Assessing Effectiveness of Financing Subsidies on Clean Vehicle Adoption by Low- and Moderate-income Consumers

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1. Introduction

Many countries and states offer financial incentives to potential purchasers of plug- in electric vehicles (PEVs). These incentives have typically taken the forms of income tax credits or rebates. Even with generous subsidies which lower the effective purchase price, PEVs may still represent too large an upfront cost, particularly for lower income households with poor credit and limited access to financing.

Recognizing these barriers, the California Air Resources Board recently introduced the Enhanced Fleet Modernization Program (EFMP) Plus-Up pilot program to increase access for low-moderate income households to vehicle retirement and replacement incentives. The exact incentive amount offered to households varies depending on two factors: Household income and type of replacement vehicle (the lowest income households purchasing the cleanest vehicles receive a $9500 incentive). Even more recently, it has started a financing pilot program (known as the Financing Assistance Pilot Project) for low-income households, which cannot be accessed concurrently with the EFMP Plus-Up. This program includes 1) low interest loans (with an 8% annual rate cap), 2) a vehicle "buy down" grant, 3) up to $2,000 for electric vehicle supply equipment (i.e., charging equipment), and 4) other education/assistance on purchasing. There is $18 million of funding from state sources, with $36 million overall including a more focused Bay area pilot program.

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While a sizeable literature exists pertaining to effectiveness of clean vehicle policies, fewer studies examine the efficiency or cost effectiveness of such policies. For example, numerous studies have quantified the impact of various hybrid vehicle and PEV adoption policies on vehicle sales in both domestic and foreign markets (e.g., Diamond, 2009; Gallagher and Muehlegger, 2011; Mian and Sufi, 2012; Li, Linn, and Spiller, 2013; Jin, Searle, and Lutsey, 2014; Sierzchula et al., 2014; Zhang et al., 2014). More recently researchers have attempted to assess efficiency (i.e., maximizing social benefits at the lowest possible cost) and cost-effectiveness (i.e., minimizing cost of achieving policy goal) of such policies (e.g., Graff Zivin, Kotchen, and Mansur, 2014; Holland et al., 2016; Tal and Nicholas, 2016; Li et al., 2017; DeShazo, Sheldon, and Carson, 2017; Sheldon and Dua, 2018).

Due to the political challenges of implementing an efficient, or first-best, policy such as a carbon tax, studying cost-effectiveness of policies can aid in improving policy design. Several recent studies have found that subsidizing PEVs is relatively expensive because a large portion of non-marginal or non-additional buyers would purchase the vehicle in the absence of a subsidy (e.g., Tal and Nicholas, 2016; DeShazo, Sheldon, and Carson, 2017; Li et al., 2017; Sheldon and Dua, 2018). However, these studies have also found that policy costs can be reduced in several ways- for example, by simultaneously subsidizing public charging (Li et al., 2017) or by targeting subsidies according to income, vehicle type, or some other source of observable heterogeneity in demand (DeShazo, Sheldon, and Carson, 2017; Sheldon and Dua, 2018). However, these papers focus on the new vehicle market, which only represents about 30% of the vehicle market. Furthermore, new car buyers tend to be different than used car buyers (e.g., higher income). Lastly, we are unaware of papers that examine financing as clean vehicle adoption policy. In this study, we examine the impact of both subsidies and financing on clean vehicle adoption rates for all vehicles (both new and used). We are also one of the first such studies to focus on moderate- and low-income consumers.

2. Data

In April-May of 2018, we administered an online survey to a representative sample of low- and moderate-income Californian households who stated that they were planning to replace an existing vehicle in the next three years. We obtained 1,604 completed surveys with a screener response rate of 81%. Respondents were at least 18 years of age and resided in households with incomes at or below 300% of the Federal Poverty Line (FPL). The survey company that administered the survey, GfK, assigned weights to render the sample representative of the low-moderate income population in the state.

Following the California Air Resource's Board income classifications for eligibility for many of its low-income transportation assistance programs, we refer to households with incomes under 225% of the FPL as low-income and those with incomes between 225%-300% of the FPL as moderate-income. Sixty-eight percent of the weighted sample (60% of the unweighted sample) is low-income and the remainder moderate-income. Fifty-two percent of the weighted sample (35% of the unweighted sample) are Spanish language speakers.

