

IDENTIFYING THE FACTORS AFFECTING THE SALES OF CLEAN VEHICLES

A Thesis

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Abstract  
of  
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Damien Francis Mimnaugh

The California Legislature has set ambitious goals to reduce its emissions of greenhouse gases (GHGs). One way the state intends to reduce GHG emissions associated with transportation is to accelerate the transition to “clean vehicles” that require less, if any, fossil fuels to operate, and therefore produce fewer GHG emissions. Despite the presence of state programs that incentivize the purchase of these vehicles, sales lag behind state goals.

My research combines a regression analysis and interviews with clean vehicle policy experts to identify the factors that may affect the sales of clean vehicles in California. Using data from the California Clean Vehicle Rebate Program, the Energy Information Administration and the Bureau of Labor Statistics, my regression analysis examines the effect of the following variables on weekly clean vehicle sales from 2010 to 2016: gasoline prices, the unemployment rate, and the number of clean vehicles that qualify for a state rebate. Building on the results of the regression analysis, my interviews with experts explore the areas where California’s efforts to promote clean vehicles have succeeded and where the efforts have not met expectations.

My regression analysis determined that an increase in gasoline prices of 1 percent over half a year causes a 1.6 percent increase in clean vehicles sales and that each 1 percent drop in unemployment rate increases the sales by about 104.5 percent. My regression analysis did not find that an increase in the number of vehicles that qualify for a clean vehicle rebate increases sales. My interviews with experts revealed that the two factors they believed to be increasing

sales were the superior performance and handling of clean vehicles and California's policy of allowing access to carpool lanes for individual drivers in clean vehicles. Each expert identified the lack of consumer awareness and knowledge of clean vehicles as a major barrier to increasing clean vehicle sales.

Based on my findings, I recommend increasing state support for programs that would improve consumers' familiarity and knowledge of clean vehicles, increasing the privileges offered to consumers who purchase clean vehicles, and changing the state's Clean Vehicle Rebate Program to expand access to clean vehicles for low-income consumers.

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## Chapter One

### INTRODUCTION

The California Legislature has set ambitious goals to reduce its emissions of greenhouse gases (GHGs). The transportation sector is the largest source of GHGs in the state, accounting for nearly 40 percent of the GHG emissions in California (California Environmental Protection Agency, 2015). One way advocates propose to reduce GHG emissions associated with the transportation sector is to accelerate the transition to “clean vehicles” – vehicles that require less, if any, fossil fuels to operate, and therefore greatly reduce GHG emissions. Several factors stand in the way of the wider adoption of these vehicles, including their relatively high price, the infrastructure needed to charge or refuel them, and the relatively short driving range of electric vehicles. As a result, the sales of clean vehicles are lagging behind state goals, despite the presence of state programs that incentivize the purchase of these vehicles.

My analysis seeks to identify factors that play a role in consumers’ decisions to purchase clean vehicles in the hopes of informing the policy discussion on this topic and increasing the effectiveness of policies seeking to help California reach its GHG emission targets. This thesis presents a regression analysis of the number of clean vehicles purchased in California, gasoline prices, unemployment data, and the number of models of clean vehicles available for purchase, paired with qualitative interviews with subject matter experts to examine the factors that influence consumers’ decisions to purchase clean vehicles.

#### **Federal and State Efforts to Reduce Greenhouse Gas Emissions**

California’s Assembly Bill 32 (AB 32), passed in 2006, requires the state to reduce its GHG emissions to 1990 levels by 2020. To meet this requirement, the state must cut its emissions by 25 percent compared to projected emissions in 2020. The bill was the result of California

lawmakers and Governor Arnold Schwarzenegger seeking to make the state a global leader in the effort to reduce humanity's impact on the global climate. Underscoring the sense of urgency the state's leaders felt at the time, at the signing ceremony for AB 32 Governor Schwarzenegger said, "We simply must do everything that we can in our power to fight global warming before it is too late" (Office of the Governor of California, 2006).

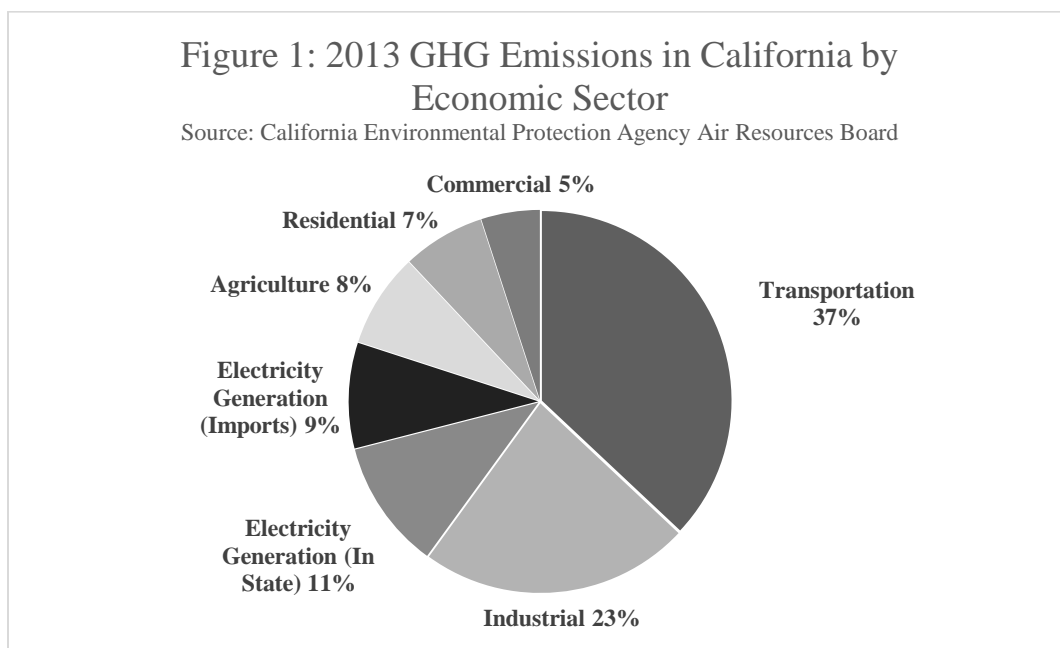
The problem of climate change merits a public policy solution because addressing the issue of climate change by reducing the output of GHGs is a public good. A public good is one for which the cost of excluding someone from gaining utility from the good is prohibitive and for which the cost of an additional marginal user is zero (Libby & Tregarthen, 2009). Because those who make efforts to address climate change cannot exclude others from benefiting from their efforts, and there is no cost for each additional person who benefits from addressing climate change, efforts to address climate change are a public good. There is scant scientific doubt that climate change is in large part caused by human activity and that failure to address it will create significant costs to humanity (Intergovernmental Panel on Climate Change, 2014). Because private firms have few incentives to reduce their GHG emissions, it is appropriate for the government to step in and address this issue.

California and the United States as a whole are doing far more than promoting clean vehicles in their efforts to reduce GHG emissions. At the state level, California has a variety of policies that work toward this goal. The state has linked its cap-and-trade program with the Canadian province of Quebec, and set goals of having 50 percent of its energy come from renewable sources by 2030 doubling energy efficiency in existing buildings by 2030 (State of California, 2016). Steps at the federal level include: establishing carbon pollution standards for existing power plants through the Clean Power Plan, sharply increasing fuel economy standards

for passenger vehicles, and modernizing the nation's electric grid to reduce waste and provide greater access to renewable energy (White House, 2016).

### **Contribution of Passenger Vehicles to California's Greenhouse Gas Emissions**

California is on track to meet its GHG emissions reduction target, and Governor Jerry Brown has issued an executive order requiring the state to cut its GHG emissions to 40 percent below 1990 levels by 2030 (Megerian & Finnegan, California's greenhouse gas emission targets are getting tougher, 2015). Emissions from the transportation sector accounted for 37 percent of the state's emissions in 2013, more than any other sector, as illustrated in Figure 1 (California Environmental Protection Agency, 2015). For the state to reach its GHG emission reduction goals, it is vital to reduce the GHG emissions from the transportation sector.



As broken down by the California Environmental Protection Agency (CalEPA), the transportation sector includes on-road and off-road vehicles, aviation, rail, water-borne vehicles, and a few other small sources. Emissions from military vehicles are not included. CalEPA's 2015 GHG Emission Inventory reports that 71 percent of the state's transportation emissions come

from light-duty vehicles such as cars, motorcycles, and light-duty trucks (California Environmental Protection Agency, 2015). With light-duty vehicles accounting for the majority of the emissions of the economic sector with the heaviest carbon footprint in the state, reducing emissions from light-duty vehicle transportation is a priority for CalEPA.

To achieve its GHG emission reduction targets, California has implemented a wide array of programs. One of these programs is a cap-and-trade program that expanded at the beginning of 2015 to include gasoline and diesel fuel (California Environmental Protection Agency Air Resources Board, 2015). Under the program, the state auctions off allowances, and companies must hold enough allowances to cover their emissions. By slowly increasing the price floor for the allowances and reducing the number of free allowances, the cap-and-trade program intends to place a “price signal” on carbon emissions to encourage investment in cleaner fuels and improved efficiency. The size of that price signal was hotly debated prior to the program’s expansion; state officials and environmentalists argued the impact would be small – only a few cents per gallon – while program opponents claimed it would increase prices by \$0.75 per gallon or more (Glover, 2015). Since its implementation, experts have estimated that including gasoline in the cap-and-trade program increased gasoline prices in California by between \$0.08 and \$0.10 (De Atley, 2015).

As the overall cap on emission falls, the price of releasing GHGs into the atmosphere in California should rise, and should in turn make purchasing gasoline more expensive. Thus, the price signal should get stronger over time, and should encourage more Californians to drive less or purchase clean vehicles. The strength of this price signal is diluted, as consumers incorporate many factors in addition to fuel efficiency into their decision to purchase a vehicle, such as price, practicality, aesthetic appeal, etc. For public officials and economists, one key question remains: how strong must this price signal have to be to encourage a substantial number of consumers to



change their driving habits or their vehicles? In other words, how high do gasoline prices have to climb before consumers will change something about their lifestyle?

### **California's Clean Vehicle Rebate Program**

In addition to sending a price signal in an attempt to change consumer behavior through the cap-and-trade program, California has other programs in place to encourage consumers to adopt clean vehicles. California has a goal of having 1.5 million zero-emission vehicles on its roads by 2025 (Office of Governor Edmund G. Brown Jr., 2012). However, consumers have not been purchasing enough of these vehicles to be on track to meet California's goal. The state had about 160,000 registered zero-emissions vehicles at the end of 2015, but Governor Brown and CalEPA officials acknowledge that more must be done for the state to reach its goal (Megerian, California falling short in push for more clean vehicles, 2015).

One reason policymakers believe consumers have been slow to adopt clean vehicles is their relatively high cost compared to traditional internal combustion engine vehicles. To address this concern, California has created the Clean Vehicle Rebate Program (CVRP). The program launched in October 2012 and provides rebates ranging from \$900 to \$5,000 to consumers and organizations that purchase a qualifying vehicle or vehicles (California Clean Vehicle Rebate Project, 2016).

As defined by the CVRP, a clean vehicle must meet a number of program requirements, and generally fall into one of five categories (California Clean Vehicle Rebate Project, 2016):

1. Zero-emission hydrogen fuel cell vehicles: full-function, freeway capable vehicles powered exclusively by electricity derived from a hydrogen, such as the Honda FCX Clarity. Consumers who purchase these vehicles may be eligible for a standard rebate of \$5,000, and low-income consumers may qualify for a higher rebate.

