

Plug-in Vehicle Attributes' Influence on U.S. Sales in 2014 in States without Preferential Incentives for ZEVs

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Short Abstract

Influence of vehicle attributes on U.S. sales of plug-in electric vehicles (PEVs) — plug-in hybrid vehicles (PHEVs) and battery electric vehicles (BEVs) in year 2014 are analysed. Attributes examined are price-related market segment, acceleration, range, and number of driven wheels. Segments were (1) luxury/performance (>\$60,000 list price), (2) mid-market (\$40-50,000), and (3) mass market (<\$40,000). A type of creditable zero emissions vehicle (ZEV) in the California Air Resource Board (CARB) regulations is the “BEVx”, using gasoline to double total range. BEVx sales dominate the mid-market. The sales weighted average range of ZEVs that can earn CARB credit declines monotonically from segment 1 to 3; PHEV share rises. Segment sales patterns were examined within states where incentives did not favour ZEVs. Worst case real world range for BEVs occurs in urban driving at coldest temperatures. January temperature was therefore used to assess cold vs. warm winter locations. For locations without preferential BEV incentives, the marketability of BEVs vs. PHEVs diminished as BEV range and/or acceleration capabilities decreased across segments, controlling for temperature. Cold temperature consistently increased PHEV share. In segment 1 a BEV with 200+ mile range and an all-wheel drive option dominated sales. Otherwise PHEVs dominated.

Key words: PEV, PHEV, BEV, electric range

1. Introduction

This paper presents results of analysis of 2014 U.S. light duty plug-in electric vehicles (PEV) registrations by make and model, for model years 2014 and 2015. Individual states and groups of states are examined to assess the influence of technical attributes of PEVs, controlling for incentive bias (favoring BEVs over PHEVs) and cold temperature. Purchase incentives helped increase sales of PEVs in the U.S. In the long run, U.S. federal incentives are designed to end. The influence of PEV attributes on sales patterns without state incentive bias is therefore of interest.

1.1 PEV Market Status in the U.S.

While this paper examines patterns of 2014 owner registrations of PEVs, its intent is to take a forward-looking perspective at what might happen in coming years. In particular, it appears that future plug-in hybrids (PHEVs) will have more electric range than prior studies assumed (see [1-5]), and will more frequently be able to operate all-electrically while the battery discharges. Similarly, coming battery electric vehicles (BEVs) will often have rated ranges of 200 miles or more. Where the cited prior studies assumed that the maximum all-electric range

of a PHEV would be 44 miles or less [1-4], two that are leading sellers have rated ranges of 53 miles (Chevrolet Volt) and 72 miles (BMW i3 REX). While the cited studies assumed BEVs with range of 100 miles or less, the shortest rated range available in a 2016 Tesla Model S is 234 miles; the longest is 270. [6] indicated that the absence of “four- or all-wheel-drive” in 2013 BEVs may have hurt their sales in regions with cold winters. This shortcoming was addressed in 2014 by Tesla and Porsche. Both introduced AWD PEVs in 2014.

In the luxury/performance space, Tesla recently introduced an electric SUV, the Model X. It is presently only available with all-wheel drive (AWD). The \$78,000 dollar Porsche Cayenne PHEV SUV, introduced in 2014, also is only available with AWD (<http://www.porsche.com/usa/models/cayenne/cayenne-s-e-hybrid/featuresandspecs/>). This Cayenne PHEV cannibalized sales of the previously introduced more expensive, less spacious, rear-wheel drive Panamera PHEV. Though from a much smaller Porsche PEV sales base, the Cayenne PHEV helped Porsche achieve the same rate of growth in PHEV sales from 2014-15 as the Tesla Model S family of passenger car BEVs (~58%). In the Tesla Model S with a 90 kWh battery pack the AWD version achieves 270 miles of range, using 34 kWh/100 mi, while the two wheel drive version achieves 265 miles and 38 kWh/100 miles. In contrast, in conventional gasoline powertrains, the addition of AWD increases fuel consumption relative to the typical car powertrain using front-wheel drive [7].