In the survey, respondents select their two most preferred body types and three most preferred makes for their next vehicle purchase. Respondent also indicate the anticipated amount they plan to spend on a down payment as well as a maximum monthly payment (were the purchase to be financed) and loan term (between two to five years). Respondents are then guided through several sets of vehicle choices in which they are shown all vehicles in the "brown" vehicle universe[1] that are one of the preferred body types, one of the preferred makes, and have a market price less than 130% of the maximum amount the respondent could afford, which is calculated based on their chosen down payment, monthly payment, and loan

[1] The "brown" vehicle universe is populated with the most popular 50 used vehicle models by market share for 2010, 2015, and 2017. Three versions of each model are included (when information was available) for 2010 and 2015 model years- one with 50,000 miles, one with 100,000 miles, and one with 150,000 miles. Two versions of each model are included for 2017 model years- one brand new and one with 50,000 miles. Market prices were obtained from www.Edmunds.com.

term, assuming a ten percent interest rate.[2] Respondents are shown five vehicles per screen, including a thumbnail picture, the make, model, year, mileage, cost per mile, fuel economy, and the market price. They choose the vehicle they would most prefer to purchase out of sets of five. Finally, they are asked to choose which two vehicles they would be most likely to purchase out of the vehicles chosen in the previous sets. We refer to these vehicles as “brown1” and “brown2.”

Next, respondents are asked to pick the vehicle they would most prefer out of a set of five vehicles from the “green” vehicle universe.[3] These are a random selection of vehicles that are both one of the respondent’s most preferred body types and one of his or her most preferred brands and have market prices less than 230% of the maximum amount the respondent could afford. These “green” or “clean” vehicles include hybrids (HEVs), battery electric vehicles (BEVs), and Plug-in Hybrid Electric Vehicles (PHEVs). If any BEVs (PHEVs) meet these criteria, then at least one BEV (PHEV) is included in the selection of five.[4] Respondents are shown a thumbnail picture, the make, model, year, mileage, engine type, cost per mile, fuel economy, electric range (if applicable) and price after incentives are applied. The price after incentives is the market price less approximate current statewide incentives. Respondents choose their two most preferred vehicles out of the set of five. We refer to these as “green1” and “green2.” In the choice experiment that follows, respondents are shown six choice sets with four vehicles in each set. The first vehicle is always brown1 at market price. The other three vehicles are a mix of green1 and green2 with varying prices and with varying financing as well as hypothetical hybrid, PHEV, and BEV versions of brown1 with varying cost per mile, price, and financing.

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[2] If fewer than five vehicles meet these criteria, the choices are populated with a random selection of vehicles that fit within 130% of the respondent’s budget and are of a preferred brand *or* a preferred body.

[3] The “green” vehicle universe is populated with the most popular 30 hybrids by market share for 2010, 2011, 2013, 2016, and 2017. Also included in this vehicle universe are the 2011 Chevrolet Volt and Nissan Leaf, the 10 most popular PEVs in 2013, the 15 most popular PEVs in 2016, and all PEVS in 2017 with price data available. When market price was available, versions of each model are included with mileages of 0, 50,000, 100,000, and 150,000 miles.

[4] If fewer than five vehicles meet the criteria, then five vehicles choices are randomly selected that fit within 230% of the respondent’s budget and are of a preferred brand *or* a preferred body.

Finally, respondents are asked to choose their most preferred vehicle out of the vehicles chosen in the preceding six choice sets. We refer to this vehicle as "overall1."

2.1 Choice Experiment Descriptive Statistics

Table 1 displays summary statistics of vehicles chosen in the choice experiment and Appendix Table A1 shows the demographics of survey respondents, most of whom were clustered in the lowest income bracket of potential CARB program eligibility. The majority of respondents chose used vehicles, with more moderate- than low-income consumers choosing new vehicles. Roughly a third of respondents chose HEVs and 8-10% chose PHEVs or BEVs. Note that these are larger percentages than market share because the choice sets included a disproportionate number of clean vehicles and few internal combustion engine vehicles (i.e., choice sets were not proportionately representative of all real-world vehicle alternatives).