2. Zero-emission battery electric vehicles: full-function, freeway capable vehicles powered exclusively by electricity from a battery, such as the Nissan LEAF. Consumers who purchase these vehicles may be eligible for a standard rebate of \$2,500, and low-income consumers may qualify for a higher rebate.
3. Plug-in hybrid electric vehicles: vehicles that can be driven using gasoline and/or electricity, such as the Chevrolet Volt. Consumers who purchase these vehicles may be eligible for a standard rebate of \$1,500, and low-income consumers may qualify for a higher rebate.
4. Neighborhood electric vehicles: low-speed battery-powered vehicles that can travel at least 20 miles per hour and at most 25 miles per hour on a paved level surface. Consumers who purchase these vehicles may be eligible for a rebate of \$900.
5. Zero-emission motorcycles: either a two-wheeled battery-powered motorcycle or a fully-enclosed, freeway-capable three-wheeled battery-powered vehicle. Consumers who purchase these vehicles may be eligible for a rebate of \$900.

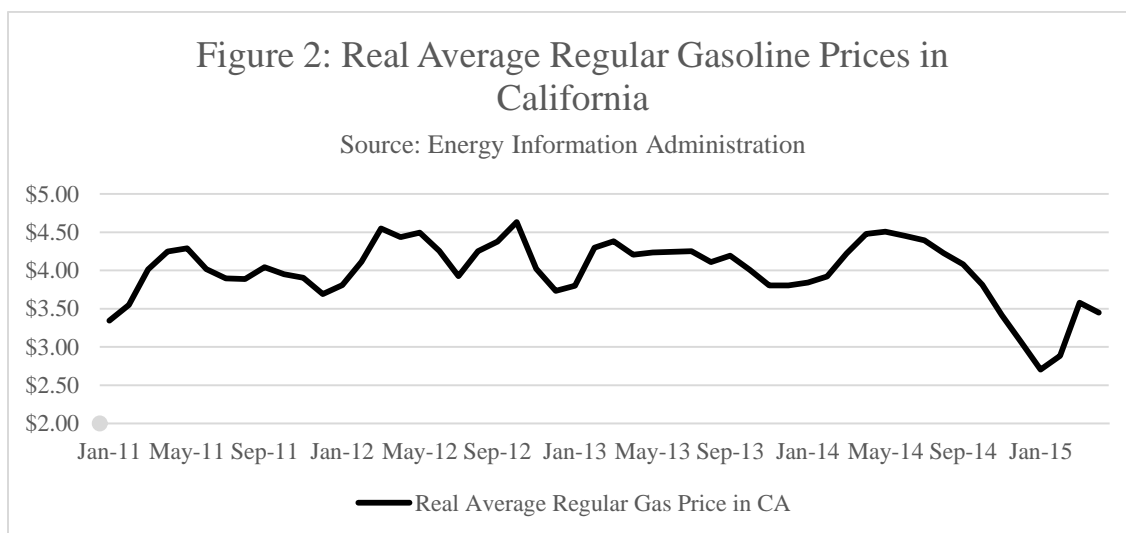
### **Greenhouse Gas Emissions of Average Vehicles Compared to Clean Vehicles**

Clean vehicles greatly reduce the carbon footprint of transportation compared with an average car or truck. The fuel economy of the average vehicle sold in the United States in 2013 was 24.1 miles per gallon (United States Environmental Protection Agency, 2014). In comparison, given the average electricity mix in the United States, the sales-weighted GHG equivalent of driving a zero-emission battery-electric vehicle is 68 miles per gallon. Because utilities in California generate electricity from less carbon-intensive sources than the national average, a zero-emission battery-electric vehicle has GHG equivalent of 87 miles per gallon (Union of Concerned Scientists, 2015). Plug-in hybrid vehicles emit far fewer GHGs as well. A plug-in Chevy Volt using electricity from the California energy grid driving under average

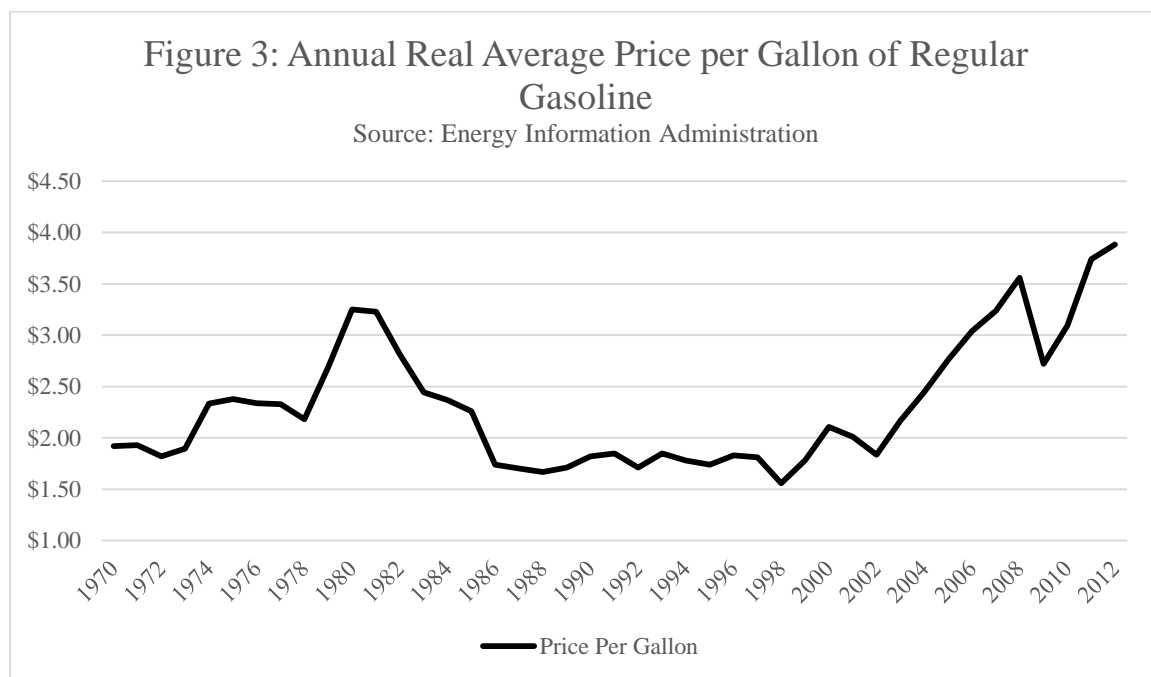
circumstances (64 percent of miles in all-electric mode) would emit the same GHGs as a gasoline-powered car that achieves 54 miles per gallon (Union of Concerned Scientists, 2012).

To assess whether the policy of increasing gasoline prices through a cap-and-trade system will be effective in changing consumers' vehicle purchasing habits, it is necessary to know what factors affect consumers' vehicle purchase decisions. Using data from the CVRP to describe clean vehicle sales in California, my analysis attempts to discern the effect of overall economic conditions, availability of clean vehicles, and gasoline prices on the overall rate of adoption of clean vehicles. Building on these data, my analysis relies on interviews of subject matter experts and policy leaders in California's effort to its GHG emissions in general and its CVRP in particular to explore the areas where California's efforts to promote clean vehicles has succeeded and where the efforts have not met expectations.

The CVRP data are useful for this exercise because gasoline prices have fluctuated considerably throughout the life of the program. The wide variation in gasoline prices throughout the duration of the program may shed light on the relationship between gasoline prices and clean vehicle sales. Figure 2 shows the change in gasoline prices in California between 2011 and 2015.



Gasoline prices have been unsteady for decades, as shown in Figure 3. The fluctuations provide researchers with an opportunity to study the effect of changing gasoline prices on the vehicles consumers choose to purchase.



Despite the protection they offer consumers from the volatility of gasoline prices, the market penetration of clean vehicles has remained low in California. In the section outlined below, this analysis will attempt to identify the factors that affect the sales of clean vehicles in California.

Chapter Two outlines the existing literature examining the effect of gasoline prices and other factors on consumers' vehicle choices and breaks down the literature into several themes.

Chapter Three outlines the theoretical model used in my regression analysis and describes the dependent and explanatory variables in the analysis, the origin of the data that describe these variables this analysis uses, and the subject matter experts interviewed to build on the quantitative research. The broad causal factors identified in the model are the savings clean vehicles offer due

to gasoline prices, the availability of clean vehicles as measured by the number of models available, and the impact of overall economic trends on clean vehicle adoption. The chapter includes a discussion of the strengths and weaknesses of these variables in measuring the causal factors, as well as the rationale for using each specific variable.

Chapter Four discusses the results of the regression analysis, explores which functional form best fits the data, identifies which corrections must be made to the data, and reports the final regression results. The chapter also analyzes the results of the interviews with subject matter experts.

Chapter Five offers a conclusion analyzing the meaning and relevance of the findings of both the quantitative and qualitative analysis, and discusses potential reasons for the areas in which subject matters and the quantitative data agree and disagree. The chapter concludes with the implications of this research on state policy and recommendations for future research.

## Chapter Two

### LITERATURE REVIEW

Identifying the factors that influence consumers to purchase clean vehicles is vital to inform policymakers as they create policy aiming to help California reach its GHG emissions targets. This chapter reviews the existing literature on this topic, identifying the key studies and themes as well as gaps that exist.

There is a large amount of research in this field, addressing issues from the price elasticity of gasoline demand to the corresponding increase in gas mileage of purchased vehicles due to gasoline price increases. This literature review will summarize the results of a sample of the available literature and categorize the literature into several broad themes that are important to understand the framing of my thesis:

- Consumers' knowledge of the fuel economy of their vehicles (i.e., to what degree consumers are aware of their vehicles' fuel efficiency and their overall response to higher gasoline prices)
- The value consumers place on fuel economy compared to other attributes of their vehicles
- The effect of gasoline prices on what type of vehicles consumers purchase
- Whether consumers treat clean vehicles as a "luxury good" in economic terms
- The effect of consumers' desire to publicly exhibit an environmentally conscious signal on the decision of whether to purchase a clean vehicle
- The efficacy of existing federal and state incentive programs to encourage consumers to purchase clean vehicles

I summarize the available literature on each of these themes below.

### **Consumer Knowledge of Fuel Efficiency and Gasoline Prices**

To explore the effect of gasoline prices on consumers' vehicle purchase decisions, one must first assume that consumers have adequate knowledge of their vehicles' fuel efficiency on which to base purchase decisions. The existing literature examining this question has not produced a clear consensus that this assumption is valid. Experiments attempting to determine consumer knowledge of fuel economy have found consumers misunderstand the value of increasing fuel efficiency, assuming the relationship between miles per gallon (MPG) and gasoline consumed is linear when it is in fact curvilinear (Larrick & Soll, 2008). According to this research, consumers generally believe increasing a vehicle's efficiency from 20 to 25 MPG is as valuable as increasing it from 25 to 30 MPG. Both are increases of five MPG, but the increase from 20 to 25 MPG would result in proportionally more gasoline savings over the same distance driven than an increase from 25 to 30 MPG. This lack of understanding causes consumers to underestimate the value of replacing inefficient vehicles and overvalue marginal increases in fuel efficiency in vehicles that are already relatively efficient. Other research has found that consumers generally do not track their fuel costs in a systematic way, leading to errors in their estimates of fuel costs (Turrentine & Kurani, 2006). However, these studies are limited in both their scope and their findings. While consumers may not understand the exact relationship between fuel efficiency and fuel consumption or track fuel costs closely, they do have a rudimentary understanding of how much fuel costs and the benefit of fuel efficiency. This is demonstrated by West (2007) who analyzed the effect of lagged gasoline prices on the probability of a consumer purchasing a specific vehicle type. West matched gasoline price data from the Energy Information Administration (EIA) with the data from the Consumer Expenditure Surveys from between 1988 and 2000 to create a multinomial logit model of the choice to buy a car, van, truck, or SUV. West found that contemporaneous gasoline prices do not affect consumers'

vehicle choices, but that an increase in the previous year's gasoline prices does have an effect. West concluded that an increase of one dollar in the average price of gasoline in a year prior to a purchase causes consumers to be 10 percent less likely to purchase an SUV compared to a car, eight percent less likely to purchase a van compared to a car, and two percent less likely to purchase a truck compared to a car (West, 2007).

