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California, where transportation accounts for over half of ozone precursors and particulate matter emissions, as well as nearly 40 percent of greenhouse gas emissions, has adopted the ambitious goal of reducing petroleum use in transportation by 50 percent by 2030. One of the proposed strategies to achieve this goal is to increase the number of alternative fuel vehicles (AFVs) on the road. In California, incentives to foster the addition of AFVs include the removal of occupancy requirements to access high occupancy vehicle (HOV) lanes and parking privileges with charging facilities for Plug-in Hybrid Electric and Battery Electric vehicles..Although popular, the effectiveness of these incentives is not well known. In this context, this paper analyzes the 2012 California Household Travel Survey using a generalized structural equation model that accounts for residential self-selection, household demographic characteristics, and a measure of environmentalism. Our findings suggest that increased proximity to HOV lanes without occupancy requirement or to preferred parking/refueling facilities have a statistically significant but quite small impact (with odds ratios of 1.004 and 1.017 respectively). Pro-environmental beliefs reflected in voting behavior for environmental propositions are also statistically significant, but they have a potentially larger impact with an odds ratio of 4.733. This suggests the need to continue educating the public about the environmental impacts of fossil fuels while working with car manufacturers to make their products more attractive compared to conventional vehicles.

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The Effectiveness of Incentives to Promote the Household Ownership of Alternative Fuel Vehicles in California

Evidence from the 2012 California Household Travel Survey

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ABSTRACT

California,.where transportation accounts for over half of ozone precursors and particulate matter emissions, as well as nearly 40 percent of greenhouse gas emissions, has adopted the ambitious goal of reducing petroleum use in transportation by 50 percent by 2030. One of the proposed strategies. to achieve this goal is to increase the number of alternative fuel vehicles (AFVs) on the road. In California, incentives to foster the addition of AFVs include the removal of occupancy requirements to access high occupancy vehicle (HOV) lanes and parking privileges with charging facilities for Plug-in Hybrid Electric and Battery Electric vehicles. Although popular, the effectiveness of these incentives is not well known. In this context, this paper analyzes the 2012 California Household Travel Survey using a generalized structural equation model that accounts for residential self-selection, household demographic characteristics and a measure of environmentalism. Our findings suggest that increased proximity to HOV lanes without occupancy requirement or to preferred parking/refueling facilities have a statistically significant but quite small impact (with odds ratios of 1.004 and 1.017 respectively). Pro-environmental beliefs reflected in voting behavior for environmental propositions are also statistically significant, but they have a potentially larger impact with an odds ratio of 4.733. This suggests the need to continue educating the public about the environmental impacts of fossil fuels while working with car manufacturers to make their products more attractive compared to conventional vehicles.

Keywords: Alternative fuel vehicles; Generalized Structural Equation Modeling; Incentives; HOV access.

Contents

INTRODUCTION

As in many other parts of the country, the transportation sector in California accounts for over half of ozone precursors and particulate matter emissions, and for nearly 40 percent of greenhouse gas (GHG) emissions [1]. To reduce the local, regional and global air pollution from transportation, Governor Jerry Brown, in his 2015 inaugural address, called for reducing petroleum consumption in California by up to 50 percent of 2015 levels by 2030 [2]. One key strategy to achieve this ambitious goal is to increase the number of alternative fuel vehicles (AFVs) on the road [1, 2], an approach that has also been adopted elsewhere [3]. Inthis study, only vehicles eligible for Clean Air Vehicle decals (which waive the occupancy requirement for accessing freeway high occupancy vehicle (HOV) lanes) are classified as AFVs.

However, expanding the market share of AFVs is no trivial task. First, AFVs tend to cost more than conventional vehicles (i.e., vehicles with internal combustion engines) because they rely on new technologies and are typically produced in smaller numbers. Second, the refueling and maintenance infrastructure for some AFVs (i.e., electric or hydrogen vehicles) is currently in its infancy, which is a major impediment to their adoption. And third, potential buyers may question the reliability, durability, or maintenance costs of some AFVs.

To overcome these obstacles, a number of incentives have been put in place by federal, state, and local governments [4-13]. In addition to various purchasing subsidies, the adoption of AFVs has been encouraged by operational (non-monetary) incentives. In California, the Clean Air Access program was designed to promote the adoption of AFVs by offering eligible vehicles access to HOV lanes without meeting the occupancy requirements [12, 13]. When it was introduced in 2004, offering access to underutilized HOV lanes was seen as a zero-cost incentive that could boost AFV sales. However, there is no consensus about the overall effectiveness of

California's HOV access program, which was originally introduced to encourage carpooling [12-14]. Parking incentives – often commingled with refueling facilities -have also been offered to AFV drivers, either in the form of cheaper parking in preferred locations, or as free or discounted fuel (for electric and hydrogen vehicles).

In this context, the goal of this paper is to analyze vehicle choice decisions at the household level to understand how households responded to incentives (HOV access and parking/refueling privileges). More specifically, using data from the 2012 California Household Travel Survey (CHTS), we estimated a generalized structural equation model [15] tha explains whether or not households own AFVs based on their socio-economic characteristics, their environmental views (proxied by voting data on environmental proposals), and AFV incentives (HOV access and parking privileges), while endogenizing residential location (proxied by residential density) and vehicle utilization.

