, Low-Low Clusters are evident in the Midwest region (Illinois, Iowa, Michigan, and Wisconsin).

[12]. Contiguity is the spatial operator for the Local Indicators of Spatial Association (LISA) maps so Figure 4 and Figure 5 include only the contiguous states/state equivalents (except the District of Columbia).

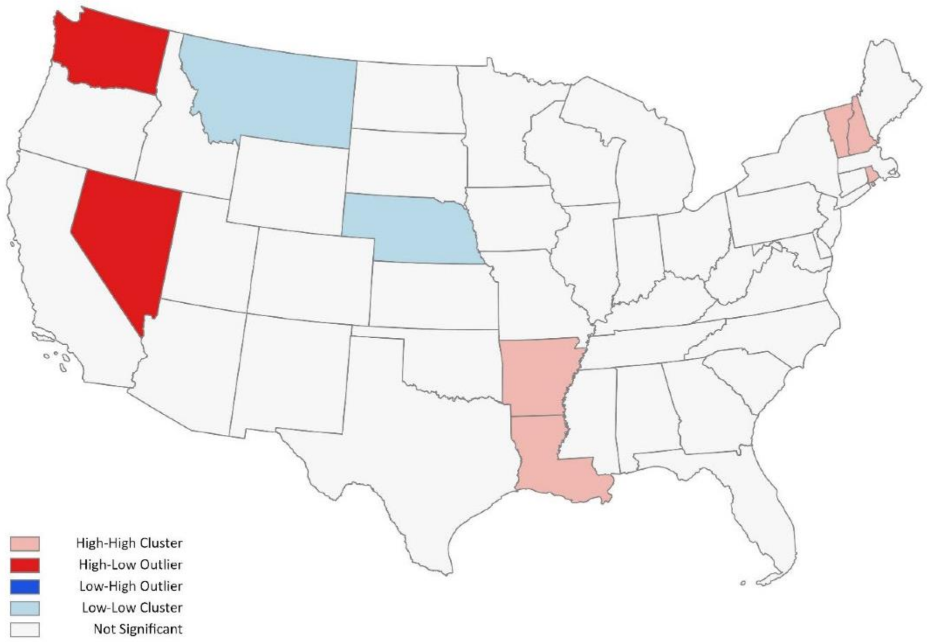

Figure 4 LISA (Local Indicators of Spatial Association) map of residuals from multilevel model with CO_2 emission reduction as the dependent variable.

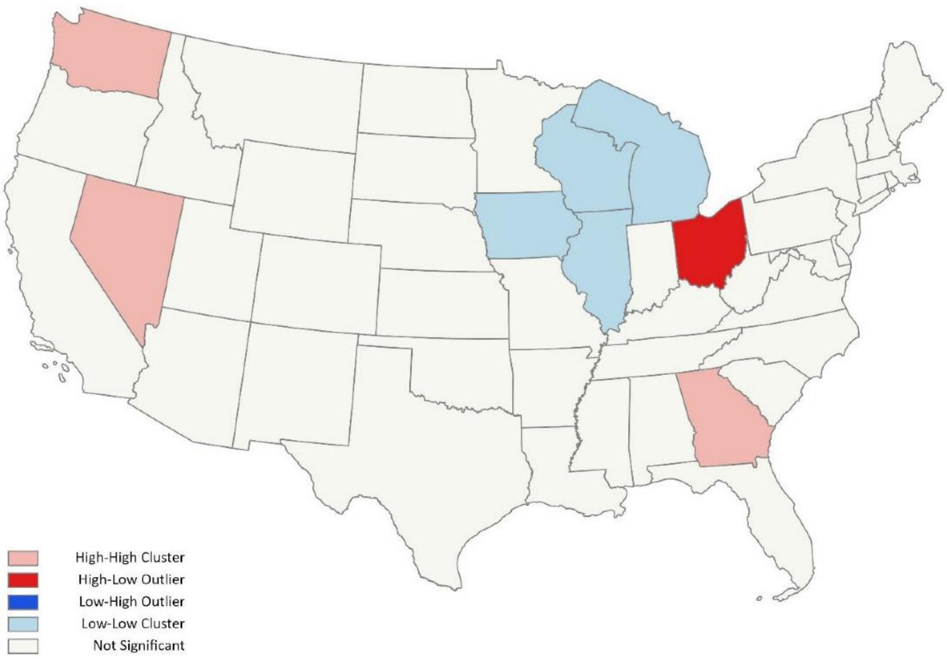

Figure 5 LISA (Local Indicators of Spatial Association) map of residuals from multilevel model with CO_2 emission reduction cost as the dependent variable.