Other studies have attempted to quantify the price elasticity of demand for gasoline, which measures the responsiveness of consumers to increases in gasoline prices. Recent studies have concluded consumers are indeed responsive to increases in gasoline prices, but that their response is limited. Studies that examined consumer responses to the "oil shocks" of the 1970s found that consumers, in general, simply ignored increased gasoline prices and made no changes to their driving behavior when prices increased unless they absolutely had to do so for financial reasons (Pitts, Willenborg, & Sherrell, 1981). Newer studies have found more conflicting results. On one hand, models of price elasticity of demand for gasoline show consumers do change behavior and reduce the number of miles driven after increases in the price of gasoline (Wei, 2012). In this study, Wei analyzed total gasoline use and vehicle miles traveled using data from the EIA, finding that a one percent increase in gasoline prices caused a drop in gasoline use by about half a percent. On the other hand, studies comparing the price elasticity of demand for gasoline over time have found that consumers are actually less responsive to gasoline price increases today than in decades past (Hughes, Knittel, & Sperling, 2008). In this study, the authors compared the price and income elasticities of demand in two six-year periods with high gasoline prices using monthly "product supplied" data from the EIA and monthly gasoline prices from the U.S. Bureau of Labor Statistics. The authors estimate price elasticity of demand for gasoline was between -0.21 and -0.34 in 1975-1980, and between -0.034 and -0.077 in 2001-2006.



The results of these studies conclude that while consumers may be aware of the cost of gasoline every time they fill up their tank, they may not necessarily be aware about how different vehicles compare when it comes to fuel efficiency or their overall fuel costs. Additionally, consumers exhibit limited responsiveness to high gasoline prices, only slightly reducing fuel costs in response to price increases.

### **Value of Fuel Efficiency Compared to Other Vehicle Attributes**

Another key to evaluating the effectiveness of using carbon taxes or other policy levers to increase the cost of gasoline is whether consumers value fuel efficiency highly compared to other vehicle attributes. Studies examining this issue have found that consumers place more value on bigger, more powerful vehicles compared to fuel efficiency. One regression analysis found that technological advances could have increased the fuel efficiency of the nation's vehicle fleet by 60 percent from 1980 to 2006, but that the consumer preference for bigger vehicles limited the actual increase to 15 percent (Knittel, 2011). This study compared model-level data from the National Highway Traffic Safety Administration about vehicle models in two years, 1980 and 2006, including data on fuel economy, weight, maximum horsepower, and torque. The method of this study overlooks the fact that many manufacturers simply do not offer vehicles comparable to those available in 1980, so a direct one-to-one comparison is not possible.

Consumers' general preference for larger, more powerful vehicles over fuel efficiency is not static. Research has demonstrated increasing gasoline prices cause consumers to increase the value they place on vehicles' fuel efficiency compared to other attributes. Mahadi and Gallagher in 2009 found that higher gasoline prices are associated with the higher sales of hybrid vehicles, but that the effect is limited to hybrids with the highest fuel economy. Using responses to annual surveys of new vehicle owners, the authors analyzed how highly consumers valued fuel economy. Their study concluded that between 2000 and 2006, rising gasoline prices accounted for 26

percent of high-mileage hybrid sales, but that social preferences accounted for 36 percent of the sales. This study may have missed a key underlying relationship, however. It is possible that only consumers who were most effected by gasoline prices pursued high-mileage hybrids, while the other consumers simply accepted the higher cost of driving instead of switching vehicles.

The results of these studies indicate that consumers broadly do not prefer vehicles with higher fuel economy, compared to other vehicle attributes, but that the preference for hybrid vehicles with the best fuel economy increases as gasoline prices increase.

### **The Effect of Gasoline Prices on What Type of Vehicles Consumers Purchase**

Researchers have conducted a wide variety of studies to assess how gasoline prices affect consumer vehicle purchase decisions, using many different data sets to consider this issue. In general, the research has concluded that increases in gasoline prices do cause consumers to purchase more fuel efficient vehicles, but estimates of the magnitude of this effect vary widely.

One of the most recent and often-cited articles in this field examined the sales numbers for individual vehicle models compared with gasoline prices, and found that a one dollar increase in fuel prices increased the average fuel efficiency of a purchased vehicle by approximately one mile per gallon (Klier & Linn, 2010). This study looked at monthly sales by vehicle model between 1978 and 2007, merged that information with average fuel economy data from the Environmental Protection Agency, and compared them to real gasoline prices using the consumer price index from the Bureau of Economic Analysis. However, this study looked only at new vehicle sales, and did not take into account the effect of gasoline prices on the market for used vehicles.

A study that attempts to incorporate the effect of gasoline price increases on the used vehicle market found similar results. In their 2009 study, Li, Timmins & von Haefen examined vehicle registration data in 20 metropolitan statistical areas, and concluded that a 10 percent

increase in gasoline prices from 2005 levels will create a 0.22 percent increase in fuel economy in the short run, and a 2.04 percent increase in fuel economy in the long run. While this study looked at long-term effects of increasing gasoline prices and incorporated all vehicles in the nation's fleet, it does not address the difference between new and used cars. That difference was examined by Busse, Knittel, & Zettelmeyer, who examined sales of new and used cars at about 20 percent of all dealerships in the United States between 1999 and 2008 and compared that data to gasoline prices and on vehicles' fuel economy. The authors concluded that a change in gasoline prices had a larger effect on the prices of used cars with high fuel economy, but a smaller change for new cars. Specifically, the authors found that a one dollar change in gasoline prices was associated with a \$1,945 increase in the price of a used car in the highest quintile of fuel economy compared to a car in the lowest quintile of fuel economy. For new cars, the difference was only \$354. One potential reason for this effect is that consumers purchasing used cars were the same consumers who were more affected by higher gasoline prices, and that the consumers in the new car market could also more easily afford higher gasoline prices. The study also found that a shift in gasoline prices led to a 21.1 percent increase in market share of vehicles with high fuel efficient vehicles, and a 27.1 percent decrease in market share for vehicles with low fuel economy. Beresteanu & Li confirmed these results using a different method, examining the market share of all vehicles sales that are hybrids over a seven-year period using vehicle registration data for 22 metropolitan statistical areas. They found if gasoline prices stayed flat between 1999 and 2006 rather than increasing, hybrid sales would have been 14 percent lower in 2006.

These studies make it clear that there is indeed a relationship between gasoline prices and the fuel efficiency of the vehicles consumers choose to purchase. The strength of that effect remains undetermined, as well as the how the effect varies for new and used car purchases.

### **Consumer Treatment of Clean Vehicles as a Luxury Good**

Clean vehicles are generally more expensive than their internal-combustion counterparts. (Edelstein, 2015). When it comes to marketing clean vehicles, some car companies such as Audi highlight that their cars are “elegant luxury performance vehicles.” Tesla, on the other hand, promotes their vehicles’ safety and performance (Bronski, 2015). Regardless of how they are marketed, clean environmentally conscious goods in general, and clean vehicles in particular, are considered by consumers to be a “luxury good.” This means that as consumers’ incomes rise by a fixed percentage, the demand for clean vehicles rises by more than that fixed percentage as well. One example of a luxury good is a high-definition TV. An improvement in the economy by a certain percentage is likely to increase sales of high-definition TVs by a higher percentage.

California’s Air Resources Board (CARB) has begun to address this issue in its 2015-2016 Funding Plan, which increases the rebate offered to consumers with incomes that are less than 300 percent of the federal poverty level (FPL). This plan increased the rebate offered to low- and moderate income consumers who purchase clean vehicles from \$2,500 to \$4,000 for battery electric vehicles, and doubled the rebate for plug-in hybrid electric vehicles to \$3,000. For consumers with annual incomes greater than 300 percent of the poverty level up to \$250,000, CARB did not increase the rebate, keeping it at \$2,500 for battery electric vehicles and \$1,500 for plug-in hybrid electric vehicles. For consumers with incomes greater than \$250,000, rebates are not available (California Air Resources Board, 2015).

Previous rules for the rebate program allowed all Californians to have equal access to incentives based on the type of vehicle purchased, regardless of income. The changes to the program, according to a CARB report, target “incentives towards those likely to value the rebate most in deciding to make a ZEV purchase.”

CARB's acknowledgment that consumers need additional incentive to purchase clean vehicles is a tacit admission that the consumers are unlikely to save enough money on gasoline over the life of the vehicle to make up for the higher initial price of clean vehicles. A J.D. Power and Associates survey found that consumers pay a premium of \$10,000 for battery-electric vehicles and a \$16,000 premium for plug-in hybrid electric vehicles. Based on average annual fuel use, the time to recoup those costs are 6.5 years for battery-electric vehicles and 11 years for plug-in hybrid electric vehicles (J.D. Power & Associates, 2012). While consumers have increased the length of time they own a vehicle to all-time highs (71.4 months new vehicles and 49.9 months for used vehicles), the average consumer will not own a clean vehicle long enough to recoup the cost premium (Kelly Blue Book, 2012).

### **Consumers' Desire to Use Their Car Purchase Decision to Express Environmental Awareness**

If consumers generally do not own their vehicles long enough to recoup an initial large investment in a clean vehicle, why do consumers purchase these vehicles? One theory is that "green consumers" – individuals who value products with a smaller impact on the environment – purchase clean vehicles and other environmentally-friendly products to reduce their impact on the environment and broadcast their political and social views.

A precise definition of who is a "green consumer" is difficult to find. Consumers act in different ways based on the context surrounding their actions (Heiskanen, 2005). Some researchers have concluded that these "green consumers" come in a variety of degrees. For most consumers, it is easy to take a few actions that may qualify them as "green" – such as practicing recycling or buying certain products. Fewer consumers are able to apply their environmental lens to the majority of their purchase decisions, and fewer still are able to make purchase decisions

that rarely if ever violate their environmental values. There are many different types of “green consumers” and their consumption decisions reflect this truth (Moisander, 2007).

However difficult it may be to specifically define a “green consumer,” the majority of consumers express concern about the environmental impact of the goods and services they purchase. One 2013 study found that 71 percent of Americans consider the environmental impact of the goods they purchase as they shop, up from up from 66 percent in 2008. The same study found that 45 percent of shoppers actively seek out information about the environmental impact of the goods they buy. Consumers’ lack of trust in the information brands publish about their products makes it difficult for them to compare one company or product with another (Cone Communications, 2013).