LITERATURE REVIEW

To select our model variables, motivate our modeling framework, and contextualize our results, this section reviews selected papers on ownership, environmentalism, and incentives for alternative fuel vehicles.

Vehicle Ownership lodeling

Studies concerned with AFVs began to emerge after AFV incentive policies and programs were introduced in the early 1990s. At the Federal level, the 1990 Clean Air Act Amendments first allowed for waiving the occupancy requirement of HOV lanes for low-emission and energy-efficient vehicles. The Transportation Equity Act for the 21st Century (TEA-21), which was enacted June 9, 1998, expanded these measures by providing incentives for the purchase oflow-emission and energy-efficient vehicles before the Safe, Accountable, Flexible, and Efficient Transportation Equity Act (SAFETEA-LU) broadened the set of HOV eligible vehicles.

A number of papers relevant to this study are part of the rich empirical literature on vehicle choice. Several recent papers [16-18] have proposed extending classical discrete choice models by endogenizing household residential neighborhood characteristics, as well as vehicle utilization.

In the first paper to control for residential self-selection in a transportation cross-sectional study, Bhat and Guo [16] estimated a mixed-logit model on San Francisco Bay Area data to understand the impact of the built environment on travel behavior. They assumed that Traffic Analysis Zones (TAZ) capture the characteristics of residential neighborhoods and that households select their vehicles based on make, model and fuel-efficiency. However, vehicle utilization was exogenous in their analyses, insulating vehicle use from policies. They found that density and other built environment attributes affect residential location, as well as vehicle ownership. In addition, both household and built environment characteristics influence household vehicle ownership decisions. Income is the most important factor in residential sorting as low-income households may choose (or are constrained to) high-density neighborhoods that make low-cost commuting possible, impacting the number of cars they own. Finally, they reported that a well-specified model with extensive socio-demographic and neighborhood characteristics can adequately account for residential and vehicle choice endogeneities.

Fang [17] examined household preferences for fuel-efficient vehicles. She estimated her model on the California sub-sample of the 2001 National Household Travel Survey (NHTS) without additional land use or location data, which prevented her from considering residential location. She captured residential characteristics through residential density and regional indicators such as rail availability, location in a Metropolitan Statistical Area (MSA), and a rural/urban indicator. To account for residential self-selection and vehicle choice endogeneity, she developed a Bayesian Multivariate Ordered Probit and Tobit model and a multiple discrete-continuous extreme value model derived from utility maximization. Her results suggest that increasing residential density within feasible ranges will have a very small impact on household vehicle holdings and vehicle fuel usage.

Salon [18] estimated a multinomial logit model to jointly explain residential selection, vehicle ownership, and commuting mode on New York City data, with a focus on household modal-choice. Due to computational limitations, she treated work location as an exogenous variable. Like Fang [17] and Bhat and Guo [16], she found that population density has a substantial impact on vehicle ownership. In her study, living farther from midtown Manhattan increases the utility of car ownership while living in a higher density area has the opposite effect.

These studies, however, did not consider the effectiveness of specific energy and environmental policies. Furthermore, as noted by Choo and Mokhtarian [19], vehicle choice studies should consider attitudes, environmental beliefs, lifestyle, and/or personality characteristics, if this information is available.

The Role of Environmentalism

Several studies have examined how environmental views (environmentalism) may explain AFV ownership. In this paper, environmentalism broadly refers to the belief that the government has an important role to play in improving environmental quality (see Kahn [20] for an overview or Guber [22] for a comprehensive discussion). In the empirical studies we reviewed, environmentalism was either proxied by membership in an environmental organization or reflected in survey responses about environmental issues and the role of government.

Kahn [20] estimated a negative binomial count regression model for various types of vehicles using a 2005 proprietary vehicle registration dataset for Los Angeles County. He found that, controlling for income, population size, population density and racial mix, a higher share of registered Green Party voters – a proxy for environmentalism – is positively associated with a higher demand for hybrids electric vehicles (HEVs) at the census tract level.

Studies of sales and market share analyses at the state-level [4] and in Virginia counties [5] found similar results to Kahn [20]. While primarily focused on the role of incentives, Gallagher & Muehlegger [4] examined whether the adoption of HEVs correlates with environmental and energy security preferences. They proposed using state-level Sierra Club membership per capita as a proxy for environmentalism and relied on this approach to explain sales of HEVs per capita, without accounting for incentives. Their results suggest that an increase in Sierra Club membership is positively correlated with HEV sales.

Diamond [5] primarily analyzed the impact of HOV incentives on HEV ownership in Virginia. His regression model controls for the share of Green.Party votes (a proxy for environmentalism) in explaining county-level HEV market share. His results show that the number of Green Party votes is positively associated with the market share of HEVs.

Models that rely on aggregate data, however, do not take into account household heterogeneity. Although Kahn [20] explicitly assumed that households tend to Tiebout-sort [1] into "like-minded" communities, it is .not clear that census tracts spatially delineate communities. Moreover, using statistical inferences based on aggregate data to examine the effectiveness of

[1] According to Tiebout, municipalities within a region offer different baskets of government services at a variety of prices (tax rates). Given that households have differing personal values for these services and differing ability to pay these taxes, they will move from one local community to another to maximize their utility.

AFV policies and incentives assumes that households' AFV ownership decision can be deduced from spatially aggregated units where households reside (also known as an ecological fallacy). Furthermore, aggregate data typically do not allow controlling for residential location, which has been shown to affect travel behavior and vehicle ownership decisions [17, 18, 22-26].

