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Can policy measures foster plug-in electric vehicle market diffusion?

Patrick Plötz[1], Till Gnann[1], Frances Sprei[2]

[1]*Fraunhofer Institute for Systems and Innovation research ISI, Breslauer Strasse 48, 76139 Karlsruhe, Germany, patrick.ploetz@isi.fraunhofer.de*

[2]*Chalmers University of Technology, Energy and Environment, 412 96 Göteborg, Sweden*

Short Abstract Summary

Plug-in Electric vehicles (PEV), both as battery electric vehicles (BEV) and plug-in hybrid vehicles (PHEV) have noteworthy potential to reduce global and local emissions. Governments around the world have implemented monetary and non-monetary policy measures to foster PEV market diffusion. However, empirical estimates of their effectiveness are scarce. Here, we analyse data on PEV sales from Europe and the US with the policy measures active in these countries, e.g., direct subsidies, tax rebates, and public charging infrastructure. The aim of the present paper is to contribute empirical evidence to the discussion of policy aided market evolution of electric vehicles. We find income, gasoline prices and both direct and indirect subsidies to positively influence PEV adoption.

1 Introduction

Plug-in Electric vehicles (PEV), both as battery electric vehicles (BEV) and plug-in hybrid vehicles (PHEV) have noteworthy potential to reduce global and local emissions. Governments around the world have implemented monetary and non-monetary policies to foster PEV market diffusion. However, empirical estimates of their effectiveness are limited. Here, we analyse market data on PEV sales from European, North American with the policy measures active in these countries. The aim of the present paper is to contribute empirical evidence to the discussion of policy aided market evolution of electric vehicles.

Analysing the effectiveness of policy instruments is broad field of research. Not only, plug-in electric vehicles, but other alternative drive trains are analyzed, mostly by trying regressions on sales and several influence factors. For example, Chandra et al. (2010) focused on HEVs sold in Canada from 1989-2006. They found, that rebates had effect, but only for people who would have bought HEVs anyway. Thus, the way rebates were granted was not the most effective way of introducing HEVs. Yet, this rebate structure is important, which was confirmed by Sprei (2013). She analysed flex fuel vehicles in Sweden where sales were increasing until 2008 and decreasing until 2011. In her regression for vehicle sales in 2002-2011 she found the changing rebate structure the most important paired with a removal of the exemption from congestion charging and negative media announcements. Gallagher and Muehlegger (2010) study the effect of different tax incentives and the use of HOV lanes on HEVs in the US for different policy levels (federal, state, local). Also, a correlation with fuel prices is tested for the years 2000-2006. In a regression, they used the log per-capita sales as dependent variable, finding that feebates are the most effective policy measure. The effects of HOV lanes remain unclear while gas prices are positively correlated with HEV sales.

De Shazo et al. 2014 analysed the performance of rebate designs in California. With a representative data sample for California (1261 respondents), they set up an optimization model for the political program evaluation. The most important findings were that without a rebate PHEVs would be prioritized to BEVs in purchase decisions, and that high-income consumers were more likely to buy. Thus, income-dependent rebates could increase the number of buyers yet the vehicle purchase price is still relevant. Sierzchula et al. (2014) study the EV adoption of 30 national EV market shares in 2012 in a multiple linear regression analysis. They find financial incentives, charging infrastructure, local presence of production facilities to be positively correlated and significant. Yet in their analysis, charging infrastructure is the most important for EV adoption. “However, descriptive analysis suggests that neither financial incentives nor charging infrastructure ensure high electric vehicle adoption rates.” (Sierzchula et al. 2014) Tal et al. (2013) base their results on a survey with 1,201 households who purchased PEV in 2011 and 2012 in California to identify the most important influence factors in the buying decision. A comparison of the survey data with the National Household Travel Survey (NHTS) showed that PEV owners are more likely to own a detached house while the other results were not conclusive. Lieven (2015) studies monetary policy measures, traffic regulations, and investments in charging infrastructure for PEVs. In a conjoint analysis paired with the Kano method to determine policy programs, they look at 20 countries from five continents totalling to 10,981 data sets. They find the installation of charging network on freeways to be a necessity while high subsidies can also be replaced by lower subsidies together with additional charging infrastructure.