Others within the business community have argued that consumers make trade-offs with every purchase decision, weighing the price premium of “green” products and their perceived lower functionality compared to conventional products. One of the key factors in the decisions of these “convenient greens” is the degree of certainty they have that their purchase decision will actually have an effect on the environment (Peattie, 2001). Many consumers may feel more inclined to purchase products or services that are advertised as environmentally friendly, but that number declines if the cost premium increases, if the good or service is more inferior to the conventional alternative, or if the perception of the ultimate benefit to the environment falls.

Despite the difficulty of exactly defining “green consumers,” researchers have shown that there is a distinct correlation between consumers’ social and political behavior and their likelihood of purchasing a clean vehicle. This correlation may explain why consumers purchase clean vehicles that do not compare favorably economically to their internal combustion engine counterparts over the average vehicle’s lifetime. One study concluded that, after primary factors

such as income and gasoline prices, secondary factors predicting the purchase of clean vehicles included environmental, social, and political behaviors. The behaviors included in this study were the proportion of a population that is a member of the Sierra Club and the local federal election results for the Democratic and Green parties (Edwards, 2010). More explicitly, other researchers have concluded consumers are purchasing status and reputation when they publicly buy “green” products (Van den Bergh, Griskevicius, & Tybur, 2010).

### **Effectiveness of Current and Past State and Federal Programs**

Programs supporting the manufacture and sale of clean vehicles are in place at both the state and federal level in the United States. Perhaps the most well-known federal program to encourage consumers to purchase more fuel-efficient vehicles is the Car Allowance Rebate System (CARS, commonly known as 'Cash-For-Clunkers'). Through CARS, the National Highway Transportation Safety Administration (NHTSA) offered Americans vouchers worth either \$3,500 or \$4,500 to trade in old, less fuel-efficient vehicles and purchase new vehicles. The value of the voucher depended on the difference in fuel economy between the two vehicles and the overall fuel economy of the new vehicle. The program initially received \$1 billion in funding, and proved to be so popular that the federal government tripled its size to \$3 billion about a month after it began. The Obama Administration designed the program to serve two goals: provide economic stimulus and improve the fuel efficiency of the nation’s vehicle fleet (Executive Office Of The President Council Of Economic Advisers, 2009).

Economists have hotly debated the effectiveness of the economic stimulus CARS provided and the number of jobs it created. There has been less debate about the effect of CARS on improving the fuel efficiency of the nation’s vehicle fleet, although the size of that effect is small. The program was responsible for approximately 392,000 vehicle sales, compared to the 250 million vehicles in the United States, and the average fuel economy of the vehicles retired

due to the program was 15.7 MPG, compared to average of 24.9 MPG for the new vehicles consumers purchased. A 2013 analysis from the Brookings Institution found that the cost per ton of carbon dioxide reduced due to the program was equal to or even lower than existing environmental policies such as the hybrid vehicle tax credit, the electric vehicle tax subsidy, the excise tax credit for ethanol, and the renewable fuel standard (Gayer & Parker, 2013)

The federal government also offers tax credits to encourage the production and purchase of clean vehicles. The program offers tax credits worth up to \$7,500 for an average plug-in hybrid vehicle that can replace a typical light-duty vehicle. A review by the Congressional Budget Office found that the cost to the government per ton of GHG emissions reduced varies widely depending on the carbon footprint of the energy used to charge the battery. Further, the study found that the credit has little or no impact on the total national gasoline use or nationwide GHGs (Congressional Budget Office, 2012).

At the state level, California has two major policies in place in addition to the CVRP. The state's zero emission vehicle mandate requires car manufacturers that sell vehicles in the state to make some of their vehicles zero-emission. A complex formula based on how many miles a vehicle can drive without polluting allows each manufacturer to meet the standard by manufacturing varying proportions of clean vehicles, such as battery-electric vehicles, plug-in hybrids, natural gas-powered vehicles, or partial zero-emission vehicles powered by gasoline (Center for Climate and Energy Solutions, 2013). The regulation also allows car companies to purchase credits from other manufacturers that have excess credits through a cap-and-trade system. Seven other states have adopted this California regulation (Wittenberg, 2016).

California also allows certain clean vehicles to access the high-occupancy (HOV) lane. The state offers stickers to purchasers of clean vehicles that allow the vehicles to use HOV lanes at all times regardless of the number of passengers. Research and surveys have demonstrated that



offering HOV access is a key factor in many clean vehicle sales. One study conducted on behalf of CARB found that offering access to HOV lanes was a motivating factor in about 40 percent of the sales of clean vehicles in California from 2010 to 2013 (Weikel, 2015). A 2013 survey of recent purchasers of clean vehicles similarly found HOV access to be a strong motivating factor for sales of clean vehicles (Nicholas & Tal, 2014).

The policies in California and at the federal level are having an effect, but neither the state nor the federal government is meeting its goal for zero-emission vehicles. On the one hand, California accounted for 40 percent of nationwide electric vehicle sales as of January 2015 (Ayre, 2015), and the United States accounts for 33 percent of all electric vehicles purchased since 2008 (Cobb, 2016). Despite reaching these milestones, California and the nation are still not on track to meet their targets for sales of zero-emission vehicles. In California, the governor and top policymakers have conceded that the state's goal of 1.5 million zero-emission vehicles is a "very big goal" and that the state is not currently on a path to achieving it (Megerian, 2015). The nation as a whole missed its target for having one million zero-emission vehicles on the road in 2015 by two-thirds (Wittenberg, 2016).

### **Summary**

Researchers have examined the influences that push consumers to purchase clean vehicles from several angles. It is clear that consumers are aware of gasoline prices, as they see them every time they fill their gas tanks. It is less clear, though, that they understand the relationship between fuel economy and the amount of gasoline consumed, or whether they have a solid grasp of how gasoline prices affect their budget. Consumers' understanding of gasoline prices is, by necessity, based on past prices, and they make decisions based on past price behavior instead of the current price. In addition, consumers demonstrate a limited willingness to reduce their gasoline consumption, even as prices increase. The literature also shows consumers

generally value fuel efficiency less than vehicle power or size, but that this effect is weaker during times of higher gasoline prices. Consumers are more apt to purchase vehicles with higher fuel economy due to higher fuel prices, but the strength of that effect is limited, and may vary depending on whether the consumer is purchasing a used or new vehicle. Because clean vehicles are more expensive than other vehicles over their lifespan, consumers who purchase them receive value from the status of being “green.”

Additionally, researchers have struggled to exactly define a “green consumer,” but have demonstrated that consumers place additional value on goods that they perceive to be beneficial to the environment. A lack of reliable information and limits to consumer willingness to pay more for environmentally-friendly goods limits this effect. State and federal programs encouraging the growth of clean vehicle sales have helped increase sales, but overall the number of clean vehicles on the streets lag far behind government targets.

The current research is limited in several ways. Some studies were limited to smaller databases, while others look at only owners of hybrids, instead of all vehicles. Additionally, no studies have examined the effect of new, affordable battery-electric vehicles on this question. Because gasoline prices shift so much, it is difficult to pinpoint at what point an increase in prices triggers a consumer to place more emphasis on fuel economy when purchasing a vehicle. Finally, because of consumers’ preference for larger more powerful vehicles, they may simply adapt to higher fuel costs over time to accommodate their preference.

## Chapter Three

### METHODOLOGY

In this chapter of my thesis, I explain the mixed-methods approach used to understand the factors that affect consumers' decisions to purchase clean vehicles. The first part of my analysis uses a quantitative regression analysis to identify the relationship between the sales of clean vehicles and the average price of gasoline in California over different lengths of time, the state's unemployment rate, and the number of vehicles eligible for a rebate through the CVRP. The second, qualitative part of my analysis expands upon the regression analysis, and it is based on interviews with policy experts. The interviews shed light on the perceptions of experts on the relative contributions of each of the factors included in the regression analysis, as well as identify some potential reasons for the size of the effect of each of the factors. The first section of this chapter explains my methods for conducting the quantitative analysis portion. The second section describes my methods for conducting the in-person interviews that comprise the qualitative analysis.

#### **Quantitative Analysis**

I use a regression analysis to quantify the independent influences (the effect of one influence, holding the other influences constant) that three factors have on the total number of automobile sales in a given week that qualify for rebates through the CVRP. The total number of sales serves as the dependent variable for this analysis. This portion of the thesis answers the question: "What is the strength of the influence on clean vehicle purchases of gasoline prices, the number of available vehicles qualifying for CVRP rebates, and the state's unemployment rate?"

#### *Regression Framework*

The dependent variable that I examine is the raw number of new CVRP-eligible vehicles purchased each week from March 15, 2010, through January 25, 2016. I chose this variable

because it is a direct representation of the consumer desire for new, clean vehicles in any given week within the period under observation. The source of information about the number of CVRP-eligible vehicles is the Center for Sustainable Energy (CSE), which administers the CVRP on behalf of CARB. CSE processed 137,202 rebates in this period.

My model describes the adoption of clean vehicles as a function of three broad factors: the savings offered to consumers resulting from the purchase, macroeconomic trends, and the availability of these vehicles.

Clean Vehicle Adoption Rate =  $f(\text{consumer savings, macroeconomic factors, vehicle availability})$

Below are the rationales for the inclusion of each of these factors and the specific variables used to represent them in this regression.

#### *Consumer Savings*

The prospect of savings on fuel cost is a major factor in the decisions of some consumers to purchase clean vehicles (Klier & Linn, 2010). When gasoline prices are high, consumers stand to save more money than otherwise from driving a clean-vehicle compared to a traditional internal combustion vehicle. Clean vehicles typically cost more than their internal-combustion counterparts, and higher fuel prices increase the savings from operating clean vehicles and decrease the amount of time before consumers “break even” on the purchase of a clean vehicle. Therefore, it is useful to use fuel prices as a proxy to estimate consumer savings.

Consumer Savings =  $f(\text{average statewide price of regular gasoline the week of the vehicle purchase})$

To represent the price of fuel, I will use the proportion of the average price of gasoline over the 4 weeks prior to the purchase of a CVRP-eligible vehicle to the average price over the 26 weeks prior to the purchase of the vehicle. This proportion attempts to capture how relatively high or low current gasoline prices appear to consumers relative to prices in the past half-year.

The use of a time lag in determining the fuel price accounts for the fact that consumers face daily variation in the price of gasoline, but longer-term changes in the price of gasoline serve as a strong indicator to consumers about the potential savings that clean vehicles offer. Because higher fuel prices increase the opportunity for savings for consumers from clean vehicles, I expect higher gasoline prices to increase the sales of clean vehicles and have a positive effect on the dependent variable (Klier & Linn, 2010).

#### *Macroeconomic trends*

Due to the relatively high price of clean vehicles compared to internal combustion vehicles, the condition of the overall economy is likely to be a factor affecting the sales of clean vehicles (Edelstein, 2015). A strong economy will increase the income of consumers and enable more consumers to purchase clean vehicles. There are many metrics to measure the performance of the California economy, such as quarterly gross state product changes, job creation statistics, statewide median income, etc. I chose to use one variable to capture changes in macroeconomic trends: the unemployment rate.

$$\text{Macroeconomic factors} = f(\text{unemployment rate})$$

The source I used for the California unemployment rate was the Bureau of Labor Statistics (BLS), which publishes the seasonally-adjusted rate as a percentage each month. I expect that consumers consider clean vehicles to be a “luxury good,” meaning that as consumers’ incomes rise by a fixed percentage, the demand for clean vehicles rises by more than that fixed percentage as well. Similarly, a decrease in consumers’ income by a fixed percentage, would decrease demand for clean vehicles by more than that fixed percentage.