In a household-level study, Sangkapichai and Saphores [11] estimated ordered choice models on 2004 stated preference (SP) survey data collected by the Public Policy Institute of California (PPIC). This survey captured public perceptions, policy preferences, and political choices about air-quality and energy issues, which can be defined as environmentalism. They relied on Principal Component Analysis (PCA) to summarize 25 survey questions and obtained a set of factors that measure environmentalism as a predictor for HEV ownership. They found that, along with potential long commutes and the possibility of driving solo in HOV lanes, awareness and beliefs about the environment are correlated with the likelihood of AFV ownership in California.

Incentives

Among incentives that can influence a household to purchase a HEV, we can distinguish between financial incentives that offset the purchase price of a vehicle, and operational incentives such as occupancy exemptions for accessing HOV lanes or parking privileges in urban areas. AFV incentives were designed to stimulate consumer demand and create a viable market for AFV manufacturers. This second-best government intervention can be justified on environmental and energy independence grounds. While skeptics may argue that manufacturers may capture an excessive share of these incentives, voters may favor these incentives for environmental reasons. Furthermore, the literature shows that consumers can benefit from incentives that promote higher fuel efficiency. In particular, consumers captured a significant share of tax benefits from the cash-for-clunkers program [8, 9].

Diamond [8] analyzed a state-level panel that covers substantial variations in gasoline prices. Using a fixed-effect model, he found that gasoline prices crowd out incentives and that HOV access has a stronger effect than financial incentives. This finding is consistent with Beresteanu & Li [9] who analyzed 2001 NHTS data and proprietary vehicle sales data.

Gallagher & Muehlegger [4] considered· quarterly national vehicle sales to evaluate the relative efficacy of state sales tax waivers, income tax credits, and non-tax incentives (HOV access) on HEY market penetration. They reported that even though state sales tax waivers tend to be less generous than state income tax credits, the mean sales tax waiver (valued at $1,077 in 2011) is associated with three times the increase in sales of the mean income tax credit. Gallagher & Muehlegger [4] also reported that the HOV access program is positively correlated with HEY sales in Virginia, but they found little evidence that opening HOV lanes to HEYs had a positive impact on HEY sales in other states.

While not specifically focused on HEVs, Greene *et al.* [10] analyzed automobile sales data to quantify the impact on vehicle fuel economy of feebates, a market-based measure in which vehicles with fuel consumption rates above a "pivot point" are charged fees while vehicles below receive rebates. They concluded that the vast majority of fuel economy increase is due to the adoption of fuel economy technologies, rather than shifts in sales.

More recently, Vergis and Chen [21] analyzed new vehicle registrations from calendar year 2013 across U.S. states to understand which factors are significantly correlated to variations in battery electric vehicle (BEV) and plug-in hybrid electric vehicle (PHEV) market shares, and how those factors compare with those identified as influential in HEY markets. While several of the factors found important in earlier HEV studies also matter for 2013 PHEV or BEV market shares, they found that different sets of variables are significantly correlated with PHEV and BEV market shares, which suggests that these markets are distinct.

DATA

To understand how households respond to vehicle choice incentives (such as HOV lane access and parking privileges), we combined geocoded data from the 2012 CHTS with incentive data (access to HOV lanes, parking privileges, and proximity to AFV refueling stations) and a measure of environmentalism based on voting data. Summary statistics for our variables are presented in Table 1.

CHTS Data

The 2012 CHTS collected detailed socio-economic information, travel information on a pre-determined survey day, and vehicle information from 42,431 randomly selected households from all 58 California counties. The 2012 CHTS was administered over a full year, starting in January 2012. The geocoded raw data include the latitude and longitude of each household residential location and travel destinations. After removing households without vehicles, excluding households who were asked to report their travel during a weekend day, and discarding records with missing information, our final sample has 17,295 households with information about households, their vehicles, and how much they drive for work or school on a weekday.

Based on our literature review [16-18, 23-26], we considered for our models a wide range of socio-demographic variables characterizing households (income, household structure, size, number of children under 16, number of young adults 16 to 24, and number of workers) and household heads (age, ethnicity, and educational attainment). Household income enters our model as two variables: we used the midpoint of each CHTS income interval and a binary variable for households with an annual income of $250,000 or more (the top income bracket is open-ended), which make up 4.2% of our sample. Household size, the number of children under 16, the number of young adults between 16 and 24, and the number of workers are count variables. Age enters our model as categorical variables to capture generational effects on residential choice, travel behavior, and AFV ownership. We used the following four groups: 1) 18 to 31 (Millennium or Generation Y, born between 1981 and 1994, since we only consider respondents 18 and older); 2) 32 to 47 (Generation X, born between 1965 and 1980); 3) 48 to 67 (Baby boomers, our baseline, born between 1946 and 1964); and 4) 68 or more (the Silent generation, born between 1927 and 1945, and the GI generation, born between 1901 and 1926; they were lumped together because our sample only included a few members of the GI generation). We followed a similar strategy for educational attainment with people who have less than a high school education as our baseline. For ethnicity, Caucasian is our baseline category (see Table 1 for details).