Here we present the first ex-post analysis of policy measures for EV market diffusion with a consistent quantitative methodology covering major European countries and all US federal states. The limited availability of public market data, however, renders the present study to a certain degree explorative. The outline is as follows. Section 2 contains the data used for our analysis and the methodology. Results will be given in section 3, followed by a summary and conclusion in section 4.

2 Data and Methods

2.1 Data

We collected data on PEV sales or stock differentiated by country. The data comprises PEV sales (in total and differentiated between PHEV and BEV sales) and PEV stock for major European countries from 2010 to 2014. PEV stock data has been collected for the 52 US states for 2013 and 2014. Information on direct and indirect subsidies active in different regions and countries around the world has been gathered and used to build a PEV policy measures data base. Furthermore, secondary sources provide information on the number of available public charging points in different regions and countries. PEV sales are normalized by the total annual passenger car registrations in a given market to make countries comparable. As an example, Table 1 shows the vehicle and PEV sales and stock for the most important EU vehicle markets

Table 1 shows the vehicle and PEV sales and stock for the most important EU vehicle markets while Table 2 holds energy prices, income and VAT for the same countries. Table 5 and Table 6 (see Appendix) contain the same information for the 52 US states. These four tables contain information for 2014 while data was collected for 2013 as well. References are given at the end of the reference list. Please note that the information in Table 5 slightly differs from Table 1 since the PEV sales are not available in a sufficient granularity. Instead the amount of charge stations and charge outlets are presented.

Country	car sales	car stock	PEV sales	PEV stock	population
Austria	304,135	4,641,000	1,281	3,386	8,506,889
France	1,795,913	31,650,000	10,561	27,816	65,835,579
Germany	3,036,773	43,851,000	8,522	12,156	80,767,463
Italy	1,359,616	36,963,000	1,098		60,782,668
Netherlands	387,835	7,932,000	2,982		16,829,289
Sweden	304,885	4,495,000	1,239		9,644,864
Switzerland	301,942	4,321,000	1,659	4,439	8,139,631
United Kingdom	2,476,435	32,103,000	14,493	20,553	64,308,261

Table 1: Vehicle / PEV sales and stock, population for certain European countries in 2014

Country	electricity price	gas price	diesel price	Income (2013)	VAT
Austria	0.20	1.35	1.30	22,073	20%
Belgium	0.21	1.53	1.35	21,501	21%
France	0.16	1.49	1.29	20,949	20%
Germany	0.30	1.52	1.35	19,545	19%
Italy	0.24	1.72	1.61	15,733	22%
Netherlands	0.18	1.70	1.41	20,834	21%
Poland	0.14	1.26	1.25	5,174	23%
Portugal	0.22	1.53	1.31	8,177	23%
Spain	0.23	1.39	1.31	13,523	21%
Sweden	0.20	1.57	1.54	26,413	25%
Switzerland	0.16	1.46	1.25	40,690	8%
United Kingdom	0.19	1.59	1.66	18,694	20%

Table 2: Electricity and fuel prices, income and VAT for some European countries in 2014 (References in Annex A)

2.2 Methods

We use two variables describing the EV market in different countries: (1) The shares of EV in total passenger car sales and (2) the number of EV that are registered per 1,000 inhabitants (EV per capita). Multiple linear regression is used to measure the joint impact of direct and indirect subsidies and controlling factors such as income. Additionally, the influence on PHEV and BEV sales shares are analysed individually. Since PEV sales data is not available for US states we analyse PEV stock for the US instead. We take the natural logarithm of both dependent variables to ensure normality of residuals.

3 Results

3.1 Qualitative Comparison

Despite the limited number of PEV markets worldwide, direct subsidies and indirect incentives are expected to have a positive effect on PEV sales. Figure 2 analyses the effect of an increasing number of indirect incentives active in the different markets on PEV sales. The left panel shows a boxplot for the effect on (the log of) PEV sales shares whereas the right panel shows a boxplot of the effect on (the log of) PEV per capita. We observe a tendency towards higher market shares in both market variables with growing number of indirect incentives in place. However, the connection is not strictly monotonic.