The Intraclass Correlation (ICC) apportions variation in the dependent variable of a random-intercept, multilevel model to the respective levels of analysis [23]. In the study, the ICC apportions variation in the dependent variables in the random-intercept, two-level models to the micro-level of analysis (transactions) versus the macro-level of analysis (states). Put succinctly, the ICC apportions variation in CO_2 emission reduction or variation in CO_2 emission reduction cost to the transaction-level independent variables versus the state-level independent variables in the respective random-intercept models. In two-level models, such as in the study, the ICC (ρ) is

$$\rho = \frac{\tau_{00}}{\tau_{00} + \sigma^2} \tag{3}$$

where: τ_{00} is the macro-level variance; and σ^2 is the micro-level variance. The ICC for the random-intercept model for CO_2 emission reduction suggests that essentially all of the variation in CO_2 emission reduction is attributable to the transaction-level of analysis (99.82%). Likewise, the ICC for the random-intercept model for CO_2 emission reduction cost suggests that essentially all of the variation in CO_2 emission reduction cost is attributable to the transaction-level of analysis (99.67%).

5. Discussion

Analysis of a subsample of transactions for new AFVs from a past, national retirement program to increase private vehicle sales tests the viability of a future, national retirement program to decrease GHG emissions from the private vehicle fleet of the United States. Results suggest that incentives for HEV transactions decrease CO_2 emissions by a respectable 6.90%. Higher vouchers decrease CO_2 emissions more. Price point in the form of Base MSRP is not a barrier to emission reduction. Incentives for transactions when new vehicles are Passenger Cars reduce emissions most; particularly when trade-in vehicles are Category 2 Trucks. Results support the empirical literature on the marginal benefits of retirement [10] given that incentives for new AFV transactions decrease GHG emissions more in states where total GHG emissions from the transportation sector are higher. Interestingly, results contradict the empirical literature on the effects of gasoline price on the effectiveness of incentives for new AFV transactions to decrease GHG emissions [36].

Exploratory spatial data analysis of the residuals from the thousands-of-pounds multilevel model and the dollars-per-thousand-pound multilevel model with choropleth maps and with LISA maps as well as calculation of the ICC for the respective models suggest the following. First, the residuals from the respective multilevel models cluster from state to state in three regions. GHG emission reduction is higher than expected in the New England region and in the South Region, while GHG emission reduction cost is lower than expected in the Midwest region. Second, the overwhelming majority of the variation is attributable to variation between transactions within states, not variation between states. Therefore, state-level, nonmonetary incentives such as emission test exemptions, High Occupancy Toll (HOT) lane exemptions, High Occupancy Vehicle (HOV) lane exemptions, vehicle inspection exemptions, and parking fee exemptions may not account for much, if any, of the variation in the effect of monetary incentives on new AFV transactions between states in a future, national retirement program.

Critical analysis of the results from a retrospective study engender questions on generalizability and on relevancy. First, how generalizable are the results from an analysis of a past vehicle retirement program to a future national program? Indeed, the size of the national subsample of new AFV transactions is important to generalize the results to a future program. Unfortunately, the subsample of fossil fuel-alternative fuel transactions represents only ((34,305/677,842) × 100% =) 5.06% of total (purchase plus lease) transactions. The subsample, nonetheless, includes a sufficient number of transactions in each state/state equivalent (except in the District of Columbia) to represent the total population of macro-level units of analysis. Second, how relevant are the results from an analysis of past transactions for new AFVs when new AFVs are presently so different? Indeed, Figure 6 shows the dramatic increase in the number of AFV models by technology/fuel from 2009 to 2020 [37]. For example, the number of HEV models in 2009 is 19, while the number of HEV models in 2020 is 81. The dramatic increase in the number of HEV models and in the number of EV models from 2009 to 2020 is evidence that new AFVs are less dependent on fuel to power an internal combustion engine and are more dependent on technology to power a battery. The decrease in the number of E85 models is attributable to the elimination of the Corporate Average Fuel Economy (CAFE) credit for FFVs, however the number of E85 models in 2020 is evidence that FFVs are presently popular with consumers.