Table 1: Summary Statistics

	Low-Income	Moderate-Income
New Vehicle	14%	22%
Used Vehicle	86%	78%
HEV	31%	31%
PHEV	8%	10%
BEV	8%	8%
Vehicle Price	$11,056	$12,710
MPG	31.3	32.2
Financed	18%	16%
Down Payment	$2,858	$3,682
Monthly Payment	$168	$174

The mean prices of selected vehicles were $11,056 and $12,710 for low- and moderate-income consumers, respectively. More low-income consumers (18%) chose a financed vehicle than did moderate income consumers (16%). Of those who chose a financed vehicle, moderate income consumers' mean down payments were notably larger than low income consumers' ($3,682 versus $2,858) and their average monthly payments were also slightly higher ($174 versus $168).

3. Methodology

First, we estimate a vehicle choice model using the choice experiment data. This model quantifies the relationship between vehicle characteristics, including price and financing, on vehicle purchase probabilities. Then, we use the estimated model to predict consumer choice under a variety of different policy scenarios, including varying levels of upfront purchase subsidies and subsidized financing programs.

3.1 Vehicle Choice Model

Using the choice experiment data, we estimate a vehicle choice model. To increase statistical power and variation in alternatives, we also include the data from the initial choice exercises (choosing amongst vehicles from the “brown” and “green” vehicle universe). Specifically, we estimate a conditional logit model, where utility is a function of upfront cost, monthly cost, vehicle age, vehicle mileage, whether or not the vehicle is financed, and indicators for if the vehicle is of the respondent’s most preferred brand, most preferred body, brown1, green1, a BEV, or a PHEV. We also include indicators for body type (SUV, small car, midsize car, large car, or van/truck) and make (American, European, Asian, or luxury) category. Upfront cost is either the vehicle price (if not financed) or down payment (if financed). Monthly cost equals monthly refuel cost (cost per mile multiplied by monthly miles driven by the respondent) plus a monthly loan payment if financed. Upfront cost, monthly cost, the financing indicator, and the BEV and PHEV indicators are all interacted with income level (above or below 225% of the federal poverty level-i.e., low and moderate income) to allow for heterogeneity in preferences along these dimensions.

Table 2 shows the estimation results. The estimated coefficients of the conditional logit model are all of the expected sign and highly statistically significant (except for the interaction coefficient between PHEV and low income, which is not statistically different from zero, indicating no significant preference of these respondents for PHEVs relative to internal combustion engine vehicles or HEVs). Estimated price coefficients are larger in magnitude for low income respondents, consistent with their being more price-responsive. All else equal (e.g., upfront payment), respondents prefer not to finance their purchase rather than purchase it outright (lower income respondents more so than moderate income respondents). Vans and trucks are the most preferred body type, followed by SUVs, large cars, small cars, and finally midsize cars. Both income groups prefer internal combustion engine vehicles and HEVs to BEVs, the moderate-income group slightly more so than the low-income group. The moderate-income group, however, favors PHEVs.

Table 2: Conditional Logit Estimation Results

Upfront Cost * Under 225% FPL	-0.000116***
	(2.72E-06)
Upfront Cost * Over 225% FPL	-0.000103***
	(3.07E-06)
Monthly Cost * Under 225% FPL	-0.00141***
	(1.61E-04)
Monthly Cost * Over 225% FPL	-0.00210***
	(2.84E-04)
Vehicle Age	-0.132***
	(0.005)
Vehicle Mileage (10,000mi)	-0.0652***
	(0.002)
Financed * Under 225% FPL	-0.511***
	(0.045)
Financed * Over 225% FPL	-0.142**
	(0.070)
Most Preferred Brand	0.151***
	(0.036)
Most Preferred Body	0.134***
	(0.023)
Brown1	1.198***
	(0.024)
Green1	1.538***
	(0.030)
BEV * Under 225% FPL	-0.311***
	(0.043)
BEV * Over 225% FPL	-0.338***
	(0.065)
PHEV * Under 225% FPL	-0.0379
	(0.042)
PHEV * Over 225% FPL	0.242***
	(0.060)
Body: Small Car	-0.449***
	(0.044)
Body: Midsize Car	-0.545***
	(0.041)
Body: Large Car	-0.304***
	(0.075)
Body: Van or Truck	0.396***
	(0.044)
Make: European	0.524***
	(0.063)
Make: Asian	0.222***
	(0.030)
Make: Luxury	0.797***
	(0.084)

Standard errors in parentheses are clustered by respondent.

