THE FACTORS INFLUENCING THE JOINT PURCHASE OF ELECTRIC VEHICLE AND SOLAR PHOTOVOLTAICS: EVIDENCE FROM CALIFORNIA

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Environmentally friendly choices can make more impact when these are taken in combination. For example, purchasing electric vehicles (EV) and solar photovoltaics (PV) simultaneously. Previous studies suggest that although EVs emit fewer pollutants than conventional vehicles, they increase energy consumption, and that usually comes with more environmental damage. Installing solar PV can be a solution by producing energy while reducing our carbon footprints. This study analyzes the factors that influence the joint purchase of EVs and solar PV. The findings show that higher income and higher education levels significantly impact making these choices. The study also reveals that there is a gender gap in the current purchase decisions, as non-binary people show significant negative effects. More specifically, female and non-binary consumers are less likely to purchase EVs. While considering future decisions, this study finds that higher education and non-binary gender show similar effects of current choice analysis for future choice analysis. However, women show a positive impact on purchasing EVs but a negative impact on installing solar in the future.

Keywords: Electric Vehicle, Solar Photovoltaics, Joint Purchase of Green Choices. Gender Gap on EV purchase
JEL category: Q42, Q55

Date: 02/17/2024
This is an unedited version of the of the accepted manuscript scheduled for publication. Readers may obtain the final version from the below link when it is published.

Suggested Citation:
Ferdousee, Atia (2024). The Factors Influencing the Joint Purchase of Electric Vehicle and Solar Photovoltaics: Evidence from California, Climate Change Economics, https://doi.org/10.1142/S2010007824400037

1. Introduction

Household-level pollution control is certainly an important policy discussion. Along with the government, people are also trying to make environment-friendly choices due to climate change concerns. In terms of emission control, several federal and state-level incentives are present for electric vehicles (EVs). These incentives are making EVs affordable to more consumers, and as a result, the EV market share is growing day by day. But, EVs have some other social costs as well (Hawkins et al., 2012; Nicholas et al., 2015). For example, previous studies have shown that electric vehicles and their supportive infrastructures, like charging stations, may significantly increase residential and commercial electricity consumption. (Ferdousee, 2022). The study also indicates that the production of electricity is still mostly dependent on non-renewable sources like gasoline and coal. While transportation (29%) is the primary source of greenhouse gas emissions in the USA, electricity generation (25%) is the second (EPA, 2021). Although electricity production is primarily not a household decision, its production certainly depends on household consumption levels in the long run.

Nonetheless, in the USA, people are now interested in getting more renewable energy than before to reduce greenhouse gas production (Borunda, 2021). People are interested in, for example, producing their own energy by installing small-scale photovoltaics or solar power generators. Just like electric vehicles, both federal and state governments are incentivizing solar PVs as well.

This study explores the factors that influence the decision to purchase EVs as well as installing solar PV at homes in California by implementing a multinomial logit regression model. As both green technologies are new and durable in nature, our hypothesis is that characteristics like education level and age should have a significant impact on making these choices. More specifically, highly educated, younger consumers possibly have more potential to make these choices. Although federal and state-level incentives are available, EVs are still expensive compared to other conventional vehicles. So, the high income level should have a positive impact on purchasing EVs. Previous studies also find evidence that age, education, and income levels have such effects on adopting these technologies (Nath, 2016; Araújo et al., 2019). Also, different household types should have different effects because of their structures and different energy consumption patterns.

Implementing a multinomial logit model to analyze the determinants of the joint purchase of Electric Vehicles (EVs) and solar photovoltaics (PV) in California, this study also analyses the future decision of this joint purchase as well.

The findings suggest that higher education levels and higher incomes have a significant positive impact on purchasing both EVs and solar panels. When we consider the future purchasing decision, higher education level remains significant, but income level does not. This study also reveals that non-binary consumers are significantly less likely to make joint purchases in the present or consider future purchase decisions. Women are less likely to have an EV, but they are willing to buy EVs in the future. However, women are less likely to consider having solar PV in the future.