Apart from the number of indirect incentives, several other factors can be expected to have an influence on PEV adoption. Accordingly, Fig. 3 shows the PEV sales shares versus average income, the household electricity price, the average price of gasoline and the direct financial incentive for PEV. The disposable income can be expected to have a positive effect on PEV sales shares. Indeed, the correlation is positive and significantly different from zero (at significance level 0.01). Furthermore, the total cost of ownership is often used in market diffusion models for PEV. Accordingly, the operating costs for conventional and electric vehicles should have an impact on PEV sales. Fig. 3 shows PEV sales shares versus the average household electricity price and the price of gasoline. The former is not significantly correlated with PEV sales shares but the latter shows a positive correlation (at significance level 0.01). From a policy perspective direct incentives are an easy to understand measure to trigger. Again, the correlation is positive (at significance level 0.05) yet weaker compared to the previous variables.

In summary and when analysing the individual connection between average income, the electricity price and the gasoline price as well direct subsidies on PEV sales shares, a positive connection is present for three out of four variables. However, the figure also demonstrates that most markets in the sample have no direct financial subsidy in place and a positive effect could be expected to be highly uncertain.

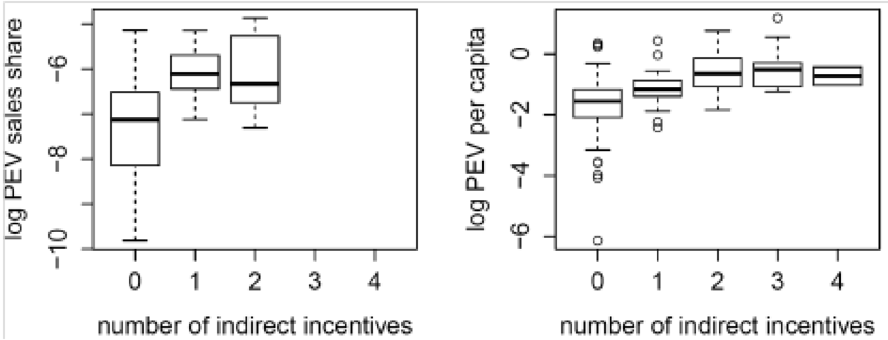

Figure 1: Effect of the number of indirect incentives on PEV market penetration.
Left panel: PEV sales shares (European data). Right panel: PEV per capita (US data)