1.2 Attributes

We divide PEVs into three market segments based on 2014 list price. Segments are (1) luxury/performance (>\$60,000 list price), (2) mid-market (\$40-50,000), and (3) mass market (<\$40,000). In the first two categories, vehicles from single manufacturers dominate. The Tesla Model S dominated sales in the luxury performance category. From 2014 to 2015 the Model S added five powertrains, four of which were AWD and two of which were “P” (performance) versions. Both of the latter two were available only with the highest kWh battery packs. With this emphasis on performance in versions with longer range, Model S sales jumped 58% from 2014-2015, despite a collapse in gasoline prices (Table 1). The sales leaders among competing PHEVs in the luxury/performance category were German makes – two from Porsche (Panamera car and Cayenne SUV) and one from BMW (i8 sports car). Collectively, these three had the highest category growth rate from 2014-15. In the mid-market the BMW i3 is the dominant vehicle. Others are BEVs – the Toyota RAV4, a since discontinued SUV, and the Mercedes Model B, both with greater all-electric range than the i3 BEV, but far less range than the i3 REX. Both were sold primarily in California. According to California’s ZEV regulations, even in the i3 REX versions that have a gasoline engine for 78 miles of range extension, it can be counted as a ZEV – for up to 50% of total i3 model sales.

Table 1. Annual U.S. calendar year manufacturer sales of leading PEVs, 2011-2015 [7]

Year	Nissan Leaf	GM EREV (Volt & ELR)	Ford Energi (Fusion & C-Max)	Toyota Prius PHEV	BMW i3 (mid-market)	Tesla Model S (luxury/performance)	German PHEVs (luxury/performance)
2011	9,674	7,671	0	0		0	0
2012	9,819	23,461	2,374	12,749		2,400	0
2013	22,610	23,100	13,243	12,088	0	19,400	51
2014	30,200	20,115	19,983	13,264	6,092	16,750	1546
2015	17,269	16,417	17,341	4,191	11,024	26,400	3835
% Δ 14-15	-43%	-18%	-13%	-68%	81%	58%	148%

As noted, the range capabilities of three real world PEVs that have actually emerged in the marketplace were not anticipated in prior research studies [1-5]. Most of these studies imply that the costs of PEVs makes them financially unattractive to consumers at today's gasoline prices. The advent of PEVs with longer range and more power than anticipated, in the presence of relatively low oil prices raises the question of direction of market adaptation. PEVs that were most successful in 2015 are not the least cost options that hypothetical consumers were previously anticipated to prefer [1]. In fact, after a short-term low point in the midst of the Great Recession (2009), the average peak kW rating of the U.S. new vehicle fleet continued to rise every year. Similarly, the share of four wheel drive has risen steadily [6]. Four-wheel, or all-wheel drive is a performance feature, improving acceleration times and poor weather traction. The fraction is now 10% in cars and 70% in trucks. If electric drive is to compete in the future without subsidy, it will have to provide features that consumers want. Based on 2014-2015 sales shifts, it appears that emphasis on all-wheel drive for up-market PEVs with rapid acceleration is leading to success. Importantly, with Tesla's electric drive powertrains, all-wheel drive is an efficiency-enhancing option compared to the base rear-wheel drive powertrains.

Electric drive with larger battery packs has a technical advantage with respect to the simultaneous provision of both power and energy. Due to properties of battery cell construction, after the maximum electrode thickness is reached in a cell, the only way to increase energy is by having more conductor and electrode surface area [9]. This means that additional power will be available in the cell, regardless of whether or not vehicle manufacturers use it. The use of the available power does come at a cost, since the vehicle powertrain's motor and power electronics costs will rise with power. The open question is what level of power and acceleration capability will the vehicle manufacturers producing future 200 mile plus range mass market (< \$40,000 retail price) BEVs provide? Given the sales trends through 2015, a reasonable guess is that the power available in the battery packs will be used.

In today's vehicles, we compiled data for the EPA/DOE rated fuel consumption (fuelconomy.gov) of a number of available cars as a function of published 0-60 time (Fig. 1), holding powertrain type constant. The plot illustrates that the provision of faster acceleration with electric drive comes with far less fuel/electricity consumption penalty than for conventional and HEV powertrains.