The rest of this study is organized as follows: first, we give a brief literature review in section 2. Section 3 presents an overview of the data and model specification. We offer the results of the analysis in Section 4 before concluding in Section 5.

2. Literature Review

The joint purchase of EVs and Solar PV has been discussed in economics literature from several perspectives. Delmas et al. (2016) showed that quality improvements and falling prices of both electric vehicles and solar panels lead to households increasingly purchasing both durable goods as a bundle. They analyzed five years of data from California and concluded that the correlation between the share of households with solar panels and electric vehicles rose over time. For the hypothesis testing, they used the number of EVs as the dependent variable and the number of solar PV as one of the explanatory variables in the regression analysis.

Nath (2016), in his MA thesis, explored the factors behind the adoption of both EV and solar PV using binomial logit regression and showed that Both EV and solar PV respondents were wealthy and highly educated. A high level of trust is placed upon technology providers and a lower degree of trust in the adopters' interpersonal network. This study also finds strong support for the theory of planned behavior through the identification of the role of personal norms, subjective norms, attitude, and perceived behavioral control on intention and, ultimately, behavior. The mix of environmental, societal, and self-oriented values was clearly observed in the decision-making process.

Araújo et al. (2019) studied electric vehicles and solar photovoltaic technology diffusion in the State of New York. Using geospatial, regression, and cluster analyses of the zip-code level and county indicators, they analyzed trends with locational, political, and socio-demographic profiles to identify areas of convergence and divergence in adoption patterns. Their study confirmed the importance of income and median home value in early-staged, electric vehicle and solar photovoltaic technology adoption. They also found that political orientation and age tendencies are more nuanced and less predictive. However, they noted key adaptive tendencies among those aged 30-44 and above 59 for solar photovoltaics. Moreover, southeastern counties near New York City, particularly on Long Island, are identified as critical niches in the early-staged diffusion of clean energy.

Based on historical diffusion data of solar PV and EV in the Netherlands, Kam et al. (2018) have characterized the adopter groups of these technologies and built scenarios for future diffusion. They also investigate how the joint deployment of these technologies may impact the local energy system and assess the viability of the integration of solar PV and EV in vehicle-to-grid systems. They find large differences in the spatial diffusion patterns of solar PV and EV using 40 regions in the Netherlands, which will have an impact on the viability of vehicle-to-grid systems. To characterize PV and EV purchasers, they performed two ordinary least squares (OLS) regressions, one with the number of PV installations per person and one with the number of EVs per person as the dependent variable.

Delmas et al. (2016) argue that the joint purchase of electric vehicles and solar panels is one way to significantly reduce carbon emissions in the suburban United States. This is because electric vehicles may lead to environmental damage due to increasing energy consumption (Graff Zivin et al., 2014; Holland et al., 2015, Ferdousee, 2022). So, Households that invest in both solar panels and electric vehicles can mitigate their carbon footprint from household and transportation activities.

3. Data and Methodology

This study uses 2019 California vehicle survey data from the Transportation Secure Data Center of The National Renewable Energy Laboratory (NREL). From the dataset, we only use the residential portion of the data, which includes 4136 observations. Table 1 shows the summary statistics of all the variables. The explanatory variables include age group, education, gender, income, household type, and number of household members. This dataset contains geographical information about respondents and divides the state into six separate regions, which will control for region-specific unobservable variables. Most of the variables are categorical variables, except the number of household members.