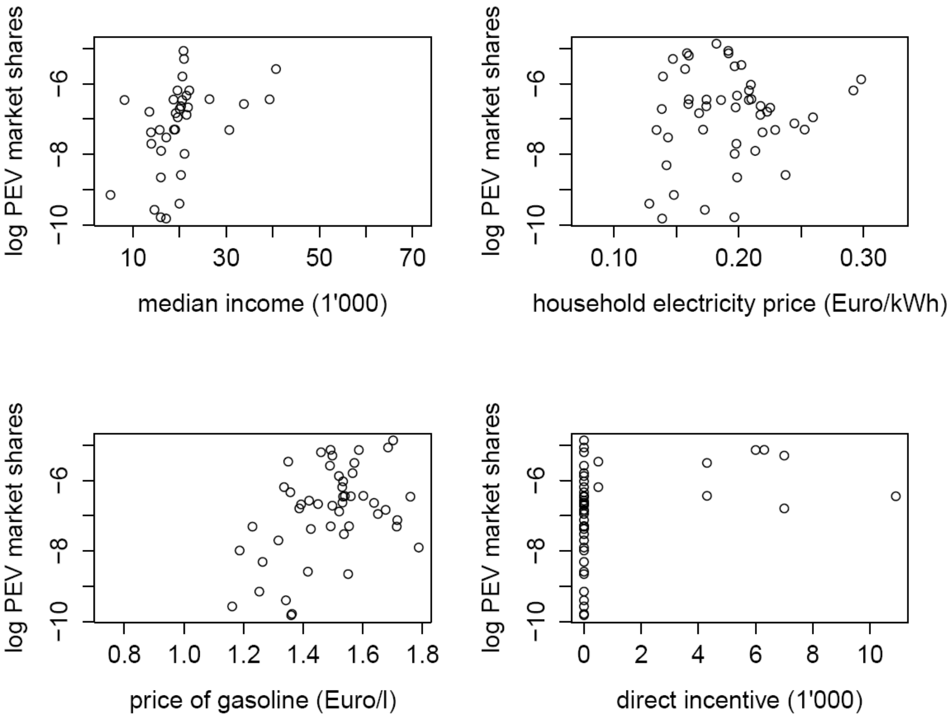

Figure 2: The effect of income (top left), household electricity price (top right), gasoline price (bottom left) and direct incentives (bottom right) on PEV sales shares.

3.2 Factors influencing PEV sales shares: Europe

We use linear regression to analyse the joint effect of several variables on PEV sales shares and identify drivers for PEV sales. Table 3 shows the results from a linear regression of several variables on (the log of) PEV sales shares. The model is highly significant (F statistic 5.583 and Prob. > P = 0.001) and explains about 50% of the variance (R^2 = 0.536; Adjusted R^2 = 0.44). Since the number of indirect incentives present is an ordered categorical variable, we use orthogonal polynomial coding, i.e., we look for the linear, quadratic trends in the variable.

Table 2: Regression results for PEV sales shares

Variable	Est.	SEr	Pr(>|t|)	
(Intercept)	-13.487	1.843	0	
Income	0.083	0.023	0.001	**
Electricity price	2.439	4.73	0.61	
Gasoline price	2.813	1.064	0.013	*
Direct incentive	0.164	0.078	0.044	*
Indirect incentives linear	0.712	0.336	0.043	*
Indirect incentives quadratic	0.541	0.594	0.37	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05; N = 35; $F(6,29)$= 5.583; Prob > P = 0.001; R^2 = 0.54; Adj-R^2 = 0.44

The regression results show that income, gasoline price and direct incentives have a positive effect on PEV sales shares. All significant influences have the expected signs. The number of indirect incentives available has been included as an ordered categorical variable and we observe a linear trend for it. We can exclude collinearity between the variables (all VIF are smaller than 1.9).

We also analysed the effect of prices and incentives on PHEV and BEV sales shares individually. The results are given in Table 3 and 4 below. The distinction between these two types of PEV leads to a reduced sample size as this information was available for some countries only. In both cases, the Gasoline price and indirect incentives are found to have a positive impact on PEV sales shares.

Table 3: Regression results for PHEV sales shares

Variable	Est	SE	Pr(>|t|)	
(Intercept)	-18.077	7.405	0.026	
Income	-0.052	0.073	0.49	
Electricity price	-31.198	18.80	0.115	
Gasoline price	11.016	4.61	0.029	*
Direct incentive	-0.177	0.254	0.496	
Indirect incentives linear	2.573	1.084	0.03	*
Indirect incentives quadratic	-0.617	1.891	0.748	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05; N = 23; $F(6,17) = 1.985$; Prob > P = 0.124; $R^2 = 0.41$; Adj-$R^2 = 0.20$

Table 4: Regression results for BEV sales shares

Variable	Est.	SE	Pr(>|t|)	
(Intercept)	-14.325	3.973	0.002	
Income	-0.064	0.039	0.117	
Electricity price	-12.869	10.242	0.227	
Gasoline price	6.95	2.523	0.014	*
Direct incentive	-0.094	0.135	0.497	
Indirect incentives linear	1.69	0.587	0.011	*
Indirect incentives quadratic	-0.533	1.005	0.603	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05; N = 22; $F(6,16) = 2.962$; Prob > P= 0.04 ; R^2= 0.53: Adj-$R^2 = 0.35$

3.3 Factors influencing PEV per capita: US federal states

In contrast to PEV sales, the PEV per capita provide a measure of the PEV in stock normalised to the different stock sizes by dividing by the number of inhabitants in a given state. Furthermore, no sales data was available for the individual US states. Accordingly, we performed linear regression on the (log of) PEV per capita (please keep in mind that we are using PEV in stock per 1000 inhabitants but refer to it as PEV per capita for brevity). The number of charging stations per capita has been included since this data was available for the US federal states. The remaining sample size for the regression on PEV sales shares is thus N = 125. Since the number of indirect incentives present is an ordered categorical variable, we use orthogonal polynomial coding, i.e., we look for the linear, quadratic and potentially higher order trends in the variable. The results are summarised in Table 5.