Second, we considered detailed vehicle information on make, model-year, and fuel type to determine eligibility for Clean Air Vehicle (CAV) decals that allow driving a vehicle with a single occupant in HOV lanes (see http://dmv.ca.gov/portal/dmv/detail/vr/decal for details). As mentioned above, in this study, only vehicles that are eligible for HOV access decals are classified as AFVs. We then relied on this information to construct our dependent variable, which equals 1 if a household owns at least one AFV and zero otherwise. Out of 17,295 households, 8.42% own at least one AFV. Overall, households in our sample own 1,842 AFVs: 86.92% (1,601) are HEVs, 3.09% (57) are plug-in hybrid electric vehicles (PHEVs), 7.44%

(137) are battery electric vehicles (BEVs), and 2.55% (47) of AFVs in our sample run on compressed natural gas (CNG).

Third, we accounted for vehicle utilization because previous studies have reported that vehicle use impacts vehicle choice decisions [16-18, 22-25]. We focused on non-discretionary travel (such as travel to work or school) for two reasons. First, it allows us to ignore spatial and temporal variations in gas prices (remember that the 2012 CHTS was administered over one year and that gas prices in California can vary substantially at a given point in time; e.g., see https://www.gasbuddy.com /GasPrices/Califomia) which would impact the number of discretionary miles driven but not non-discretionary miles since they are not responsive to short-term variations in gas prices [23]. Second, households who drive more for non-discretionary purposes are more likely to consider AFVs because these vehicles have lower operating costs. To calculate non-discretionary miles driven from the 2012 CHTS one-day travel diaries, we summed the distance of work and school trips on weekdays for each household, taking care not to double count when more than one household member traveled in the same vehicle. Visited places were then geocoded and trip distances were computed using the PostGIS 2.0's ST_Length function.

Incentives: HOV Network and Preferred Parking/Alternative Fuel Stations

Our model can only help us understand the impact of incentives that were not uniformly available to all CHTS respondents, so we disregarded federal and statewide incentives. The incentives we considered are HOV access with no vehicle occupancy requirement and parking privileges.

Households who could drive on freeways with HOV lanes to reach desired locations would benefit from an HOV exemption. We proxied this benefit by calculating the proximity of each household residence in our sample to the nearest freeway with HOV lanes using Geographical Information System (GIS) software. The location of HOV lanes was obtained from the California Department of Transportation's GIS database (see http://www.dot.ca.gov/hq/tsip/gis/datalibrary/).

Another incentive is proximity from home or work to a parking facility that gives discounts to AFV drivers or that allocates parking spaces for recharging electric vehicles or PHEVs. The U.S. Department of Energy Alternative Fuels Data Center (AFDC) provides detailed geospatial information about alternative refueling stations (http://www.afdc.energy.gov/locator/stations/). We used the location information provided by the CHTS to calculate the shortest distance between these facilities and work location of households in our sample.

We also explored year 2013 data that the Governor's Office of Planning and Research (OPR) obtained by surveying the planning department of every city and county in California to track how local governments are promoting the State's goal of having 1.5 million zero-emission vehicles in California by 2025 – a target set by Governor Brown's March 2012 Executive Order. Unfortunately, only 267 of California's 540 cities and counties (49.4%) completed that survey, which cut our sample size in half. On this reduced sample, our robustness checks showed that the binary variable indicating whether or not a jurisdiction had updated zoning and parking policies to accommodate electric vehicle charging infrastructure in public facilities is not statistically significant, so we did not include this variable in our final model.

Table 1. Summar statistics (N = 16,367 households)

Variable	Mean	Standard deviation	Min	Max
Endogenous Variables				
Count of Household AFVs	0.092	0.312	0	3
Work and School vehicle miles traveled	3.801	8.617	0	76.546
Residential density (10,000 persons /sq. mi)	0.699	0.738	2.0E-05a	11.363
Incentives & Environmentalism				
Environmentalism	0.518	0.154	0	1
Distance to HOV lane (miles)	32.431	54.202	0	327.542
Distance to AFV parking (miles)	5.077	17.623	0	190.405
Household (HH) Characteristics				
Midpoint of annual HH income (in $1,000)	98.631	62.069	5	250
HH annual income is more than $250,0000	0.042	0.201	0	1
Household size	2.919	1.386	1	8
Number of children under 16	0.596	0.983	0	7
Number of persons between 16 and 24	0.304	0.620	0	5
Number of workers	1.635	0.705	1	6
Education: High School degree	0.129	0.335	0	1
Education: some college	0.285	0.451	0	1
Education: Bachelor's degree	0.291	0.454	0	1
Graduate or professional degree	0.239	0.426	0	1
Age: 18 to 31	0.066	0.249	0	1
Age: 32 to 47	0.281	0.450	0	1
Age: 67 and up	0.075	0.263	0	1
Hispanic	0.182	0.386	0	1
African American	0.027	0.161	0	1
Asian	0.064	0.245	0	1
Native American	0.038	0.192	0	1
Other ethnicity	0.004	0.060	0	1

a Extremely low density neighborhoods are found in the Californian High Deserts

Environmentalism

Following Sangkapichai & Saphores [11], we hypothesized that AFV ownership may also depend on a household's willingness to voluntarily reduce the external costs of their mobility, and more generally on a household's environmental views.