Table 1. Summary statistics

Variable	Category	Value
Gender		
	Male	47.78%
	Female	51.06%
	Other	0.15%
	Do not wish to answer	1.02%
Age Group		
	Below 18	0
	18 to 34	12.33%
	35 to 64	52.85%
	65 or above	34.82%
EV		
	Yes	6.67%
	No	93.33%
EV Future		
	Yes	4.30%
	No	95.70%
Solar		
	Yes	15.96%
	No	84.04%
Solar Future		
	Yes	15.38%
	No	81.7%
Housing		
	Single	76.33%
	Mobile	2.59%
	Multi	20.65%
	Other	0.44%
Education		
	High School	15.21%
	Some College Degree	21.74%
	College Graduate	37.98%
	Postgraduate	25.07%
Income		
	Below 50k	19.15%
	50k – 99.9k	14.7%
	100k – 149.9k	18.74%
	150k – 199.9k	10.28%
	200k – 249.9k	20.79%
	250k or more	7.59%
	Not willing to answer	8.75%
Region		
	Central Valley	5.85%
	Los Angeles	45.21%
	San Diego	7.88%
	San Francisco	9.28%
	Sacramento	23.55%
	Rest of the State	8.15%
	Unknown	0.07%
Total HH Members		
	Min	1

	Mean	2.3
	Max	16
Total sample size is 4136		

The multinomial logit model (MNL) applies when an individual i's choice or response depends on the characteristics of the chooser, not the choice (i.e. x_i). We can express the latent value of choice j for individual i (V_{ij}) as:

$$V_{ij} = x'_i\beta_j + \varepsilon_{ij} \tag{1}$$

The explanatory variables (x_i) are age group, education, gender, income, household type, region, and number of household members.

where β_j is a vector of choice-specific parameters and ε is distributed independent and identically distributed (IID) type I extreme value. If we define y_i as the observed choice of person i, then we can derive the relevant choice probability as follows:

$$\Pr(y_{i\,=\,}j) = \frac{e^{x_i\beta_j}}{1 + \sum_{k=1}^{2} e^{x_i\beta_k}} \tag{2}$$

In this scenario, the households have four choices. They can choose a regular car and no solar, an EV car and no solar, solar and a regular car, or both EV and solar. As we are mostly interested in estimating these decisions together, we construct four choice variables and run a multinomial logit analysis on these choices, leaving out the choice of no solar and a regular car for comparison.

Table 2 shows the conditional summary statistics for all variable categories in the percentage level. In this study, EV represents both plug-in-hybrid vehicles and fully battery electric vehicles. In the data, we have information on the future decisions of vehicles and solar. So, EV Future and Solar Future variables represent the survey respondents who are interested in purchasing an EV and solar in the future.

Table 2. Conditional summary statistics of EV and Solar consumers

Variable	Category	EV	Solar	EV Future	Solar Future
Consumer (Total)	---------	6.67%	15.96%	4.30%	15.38%
Education					
	High School	0.58%	2.10%	0.24%	2.18%
	Some College	1.06%	3.00%	1.02%	3.22%
	College Grad	2.35%	5.75%	1.84%	5.85%
	Postgraduate	2.68%	5.10%	1.21%	4.13%
Gender					
	Male	3.82%	8.29%	1.55%	7.98%
	Female	2.73%	7.52%	2.68%	7.23%
	Other	0.00%	0.02%	0.00%	0.02%
	Not willing to Answer	0.12%	0.12%	0.07%	0.15%
Income					
	Below 50k	0.36%	1.64%	0.80%	2.15%
	50k – 99.9k	0.60%	2.25%	0.56%	2.10%
	100k – 149.9k	1.35%	3.09%	0.97%	3.07%
	150k – 199.9k	1.02%	2.08%	0.36%	2.01%
	200k – 249.9k	1.50%	2.85%	1.02%	3.38%
	250k or more	1.21%	2.37%	0.17%	1.47%
	Not willing to Ans	0.36%	1.67%	0.44%	1.18%
Region					
	Central Valley	0.17%	0.85%	0.12%	0.94%
	Los Angeles	2.61%	6.21%	1.91%	6.33%
	Rest of the State	0.46%	1.84%	0.39%	1.21%
	San Diego	0.65%	1.93%	0.31%	1.31%
	San Francisco	2.39%	3.58%	0.31%	4.33%
	Sacramento	0.36%	1.55%	1.33%	1.23%

	Unknown	0.02%	0.00%	0.24%	0.02%
Housing					
	Single	5.59%	14.94%	2.76%	13.39%
	Mobile	0.00%	0.10%	0.12%	0.41%
	Multi	1.09%	0.82%	1.40%	1.52%
	Other	0.00%	0.10%	0.02%	0.05%
Age Group					
	18 to 34	0.92%	1.28%	0.87%	2.08%
	35 to 64	4.18%	8.22%	2.18%	8.80%
	65 or older	1.57%	6.46%	1.26%	4.50%

We also use total household members as an explanatory variable ranging from one member to sixteen members. 44% of households consist of two members. 24% of households are single-member households.