#### *Availability of Clean Vehicles*

Observers cite the lack of a suitable selection of clean vehicles as a reason why clean vehicle sales remain low (Ready, Set, Charge California!, 2011). Consumers are more likely to be

able to find a vehicle that fit their needs as the variety of clean vehicles increases. To measure the number of clean vehicles on the market, I chose the number of vehicles that qualify for a rebate through the CVRP.

$$\text{Availability of Clean Vehicles} = f(\text{number of CVRP-eligible models})$$

When the CVRP launched, six vehicles qualified for a rebate. The California Air Resources Board increased the number of vehicles that qualify for a rebate as they became available on the California market. As of January 2016, the CVRP program offered rebates for the purchase of 51 different vehicle models. Data about the number of CVRP-eligible vehicles are available from the CSE. Note that business purchases are not eligible for more than two CVRP rebates, so business vehicle fleets are not eligible for the CVRP rebates.

Because a larger number of models of CVRP-eligible vehicles would offer consumers more choices, I expect that an increase in the number of models of CVRP-eligible vehicles will lead to an increase in the sales of CVRP-eligible vehicles.

#### *Summary of Explanatory Variables*

The broad factors expected to affect the Clean Vehicle Adoption Rate are the economic benefits the vehicles offer consumers, the overall health of the economy, and the availability of the vehicles:

$$\text{Clean Vehicle Adoption Rate} = f(\text{consumer savings, macroeconomic factors, vehicle availability})$$

Inserting specific variables that explain each of those broad factors into the model makes it appear as follows:

Clean Vehicle Adoption Rate = total clean vehicle sales in a given week that qualify for rebates through the

$$\begin{aligned} \text{CVRP} = & \beta_0 + \beta_1 (\text{proportion of 4-week average gas before purchase to the 26-week average gas price} \\ & \text{before purchase}) + \beta_2 (\text{unemployment rate in the month of the purchase}) + \beta_3 (\text{number of CVRP-eligible} \\ & \text{models during the week of the purchase}) + \varepsilon \end{aligned}$$

With abbreviated variable terms, the model appears as follows:

Clean Vehicle Adoption Rate =  $\beta_0 + \beta_1$  (recent change in gas price) +  $\beta_2$  (unemployment rate) +  $\beta_3$  (CVRP-eligible models) +  $\varepsilon$

The table below summarizes the specific variables, the broad factors they represent, and the predicted effect of an increase in each variable on the dependent variable.

**Table 1: Explanatory Variables and Their Predicted Effect on the Clean Vehicle Adoption**

**Rate**

<b>Explanatory Variable</b>	<b>Broad Factor Variable Explains</b>	<b>Unit of Observation</b>	<b>Predicted Correlation with Dependent Variable</b>
<b>Recent Change in Gas Price</b>	Consumer Savings	Percentage	<b>Positive</b>
<b>Unemployment Rate in Month of Purchase</b>	Macroeconomic Factors	Percentage	<b>Negative</b>
<b>Number of CVRP-Eligible Models in Year of Purchase</b>	Vehicle Availability	Number of Models	<b>Positive</b>

Table 2 summarizes the source of the data for each variable and descriptive statistics for each variable in the regression analysis. The analysis includes data for 307 weeks from March 15, 2010 through January 25, 2016.

**Table 2: Sources of Data in Explanatory Variables**

<b>Variable Name</b>	<b>Variable Description</b>	<b>Source of Data</b>	<b>Mean</b>	<b>Standard Deviation</b>	<b>Minimum Value</b>	<b>Maximum Value</b>
CVRP Purchases	Number of CVRP-eligible vehicles purchased per week	Center for Sustainable Energy	440.50	367.81	0	1335
Recent Change in Gasoline Price	Proportion of 4-week average gas before purchase to the 26-week average gas price before purchase	California Energy Almanac	99.64	8.30	76.68	122.10

Unemployment Rate	Unemployment Rate in Month of Purchase	U.S. Bureau of Labor Statistics	28.33	13.17	11.00	51.00
Eligible Vehicles	Number of CVRP-Eligible Models in Year of Purchase	Center for Sustainable Energy	9.29	2.15	5.70	12.20

### *Regression Framework*

This analysis seeks to identify which of the explanatory variables has a statistically significant effect on the dependent variable. First, I will identify the preferred functional form that best fits the data. I will start with a linear Ordinary Least Squares (OLS) model, and then proceed to try other functional forms in order to identify the form that has the best fit with the data. Finally, I will check the preferred functional form for multicollinearity, heteroskedasticity and correct the data if necessary. The results of these analyses are in Chapter 4.

### *Data Limitations*

This study includes only a limited number of variables. Other variables discussed in the literature review may also exert an influence on consumers' decisions to purchase clean vehicles. For instance, researchers have identified the desire to use a clean vehicle purchase to demonstrate environmental awareness as a motivating factor behind the sale of clean vehicles. Data from surveys and other tools have demonstrated this trend, but these data are not suitable for use in this regression analysis because researchers have not published enough survey results in the short time period that this regression analysis covers.

The data that this analysis uses have limitations as well. The dependent variable, the number of CVRP-eligible vehicles purchased per week, does not fully capture the number of clean vehicles sold each week. This is because it is not a requirement for a purchaser of a qualifying vehicle to apply for the rebate, and the data only count the vehicle sales when the new owner applies for the rebate. While the vast majority of purchasers do apply for the rebate, some



do not, and this metric does not capture those purchases. Also, the average price of gasoline is a statewide measure, and does not take into account regional variations in gasoline prices throughout California. On average, some areas of the state have significantly higher gasoline prices than others. Additionally, the BLS data regarding average weekly wage only count salaries and wages for full-time workers. Changes in the income for part-time workers and individuals who earn income through other avenues are left out of this metric. These data are not seasonally adjusted because the BLS does not make that data available on a monthly basis.

### **Qualitative Analysis**

The qualitative portion of this thesis seeks to address some of the questions that the quantitative analysis leaves unanswered.

#### *Interview Participants and Questions*

I conducted and recorded in-person interviews with experts in the following fields concerning clean vehicles: researchers, policymakers, regulators, clean vehicle program managers, and clean energy consultants. I conducted the interviews either in-person or over the telephone. I selected the interview subjects based upon their history of conducting research in this field, developing or advocating for policy in this field, or involvement in administering a clean vehicle program.

I designed my interview questions to gather the experts' perspective on the role they believe the variables in this study play in encouraging consumers to purchase clean vehicles, as well as to identify other factors that this analysis did not consider. I also asked about any changes, if any, experts believe should be made to the CVRP in order to help California meet its zero-emission vehicle goal, and other actions California should consider taking in order to promote the transition to clean vehicles. Finally, I asked experts about how they believe the introduction of newer, less expensive clean vehicles may have on consumers to purchase more clean vehicles,

and what effect the introduction of these vehicles may have on the CVRP. I carefully designed my questions to minimize response bias and to solicit the most relevant information to accompany my regression findings. A complete list of all interview questions and the script that guided my field research can be found in Appendices A and B.

#### *Data Collection*

I invited participants to take part in the interview through an initial email followed by a follow-up email and telephone call. I did not offer any incentive to participate. Prior to the interview, I emailed a consent form to provide more information about my research (see attached Appendix B), which I collected prior to the start of the interview. My research design and questions received approval thorough the Human Subjects Review in the Department of Public Policy and Administration at California State University, Sacramento. The interviews lasted between 30 and 60 minutes, and I recorded them to allow me to speak more conversationally throughout the interview. To protect the identity of my interview subjects, this thesis does not include any names or titles, and I destroyed all interview recordings and transcripts upon completion of this thesis.

Chapter 4 summarizes the findings of my quantitative and qualitative analyses as identified in this chapter. The first part provides the results of my regression analysis. The second part of the chapter organizes my interview results.

## Chapter 4

### RESULTS

This chapter describes the results of my quantitative and qualitative analyses. First, I discuss the findings from the regression analysis, and then I discuss the findings from the interviews I conducted with subject matter experts.

#### **Results of the Quantitative Analysis**

In this section, I describe the regression analysis I used to identify which of the explanatory variables has a statistically significant effect on the dependent variable. First, I discuss the correlation coefficients of the explanatory variables and any concerns they raise. Next, I describe the process I used to check for heteroskedasticity and autocorrelation. Finally, I review the steps I took to identify the preferred functional form with which to perform the regression analysis and analyze the strengths and weaknesses of the preferred functional form. I conclude with an analysis of the overall regression results and their implications.

#### *Correlation Coefficient*

The first step in the regression analysis was to identify the correlation coefficients between each of the explanatory variables used in the planned regression. The correlation coefficient is a number between negative one and positive one that describes the degree to which two variables are correlated. A coefficient close to one indicates a strong positive linear relationship between two variables, meaning that as one variable increases over time, the other variable increases by a steady amount. A coefficient close to negative one indicates a strong negative linear relationship between two variables, meaning that as one variable increases over time, the other variable decreases over time by a consistent amount. A coefficient close to zero indicates a very weak linear relationship between the two variables, which means a change in one variable, has almost no correlation to a change in the other variable.

I provide the pairwise correlation coefficients below in Table 3. I note the level of statistical significance using asterisks: one asterisk indicates the correlation value is significant at the 90 percent confidence level or higher; two asterisks indicates the correlational value is significant at the 95 percent confidence level or higher; and three asterisks mean the correlation is significant at the 99 percent confidence level or higher.

**Table 3: Pairwise Correlation Coefficients**

	Proportion of 4-Week Average Gas Before Purchase Price to the 26-Week Average Gas Price Before Purchase	Number of CVRP-Eligible Models in Year of Purchase	Unemployment Rate
Proportion of 4-Week Average Gas Before Purchase Price to the 26-Week Average Gas Price Before Purchase	1		
Number of CVRP-Eligible Models in Year of Purchase	-0.261***	1	
Unemployment Rate	0.286***	-0.984 ***	1

**\*indicates statistical significance at the 90 percent level**

**\*\*indicates statistical significance at the 95 percent level**

**\*\*\*indicates statistical significance at the 99 percent level**

The correlation coefficients help determine the presence of multicollinearity, which can cause errors in the regression analysis determining the strength of the influence of these variables on the dependent variable. In general, a correlational value that is statistically significant and either above 0.8 or below -0.8 may indicate multicollinearity (Gujarati, 2011).

The results show a large amount of statistically significant correlation between the explanatory variables. The correlation coefficients between the number of CVRP-eligible vehicles and the unemployment rate is both statistically significant at the 99 percent confidence level and have an absolute value greater than 0.8. This raises concerns that multicollinearity may be having an effect on a model that utilizes all three variables that describe the economy. Multicollinearity increases the reported values of the variance of the coefficients, making them

less likely to appear to be statistically significant. The high correlation coefficient between the number of CVRP-eligible vehicles and the unemployment term is concerning, and may offer an explanation as to why I may find one or both of these explanatory variables not statistically significant. If both are statistically significant, then multicollinearity is not a concern.