Table 2. California Environmental Ballot Propositions, 2010 - 2014

Proposition (Year-number) and brief Description [a]	Average (Standard deviation)	Normalized factor loadings [b]
2010 – 21. Vehicle License Fee for Parks. Would have increased vehicle license fee by $18 a year to increase funding for State Parks. Endorsed position : Support	44.3% (13.82)	0.89
2010 – 23. Suspension of AB 32 (2010), the "Global Warming Act of 2006". Would have suspended implementation of comprehensive greenhouse gas reduction programs, including renewable energy and cleaner fuel requirements. Endorsed position: Opposition	62.4% (13.55)	0.92
2014 – 01. Water Bond (AB 1471) Authorizes obligation bonds for state water projects, including ecosystem protection and restoration. Endorsed position: Support	65.06% (11.1)	0.57

Notes: a. Endorsed position describes the position of prominent pro-environment organizations, such as the Sierra Club, the Audubon Society, the Nature Conservancy, the Natural Resources Defense Council, the Environmental Defense Fund and the National Wildlife Federation.
b. Normalized factor loadings are results from the Principal Component Analysis. The factor score for environmentalism is the sum of the percentage of endorsed votes, weighted by the normalized factor loadings. This weighted sum is then normalized to be between 0 and 1. A higher value of the factor indicates higher willingness to spend on environmental goods and support for greenhouse gas reduction programs. Cronbach 's Alpha is 0.84, with a KMO statistics of0.617 and a highly significant Bartlett's test ($p<0.0001$).

Since household-level information about environmental beliefs was not collected by the CRTS, we followed Kahn's [20] strategy. We assumed that households tend to self-select into "like-minded" communities as argued by Tiebout [20, 27], and used precinct-level voting data as a proxy for households' environmental views. More specifically, we went through the California Ballot Propositions on environmental issues available from the Berkeley Law School's Statewide Database (http://statewidedatabase.org), which stores precinct-level voting data, and selected the most relevant propositions on the ballot slightly before or after the 2012 CRTS was administered. Like Kahn & Matsusaka [27], we used the share of votes in favor of positions endorsed by prominent pro-environment organizations, such as the Sierra Club, the Audubon Society, the Nature Conservancy, the Natural Resources Defense Council, the Environmental Defense Fund, and the National Wildlife Federation. Table 2 provides a brief summary of the three propositions we selected and how they fared at the ballot box. The second column reports the average and standard deviation (in parentheses) of the proportion of endorsed votes. The last column reports normalized factor loadings (see next section).

MODELING FRAMEWORK

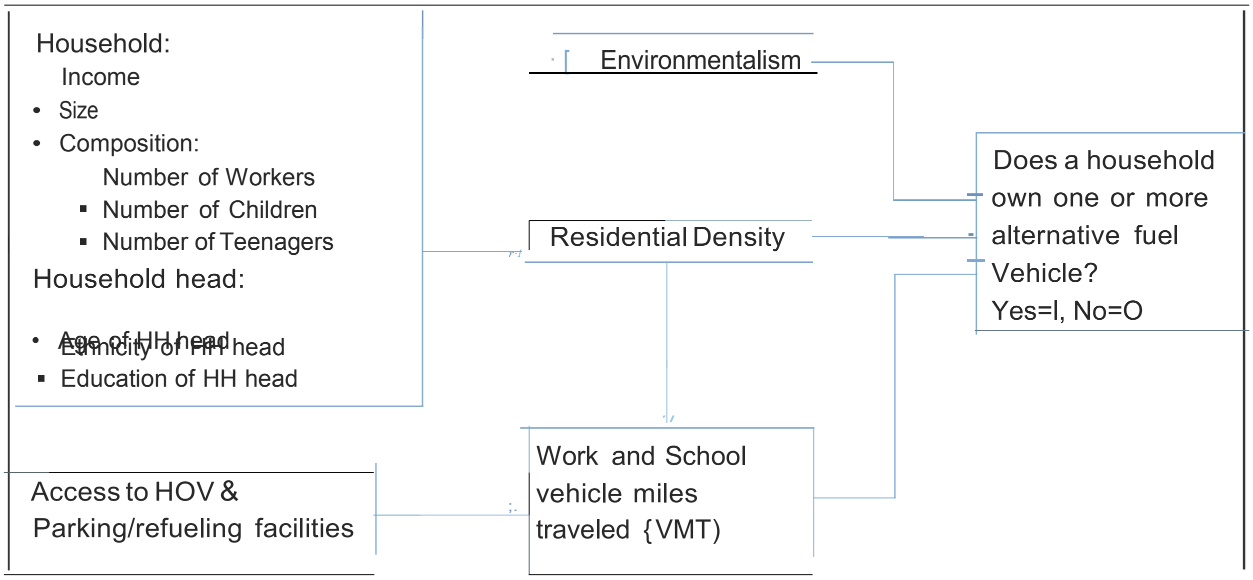
To explain household AFV ownership, we estimated a recursive generalized structural equation model (GSEM) [15] with a logit link function that endogenizes residential self-selection and driving for work and school purposes. Structural Equation Modeling (SEM) has been applied numerous times in models of vehicle use and ownership to capture the endogenous causal effects between vehicle ownership and use [23-26, 28]. However, SEM can only handle continuous dependent variables so we resorted to GSEM to handle our binomial dependent variable.

Our conceptual model is shown in Figure 1. Causal flows between two variables are represented by an arrow. A variable is endogenous when an arrow is directed towards it and exogenous when arrows only depart from it. All causal paths are directed towards the household holdings of AFV, which reflects the recursivity of our model.