4. Results

Table 3 represents the marginal effects of multinomial logit regression for the current purchase of EV and Solar. The first column shows the marginal effects of multinomial logit regression for purchasing both EV and solar PV simultaneously. Columns 2 and 3 show the marginal effect of purchasing EVs and Solar only.

For purchasing both EVs and Solar, the Postgraduate level of education has a significant positive effect, which supports our hypothesis that educated people may want to make more environmentally friendly choices. Age and number of household members do not have any significant effect. However, the “Other Gender” category shows a significantly negative effect on making those choices together. If we look at the EV purchasing decision in column 2, we can see that females and other genders also show a significant negative impact. Several consumer surveys support this behavior and report that women (and non-binary people) are still less likely to buy EVs. Kutz (2023) reveals that the lack of reliability in charging infrastructure and considerations for safety could help explain why women (along with non-binary people) make up the minority of electric car drivers. She also mentioned several other reasons behind this gender gap, like socioeconomic status, experiences at car dealerships, less awareness of how electric cars work, etc. S&P Global Mobility survey revealed that, in the first half of 2021, only 28% were purchased by women.

Table 3. The Marginal Effect of Multinomial Logit on Current Purchase

Variable	Category	Both EV & Solar	EV Only	Solar Only
Age Group				
	18-34	-------	---------	--------
	35-64	0.008	-0.018	0.020
		(0.007)	(0.012)	(0.015)
	65 or older	0.007	-0.043*	0.072**
		(0.008)	(0.013)	(0.018)
Education				
	High School	--------	--------	--------
	Some College	-0.002	0.012	-0.006
		(0.007)	(0.010)	(0.018)
	College Grad	-0.004	0.018	0.012
			(0.009)	(0.016)
	Postgrad	0.020**	0.021*	0.011
		(0.008)	(0.010)	(0.018)
Gender				
	Male	--------	--------	--------
	Female	-0.008	-0.014*	-0.014
		(0.005)	(0.006)	(0.011)
	Other	-0.026***	-0.051***	0.060
		(0.003)	(0.005)	(0.168)
	Gender (Not willing to answer)	0.004	0.031	-0.036
		(0.030)	(0.040)	(0.051)
Housing				

	Single	--------	--------	--------
	Mobile	-0.026***	-0.044***	-0.116***
		(0.003)	(0.004)	(0.022)
	Multi	-0.023***	0.007	-0.108***
		(0.004)	(0.009)	(0.011)
	Other	-0.026***	-0.044***	0.122
		(0.003)	(0.004)	(0.111)
Income				
	Below 50k	---------	--------	---------
	50k-99.9K	0.007	0.009	0.031
		(0.006)	(0.009)	(0.018)
	100k-149.9K	0.019**	0.022*	0.031
		(0.007)	(0.009)	(0.017)
	150K-199.9K	0.022**	0.038**	0.056*
		(0.008)	(0.013)	(0.021)
	200K-249.9K	0.016**	0.028**	0.012
		(0.006)	(0.009)	(0.016)
	250K or more	0.029**	0.061***	0.132***
		(0.010)	(0.016)	(0.027)
	Not willing to answer	0.019*	0.023	0.057*
		(0.009)	(0.013)	(0.023)
Region				
	Central Valley	---------	--------	
	Los Angeles	0.013*	0.009	-0.029
		(0.006)	(0.013)	(0.025)
	Rest of the State	0.055***	-0.019	0.040
		(0.015)	(0.014)	(0.032)
	San Diego	0.020*	0.014	0.035
		(0.010)	(0.017)	(0.031)
	San Francisco	0.018*	0.032	-0.038
		(0.007)	(0.015)	(0.026)
	Sacramento	0.006	0.003	0.015
		(0.008)	(0.016)	(0.030)
	Unknown	-0.006	0.248	-0.153***
		(0.006)	(0.224)	(0.023)
HH Members	---------	0.002	0.002	0.024***
		(0.002)	(0.003)	(0.004)