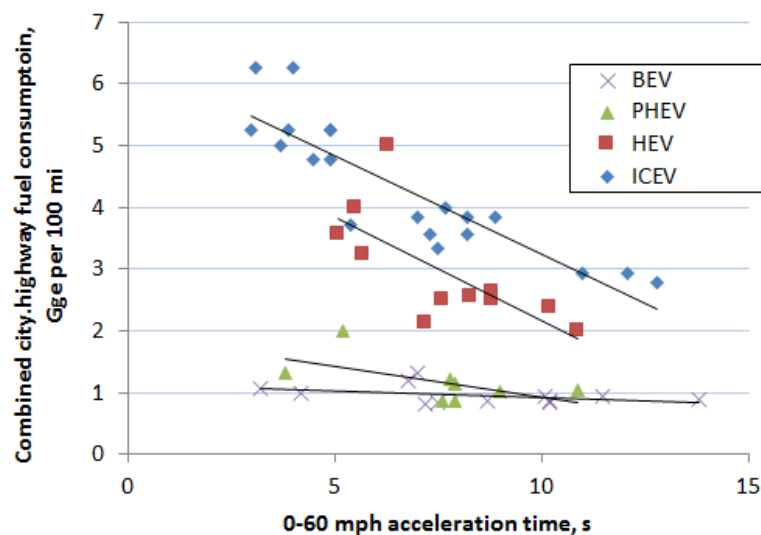


Figure 1 Acceleration time (0-60 mph) by Powertrain Type

Our presumption is that manufacturers have to plan for the day that federal and state subsidies of PEVs are eliminated. In an era of low oil prices, it will be difficult to sell PEVs on the basis of fuel savings alone. A recent CARB [10] survey asked Californians who had purchased PEVs from the five manufacturers with leading sales in Table 1 their primary reasons for PEV purchase. Respondents indicated that, for the four leading mass-market manufacturers examined aside from Tesla, saving money on fuel costs was the top priority, averaging around 40% frequency of response for that attribute. For Tesla, the share was 15%. When fuel savings is the leading reason for purchase and gasoline prices decline, sales would be expected to decline. This is consistent with 2014-15 changes shown in Table 1. The top four attributes valued by Tesla purchasers were (1) reducing environmental impact (2) vehicle performance (3) desire for newest technology and (4) saving on fuel cost. Compared to its 2014 offerings, Tesla's 2015 portfolio of powertrains gave its purchasers the first three of the four desired attributes, and a greater ability to improve the fourth, holding gasoline prices constant.

For PHEV buyers responding to the survey, the second most mentioned priority was high occupancy vehicle (HOV) lane access. The third, which averaged about 20% was "reducing environmental impacts". While environmental impact may have a high priority for California consumers, where air quality is the worst in the nation, this may not be as much of a marketing "hook" in the rest of the U.S. HOV lane exemptions were only available in 11 states in 2014 [11]. Further, the availability generally applied equally to PHEVs and BEVs. HOV lane access was more important to PHEV purchasers than BEV purchasers in CA [10]. It is likely that the access to HOV lanes was most important to individuals who drive a lot of miles per day at high speed, a circumstance where the added range of the PHEV makes it relatively more attractive than range limited mass market BEVs.

Evaluations of charging behavior of PHEV owners in CA [12-13] indicated that the limited range, blended mode Plug-in Prius was not a desirable way to electrify miles. Instead of plugging in more frequently to offset the limited electric range, Plug-in Prius owners plugged in less because the time it took to arrange for a charge was not worth the amount of kWh of electricity obtained. The evidence is that the CA HOV lane exemption for the Plug-in Prius created the illusion that it was nationally marketable. The ICCT estimated that the HOV lane access dollar value was greater in California than in any other state that implemented it, often by a considerable amount [11]. The Plug-in Prius was second in 2014 national PHEV registrations, when each of the two Ford Energi PHEVs were individually compared to it. However, despite being registered in 44 states and DC, the Prius PHEV had 80% of its registrations in CA (Table 2). If one treats the Ford Energi PHEV powertrain in total (both available models summed) outside of California, registrations were 3.6 times as great as for the Prius PHEV powertrain. The lesson has been learned. Probably in response to the analysis by Tal and colleagues, the next generation Plug-in Prius will have significantly more all-electric operations capability.

Examination of what happened since 2014 (Table 1) suggests that a manufacturer's emphasis on just California is an indicator of a lack of commitment to the PEV technology. Using Polk registration data we examined the fraction of PEVs sold in California and the number of states in which at least one registration of a given PEV make and model occurred. Of the eight PEVs we chose to describe as California "compliance vehicles", three have since been discontinued – the Honda Accord PHEV and the Honda Fit EV, or redesigned, e.g., Toyota Prius PHEV. The Honda Accord PHEV, like the Prius, had limited all electric range (Table 2).