*** p<0.01, ** p<0.05, * p<0.1

For Body type, the omitted category is SUV. For Make, the omitted category is American.

3.2 Policy Simulations

Using the estimated coefficients from the vehicle choice model described above, we predict vehicle choice and clean vehicle uptake in various scenarios. The set of vehicles respondents choose from in the simulations includes all vehicles from the “brown” and “green” vehicle universes. Note that unlike the choice sets in the choice experiment, the simulated choice set is well representative of real-world vehicle alternatives. Choice model simulations tell us what percent of representative sample of low- and moderate-income households would purchase new and used HEVs, BEVs, and PHEVs out of those planning to replace a vehicle within next 3 years.

For policy simulations, we need to scale our representative sample up to the total number of low- and moderate-income households that buy a vehicle (new or used) in a year. We do so as follows using three datasets. In 2017, according to 2018 Cox Automotive/AAA, 39.9 million used and 17.1 new vehicles were purchased nationally. According to the Census Bureau’s 2013-2017 American Community Survey, California accounted for 12.8 of 117.7 million households (10.88%) in the US. Thus, we assume California accounted for 10.88% of 2017 new and used vehicle sales, or 4.27 million used and 1.86 million new vehicle sales.

According to the Census Bureau, median household size in California is three, and in our survey, mean and median household size is also three. The 2017 Federal Poverty Line ranges by household size. For a three-person household, it was $20,420. Three hundred percent of this income level is $61,260. According to the 2017 American Community Survey, 48.9% of families in California had incomes under $75,000 (the category is $50k-$74,999). Therefore, we assume 45% of California households in 2017 had incomes under $70,000.

Finally, using the relative proportions of households with incomes over and under $70,000 who purchased new and used vehicles from the 2017 Consumer Expenditure Survey (CEX), we estimate that in California in 2017, there were 1.98 million used and 0.59 million new car purchases by households with incomes under $70,000. In our simulations, when we predict the number of vehicles sold under different policies, we assume the total number of used and new vehicle sales to low- and moderate-income consumers are 1.98 and 0.59 million, respectively. Note that this implicitly assumes that the policies change only which vehicles are sold, not the total number of vehicles sold, which is consistent with CARB's emphasis on paired retirement and replacement programs.

4. Results

In California, PEV new market share was just over 5% in 2017 (Lutsey, 2018). Baseline simulations (no policy intervention) predict the share of low- and middle-income consumers purchasing HEVs to be 1.8% and that of PHEVs and BEVs to be around 0.6% for our representative sample of low- and moderate-income households. Predicted shares are less than the actual market share for two reasons- first, they do not account for existing PEV subsidies. Second, higher income households account for a larger share of PEV purchases. In terms of the used market, simulations predict shares of low- and middle-income consumers to be just under a quarter for HEVs, around 4.3% for PHEVs, and 4.1% for BEVs. By comparison, according to Tal and Nicholas (2017), PEVs account for 5-8% of the secondary vehicle market in California.

We simulate two types of policies: subsidized financing and direct upfront subsidies. In the financing simulations, we assess how clean vehicle demand changes as financing becomes available for these vehicles at varying interest rates. We assume that the state's cost of the financing program is the aggregate return to the portfolio of loans, where the return is equal to the interest rate earned minus the opportunity cost of capital, minus the expected default rate. The loan amount equals the vehicle price minus the down payment. We simulate varying interest rates between 8% and 15%. We assume an opportunity cost of capital of 2%. Finally, we assume an expected default rate of 13%.In the direct subsidy simulations, we assess how demand changes as clean vehicle purchase prices decrease by varying subsidy amounts. The state's cost in these cases is simply the sum of subsidy amounts multiplied by the number of clean vehicle purchases.