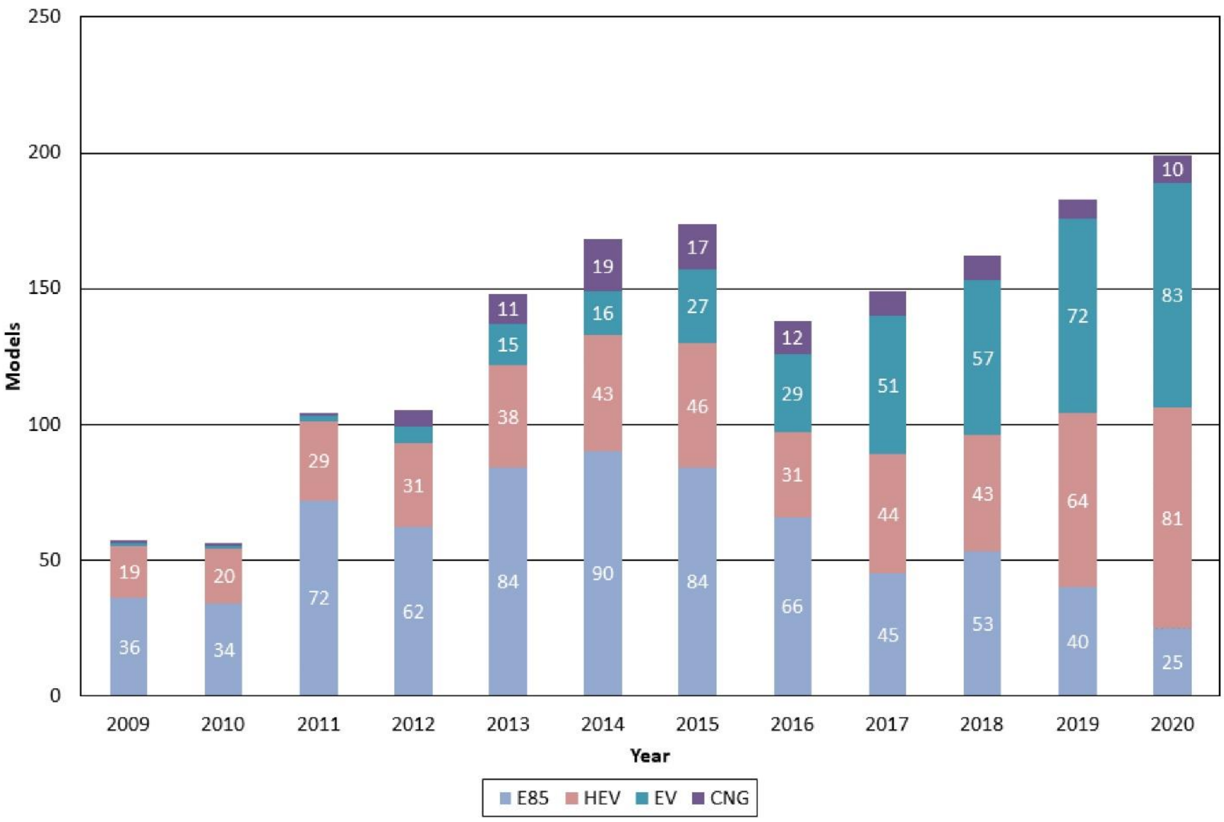

Figure 6 Total Alternative Fuel Vehicle (AFV) models by fuel/technology from 2009 to 2020. E85 = Ethanol (85%) + Gasoline (15%); HEV = Hybrid Electric Vehicle; EV = Electric Vehicle; and CNG = Compressed Natural Gas.

6. Conclusions

Retrospective analysis of a subsample of fossil fuel-alternative fuel transactions from a past vehicle retirement program provides policy stakeholders with valuable empirical evidence on the viability of a future national program to incentivize new AFV transactions. Overall, the empirical evidence from the inferential models in the study suggests that incentivizing new AFV transactions benefits the environment by effectively reducing GHG emissions nationally even if such transactions are costlier economically. Likewise, incentivizing new AFV transactions reduces GHG emissions more in states where GHG emissions are higher and in states where the incidence of passenger cars is greater than in the United States.

The empirical evidence from the present study suggests two important tracks for ongoing research on new AFV transaction incentives. The first track for ongoing research emanates from the results on the environmental benefits of new AFV transactions; particularly new HEV transactions. The respectable 6.90% decrease in CO_2 emissions from such transactions and a recommendation on the basis of retrospective analyses of vehicle retirement programs worldwide to limit incentives to only transactions for new battery EVs (BEVs) [38] is justification for ongoing research to extrapolate the results from 2009 to the present. The past-present mismatch in the fuel/technology of AFV models from 2009 to 2020 highlights the importance of ongoing research to supplement the results of the present study with an analysis of a state (California) vehicle rebate program known as the Clean Vehicle Rebate Program (CVRP) on the effectiveness of incentives for new EVs and for new HEVs from 2010 onwards [22]. The second track for ongoing research emanates from the results on the dramatic differences in the economic costs of new AFV transaction incentives given the regional differences in the vouchers for such transactions. Static voucher amounts ($3,500.00 or $4,500.00) may ease implementation of a national program, but dynamic voucher amounts which vary by vehicle category and by the fuel economy difference from the new vehicle to the trade-in vehicle may help to harmonize GHG emission reduction and GHG emission reduction cost from region to region. Indeed, regional differences in GHG emission reduction and regional differences in GHG emission reduction cost justify ongoing research to infer the cause of such regional differences. A defensible approach, akin to a difference-in-differences (DID) approach [39], is to match fossil fuel-fossil fuel transactions with comparable fossil fuel-alternative fuel transactions. In such an approach, the fossil fuel-fossil fuel transaction is the control and the fossil fuel-alternative fuel transaction is the experiment so as to infer the cause of the difference in the CO_2 emission reduction between the two groups as well as to infer the cause of the difference in the cost of the CO_2 emission reduction between the two groups.

Author Contributions

The author did all of the research work for this study.

Competing Interests

The author has declared that no competing interests exist.

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