Outside of California, the Ford Energi PHEV system (9,650 registrations) and the Volt (10,800) were closely competitive among PHEV powertrain types, vs. the Prius (2,700). The LEAF (14,700), as an individual model, sold more than either leading PHEV powertrain. However, 7,500 of those were sold in Georgia, the only state to exclusively subsidize BEVs. The subsidy was \$5,000 per vehicle, a higher subsidy than provided by any other state. Georgia (Atlanta metro area) also allowed free single occupant use of BEVs on high occupancy toll (HOT) lanes, as did California. Thus, just by removing the two states that have most strongly promoted BEVs,

the “rest of the U.S.” registration estimates for leading BEV vs. PHEV models favor the PHEV powertrains with electric range from 19-38 miles over the BEV with a rated range of 84 miles. However, this does not eliminate effects of financial incentives. Only 20 states did not have any financial incentives, negative or positive.

Table 2. Share of registrations in California and number of states with at least one registration

	Make and Model	% 2014 Registrations in CA	# States with registrations (+ indicates DC also)	Total Registered in Calendar Year 2014
Compliance Vehicles	<i>RAV4 EV</i>	99%	12	1164
	Soul EV	98%	5	235
	Fiat 500e EV	97%	8+	5387
	Chevrolet Spark EV	89%	25	1621
	Toyota Prius PHEV	80%	44+	13319
	<i>Mercedes B EV</i>	77%	21	451
	Honda Accord PHEV	76%	23	898
	Honda Fit EV	69%	8	596
National Vehicles	VW E-Golf	64%	15	165
	Ford Focus EV	63%	46+	2123
	Smart ForTwo EV	60%	43	2255
	Chevrolet Volt PHEV	49%	50+	21240
	Tesla Model S EV	45%	49+	12260
	<i>BMW i3 PHEV & EV</i>	44%	47+	3862
	Ford Energi PHEVs	43%	50+	16956
	Porsche Panamera	35%	39+	706
	Nissan Leaf EV	33%	50+	21958
	Porsche 918	28%	18	50
	Mitsubishi i-MiEV	25%	28	128
	Porsche Cayenne	22%	17	51
	Cadillac ELR	22%	41	1350
	BMW i8	22%	38	366
	McLaren P1	19%	12	59
	CA Population	12%		
	Bold = luxury/performance. Italics = mid-market			

2. Critical Range and Travel Time

For mass market success of BEVs, it is generally recognized that a new daytime electric vehicle supply equipment (EVSE) charging infrastructure away from the overnight charging location is necessary. The longer the range of the BEV, the less daytime charging will be necessary. For BEVs with 200 or more miles of realizable range, most owners should not need intra-metropolitan EVSE. The necessary EVSE infrastructure for such BEVs is primarily for inter-city travel. In 2014 BEVs that we classify as mass market had officially rated ranges from 62-84 miles. The term “rated range” is used because an electric vehicle’s actual “in-use” range is highly variable as a function of air temperature [14-18]. Using 2013 vehicle registrations, [6] determined for BEVs that “decreases in average winter temperatures are correlated with lower market shares.” They offered three explanations for the lower BEV market share: (1) absence of “four- or all-wheel drive

vehicles”, which were not available in PEVs in 2013, (2) battery efficiency effects, and (3) electricity requirements to provide cabin heat. All three effects are plausible. The addition of AWD should have addressed the first effect and helped Tesla in 2014 and 2015.

The average range of a fleet of Nissan LEAFs tested by Fleet Karma dropped by more than half from a temperature of about 19° C to -28° C [17]. Information on the existence of cold temperature range effects was readily available on the web in early 2014. The effects on consumer satisfaction were discussed then. “Reduction in range on a vehicle with 200 or more miles of range has much less impact on driving patterns than the same reduction in a car with only 60 to 80 miles of range in normal weather conditions.” [15]. The American Automobile Association also tested BEVs and reported the effects in early 2014 “The average EV battery range in AAA’s test was 105 miles at 75°F, but dropped 57 percent to 43 miles when the temperature was held steady at 20°F. Warm temperatures were less stressful on battery range, but still delivered a lower average of 69 miles per full charge at 95°F.” [16].