The majority of loans provided through California's pilot program have interest rates between 8% and 10%. There has been discussion of increasing rates up to 16% to allow for inclusion of lower income and less credit worthy borrowers in the program. Hence our simulations allow for interest rates between 8% and 15%.

The opportunity cost of capital is the return on investment that the state foregoes by lending its capital to borrowers under the financing program. Absent the financing program, the money presumably would not simply sit in an account earning no return (equivalent to assuming a zero cost of capital). Either it would be invested in another project with some return on the capital, or it would be invested in financial markets to earn interest. Given the state's limited risk appetite, for example, it could invest in Federal Treasury bonds or municipal bonds. Given typical automobile loan durations and the likely program lifespan, a ten-year investment period is relevant. Ten-year Treasury bond yields from January through September 2019 ranged from 1.47% to 2.79%. As of early October, 2019, California municipal bonds with 2029 maturity ranged from approximately 1% to 4%. Therefore, we assume an opportunity cost of capital of 2.5%.

According to the Federal Reserve Bank of Kansas City, auto delinquency rates (90+ days delinquent) of subprime borrowers in the U.S. rose from around 12% in 2014 to over 16% in 2017. [5] Data collected by the Urban Institute suggests subprime auto loan delinquency rates to be 13% nationally and 11% in California.[6] Therefore, we assume an expected default rate of 13%, with a sensitivity analysis using expected default rates of 10% and 16%. Note that the lower the credit worthiness of borrowers under the program, the higher the expected default rate will be.

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[5] See https://www.kansascityfed.org/en/publications/research/mb/articles/2018/auto-loan-delinquency-rates-rising.

[6] See https://apps.urban.org/features/debt-interactive-map/.

We assume a total budget of $600 million for each program. Although given historical policy scales a financing program would likely be of a smaller magnitude than a subsidy program, our simulations assume a comparable budget for the sake of comparability. However, we do account for potential differences in overhead administrative costs. Overhead costs for California's EFMP Plus Up subsidy program are estimated to be 15-25%. It is likely that overhead costs for a financing program would be greater given the numerous additional administrative tasks associated with the front end (e.g., credit checks) and ongoing loan servicing. Therefore, in our simulated policies, we assume overhead costs of 25% and 40% for the subsidy and financing programs, respectively, taken directly out of the $600 million budget.

We calculate the policy cost per additional HEV, PHEV, or BEV sold as the *increase* in vehicle sales due to the policy divided by the total policy cost (not including overhead). The cost per additional vehicle is greater than the subsidy amount because the subsidy must be given to all qualifying purchases, regardless of whether or not the purchase is additional (i.e., whether or not the consumer would have purchased it in the absence of the subsidy).

Table 3 shows the results of five policy simulations, A through E. Policy A provides financing at a 15% annual rate to all low- and moderate-income consumers. Policy B provides financing at 8%. For each of these policies, the table shows uptake shares of HEVs, PHEVs, and BEVs for both low- and moderate- income consumers and for both the new and used vehicle markets.

The financing policies substantially increase clean vehicle uptake shares in most cases. When financing is available, many consumers who would have selected a used BEV in the absence of financing instead substitute towards new BEVs. This leads to a large increase in new BEV share at the expense of a very small increase in used BEV share for moderate-income consumers and a *decrease* in used BEV share for low-income consumers. Excluding used BEVs, the cost per additional PEV for Policy A ranges from $209 to $506 and that for Policy B ranges from $3,019 to $6,632. Table 4 summarizes the main metrics of the alternative policies as compared to a baseline of no policy intervention and also shows the total cost of the policies.