Table 5: Regression results for PEV per capita

	Est	SE	Pr(>|t|)	
(Intercept)	-8.517	1.189	$<10^{-4}$	
Income	0.009	0.007	0.194	
Electricity price HH	-0.727	1.469	0.622	
Gasoline price	8.471	1.664	$<10^{-4}$	***
Charging stations	15.234	2.109	$<10^{-4}$	***
Direct incentive	0.045	0.026	0.082	†
Indirect incentives linear	0.151	0.215	0.485	
Indirect incentives quadratic	-0.483	0.198	0.017	*
Indirect incentives cubic	-0.04	0.146	0.785	
Indirect incentives quartic	-0.126	0.112	0.263	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1; N = 125; $F(8,117) = 15.913$; Prob > P = 0; $R^2 = 0.521$; Adj-$R^2 = 0.49$

The model is highly significant (F statistic 15.9 and Prob > P < 10^{-4}) and explains about 50% of the variance (R-Squared = 0.521; Adjusted R2 = 0.49). Similar to the regression on PEV sales share for Europe, the gasoline price and direct incentives have a significantly positive effect on PEV per capita. However, income is not significant in the regression of PEV per capita. This could be associated with the lack of variance in average income among the US states as compared to the variance in average income in Europe as used for the regression on PEV sales shares. Furthermore, the linear trend in the indirect incentives is not significant for PEV per capita and the quadratic term – despite being significant – does not show the expected sign. For the PEV per capita, the number of charging stations per 1000 inhabitants could be included in the regression and is highly significant with the expected sign. In summary, the number of PEV per capita are positively impacted by the gasoline price and direct incentives and are positively connected to the number of charging stations available.

With between zero and five indirect incentives present in the different US states, the use of indirect incentives as categorical variable can be questioned. Furthermore, potential PEV adopters could rather be affected by the total number. We thus included the number of active indirect incentives is as metric variable in the regression and found a positive and highly significant effect on PEV per capita (estimate: 0.229; SE: 0.066; tvalue: 3.482, p-value: 0.0007). The results for this additional regression on PEV per capita are summarised in Table 6.

Table 6: Regression results for PEV per capita with number of indirect incentives as metric variable

	Est	SE	Pr(>|t|)	
(Intercept)	-8.013	1.164	$<10^{-4}$	***
Income	0.013	0.007	0.072	†
Electricity price HH	-0.197	1.488	0.895	
Gasoline price	7.006	1.633	$<10^{-4}$	***
Charging stations	14.517	2.174	$<10^{-4}$	***
Direct incentive	0.047	0.025	0.067	†
Indirect incentives metric	0.185	0.043	$<10^{-4}$	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1; N = 100; $F(6,94) = 30.04$; p-value: < 2.2e-16; R^2=0.66, Adj. R2=0.64

The model is highly significant and explains more variance than the model with indirect incentives as categorical variable. In addition to this, the income is marginally significant and the other variables remain significant. Thus, including the number of indirect incentives seems to be preferably included as metric variable if the number of active indirect incentives can be high.

4 Discussion and Conclusions

Our results come with some uncertainty. Firstly, the aggregation of sales and stock data to state or national levels ignores variance on the city or regional level. Particularly in the US, several major cities have introduced additional incentives for PEV users. Secondly, incentives can be included in regressions in several ways. For example, all indirect incentives could be included as separate categorical variables.

No or only significant effects were found for direct financial incentives. This might be due the limited number of countries with positive direct financial incentives (cf. Figure 2) and requires further inquiry. Additionally, we neglected the longitudinal nature of the data and future analysis should include general or country specific trend and autoregressive variables.