The problem is not just related to everyday driving. The desired functionality of a vehicle capable of comfortably carrying four persons and luggage is likely in most cases to include long-distance travel between cities. [19] divide long-distance pleasure travel into two categories – visiting friends and relatives (VFR) and other leisure. They find that the average distance of such trips is about the same, 598 miles for VFR and 507 for other. The timing of the VFR trips involves a fourth quarter (Oct.-Dec.) peak share of 30%, while other leisure travel is summer peaking, with 39% occurring in the July-Sept. quarter. Shortening of range in cold temperatures in the winter holiday season is thus important to many vehicle purchasers. Aside from temperature effects, there are also negative effects on range from high speed Interstate Highway driving. Range decreases with average speed driven because consumption per unit distance rises: 210 w/km @ 100 km/h; 175 @ 50-60 km/h [19]. None of the reviewed discussions of range loss [14-18] quantify effects of a full passenger load and luggage.

Not all BEVs come equipped for DC fast charging, which is supposed to enable reasonably convenient intercity travel for BEVs. When available it is often an extra cost option. DC fast charging is not rated to provide a full charge. Time to charge estimates are based on an 80% charge. Charging takes longer in extreme temperatures. The 2014 Nissan Leaf owners’ manual predicted an increase in time to charge to 80% from 30 to 90 minutes in coldest conditions, and from 30 to more than 60 minutes in hot conditions. The combination of shortened range, limits of battery charge to 80%, and extended charge times in extreme temperatures make the mass market BEVs available in 2014 very undesirable for rapid intercity travel at the summer peak, or in a cold December in northern, or high altitude U.S. states.

Candidate purchasers of BEVs must carefully consider what distances they want the vehicle to be able to travel in extreme temperatures, particularly in the winter. In many states in 2014 there were no DC fast chargers available for intercity travel even if well informed BEV owners were willing to accept the associated problems.

3. Methodology and Discussion

To address critical range issues for BEVs vs. seasonal temperature peaks we compare results for warm, moderate and cold temperature regions. Theoretically, moderate temperature states should be most advantageous for BEVs because there would be minimal extreme temperature problems for the vehicles. The three Pacific Coast states, which have been leaders in BEV advocacy, are the only moderate temperature states. We cross match these climate groupings against three kind and degree of incentives groupings. State incentive categories used are: (1) none, (2) balanced incentives neither favoring a BEV or PHEV, and (3) “BEV-favorable” incentives that are higher for BEVs than PHEVs. Once we have illustrated the relative position of

the group of states without incentives relative to those with balanced and BEV-favorable incentives, we present a market segment investigation for the group of states without incentives.

For our final estimates for states without subsidies, we use R. L. Polk records of new vehicle registrations for model year 2014 and 2015 in the U.S. during calendar year 2014. Using manufacturer's suggested retail price (MSRP), the PEV market for our final table is segmented as follows: (1) luxury/performance (>\$60,000), (2) mid- (\$40-50,000), and (3) mass-market (<\$40,000).

Cold regions were those where the sum of *peak* daily percentages of freezing (15°F to 32°F) and frigid (below 15°F) temperatures (always January) exceeded 41%. Moderate locations had (A) < 23% freezing and frigid days in January and (B) < 10% hot (85°F to 100°F) and sweltering (above 100°F) temperature peak days in July. Only California, Oregon and Washington had moderate climates by this definition. All remaining states were in the warm category. Therefore, moderate states were those having relatively mild temperatures in the summer *and* winter. Within these three climate groupings, sales of BEVs as a share of PEVs, are examined. Also, to examine general success of PEV introduction efforts, we present the share of PEVs registered relative to all vehicles registered.

Our cut point for cold vs. warm was Baltimore Maryland. Although this resulted in a significantly larger share of states being identified as “cold”, it had a significant advantage with respect to consideration of another incentive program – the California Air Resources Board ZEV regulations. Under section 177 of the Clean Air Act the Supreme Court allowed other states to adopt California motor vehicle emission control regulations instead of federal regulations. As of 2014 seven states east of the Mississippi had done so [20]. These are states where recent estimates of greenhouse gases via electric miles are consistently [21], or predominantly [22] estimated to be favorable relative to even the most efficient gasoline hybrid, the Prius. By allowing the warmest of these states to define the boundary between the warm and cold groups, we are able to test whether the adoption of the California regulations {Section 177 East (cold)} led to more success than in the “Other cold states” that remained under federal regulation (Table 3).