An additional method I used to identify the presence of multicollinearity is finding variance inflation factor (VIF) for each coefficient in each form of the regression. The VIF is an index that measures how much collinearity increases the variance of each estimated regression coefficient. For each variable, the VIF shows how much larger the standard error is compared to the scenario in which the variable is not correlated with any other explanatory variables in the model. A VIF of less than 1 indicates no correlation; a VIF between 1 and 5 indicates minor correlation; and a VIF greater than 5 indicates high correlation. I report the values of the VIF for each of the variables in the regression results tables below. My

#### *Checking for Heteroskedasticity and Autocorrelation*

Another concern when running a regression analysis is the effect that heteroskedasticity and autocorrelation may have on the data. Heteroskedasticity occurs when there is a pattern in the difference between the predicted value of the dependent variable and the actual value across the range of values. For instance, a chart showing the weight of humans as they age would have heteroskedastic error terms. The differences between the weights for infants are small, but as people age, their weights begin to vary much more. A model that tries to predict these weights would suffer from heteroskedasticity, because the errors for young individuals would be much smaller than the variables for older individuals. The presence of heteroskedasticity can make the ordinary least squares regression method unable to produce a result with the smallest variance. Heteroskedasticity in data can bias the standard error of the coefficients in a regression, making it more difficult to determine which variables are significant. Failing to correct for

heteroskedasticity can make confidence intervals and hypothesis tests based on the F and t distributions less reliable.

I used the Breusch-Pagan/Cook-Weisberg test to determine whether heteroskedasticity is present in the ordinary least squares (OLS) regression model. The p-value of the resulting chi-squared statistic is 0, which indicates with greater than 99.9 percent confidence that the heteroskedasticity exists in the OLS model. Next, I performed Szroeter's test for homoskedasticity to identify which of the variables has a high likelihood of causing heteroskedasticity. The results show that all of my variables except one are likely to suffer from heteroskedasticity. The variable that does not suffer from heteroskedasticity is the proportion of the 4-week gasoline price average to the 26-week gasoline price average. In the Szroeter's test, the null hypothesis is that the variable is not heteroskedastic, and the alternative hypothesis is that the variable is heteroskedastic. The p-value indicates the probability of obtaining the resulting chi-squared value for each variable if the variable is in fact not heteroskedastic. I show the results below in Table 4.

**Table 4: Results of Szroeter's Test for Homoskedasticity**

	Chi-Squared Value	P-value
Proportion of 4-Week Average Gas Before Purchase Price to the 26-Week Average Gas Price Before Purchase	0.91	0.339
Number of CVRP-Eligible Models in Year of Purchase	74.51	0.000***
Unemployment Rate	73.96	0.000***

**\*indicates statistical significance at the 90 percent level**

**\*\*indicates statistical significance at the 95 percent level**

**\*\*\*indicates statistical significance at the 99 percent level**

The results of these tests two tests demonstrate the data suffer from heteroscedasticity related to number of CVRP-eligible models at the time of purchase and the unemployment rate.

To compensate, I will run the regression analysis with a modification to correct for heteroskedasticity.

Finally, because the data occur over time, there is a high probability that the results will suffer from autocorrelation, which occurs when the time lag between observations in a dataset results in dependence between the observations. For example, data describing the outbreak of an infectious disease would suffer from autocorrelation, because the number of infected individuals in one period of time is dependent on the number of previously infected individuals. Similar to the heteroskedasticity, failing to correct for autocorrelation can make the ordinary least squares method unable to produce an estimate with the smallest variance, causing confidence intervals and hypothesis tests based on the F and t distributions less reliable.

In the case of my data, the fact that each variable is a snapshot of activity in a single week may allow the events of past weeks to affect the data in a given week. To identify if autocorrelation exists within the dataset, I used the Prais-Winsten estimation procedure to run my regression analysis, and examined the resulting Durbin-Watson statistic. Each time, the resulting statistic was below the lower-bound critical value at the one percent level of significance, meaning I could determine with greater than 99 percent confidence that the autocorrelation exists within the data. The Durbin-Watson statistic is included in each of the statistical model summaries in the next section.

#### *Identifying the Preferred Functional Form*

To identify the functional form, I used the Prais-Winsten estimation procedure on different transformations of the data. First, I used the linear-linear model, in which I did not transform the data. Then I used the natural logarithm combined form, in which I transformed the dependent variable using a natural logarithm, and tested each variable to determine if it fit the transformed dependent variable better when transformed using the natural logarithm form or

remaining unaltered in the linear form. Finally, I used the quadratic form, in which the dependent variable remains untransformed, and I add a term with the squared value of each of the explanatory variables. Again, I tested each variable in turn to see if the combination of the linear and quadratic form of each variable fit the model better than the linear term alone. I report the results of each of these analyses in the tables below.



**Table 5: Regression Analysis Results Using Different Functional Forms**

	Linear model		Log-Lin form		Log-Log form		VIF <sup>1</sup>
	<i>Coefficient</i>	<i>Standard Error</i>	<i>Coefficient</i>	<i>Standard Error</i>	<i>Coefficient</i>	<i>Standard Error</i>	
Constant	2622.648***	428.695	13.961***	2.162	13.981**	5.570	
<b>Explanatory Variable</b>							
Proportion of 4-Week Average Gas Before Purchase Price to the 26-Week Average Gas Price Before Purchase	4.340**	2.037	.016*	.009	1.490*	.903	1.12
Number of CVRP-Eligible Models in Year of Purchase	-12.757**	5.278	-.032	.023	-.040	.520	32.11
Unemployment Rate	-242.475***	32.425	-1.045***	.179	-7.205***	1.390	32.60
R-Squared Value	0.693		0.081		0.032		
Number of Significant Results	3		2		2		
Durbin-Watson Statistic	0.833648		0.193807		0.291071		

**\*indicates statistical significance at the 90 percent level**

**\*\*indicates statistical significance at the 95 percent level**

**\*\*\*indicates statistical significance at the 99 percent level**

<sup>1</sup> The VIF values cannot be calculated for the Prais-Winsten estimation procedure. The reported VIF values are calculated using a linear regression using the given variables and subsequently running the VIF generation command to generate values for the VIF for each variable in Stata. I report these VIF values to demonstrate the level of multicollinearity present in the data, but they cannot be used to identify the proportion of the standard error from the Prais-Winsten estimation procedure that is due to the presence of collinearity.

**Table 6: Regression Analysis Results with Only the Gasoline Price Proportion Term in Log Form**

	<i>Coefficient</i>	<i>Standard Error</i>	VIF
Constant	8.429**	4.348	
<b>Explanatory Variable</b>			
Proportion of 4-Week Average Gas Before Purchase Price to the 26-Week Average Gas Price Before Purchase (natural log)	1.554*	0.899	1.12
Number of CVRP-Eligible Models in Year of Purchase	-0.032	0.023	32.11
Unemployment Rate	-1.045***	.179	32.60
R-Squared Value	0.0814		
Number of Significant Results	2		
Durbin-Watson Statistic	0.194		

\*indicates statistical significance at the 90 percent level

\*\*indicates statistical significance at the 95 percent level

\*\*\*indicates statistical significance at the 99 percent level

**Table 7: Regression Analysis Results with Only the Number of CVRP-Eligible Vehicles Term in Log form**

	<i>Coefficient</i>	<i>Standard Error</i>	VIF
Constant	12.741***	2.637	
<b>Explanatory Variable</b>			
Proportion of 4-Week Average Gas Before Purchase Price to the 26-Week Average Gas Price Before Purchase	0.016*	0.009	1.10
Number of CVRP-Eligible Models in Year of Purchase (natural log)	-0.284	0.481	13.84
Unemployment Rate	-0.918***	0.148	14.07
R-Squared Value	0.070		
Number of Significant Results	2		
Durbin-Watson Statistic	0.276		

\*indicates statistical significance at the 90 percent level

\*\*indicates statistical significance at the 95 percent level

\*\*\*indicates statistical significance at the 99 percent level

**Table 8: Regression Analysis Results with Only the Number of Unemployment Rate Term in Log Form**

	<i>Coefficient</i>	<i>Standard Error</i>	VIF
Constant	21.779***	3.516	
<b>Explanatory Variable</b>			
Proportion of 4-Week Average Gas Before Purchase Price to the 26-Week Average Gas Price Before Purchase	0.015*	0.009	1.10
Number of CVRP-Eligible Models in Year of Purchase	-0.019	0.019	24.90
Unemployment Rate (natural log)	-8.139***	1.508	25.24
R-Squared Value	0.032		
Number of Significant Results	2		
Durbin-Watson Statistic	0.188		

**\*indicates statistical significance at the 90 percent level**

**\*\*indicates statistical significance at the 95 percent level**

**\*\*\*indicates statistical significance at the 99 percent level**

**Table 9: Regression Analysis Results Using the Quadratic Form with Only the Gasoline Price Proportion Term Squared**

	<i>Coefficient</i>	<i>Standard Error</i>	VIF
Constant	488.037	1758.023	
<b>Explanatory Variable</b>			
Proportion of 4-Week Average Gas Before Purchase Price to the 26-Week Average Gas Price Before Purchase	47.183	35.523	295.39
Proportion of 4-Week Average Gas Before Purchase Price to the 26-Week Average Gas Price Before Purchase (squared)	-0.215	0.173	291.99
Number of CVRP-Eligible Models in Year of Purchase	-12.088**	5.109	33.63
Unemployment Rate	-242.679***	31.858	33.37
R-Squared Value	0.713		
Number of Significant Results	2		
Durbin-Watson Statistic	0.860		

**\*indicates statistical significance at the 90 percent level**

**\*\*indicates statistical significance at the 95 percent level**

**\*\*\*indicates statistical significance at the 99 percent level**

**Table 10: Regression Analysis Results Using the Quadratic Form with Only the Number of CVRP-Eligible Models Term Squared**

	<i>Coefficient</i>	<i>Standard Error</i>	VIF
Constant	2596.144***	421.040	
<b>Explanatory Variable</b>			
Proportion of 4-Week Average Gas Before Purchase Price to the 26-Week Average Gas Price Before Purchase	4.353**	2.038	1.11
Number of CVRP-Eligible Models in Year of Purchase	-10.621*	6.084	61.08
Number of CVRP-Eligible Models in Year of Purchase (squared)	-0.036	0.088	28.21
Unemployment Rate	-242.429***	32.726	33.02
R-Squared Value	0.695		
Number of Significant Results	2		
Durbin-Watson Statistic	0.839		

**\*indicates statistical significance at the 90 percent level**

**\*\*indicates statistical significance at the 95 percent level**

**\*\*\*indicates statistical significance at the 99 percent level**

**Table 11: Regression Analysis Results Using the Quadratic Form with Only the Unemployment Rate Term Squared**

	<i>Coefficient</i>	<i>Standard Error</i>	VIF
Constant	2508.267***	493.686	
<b>Explanatory Variable</b>			
Proportion of 4-Week Average Gas Before Purchase Price to the 26-Week Average Gas Price Before Purchase	4.345**	2.031	1.11
Number of CVRP-Eligible Models in Year of Purchase	-12.805**	5.292	32.53
Unemployment Rate	-215.478***	69.049	150.63
Unemployment Rate (squared)	-1.489	3.395	121.32
R-Squared Value	0.694		
Number of Significant Results	2		
Durbin-Watson Statistic	0.836		

**\*indicates statistical significance at the 90 percent level**

**\*\*indicates statistical significance at the 95 percent level**

**\*\*\*indicates statistical significance at the 99 percent level**

Of the different functional forms I tested, the log-linear form that best fit the data. In this form, I transformed the dependent variable using a natural logarithm and the remaining explanatory variables remained in linear form. This model resulted in two significant variables in the expected direction: the gasoline price term and the unemployment term.