Note: *** p<.001, ** p<.01, * p<.05. p values reported in parenthesis

Comparing a single type of housing as the base type, mobile, multi, and other type of housing reveals negative effects on purchasing both, and the result is highly significant. Understandably, multi- and mobile housing types are less likely to purchase EVs, mostly due to the modest socioeconomic status and unavailability of charging infrastructures on the premises. Multi-housing may not be compatible with the solar PV set-up, as that would have to be a collective agreement of all residents, which is rather easier for a single type of household. The results are presented in columns 2 and 3. These findings are consistent with Lisa (2023), who pointed out that those who buy electric cars tend to own their homes. By doing so, they can install chargers and plug in their cars overnight, avoiding using a public charger for day-to-day commutes. As women are less likely to own homes and are more likely to live in multifamily dwellings where charging stations are often not part of the parking infrastructure, charging their cars becomes an additional task.

We also see that modest-income families are less likely to purchase both. We can see that the effect remains the same for the EV-only and solar-only purchase decisions. Although there are incentives from the state and federal governments, EVs are still an expensive option for any average buyer. Solar is no different as well. The cost of installing solar panels in California varies depending on region, the system size, and which company consumers may use. For example, Fixr.com lists the average cost to install solar panels in California as follows:

- $4,880–$25,680 for a 1,000 sq ft house
- $6,420–$29,280 for a 1,500 sq ft house
- $9,760–$32,100 for a 2,000 sq ft house
- $14,640–$38,520 for a 2,500 sq ft house

Considering Central Valley as the base region, the regional effect shows that Sacramento significantly negatively affects installing solar. However, the unknown region shows a positive effect. There is no regional effect on EV purchases. However, Los Angeles, San Diego, and San Francisco show positive effects at a 5% significant level for purchasing both. The rest of the state shows a highly significant positive effect on that.

Besides analyzing the present factors of EV and solar purchases, we are also interested in analyzing people's future decisions on these two choices. In the dataset, there were survey questions about the future decision of their vehicle choice as well as about having solar. In the survey, respondents were asked about the types of fuel they would consider for their future car/cars. Based on the responses, we create variables on future EVs and solar purchase decisions and then run a similar analysis. Table 4 shows the marginal effect of this analysis for the multinomial logit model.

In this case, the age group of 65 or older shows a negative effect on Future EV purchases. The postgraduate level of education shows a similar significant effect as the current purchase decision for EVs and Solar together. However, some college graduate levels also become significant while considering future EV purchases only. Other or non-binary gender still reveals significant negative effects on future purchases of both EVs and Solar. However, females become positively significant when considering EV purchases in the future. Whalen (2022) reports a survey conducted by Morning Consult Pro finding that 47 percent of women say that in the next five years, they'd be interested in purchasing one, which is much higher than the current market share (28%), although still lower than 53 percent of interested male consumers. There is no available data on nonbinary people in either data set. In our result, we see the non-binary people's significant negative effect. Females also show a negative effect on future solar purchases, which could be explained by the fact that women have less home ownership, as we mentioned above. Installing a solar panel while living in a multifamily housing may not be convenient.

Income levels show no significant effect on purchasing both or EVs only in the future. However, higher income levels show a positive impact on installing solar in the future, which could be explained by homeownership as well. Our result also reflects the fact that other types of housing show a significant negative impact on purchasing in the future, and multi-housing shows a significant negative impact on installing solar in the future.