The “no incentives” group of states for this paper is reduced by a modification of the dollar values of incentives in 2014 estimated by the International Council on Clean Transportation (ICCT) [11]. Because that study was completed during 2014, the effects of incentives programs beginning in June in Massachusetts and Texas were not included in the data base. We reexamined the vehicle subsidy programs for BEVs and PHEVs and made several adjustments. Otherwise, we used the ICCT data as provided. We examined the relative patterns of *total* incentives (sum of \$ values of: vehicle subsidies, vehicle ownership fees, home and public charging subsidies, high occupancy vehicle lane one driver use privileges, free parking, and emissions test exemptions). The total benefit estimates for BEVs were compared to PHEVs. When the estimates for BEVs exceeded those for PHEVs by \$600 or more, we defined the state as having provided “BEV-favorable” incentives. 7 states fit into this category based on our modified ICCT incentives benefit totals. Oregon was added to this group because of its exceptionally successful installation of public charging infrastructure along Interstates and scenic highways [23], which is very important for BEVs, but not PHEVs (Fig. 1). Otherwise when the estimates were positive and differed by \$600 or less, we put the state into the “balanced” incentives group. 21 states fell in this category. Twenty states had no incentives of any kind. Two states – Nebraska (-\$400) and Virginia (-\$262) had balanced negative incentives.

Our first set of compilations for 48 states and DC were based on an earlier Polk data file that did not yet include registrations for all of 2014 (Table 3). Having thus isolated the states that had no subsidies, we then used a later Polk data tabulation of registrations for the entire 2014 calendar year to compile the market shares of BEVs for each of our three market segments (Table 4). Comparable results across the two tables, using the different data files, differ slightly but are close enough that interpretations remain the same. Values in parentheses in Table 3

are averages of state percentages. Other values are based on the total number of vehicles in the listed groups of states.

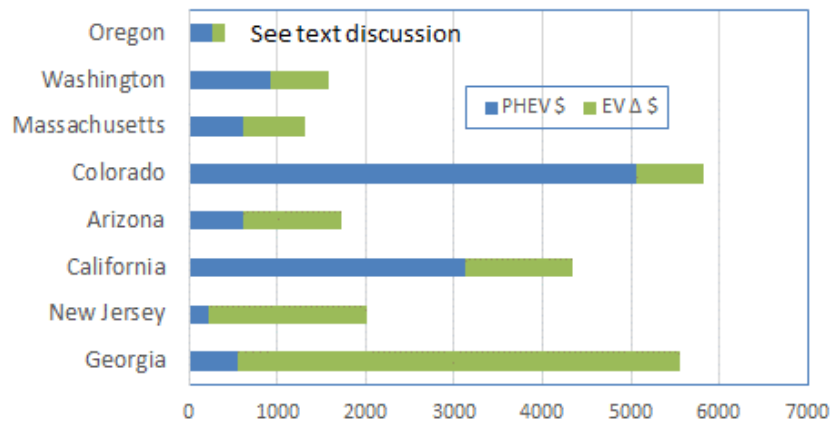


Figure 2 Dollar Sum of Values by "BEV-favorable" States

Table 3. BEV shares of PEV registrations and PEV shares of light-duty vehicle (LDV) registrations for selected groups of states.

		Incentives Category		
		None	Balanced	BEV-favorable
Moderate temperature states				
	BEV share of PEVs (%)	No states	No states	41 (50)
	PEV share of LDV registrations (%)	No states	No states	2.52 (1.66)
	Number of states	0	0	3
Warm states				
	BEV share of PEVs (%)	31 (31)	47 (45) ¹	75 (62)
	PEV share of LDV registrations (%)	0.07 (0.06)	0.19 (0.31) ²	0.73 (0.69)
	Number of states	3	10	2
Section 177 east (cold) states				
	BEV share of PEVs (%)	21 (22)	25 (27)	43 (44)
	PEV share of LDV registrations (%)	0.34 (0.36)	0.41 (0.36)	0.32 (0.33)
	Number of states	2	5	2
Other cold states				
	BEV share of PEVs (%)	18 (23)	29 (37) ²	35 (35)
	PEV share of LDV registrations (%)	0.25 (0.17)	0.22 (0.22) ²	0.44 (0.44)
	Number of states	15	6	1
Sum of above markets				
	BEV share of PEVs (%)	18	38	44
	PEV share of LDV registrations (%)	0.23	0.24	1.57
	Number of states	20	21	8
¹ Virginia had mild PEV penalties. There were 35% BEVs (of PEVs) and 0.34% PEVs (of LDVs)				
² Nebraska had mild PEV penalties. There were 16% BEV (of PEVs), and 0.18% PEVs (of LDVs)				

4. Results

4.1 Incentives vs. No Incentives

As a group, the three Pacific coast states with moderate temperatures and BEV-favorable incentives have had the greatest overall success in implementing PEVs in 2014. The next most successful were the two warm states with BEV-favorable subsidies, Georgia and Arizona (see Fig. 2). Georgia was an outlier among the warm states, with by far the highest share of PEVs in those states, with the highest share of BEVs in the group as well.