The other two forms were not good fits for the data. For the quadratic form to be appropriate, the coefficient of a variable must be statistically significant for both its normal and squared term. This did not occur when I added a squared term for each variable and re-ran the regression. For the linear form, all three variables are significant, which would usually be a sign that this is the best form to describe the data. However, the sign of the coefficient for the variable describing the effect of the number of CVRP-eligible vehicles was negative, indicating that as the number of CVRP-eligible vehicles increase, sales of vehicles decrease. This is concerning because the overall association of the data is positive, as shown in Figure 3.

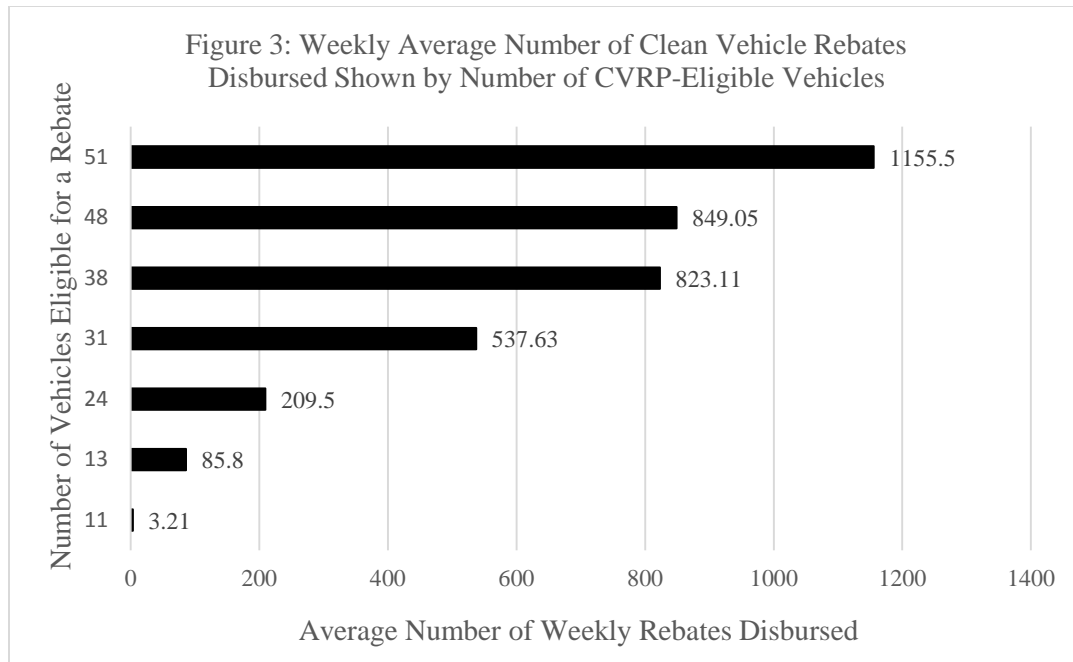


Figure 3 shows that when there were 11 vehicles eligible for a rebate, the weekly number of CVRP rebates the state issued was 3.21. As the number of eligible vehicles increased, the number of rebates increased as well.

The likeliest explanation for the disconnect between the positive association between the two variables and the result of the regression is omitted variable bias, which occurs when a statistical model omits one or more important factors. It is possible that I did not include a factor in the data that is important. I suggest additional variables to include in future research in Chapter 5 that may cause future regression analyses to find a positive relationship between the two variables.

The results for the other two variables in the log-linear regression are still instructive, despite the concern about third variable. These results indicate that:

- When the proportion of the 4-week average gasoline price to the 26-week average price increases by one percent from the proportion in the previous week, sales of clean vehicles increase by about 1.6%

- Each 1 percent drop in unemployment rate increases the sales increased by about 104.5 percent.

These findings corroborate the results of Beresteanu & Li (2008) cited in Chapter 2, which demonstrated that consumers react to higher gasoline prices by purchasing hybrid vehicles. That study determined that the increase in gasoline prices from an average of \$1.35 per gallon in 1999 to \$2.53 in 2006 could explain between 14 and 27 percent of the increase in hybrid car sales.

These results also fit the anecdotal increases in sales reported by automobile dealerships in times of high gasoline prices. The results show that the overall performance of the economy is a significant factor in the sales of clean vehicles. While sales of other vehicles rise and fall as well with the economy, this finding fits in with the theme I discuss in Chapter 2 that consumers may approach clean vehicles more as a luxury good than a normal good.

The coefficient of the gasoline price variable in the log-linear model is statistically significant, but suggest that size of the effect is not large. At the rate the model describes, a long, sustained increase in gasoline prices would be necessary to cause a sizable increase the purchases of clean vehicles. A better model to look at for this term may be the one in which I transform both the dependent variable and the gasoline price term using a natural logarithm. The results from this regression show that when the proportion of the 4-week average gasoline price to the 26-week average price increases by 1 percent from the previous week, sales of clean vehicles increase by 1.55 percent. This increase is far more robust.

This regression analysis does not find evidence that sales of clean vehicles increase as the number of CVRP-eligible vehicles increases. Multicollinearity may be contributing to this result because it artificially inflates the standard error of the coefficient and makes it less likely that the



result will be statistically significant. The value of the VIF for the term is 32.11, which suggests a high degree of correlation that may make the results of the regression less reliable.

### **Results of the Qualitative Analysis**

This section describes the results of the qualitative portion of my analysis. As discussed in the previous chapter, I interviewed five experts who represented a variety of viewpoints in the discussion regarding clean vehicles. Due to career shifts, the respondents were able to represent more than five perspectives. The respondents had experience as a legislative director for a member of the California Legislature, a former member of the California Legislature, a consultant to a clean vehicle association, academic researchers, a program director of a nonprofit dedicated to expanding the use of clean vehicles, and a recipient of a rebate for a clean vehicle. I organize the interview responses into three broad themes:

- 1) Factors encouraging or delaying the rate of adoption of clean vehicles in California, including respondents' thoughts on the strength of the factors included in my regression analysis
- 2) Additional steps the state can or should take to meet its 1.5 million zero-emission vehicles goal;
- 3) How the state should change the CVRP to make it more effective.

I provide a summary of the responses in Appendix C.

#### *Factors Encouraging or Delaying the Purchase of Clean Vehicles*

Subject matter experts mentioned many similar factors that they believe encourage or discourage the sales of clean vehicles. The experts broadly agreed about the factors encouraging the sales of clean vehicles, and discussed a wide array of answers regarding factors discouraging the sale of clean vehicles.

### *Factors Encouraging the Purchase of Clean Vehicles*

Among the factors encouraging the sales of clean vehicles, the two most commonly cited factors were the vehicles' performance and handling, and the access to carpool lanes. Because clean vehicles with a battery generally have the battery placed along the bottom of the vehicle, the vehicles have a low center of gravity. The low center of gravity enables these vehicles to handle corners better than their internal combustion engine counterparts. Additionally, vehicles with an electric drive-train generally have a faster rate of acceleration compared to internal combustion engines with similar power. The vehicles are also generally very quiet. These factors combine to make the driving experience for clean vehicles a factor that three out of the five interview respondents identified as one of the biggest factors when consumer purchase clean vehicles.

The other common factor multiple respondents mentioned was that California offers clean vehicles access to carpool lanes even when there is only one occupant. One respondent who had researched this factor indicated that many individuals bought the vehicle solely for the access to the carpool lane. Respondents noted that while this may be a factor in large metropolitan areas, many areas of the state do not have carpool lanes, and so the geographic effect of this factor is limited.

Additional factors respondents mentioned include the desire of consumers to be more environmentally conscious, the recent increase in the number of available models of clean vehicles, California's rebate program, the convenience of overnight charging and having a full charge every day, and access to preferential parking.

### *Factors Discouraging the Purchase of Clean Vehicles*

Experts gave a wide variety of answers to this question, but each expert identified the lack of consumer awareness and knowledge of clean vehicles as a major hurdle standing in the

way of increasing sales. Variations of this answer included consumers being unaware that clean vehicles are even for sale, not knowing how they differ from internal-combustion vehicles, and having little or no personal experience with clean vehicles, especially with plug-in hybrid or battery-electric vehicles. Experts believed that the lack of knowledge about and experience with these vehicles made them exotic to many consumers, and made them less likely to consider purchasing the vehicles for everyday use. For those consumers that were aware of the vehicles, experts believes the lack of familiarity with the technology made them less likely to understand how a clean vehicle could meet their needs. Finally, the lack of hands-on experience with clean vehicles made consumers unaware of the driving experience, which experts believed is a major factor in encouraging the sales of clean vehicles.

For consumers that were aware and familiar with these vehicles, the experts cited many additional factors discouraging consumers from purchasing them. These included concern about the practicality of the vehicles, such as the range of the vehicles and the length of time needed to charge; the recent low gasoline prices that decreased the financial savings the vehicles offered; the difficulty of gaining access to vehicle charging stations in mutli-family housing; and the lack of a wide variety in of types and price points for clean vehicles, such as an entry-level luxury vehicle or sport-utility vehicles.

#### *Additional Steps California Can or Should Take to Promote Clean Vehicles*

Experts offered a variety of suggestions for steps that California might consider taking to increase sales of clean vehicles. Experts broadly agreed that the state should take steps to promote additional awareness of the presence of clean vehicles in the marketplace and the advantages they offer consumers. Suggestions for how the state could increase consumers' awareness included promotion of events designed to give consumers a personal experience with a clean vehicle and policies to encourage clean vehicle manufacturers to more aggressively promote their products.

Other ideas the experts suggested for state policies included further tightening the minimum standards for vehicles to qualify for a sticker granting access to the carpool lane. Because carpool lane access is a major factor for many consumers, making the requirements more stringent would discourage manufacturers from building cars that meet only the minimum threshold to qualify for a sticker, and encourage greater innovation in the market.

Based on the success of the carpool stickers, experts also suggested increasing the privileges offered to consumers who purchase clean vehicles. These may potentially include priority access to convenient and prominent parking in congested areas, subsidized or free access to toll roads, and access to streets where the law prohibits other vehicles from driving.

*Changes Respondents Suggested California Should Make to the Clean Vehicle Rebate Program*

When asked if California should make additional changes to the CVRP, experts all agreed that the state should not increase the broadly-targeted financial incentives offered to consumers who purchase clean vehicles. One expert highlighted the experience of the San Joaquin Air Quality Management District, which offers an additional financial incentive for the purchase of a clean vehicle on top of the state and federal rebates. Research demonstrated that awareness of clean vehicles was lower within the district, despite the presence of the additional rebate, offering evidence that additional financial incentives would not be effective in encouraging additional sales of clean vehicles.

Experts generally supported the state's placement of income limits for the recipients of rebates as well as the increase in the amount of the rebate available for low-income consumers, as discussed in Chapter 2. Several experts suggested the state should expand the program to support rebates in the used vehicle market. Because many low-income consumers simply cannot afford a new vehicle, the existing clean vehicle rebate does not affect them. Expanding the program to

include used vehicles would provide access to clean vehicles to low-income consumers who now receive no incentives to purchase them.

Experts also suggested changing the CVRP to base its rebates for plug-in hybrids and battery-electric vehicles based on the distance the vehicles can drive on electric-only power. This change would increase the incentives for vehicles with a larger battery pack and help offset the cost of the battery, which is a major contributor to the overall cost of the vehicle. Creating market incentives to increase the range of clean vehicles would also help address consumers' range anxiety, which experts broadly identified as a factor holding back the sales of clean vehicles.