Table 3: Alternative Policy Simulations

Policy A **Flat 15% financing**

		New Vehicles				Used Vehicles			
			Percent Choosing				Percent Choosing		
	Income	Interest Rate	w/o Financing	w/Financing	Cost per Addtl	Interest Rate	w/o Financing	w/Financing	Cost per Addtl
HEV	Low	15.0%	1.73%	4.09%	$209	15.0%	24.21%	27.20%	$506
HEV	Moderate	15.0%	2.03%	3.32%	$266	15.0%	24.10%	26.52%	$497
PHEV	Low	15.0%	0.53%	1.63%	$234	15.0%	3.93%	5.08%	$346
PHEV	Moderate	15.0%	0.86%	1.62%	$276	15.0%	5.40%	6.39%	$389
BEV	Low	15.0%	0.57%	1.31%	$220	15.0%	4.19%	3.97%	-$727
BEV	Moderate	15.0%	0.65%	1.05%	$273	15.0%	4.00%	4.03%	$4,089

Policy B **Flat 8% financing**

		New Vehicles				Used Vehicles			
			Percent Choosing				Percent Choosing		
	Income	Interest Rate	w/o Financing	w/Financing	Cost per Addtl	Interest Rate	w/o Financing	w/Financing	Cost per Addtl
HEV	Low	8.0%	1.73%	4.43%	$3,019	8.0%	24.21%	27.81%	$6,632
HEV	Moderate	8.0%	2.03%	3.70%	$3,555	8.0%	24.10%	27.26%	$6,122
PHEV	Low	8.0%	0.53%	1.84%	$3,468	8.0%	3.93%	5.31%	$4,792
PHEV	Moderate	8.0%	0.86%	1.88%	$3,799	8.0%	5.40%	6.71%	$4,992
BEV	Low	8.0%	0.57%	1.42%	$3,189	8.0%	4.19%	4.00%	-$13,632
BEV	Moderate	8.0%	0.65%	1.18%	$3,659	8.0%	4.00%	4.07%	$30,236

Policy C **Financing, equilibrating cost per additional PEV and subject to $600m budget**

		New Vehicles				Used Vehicles			
			Percent Choosing				Percent Choosing		
	Income	Interest Rate	w/o Financing	w/Financing	Cost per Addtl	Interest Rate	w/o Financing	w/Financing	Cost per Addtl
HEV	Low	8.0%	1.73%	4.43%	$3,019	12.0%	24.21%	27.47%	$3,324
HEV	Moderate	8.0%	2.03%	3.70%	$3,555	12.0%	24.10%	26.85%	$3,162
PHEV	Low	8.0%	0.53%	1.84%	$3,468	10.5%	3.93%	5.23%	$3,277
PHEV	Moderate	8.0%	0.86%	1.88%	$3,799	10.5%	5.40%	6.59%	$3,491
BEV	Low	8.0%	0.57%	1.42%	$3,189		4.19%	4.19%	
BEV	Moderate	8.0%	0.65%	1.18%	$3,659		4.00%	4.00%	

Policy D **Subsidy with same adoption levels as Policy C**

		New Vehicles				Used Vehicles			
			Percent Choosing				Percent Choosing		
	Income	Subsidy	w/o Subsidy	w/Subsidy	Cost per Addtl	Subsidy	w/o Subsidy	w/Subsidy	Cost per Addtl
HEV	Low	1540000.0%	1.73%	4.77%	$24,165	260000.0%	24.21%	27.58%	$15,399
HEV	Moderate	1120000.0%	2.03%	3.78%	$24,216	0.0%	24.10%	27.13%	
PHEV	Low	1530000.0%	0.53%	1.44%	$24,194	240000.0%	3.93%	5.32%	$15,372
PHEV	Moderate	1110000.0%	0.86%	1.58%	$24,224	0.0%	5.40%	6.70%	
BEV	Low	1530000.0%	0.57%	1.54%	$24,207	230000.0%	4.19%	4.19%	$15,335
BEV	Moderate	1110000.0%	0.65%	1.21%	$24,231	0.0%	4.00%	4.00%	