At 2.8% of LDVs, California had nearly triple the PEV share of the next three leading states, which ranged from 1.0 to 1.1%. Among these four states, California, the nominal and original leader in promoting zero emissions vehicles (ZEVs), had a significantly lower BEV share of PEVs. These results appear to be influenced by the Plug-in Prius' exclusive success in California. [12] found that many Plug-in Prius owners did not plug in very frequently. This is likely the result of purchase of the Plug-in Prius for use on high speed high occupancy vehicle (HOV) lanes. This is a use where the Plug-in Prius' battery pack takes far more miles to deplete than indicated by its rated range. Where California had 18% Plug-in Prius among PEVs, Washington and Georgia each had 1%, Oregon 3%. Nationally, HOV lanes are an exception. Thus, HOV incentives, which were important both in CA and Georgia, are not possible in about 80% of states.

Collectively the cold states that adopted CARB regulation had higher PEV shares than the cold states that did not. BEV shares, though variable, were similar overall across cold states. The percent of BEVs in the no incentive states was consistently lower than in states that had incentives. Cold temperature consistently reduced the share of BEVs relative to warm states. However, in the three moderate temperature states (California, Oregon, Washington), which are all "BEV favorable" incentive states, the share of BEVs was less than the average of the other five BEV-favorable incentive states (Fig. 2). The BEV bias did not lead to a *consistently* higher BEV share relative to states that had incentives but no bias. On average, for the total market, the BEV share was more than doubled by incentives. Without incentives, BEVs only captured 18% of the market (Table 3).

In the cold states incentives did not lead to greater shares of PEVs among registered vehicles. In warm states incentives were very effective in getting more PEVs deployed relative to the no incentives case. For the warm states it can be argued that incentives did successfully promote BEVs and PEVs. For cold states that argument cannot be supported. In every case, the absence of incentives led to a lower share of BEVs. To the extent that BEVs are succeeding on a national average basis, these statistics imply that 2014 state incentives were critical.

4.2 No Incentives

In Table 4 we examine the details of registration patterns in the 20 states without incentives. Using the later Polk data set for all of 2014, we estimate that 20% (Table 4), rather than 18% of PEVs were battery electric when no financial incentives were present. However, for the mass market, in this case, it was estimated that only 13% of PEVs sold were BEVs. In cold states that had not incorporated California emissions standards (non-177), the figure was only 11%. Clearly, given PEV technology available in 2014, the most promising way to promote electrification of miles without financial or regulatory incentives is by promotion of PHEVs. However, the share of BEVs rose to 37% in the mid-market and to 57% in the luxury/performance market. Thus, if future mass market BEVs are able to adopt some of the features of the luxury/performance vehicles, significantly greater success may result. Those features would be (1) more power and acceleration, (2) range of

200 miles or more, and/or (3) all-wheel drive. The PHEV would certainly still play an important role, but would be less important than the BEV in electrifying miles.

A key question though is whether PHEVs will also improve as the BEV of the future improves, holding tenaciously on to a larger market share than BEVs. This is a distinct possibility. The 2016 Volt PHEV and Bolt BEVs from GM will soon test the market for next generation PEVs.

A “wild card” would be the addition of range extension to the portfolio of BEVs sold. To appeal to innovators and early adopters who value the environment, initial dedication to the pure electric vehicle may be a good starting strategy. In 2013 Tesla certified a Model S with a 40 kWh battery pack and 139 miles of range. This option was abandoned in 2014, with the 60 kWh model with 208 miles of range being the least expensive model in the line-up (fuel economy.gov). This suggests that longer range, possibly 200 miles, is an important number for BEV purchasers. Though the 40 kWh model would have had enough space for a range extending engine, Tesla did not test this option.