We assumed that households first choose their residential neighborhood (characterized by its density) based on their exogenous socio-demographic characteristics, prior to traveling and selecting their vehicles. Then, the amount of non-discretionary driving for work and school is determined by incentives, household socio-economic characteristics, and residential density. Higher density neighborhoods are more likely to be found near employment centers and better transit access – land use features that may reduce the need for driving [23]. A recursive path model is appropriate here because non-discretionary driving is not sensitive to vehicle fuel economy [23], which is a proxy for the variable cost of driving, a quantity that households may want to minimize when considering the purchase of an AFV. Lastly, we assumed that environmentalism, proxied by environmental voting outcomes, directly influences household vehicle choices (households in neighborhoods with higher concerns for the environment are more likely to own AFVs than conventional vehicles) along with residential density and non-discretionary driving for work and school.

Since our model does not include any latent variable measurement component, it only has a structural component, i.e., a simultaneous equation system. We used principal component analysis (PCA) to measure environmentalism because we only have data for three ballot proposals, and a Confirmatory Factor Analysis (CFA) would require more than three ballot measures to guarantee model over-identification.

Figure 1. Conceptual Model Structure



Principal component analysis.for Environmentalism

We hypothesize the existence of a latent construct we call Environmentalism that captures attitudes and beliefs about the environment. We used Principal component analysis (PCA) to estimate this latent construct that explains the variation in precinct-level voting outcomes for the three environmental propositions shown in Table 2. This led to a single factor – which we labeled Environmentalism – based on eigenvalues . To simplify its interpretation, we normalized this factor to be between 0 and 1, where 1 corresponds to high pro-environmental beliefs.

We assessed the adequacy of our factor using a standard approach. First, we used Bartlett's test of sphericity to check for the appropriate level of inter-correlation between the voting outcomes analyzed. Inter-correlations have to be sufficiently high to limit the number of factors, but not too high to avoid multicollinearity, which we detected using the Kaiser-Meyer-Olkin (KMO) statistic – a measure of sampling adequacy. We also used Cronbach' s alpha to measure the reliability of our factor.

For a PCA model to work well, Bartlett's test should reject the null hypothesis that the correlation matrix is an identity matrix. The KMO statistic (which ranges between 0 and 1, with small values suggesting that the variables do not have enough in common) should be larger than 1.6 to be satisfactory. Finally, Cronbach's alpha (which has a maximum value of 1) should be at least 0.6.

GSEilJ with a logit link

Before specifying a structural model, we estimated a 'reduced form' logit model to assess goodness of fit. We also used variance inflation factors to detect multicollinearity among our explanatory variables (none was found).

Overall, we have a recursive model with causality paths directed at AFV ownership; so our model is guaranteed to be identified [15, 30]. In estimating unknown model parameters, GSEM minimizes the difference between sample covariance and the covariance predicted by the model [30].

RESULTS

We estimated our model using quasi-maximum likelihood, which is the approach used by Stata 14 when the covariance structure is obtained using the Huber-White-Sandwich estimator. This option relaxes the assumption that errors are identically and normally distributed, and requires only the errors to be independently distributed.

In SEM/GSEM, model fit refers to the ability of a model to reproduce the observed variance-covariance matrix [30]. While a number of fit statistics have been developed for SEM, they are not valid for GSEM because those fit statistics assume that endogenous variables are jointly normally distributed, which is clearly not the case for a binary variable. We therefore report only the common fit statistics for our principal component analysis.

Principal component analysis for Environmentalism

Results of the principal component analysis are presented in the last column of Table 2. We obtained a single factor for Environmentalism using the sum of the percentage of endorsed votes (item score) at the precinct level, weighted by the corresponding factor loading shown in the last column. This weighted sum was normalized to be between 0 and 1 to simplify interpretation. A higher value of Environmentalism indicates both a higher willingness to spend on environmental goods, and a higher support for GHG reduction programs.

Table 3. Generalized SEM structural model coefficients

	Direct Effects				Indirect Effects	Total Effects
Column number	Ia -Ib	II	III	IV	V	
Exogenous t I Endogenous	Household Alternative Fuel Vehicle (AFV) ownership		Work & school vehicle miles traveled (VMT)	Residential density	Household AFV ownership	Household AFV ownership
	Coefficient	OR	Coefficient	Coefficient	Coefficient	Coefficient
Work and School VMT	0.009***	1.009***	--	--	--	0.009***
Residential Density	-0.165***	0.848***	-0.265**	--	0.044***	. -0.121***
Environmentalism	1.554***	4.733***	--	--	--	1.554***
Distance to HOV lane	-- .		-0.004**	--	0.000	-0.004**
Distance to AFV parking	--		-0.017***	--	0.000	-0.017***
Household (HH) characteristics						
Midpoint of annual HH income	0.008***	1.008***	0.006***	-0.001***	0.000	0.008***
HH annual income is 2 $250K	-0.325***	0.723***	-0.182	0.047	0.059***	-0.266***
Household size	-0.062	0.939	0.171	-0.036***	-0.011	-0.073
Number of children under 16	0.001	1.001	-0.709***	-0.011	-0.001	0.000
Number of persons 16 to 24	0.049	1.051	-0.353**	0.017	-0.017	0.032
Number of workers	-0.044	0.957	1.267***	-0.005	-0.056	-0.100
Characteristics of household heads						
Education: High School degree	-0.247	0.781	0.086	-0.186***	-0.021	-0.268
Education: some college	0.178	1.194	0.404	-0.183***	0.072	0.249
Education: Bachelor's degree	0.515**	1.674**	0.034	-0.090***	0.018**	0.533**
Graduate or professional degree	0.812***	2.253***	-0.319	-0.060**	-0.259***.	0.553***
Age: 18 to 31 (Gen Y)	-0.396**	0.673**	0.629**	0.227***	-0.249**	-0.646**
Age: 32 to 47 (Gen X)	-0.034	0.967	0.391**	0.136***	-0.013	-0.047
Age: 68 and up (Silent and GI generations)	-0.147	0.863	-0.921***	-0.030	0.136	-0.012