Policy E **Subsidy with same total cost ($600m) as Policy C**

		New Vehicles				Used Vehicles			
			Percent Choosing				Percent Choosing		
	Income	Subsidy	w/o Subsidy	w/Subsidy	Cost per Addtl	Subsidy	w/o Subsidy	w/Subsidy	Cost per Addtl
HEV	Low	100000.0%	1.73%	1.86%	$14,097	100000.0%	24.21%	26.06%	$14,082
HEV	Moderate	0.0%	2.03%	2.03%		0.0%	24.10%	24.10%	
PHEV	Low	80000.0%	0.53%	0.56%	$14,059	80000.0%	3.93%	4.16%	$14,060
PHEV	Moderate	0.0%	0.86%	0.86%		0.0%	5.40%	5.40%	
BEV	Low	80000.0%	0.57%	0.60%	$14,089	80000.0%	4.19%	4.44%	$14,106
BEV	Moderate	0.0%	0.65%	0.65%		0.0%	4.00%	4.00%	

Table 4: Policy Simulation Cost Effectiveness

		Total Cost (millions)		Clean Vehicles Adopted			% of Low- and Moderate- Income Consumers Choosing: New			% of Low- and Moderate- Income Consumers Choosing: Used			Mean Cost
		w/o Overhead	w/Overhead	New	Used	Total	HEVs	PHEVs	BEVs	HEVs	PHEVs	BEVs	per Addt'l
Baseline				15,959	645,989	661,948	1.80%	0.61%	0.59%	24.18%	4.28%	4.14%	
Financing	A	$43	$72	36,125	720,485	756,611	3.85%	1.63%	1.23%	26.99%	5.49%	3.99%	$457
	B	$697	$1,162	39,772	739,068	778,839	4.20%	1.85%	1.34%	26.99%	5.49%	3.99%	$5,963
	C	$361	$602	39,772	732,151	771,923	4.20%	1.85%	1.34%	24.18%	4.39%	4.13%	$3,287
Subsidy	D	$1,904	$2,538	39,748	732,318	772,067	4.46%	3.76%	3.64%	27.44%	5.75%	4.14%	$16,534
	E	$457	$609	16,761	677,625	694,386	1.91%	0.65%	0.62%	25.44%	4.56%	4.30%	$14,083

Policy C is a financing program with interest rates that vary across vehicles.[7] The interest rate schedule is designed to minimize the cost per additional clean vehicle (and hence maximize clean vehicle adoption) subject to a budget constraint of $600 million (including 40% overhead). As compared to Policy B, keeping the interest rate low for new clean vehicles, increasing it slightly for used HEVs and PHEVs, and eliminating financing for used BEVs, Policy C can also achieve a large increase in adoption with an average cost per additional clean vehicle of $3,287 versus $5,963 in Policy B. Adjusting interest rates by vehicle type and income thus improves cost effectiveness.

Policies D and E provide upfront subsidies rather than financing for clean vehicle purchases. Policies D and E both underperform Policy C. Policy D achieves similar clean vehicle adoption levels as Policy C but does so at a much higher cost. This leads to poor relative cost effectiveness of the subsidy with an average cost per additional PEV of around $16,500. Policy E minimizes cost per additional PEV subject to the same total budget (including overhead) as Policy C but results in significantly lower adoption levels. Together, these simulations show that a financing program could be a substantially more cost-effective policy for promoting clean vehicle adoption than an upfront subsidy program.

Conclusion

Policy makers in California have developed several programs to promote clean vehicle adoption, particularly by moderate- and lower-income households. In addition to reducing

[7] Table A2 in the Appendix shows a sensitivity analysis of Policy C to alternative expected default rates. Lower (higher) default rates decrease (increase) the cost of the program.

greenhouse gas emissions, the rationale of these policies is twofold. First, lower income households in the State have longer commutes on average and spend a disproportionate amount of their household budget on gasoline. Second, these households are also more likely to reside in areas with worse local air quality. However, uptake of these policies, most of which are rebates, has been limited. Here we find that a financing program that offers lower/subsidized rates to these households, who may otherwise be credit constrained, could be a significantly more cost-effective means of incentivizing clean vehicle purchases.