Table 4. BEV vs. PHEV success in mass-, mid- and luxury/performance markets, absent incentives

BEV share of PEVs: States with no Incentives				
	Cold, non-177	Cold, East, 177	Warm, non-177	Total Market
Mass Market	11%	24%	29%	13%
Mid Market	37%	50%	28%	37%
Luxury/Performance	55%	88%	70%	57%
Total Market (temp.)	19%	28%	37%	20%
# states	15	2	3	20
Share of BEVs Within Market Segment Categories Within State Group: no Incentives				
	Cold, non-177	Cold, East, 177	Warm, non-177	Total Market
Mass Market	50%	81%	57%	53%
Mid Market	6%	5%	4%	6%
Luxury/Performance	44%	14%	38%	41%
Share of PHEVs Within Market Segments Within State Group: no Incentives				
	Cold, non-177	Cold, East, 177	Warm, non-177	Total Market
Mass Market	90%	98%	84%	90%
Mid Market	2%	2%	7%	2%
Luxury/Performance	8%	1%	10%	8%

With regard to potential benefits of BEV range extenders when moving beyond early adopters into the early majority mass market, the 2014 mid-market results are very interesting. The primary reason for the lower share of BEVs in this segment is the existence of the BMW i3 REX PHEV, which has a very poor (intentionally, to satisfy California regulators) range extension feature that allows only 150 miles of total range, by extending electric operations range beyond 72 miles. Compared to the BEV version, this range extender is heavier, more expensive and slower to accelerate electrically. As a gasoline vehicle it has relatively poor efficiency. Yet, in total in the states without incentives it is outselling the less expensive i3 almost two to one. If it had a larger gasoline tank and was modified to have the same (Volt), or better performance (Ford, Energi, Porsche S E-Hybrids) when running on gasoline, the market for the REX should be even larger. For those manufacturers

seriously committed to electric drive regardless of regulation, building production volume to enable cost-reducing economies of scale will be important. Range extenders as a part of a primarily BEV portfolio could test the market to see if results obtained by BMW in the mid-market are indicative of a much larger market when range extension is made available.

Finally, the move of electric drive into the SUV market, taking advantage of the efficiency and acceleration enhancing features of all-wheel drive may be enticing to more manufacturers in the long run. Fig. 1 implies that fuel savings could be significant. The Porsche Cayenne AWD SUV, which accelerates from 0-60 in 5.4 seconds, starts from \$77,200. The Cayenne requires premium gasoline, which is a cost feature that encourages use of electric drive on an everyday basis. The base Tesla Model X 70D AWD SUV accelerates to 60 in 6.0 seconds, for about the same starting price (\$81,200), having a rated range of 208 miles.

For now, after considering the effects of climate, the implications of this study are that the minimum-incentive mass-market success of plug-in electric drive will be achieved by emphasis on PHEVs rather than BEVs. Among the states with no incentives, the one that was relatively outstanding in putting PEVs into the market was Michigan, with 0.54% PEV share of registrations. This was more than double the 0.23% group average for no incentive states. Among all cold states Michigan had the highest PEV share of LDV registrations. Michigan had the lowest BEV share of PEVs of any state. Among the three moderate climate states on the Pacific Coast, California had more than double the PEV share of registrations of the other two states, while having a lower BEV share. Only Georgia, with the largest BEV over PHEV incentive values increase (Fig. 2), reversed this pattern, having the largest PEV share of registrations in the warm states group.

Note: Reasons for success in Vermont have recently been studied [24]. The report, received after our analysis, indicated that vehicle purchase incentives offered in summer of 2014, played a role. The incentive consisted of \$500 for the consumer and \$200 for the dealer. This was not large among states with incentives and the incentives were available for fewer months than any other state. The contribution of one very active Ford dealer was important. This dealer was number 2 nationally in sales of Ford Energi PHEVs. In 2014 the Energi PHEVs accounted for 55% of Vermont's PEV registrations. Vermont's PEV sales would have been unremarkable if placed in the incentives group. Overall interpretations of this study would remain the same.

5. Conclusions/Findings

- Regulatory and financial incentives were necessary to increase BEV share of PEV sales.
- In 15 cold states without regulatory or financial incentives mass market BEVs held an 11% share of PEVs.
- The fuel savings advantage of BEVs vs. conventional gasoline vehicles increases as acceleration capability improves.
- BEV share of PEV sales rose as market segment range and acceleration capability (and therefore price) increased.
- Even in the best cold state “no incentives, non-177” case for the BEV (i.e. luxury/performance), PHEVs held 45% market share.
- 15 of 18 “no incentives, non-177” states were cold. Addition of 2015 model year AWD BEVs in the luxury/performance segment may have boosted BEV share in these states.

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