Table 4. Marginal effect of Multinomial Logit on Future Choices

Variable	Category	Both EV & Solar	EV Only	Solar Only
Age Group				
	18-34	--------	--------	--------
	35-64	-0.003 (0.005)	-0.024 (0.013)	-0.015 (0.021)
	65 or older	-0.004 (0.006)	-0.032* (0.013)	-0.029 (0.022)
Education				
	High School	--------	--------	--------
	Some College	0.005 (0.003)	0.032** (0.010)	0.013 (0.020)
	College Grad	0.008* (0.003)	0.028** (0.008)	0.017 (0.019)
	Postgrad	0.013** (0.005)	0.029** (0.010)	0.025 (0.021)
Gender				
	Male	--------	--------	--------
	Female	0.000 (0.003)	0.024*** (0.007)	-0.034** (0.013)
	Other	-0.008*** (0.002)	-0.030*** (0.004)	0.021 (0.179)
	Not willing to answer	-0.008*** (0.002)	0.040 (0.040)	-0.029 (0.060)
Housing				
	Single	--------	--------	--------
	Mobile	0.004 (0.013)	0.007 (0.023)	0.002 (0.045)
	Multi	-0.001 (0.004)	0.016 (0.009)	-0.122*** (0.013)
	Other	-0.009***	0.021	-0.038

		(0.002)	(0.057)	(0.012)
Income				
	Below 50K	--------	--------	--------
	50k-99.9K	-0.003	0.001	0.021
		(0.006)	(0.011)	(0.022)
	100k-149.9K	-0.002	0.015	0.035
		(0.006)	(0.012)	(0.021)
	150K-199.9K	-0.004	-0.002	0.076**
		(0.007)	(0.013)	(0.026)
	200K-249.9K	-0.007	0.016	0.044*
		(0.006)	(0.011)	(0.020)
	250K or more	-0.002	-0.017	0.074*
		(0.008)	(0.013)	(0.031)
	Not willing to answer)	-0.002	0.009	0.019
		(0.008)	(0.014)	(0.026)
Region				
	Central Valley	--------	--------	--------
	Los Angeles	0.004	0.019	-0.021
		(0.006)	(0.011)	(0.027)
	Rest of the State	0.007	0.034	0.019
		(0.009)	(0.018)	(0.036)
	San Diego	-0.005	0.018	0.011
		(0.005)	(0.015)	(0.034)
	San Francisco	0.004	0.036**	0.017
		(0.006)	(0.013)	(0.030)
	Sacramento	0.002	0.009	-0.013
		(0.008)	(0.014)	(0.033)
	Unknown	-0.005	-0.021*	0.102
		(0.005)	(0.010)	(0.234)
HH Members	HH Members	0.001	-0.007*	0.033***
		(0.001)	(0.004)	(0.005)

Note: *** p<.001, ** p<.01, * p<.05. p values reported in parenthesis

There is no regional effect on purchasing both in the future; only San Francisco shows a positive effect on purchasing EVs in the future.

Lastly, the number of household members shows a positive impact on installing solar panels. Bigger households may own bigger houses, which can be a favorable factor in installing solar panels and can reduce household energy costs. It also shows the negative impact of buying an EV in the future, possibly saving energy costs by avoiding charging a bigger car.

5. Conclusion

This research scrutinizes the determinants shaping the simultaneous purchase of Electric Vehicles (EVs) and solar photovoltaics (PV) in California. The empirical findings derived from this study underline the pivotal role played by income and education levels in influencing these purchasing decisions. Notably, higher income levels and elevated educational attainment emerge as influential factors in this decision-making process. The interesting finding of this study is to see the gender gap in both current and future purchases. Specifically, non-binary consumers reveal a significant negative impact in both cases. Female consumers are less likely to have an EV currently but show a positive effect on future purchases. Moreover, females are less likely to install solar panels in the future.

The findings of this study are consistent with previous literature. There is room for future research to explore the causes of gender gaps we find in this study. As the EV market share is growing and there are significant incentives available for both EV and Solar PV, this could be an important viewpoint to argue how to incentivize more female and non-binary consumers.

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