	Direct Effects				Indirect Effects	Total Effects
Column number	Ia	Ib	II	III	IV	V
Exogenous 11 Endogenous	Household Alternative Fuel Vehicle (AFV) ownership		Work & school vehicle miles traveled {VMT)	Residential density	Household AFV ownership	Household AFV ownership
	Coefficient	OR	Coefficient	Coefficient	Coefficient	Coefficient
Hispanic	-0.430***	0.650***	0.521**	0.256***	-0.224***	-0.654***
African American	-0.675***	0.509***	0.384	0.479***	-0.259***	-0.933***
Asian	0.210*	1.234*	0.415	0.365***	0.087*	0.297*
Native American	-0.192	0.826	-0.232	0.021	0.044	-0.147
Other Ethnicity	0.408	1.503	-1.186	0.112	-0.484	-0.076

Notes:
1. *, **, and *** denote p-values ::;O.l, p::;0.05, and p::;0.01respectively.
2. Sample size: N = 16,367
3. Log-likelihood, AIC, and BIC scores are -74,816.6, 149,765.1, and 150,268.9 respectively.

Our factor passed standard fitness tests. Bartlett's test of sphericity yielded a Chi-square statistic of 3,007 (df = 3) which is overwhelming evidence against the null-hypothesis ($p<0.0001$) that the voting outcomes analyzed are not correlated. Our KMO measure of sampling adequacy yielded a value of 0.619, which suggests that the voting outcomes considered have enough in common to warrant a PCA. Finally, Cronbach's alpha is 0.84, which suggests that our factor has good internal consistency.

GSE!i-'1 Results

GSEM decomposes the mediating effect of residential selection on AFV ownership by estimating direct, indirect and total effects of endogenous and exogenous variables. Direct effects refer to how household characteristics directly influence the level of AFV ownership, and indirect effects capture how they influence AFV ownership through other variables. Total effects are the sum of direct and indirect effects. Table 3 presents our results, which include structural model coefficients (direct effects), as well as indirect and total effects. Let us first discuss direct effects for household ownership of AFVs, followed by home and school vehicle miles traveled (VMT), and household residential density.

Direct Effects on AFV OH'nership (Column I o.f Table 3)

One of our main results is that households who drive a lot for non-discretionary purposes, such as commuting to work and school, are slightly more likely to own an AFV (OR = 1.009***)[2]. In contrast, households who reside in higher density neighborhoods are less likely to own AFVs (OR = -0.848***), which is not surprising since suburban households may favor AFVs compared to urban families because of their longer commutes and the lower cost per mile driven of AFVs. As expected,

[2] OR stands for odds ratio. *, **, and *** denote p-values :SO.1, p:S0.05, and p:SO.O1 respectively.

households with a higher level of the environmentalism factor are much more likely to be AFV owners (OR=4.733***).

Exogenous household characteristics also play a role in AFV ownership decision. Notably, as their income increases, households are slightly more likely to own AFVs (OR=l.008***), although the reverse holds for higher income households (households with an annual income over $250,000). These households are less likely to own AFVs (OR=0.723***), perhaps because they are less sensitive to costs, or tend to decide on vehicles for attributes other than fuel efficiency. The relatively restricted offering of AFVs in 2012 may also have played a role here. Interestingly, household structure does not directly impact AFV ownership. However, educational attainment of the head of household is an important predictor of AFV ownership. Compared to households with less than a high school degree, households with a bachelor degree (OR=l.674**) and a graduate degree (OR=2.253***) are more likely to be AFV owners. Lastly, ethnicity also impacts AFV ownership: Hispanic (OR=0.650***) and African American (OR=0.509***) households are substantially less likely to be AFV owners compared to otherwise similar Caucasian households.

Direct Effects for Home to Work and School VMT (Column II of Table 3).

As expected, households who reside in denser areas drive fewer miles for work and school (-0.265**). Households with better access to highways with HOV lanes (-0.004**) and who work in places with access to AFV parking privileges (-0.017***) tend to drive more non-discretionary work and school miles, although this effect is small. These results are not surprising since HOV lanes and parking privileges make driving more attractive compared to alternative modes and incentivize vehicle utilization.

Among socio-economic variables, we first see that household structure plays an important role for non-discretionary travel. Households with more children under 16 (-0.709***) and children aged 16 to 24 (-0.353**) tend to drive fewer non-discretionary miles, but those with more workers drive more (1.267***) for non-discretionary purposes since more workers imply more driving to workplaces. Compared to the baseline age group (household heads aged 48 to 67, baby boomers), younger households are also more likely to drive more (0.629** for the 18 to 31 age group, and 0.391** for the 32 to 47 age group), while households aged 68 and up drive much less to work or school (-0.921**) as they are more likely to be retired.