In summary, we analysed the effect of different controlling factors and policy measures on PEV adoption measured as PEV sales shares and PEV in stock per capita. Our results show that income and gasoline prices should be included in the analysis of policies since they help explain variance in PEV adoption rates. From a policy perspective, both direct and direct incentives seem to have a positive effect on PEV adoption. This has been shown with empirical PEV market data from the US and Europe. However, the efficiency of different measures and the effect of public charging infrastructure remain open issues for further research.

5 Summary

We analysed the effect of different controlling factors and policy measures on PEV adoption measured as PEV sales shares and PEV in stock per capita. Our results show that controlling factors such as income and gasoline prices should be included in the analysis of policies since they help explain variance in PEV adoption rates. From a policy perspective, both direct and direct incentives seem to have a positive effect on PEV adoption. This has been shown with empirical PEV market data from the US and Europe. However, the efficiency of different measures and the effect of public charging infrastructure remain open issues for further research.

Acknowledgments

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Appendix

The following tables contain the data used for the US states.

Appendix A. Table 5. Vehicle / PEV sales and stock, population for US states in 2014

State	Car stock	PEVstock	Population	Charge stations	Charge outlets
Alabama	2,074,969	773	4,849,377	41	85
Alaska	201,042	155	736,732	2	3
Arizona	2,257,249	4,361	6,731,484	276	705
Arkansas	865,210	374	2,966,369	32	49
California	13,822,505	126,283	38,802,500	2,134	6,958
Colorado	1,819,608	4,001	5,355,866	211	461
Connecticut	1,474,581	2,476	3,596,677	176	352
Delaware	448,155	383	935,614	14	25
Dist. of Col.	218,642	493	658,893	57	134
Florida	7,425,492	10,383	19,893,297	515	1,228
Georgia	3,435,040	15,551	10,097,343	333	825

Hawaii	568,238	3,050	1,419,561	190	435
Idaho	598,877	409	1,634,464	19	39
Illinois	4,796,992	6,694	12,880,580	355	796
Indiana	2,264,905	1,697	6,596,855	107	210
Iowa	1,366,389	928	3,107,126	58	124
Kansas	1,031,234	750	2,904,021	110	379
Kentucky	1,714,904	701	4,413,457	30	120
Louisiana	1,506,504	527	4,649,676	29	60
Maine	487,896	695	1,330,089	38	59
Maryland	1,918,606	5,028	5,976,407	260	612
Massachusetts	2,510,780	4,612	6,745,408	290	808
Michigan	3,593,751	8,844	9,909,877	258	662
Minnesota	2,212,406	2,775	5,457,173	186	400
Mississippi	871,806	201	2,994,079	16	17
Missouri	2,484,904	1,859	6,063,589	126	268
Montana	444,707	362	1,023,579	9	35
Nebraska	733,008	579	1,881,503	26	47
Nevada	977,852	1,509	2,839,099	94	289
New Hampshire	625,391	761	1,326,813	40	69
New Jersey	3,644,546	6,021	8,938,175	127	343
New Mexico	716,439	637	2,085,572	27	71
New York	5,203,357	11,278	19,746,227	469	1,074
North Carolina	3,495,804	3,384	9,943,964	224	550
North Dakota	255,183	91	739,482	3	4
Ohio	4,862,768	3,814	11,594,163	125	236
Oklahoma	1,376,118	806	3,878,051	n.a.	n.a.
Oregon	1,520,784	5,681	3,970,239	402	950
Pennsylvania	4,809,900	4,540	12,787,209	192	344
Rhode Island	459,393	417	1,055,173	60	162
South Carolina	1,750,642	1,056	4,832,482	130	251
South Dakota	331,920	160	853,175	8	29
Tennessee	2,284,326	2,730	6,549,352	304	698
Texas	7,954,906	9,925	26,956,958	578	1,547
Utah	876,036	1,565	2,942,902	68	162
Vermont	258,801	840	626,562	69	167
Virginia	3,296,365	3,628	8,326,289	214	569
Washington	2,800,255	12,291	7,061,530	456	1,205
West Virginia	541,900	271	1,850,326	1	4
Wisconsin	2,256,529	2,429	5,757,564	10	38
Wyoming	228,731	73	584,153	9	16