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Appendix

Table A1: Summary Statistics of Respondents (weighted sample)

Age	42.4
	(16.0)
Household Size	3.5
	(1.8)
Female	46.50%
Household Income Category	
Less than $25,000	31.2%
$25,000 to $49,999	37.3%
$50,000 to $74,999	22.8%
$75,000 or Above	8.7%
Federal Poverty Line	
225% or below FPL	68.3%
Above 225% FPL	31.7%
300% or below FPL	100.0%
Race/Ethnicity	
White, Non-Hispanic	27.1%
Black, Non-Hispanic	9.2%
Asian, Non-Hispanic	5.1%
Other, Non-Hispanic	4.7%
2+ Races, Non-Hispanic	2.2%
Hispanic	51.6%
Education	
Less than high school	15.3%
High school	45.6%
Some college	26.9%
Bachelor's degree or higher	12.2%
California Air Quality District	
Bay Area	10.8%
Sacramento Metro	3.0%
San Diego	9.3%
San Joaquin Valley Unified	11.8%
South Coast	46.3%
Other	18.9%
Geography	
Urban	43.0%
Suburban	42.5%
Rural	14.5%

Standard deviations in parentheses

Table A2: Sensitivity to Expected Default Rate Assumption

Policy C	**Financing, equilibrating cost per additional PEV and subject to $600m budget, 13% expected default rate**								
		New Vehicles				Used Vehicles			
			Percent Choosing				Percent Choosing		
	Income	Interest Rate	w/o Financing	w/Financing	Cost per Addtl	Interest Rate	w/o Financing	w/Financing	Cost per Addtl
HEV	Low	8.0%	1.73%	4.43%	$3,019	12.0%	24.21%	27.47%	$3,324
HEV	Moderate	8.0%	2.03%	3.70%	$3,555	12.0%	24.10%	26.85%	$3,162
PHEV	Low	8.0%	0.53%	1.84%	$3,468	10.5%	3.93%	5.23%	$3,277
PHEV	Moderate	8.0%	0.86%	1.88%	$3,799	10.5%	5.40%	6.59%	$3,491
BEV	Low	8.0%	0.57%	1.42%	$3,189		4.19%	4.19%	
BEV	Moderate	8.0%	0.65%	1.18%	$3,659		4.00%	4.00%	

Policy F	**Financing, equilibrating cost per additional PEV and subject to $600m budget, 10% expected default rate**								
		New Vehicles				Used Vehicles			
			Percent Choosing				Percent Choosing		
	Income	Interest Rate	w/o Financing	w/Financing	Cost per Addtl	Interest Rate	w/o Financing	w/Financing	Cost per Addtl
HEV	Low	8.0%	1.73%	4.43%	$1,811	8.5%	24.21%	27.76%	$3,566
HEV	Moderate	8.0%	2.03%	3.70%	$2,133	8.5%	24.10%	27.21%	$3,302
PHEV	Low	8.0%	0.53%	1.84%	$2,081	8.0%	3.93%	5.31%	$2,875
PHEV	Moderate	8.0%	0.86%	1.88%	$2,279	8.0%	5.40%	6.71%	$2,995
BEV	Low	8.0%	0.57%	1.42%	$1,913		4.19%	4.19%	
BEV	Moderate	8.0%	0.65%	1.18%	$2,195		4.00%	4.00%	

Policy G	**Financing, equilibrating cost per additional PEV and subject to $600m budget, 16% expected default rate**								
		New Vehicles				Used Vehicles			
			Percent Choosing				Percent Choosing		
	Income	Interest Rate	w/o Financing	w/Financing	Cost per Addtl	Interest Rate	w/o Financing	w/Financing	Cost per Addtl
HEV	Low	9.5%	1.73%	4.36%	$3,649	15.0%	24.21%	27.20%	$3,544
HEV	Moderate	11.0%	2.03%	3.53%	$3,717	15.0%	24.10%	26.52%	$3,482
PHEV	Low	10.5%	0.53%	1.77%	$3,714	13.0%	3.93%	5.15%	$3,709
PHEV	Moderate	11.5%	0.86%	1.75%	$3,679	14.0%	5.40%	6.43%	$3,409
BEV	Low	10.0%	0.57%	1.39%	$3,644		4.19%	4.19%	
BEV	Moderate	11.5%	0.65%	1.11%	$3,589		4.00%	4.00%	