Direct Eff'ects for Household Residential Density (Column III of Table 3)

Let us now consider the impact of socio-economic variables on household residential location. First, we note that households with higher incomes tend to choose lower density neighborhoods (-0.001***), which is not surprising because higher income neighborhoods tend to have houses with larger lots. Likewise, larger households appear to prefer lower density neighborhoods (-0.036***) because they typically need housing with larger lots. Education matters: compared to households where the household head did not finish high school, more educated households tend to reside in lower density neighborhoods, although this effect decreases with the level of education of the household head (-0.186*** for a high school degree, -0.183*** for some college, -0.090*** for a bachelor's degree, and -0.060** for a graduate or professional degree). The age of the head of household seems especially important as younger adults (0.227*** for the 18 to 31 group, and 0.136*** for the 32 to 47 group) prefer neighborhoods with a higher density than the 48 to 67 baseline group. Ethnicity also matters as Hispanics (0.256***), African American (0.479***), and Asians (0.365***) tend to live in higher density areas compared to their Caucasian socio-economic counterparts.

Indirect and total effects

The last two columns of Table 3 report indirect and total effects of endogenous and socio-demographic exogenous variables on AFV ownership, non-discretionary commuting, and residential density selection. Indirect effects refer to how these variables affect AFV ownership decisions through residential self-selection, as well as work and school commuting.

Several variables exhibit interesting indirect effects on AFV ownership. First we see that while the estimated direct effect of residential density on household AFV ownership is negative and significant (-0.165***; see column Ia), the estimated indirect effect through work and school commuting is positive and significant (0.044*** in column IV) but smaller, resulting in a negative net direct effect (-0.121***). Households who reside in high-density urban neighborhood do not commute as much as their suburban counterparts, and those who live in low-density suburban neighborhoods might prefer AFVs because of their lower operating cost. The positive indirect effect points to the existence of a moderating effect of work and school commutes on the residential density effects of AFV preferences. This suggests that while households who live in lower density neighborhoods are more likely to be AFV owners, they do so partly because they need to commute longer for work and school.

Second, the indirect effect of income on AFV ownership for households whose annual income exceeds $250,000 (0.059***) slightly mediates the direct effect (0.325***), leading to a slightly smaller negative impact (-0.266***). This shows that while the likelihood of AFV ownership increases with income, this does not hold for the wealthiest California households.

Third, indirect effects of education for heads of household with a bachelor's degree (0.018**) and graduate or professional degrees (-0.259***) modify direct effects so that total effects are equal for these two levels of educational achievement. Interestingly, everything being equal, education and annual income have opposite effects on AFV ownership, but the total impact of education for heads of household who finished college is larger.

Fourth, indirect effects for age reinforce the likelihood that Gen Y households do not own AFVs (partly because they prefer higher residential densities). Likewise, indirect effects of ethnicity reinforce direct effects: Hispanics and African Americans are less likely to own AFVs (total effects are -0.654*** and -0.933***, respectively), while the opposite holds for Asians (total effect = 0.297*).

CONCLUSIONS

This paper presents a generalized SEM model with a logit link that jointly explains household ownership of AFVs, vehicle use for work and school purposes, and residential density, while accounting for residential self-selection, environmentalism, and the impact of incentives (in the form of HOV access and parking/refueling privileges) on the adoption by households of alternative fuel vehicles. To build our dataset, we combined household level data from the 2012 California Household Travel Survey with geospatial information about residential density, voting outcomes on selected California environmental ballot propositions, information about the HOV network, and the location of parking/refueling stations for alternative vehicles.

Our approach offers several advantages. First, we used household-level data with a rich set of socio-demographic variables to account for household heterogeneity. Second, we used proximity to freeways with HOV lanes and AFV parking/refueling facilities to measure operational (non-monetary) incentives for AFVs, while most previous studies [4, 5, 8] relied on binary variables and used administrative units to measure the impacts of these types of incentives. Third, our GSEM framework endogenizes residential selection and non-discretionary driving.

Our results show that while access to HOV lanes without occupancy requirement and parking privileges are statistically significant, their impact is small. Based on total effects, the odds that a California household purchases an AFV increase by only 0.4% if it is 1 mile closer to a freeway with HOV lanes. These odds increase by 1.7% for each mile it is closer to a parking/refueling facility with AFV privileges.

Furthermore, our results show that environmental views (environmentalism) matter and possibly have a stronger impact on AFV ownership (OR=4.733*** based on total effects) than the incentives we analyzed. Indeed, our results indicate that households who live in neighborhoods favorable to pro-environment agendas are more likely to own AFVs – a finding consistent with a number of previous studies [4, 5, 11, 20].

Our research is not without limitations, which are partly due to data availability. One limitation is our use of votes on ballot propositions to proxy for environmental beliefs (environmentalism). A second limitation is that the 2012 CH!S, like most travel diary surveys, provides only a cross-sectional snapshot of household travel behavior, so we can only test a unidirectional relationship between vehicle utilization and AFV ownership via a recursive GSEM model. It would be of interest to explore if there is a bi-directional link between VMT and AFV ownership. Testing this relationship would require estimating a non-recursive model on panel survey data. This is left for future work.

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