Appendix B. Table 6. Electricity and fuel prices, avg. income and VAT for US states in 2014

State	Electricity price HH	Electricity price ind.	Gasoline price	Diesel price	Income	VAT
Alabama	0.10	0.05	0.74	0.85	41,381	4.0%
Alaska	0.17	0.14	0.85	0.91	61,137	n.a.
Arizona	0.10	0.06	0.85	0.91	50,602	5.6%
Arkansas	0.08	0.05	0.74	0.85	39,919	6.5%
California	0.14	0.10	0.85	0.91	57,528	7.5%
Colorado	0.11	0.06	0.78	0.89	63,371	2.9%
Connecticut	0.17	0.11	0.82	0.92	67,781	6.4%
Delaware	0.12	n.a.	0.82	0.92	52,219	n.a.
Dist. of Col.	0.11	0.07	0.82	0.92	60,675	5.8%
Florida	0.10	0.07	0.78	0.87	47,886	6.0%
Georgia	0.10	0.06	0.78	0.87	47,439	4.0%
Hawaii	0.33	0.26	0.85	0.91	61,408	4.0%
Idaho	0.09	0.06	0.78	0.89	51,767	6.0%
Illinois	0.10	0.06	0.77	0.88	57,196	6.3%
Indiana	0.10	0.06	0.77	0.88	50,553	7.0%
Iowa	0.10	0.05	0.77	0.88	54,855	6.0%
Kansas	0.11	0.07	0.77	0.88	51,485	6.2%
Kentucky	0.09	0.05	0.77	0.88	42,158	6.0%
Louisiana	0.08	0.05	0.74	0.85	39,622	4.0%
Maine	0.13	0.08	0.82	0.92	50,121	5.5%
Maryland	0.12	0.08	0.82	0.92	65,262	6.0%
Massachusetts	0.15	0.11	0.82	0.92	62,963	6.3%
Michigan	0.13	0.07	0.77	0.88	48,801	6.0%
Minnesota	0.11	0.06	0.77	0.88	60,907	6.9%
Mississippi	0.10	0.06	0.74	0.85	40,850	7.0%
Missouri	0.09	0.05	0.77	0.88	50,311	4.2%
Montana	0.09	0.05	0.78	0.89	44,132	n.a.
Nebraska	0.09	0.06	0.77	0.88	53,774	5.5%
Nevada	0.11	0.06	0.77	0.88	45,369	6.9%

New Hampshire	0.15	0.10	0.82	0.92	71,322	n.a.
New Jersey	0.14	0.10	0.82	0.92	61,782	7.0%
New Mexico	0.11	0.06	0.74	0.85	42,127	5.1%
New York	0.17	0.06	0.82	0.92	53,843	4.0%
North Carolina	0.10	0.06	0.78	0.87	41,208	4.8%
North Dakota	0.08	0.07	0.77	0.88	52,888	5.0%
Ohio	0.11	0.06	0.77	0.88	46,398	5.8%
Oklahoma	0.09	0.05	0.77	0.88	43,777	4.5%
Oregon	0.09	0.05	0.85	0.91	56,307	n.a.
Pennsylvania	0.12	0.06	0.82	0.92	53,952	6.0%
Rhode Island	0.15	0.11	0.82	0.92	57,812	7.0%
South Carolina	0.11	0.05	0.78	0.87	43,749	6.0%
South Dakota	0.09	0.06	0.77	0.88	54,453	4.0%
Tennessee	0.09	0.06	0.77	0.88	42,499	7.0%
Texas	0.10	0.05	0.74	0.85	53,027	6.3%
Utah	0.09	0.05	0.78	0.89	62,967	6.0%
Vermont	0.15	0.09	0.82	0.92	54,842	6.0%
Virginia	0.10	0.06	0.78	0.87	67,620	5.3%
Washington	0.08	0.04	0.85	0.91	60,106	6.5%
West Virginia	0.08	0.05	0.78	0.87	40,241	6.0%
Wisconsin	0.12	0.07	0.77	0.88	55,258	5.0%
Wyoming	0.09	0.06	0.78	0.89	55,700	4.0%

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