## Chapter 5

### CONCLUSION

This thesis analyzed some of the factors that affect the sales of clean vehicles. The dependent variable was the number of rebates the CVRP distributed each week since the program began in 2010. I identified three broad factors that could have an effect on the sales of clean vehicles in a given week: the savings clean vehicles offer to consumers, the overall health of the economy, and the availability of clean vehicles. The variable I identified to describe the savings that clean vehicles offer to consumers was the price of gasoline. I calculated this variable as the proportion of the average price of gasoline 4 weeks prior to the purchase of a vehicle to the average price 26 weeks prior to the purchase of a vehicle. This proportion attempts to capture how relatively high or low current gasoline prices appear to consumers relative to prices in the past half-year. The variable I used to describe the economy was the unemployment rate, which attempted to capture how well the economy was performing. The variable I chose to describe the availability of clean vehicles was the number of vehicles that qualify for a rebate through the CVRP. This variable attempted to capture the effect that greater vehicle variety would have on sales, as researchers have previously found that the lack of vehicle options is one factor discouraging consumers from purchasing clean vehicles (Ready, Set, Charge California!, 2011).

In Chapter 4, I described the findings of my regression analysis and qualitative interviews. The chapter identified factors that were statistically significant in the regression and compared those variables to the factors that subject matter experts identified as having strong positive or negative effects on the sale of clean vehicles. This final chapter synthesizes the findings from my quantitative and qualitative analysis and discusses how the findings for each variable relate to the findings of previous research. I also highlight the policy implications of my

research, identify weaknesses in my study, and suggest ways in which future studies may build upon my results.

### **Findings by Variable**

In this section, I discuss the implications of the results of the regression analysis and interviews with subject matter experts and describe how the results of my research fit into the existing research. In a nutshell, my regression analysis determined that an increase in gasoline prices of 1 percent over half a year causes a 1.6 percent increase in clean vehicles sales and that each 1 percent drop in unemployment rate increases the sales by about 104.5 percent. My regression analysis did not find that an increase in the number of vehicles that qualify for a clean vehicle rebate increases sales. My interviews with experts revealed that the two factors they believed to be increasing sales were the superior performance and handling of clean vehicles and California's policy of allowing access to carpool lanes for individual drivers in clean vehicles. Each expert identified the lack of consumer awareness and knowledge of clean vehicles as a major barrier to increasing clean vehicle sales.

#### *Consumer Savings*

One of the most important factors in many consumers' decisions to purchase clean vehicles is the savings on fuel that these vehicles offer (Klier & Linn, 2010). My regression analysis reported a statistically significant positive correlation between gasoline prices and the sales of clean vehicles. More precisely, sales of clean vehicles increase by about 1.6 percent when the variable describing the price of gasoline increased 1 percent. In my dataset, the gasoline price variable had a minimum value of 76.6 and a maximum value of 122.1. Thus, when gasoline prices were at their highest, my model predicts that this variable was associated with a 35.2 percent increase in clean vehicle sales. Likewise, my model shows that low prices are associated

with lower sales of clean vehicles. My model predicts that the week with the lowest value of this variable was associated with a 37.4 percent decrease in clean vehicle sales.

Only one of the subject matter experts I interviewed identified the recent run of low gasoline prices as a major factor discouraging the sale of clean vehicles. Two other respondents referred broadly to consumers' lack of awareness of the benefits of clean vehicles, which likely include savings on gasoline. These findings corroborate the results of previous studies exploring the relationship between gasoline prices and the fuel-efficiency of vehicles consumers purchase. Previous research has found a statistical relationship between the price of gasoline in the previous year and the type of vehicle that consumers purchase (West, 2007). Researchers have also found that consumers drive fewer miles in reaction to high gasoline prices (Wei, 2012).

Additionally, four interview respondents stated that California policymakers should create or expand programs to educate consumers about clean vehicles to encourage the sales of clean vehicles. Presumably, this information would include information about the potential savings these vehicles offer. Research has also shown consumers are generally not aware of their gasoline costs (Turrentine & Kurani, 2006), and that consumers misunderstand the value of increasing fuel efficiency (Larrick & Soll, 2008). Clearly, gasoline prices are having an effect on the vehicle purchase decisions of some consumers. My qualitative research builds on the conclusions of existing research that many other consumers lack information about the savings clean vehicles may offer. I offer potential policy implications of this finding in the next section.

#### *Strength of the Economy*

Manufacturers have increased the number of models of clean vehicles for sale, but these vehicles remain generally more expensive than their internal-combustion counterparts (Edelstein, 2015). Even with the release of the Chevy Bolt and Tesla Model 3, both of which will cost in the high \$20,000s or low \$30,000s after state and local incentives, clean vehicles will remain



generally more expensive than vehicles using an internal combustion engine. For comparison, the 2016 Honda Civic has an introductory sales price of \$18,640 (Honda, 2016). In 2012, J.D. Power and Associates found that the price premium of clean vehicles required the average consumer to own the vehicle between 6.5 and 11 years before they began to save money (J.D. Power & Associates, 2012). As noted in Chapter 2, the average consumer owns a new vehicle for less than six years (Kelly Blue Book, 2012).

The price premium of clean vehicles means that consumers may be likely to treat them as a “luxury good.” This means that as the economy improves by a certain percentage, consumers’ demand for clean vehicles rises by a higher percentage, and vice versa. The CVRP is an attempt to make new clean vehicles less expensive and therefore decrease the amount that consumers treat clean vehicles as a luxury good.

My regression analysis identified a strong statistical relationship between the unemployment rate and sales of clean vehicles. My model predicts that each 1 percent drop in unemployment rate increases the sales by about 104.5 percent.

This finding shows a much greater effect of the economy on the sales of clean vehicles than other studies have identified on new car sales overall. For instance, one study found that an increase in the unemployment rate reduced the sales of new cars in the greater St. Louis, Missouri region by 2.42 percent (Belasen, 2016).

Notably, none of the subject matter experts I interviewed identified the improving economy as an important factor in increasing clean vehicles sales when asked about what top three factors were encouraging clean vehicle sales in California. Because the results of my initial research had also identified the effect of the improving economy on clean vehicle sales, I asked each respondent specifically about their thoughts regarding this correlation. All five of the experts agreed that this result was not surprising. Four of the experts mentioned that due to the price and

relative lack of versatility of existing clean vehicle models (e.g., limited range and few model choices), consumers would think of them as a luxury good, not as a true replacement for an internal combustion vehicle. Therefore, it was logical that an improving economy would lead to a large increase in clean vehicle sales. One expert noted specifically that consumers still saw clean vehicles as “something special,” and that clean vehicles were still more of a treat to themselves rather than a financial investment.

On the other hand, two experts cautioned that this finding may be misleading precisely because of the relative high price of clean vehicles. They reasoned that because only moderately or very wealthy consumers could afford clean vehicles in the first place and the Great Recession did not affect these consumers as much as working and lower-class consumers, the increase in sales and improving economy was likely more of a coincidence than a result of a cause and effect. They noted that the economy began its sharp recovery just as the CVRP was gaining steam and manufacturers greatly increased the number of clean vehicles for sale.

#### *Variety of Clean Vehicles Available*

The number of clean vehicles available has increased sharply since the CVRP took effect in March 2010. At that time, only six vehicle models were eligible for a rebate. Only one of these vehicles was close to being a substitute for a personal vehicle: the original Tesla Roadster, which cost \$110,000, had two seats, and had a range of about 240 miles (Robinson, 2009). By January 2016, California offered rebates for the purchase of 51 different vehicle models. I was especially interested in the how my quantitative and qualitative research described the relationship between availability of clean vehicles and sales, because I could not find any research quantifying that relationship.

As noted in Chapter 4, my regression analysis did not find evidence that sales of clean vehicles increase as the number of CVRP-eligible vehicles increases. This result may have been

due to multicollinearity, because there is a strong positive correlation between the two variables. In the linear model, my regression actually found a statistically significant *negative* relationship between the number of CVRP-eligible vehicles and sales of clean vehicles. Omitted variable bias may be contributing to this result, and I suggest later in this chapter potential variables for inclusion in future studies that may help clear up this result.

In my interviews with subject matter experts, two respondents identified the rising number of available clean vehicles as one of the top factors encouraging the sales of clean vehicles. One expert specifically mentioned the publicity surrounding the launch of Tesla's Model 3, and the other mentioned that additional clean vehicle models meant that clean vehicles could fit more needs for consumers. Other respondents did not specifically mention the number of available clean vehicles, but all respondents focused on how increased competition from additional entries into the clean vehicle market had the effect of driving down prices, which would in turn increase sales.

#### *Other Variables Affecting Clean Vehicle Sales*

Additional variables that the multiple subject matter experts identified included clean vehicles' performance and handling. Experts noted many aspects of the vehicles' performance that attract consumers: the elimination of the need to stop at gas stations, the ability to start each day on a "full tank" due to overnight charging, and the quiet ride and fast acceleration offered by an electric motor. As more vehicles enter the market and more consumer data become available, future researchers may be able to identify which types of consumers place value on these different qualities.

Experts also identified how California's program offering access to carpool lanes for solo drivers of certain clean vehicles was a major factor in clean vehicle sales. As noted in Chapter 4,

recent research has identified that access to carpool lanes accounted for about 40 percent of clean vehicle sales between 2010 and 2013, or about 24,000 vehicles (Weikel, 2015).

### **Policy Implications of My Findings**

California Governor Jerry Brown has set a goal of having 1.5 million zero-emission vehicles on its roads by 2025 (Office of Governor Edmund G. Brown Jr., 2012). The state and its local governments have implemented a wide range of programs aiming to increase the sale of clean vehicles, including the CVRP, additional rebates for clean vehicles in certain geographic regions, access to carpool lanes, preferential parking, and subsidies for charging infrastructure. Still, the state is not on track to reach this goal (Megerian, California falling short in push for more clean vehicles, 2015). The findings of this thesis offer policy suggestions for steps California can take that may help the state reach its target for zero-emission vehicles.

#### *Improve Consumers' Familiarity with Clean Vehicles*

In my interviews with subject matter experts, each respondent believed that consumers' lack of awareness and knowledge of clean vehicles was a major factor lowering clean vehicle sales. Experts identified three ways consumers were unfamiliar with clean vehicles: a lack of awareness that the vehicles were available for sale, a lack of understanding how clean vehicles could fit their needs, and a lack of in-person experience with clean vehicles. To increase consumers' awareness and familiarity with clean vehicles, experts suggested policies such as measures to encourage vehicle manufactures to more aggressively advertise and promote clean vehicles or provide greater funding for educational and experiential events that place consumers face-to-face with clean vehicles. One expert suggested state support for car-sharing or ridesharing programs that utilize clean vehicles, or opportunities for consumers to have a trial ownership period for clean vehicles to learn how a clean vehicle could fit their lifestyle.

Of these, the policy that would be easiest to implement would be additional state funding for educational and experiential events that provide consumers hands-on experience with clean vehicles. The state may choose to offer this funding through grants to local air quality management districts and other local government entities or organizations that wish to hold such events. The state may also encourage or offer specific funding to CARB to hold experiential events. Because the cost of these events is likely to be low compared to other policy options, the state may be able to introduce many consumers to clean vehicle technology for relatively little cost.

#### *Additional Changes and Expansion to the CVRP*

The experts broadly agreed that the CVRP has had a positive effect on the sales of clean vehicles in the state, and that recent changes to the program would have an additional benefit. These recent changes include income limits for high-income purchasers to ensure that those who receive the rebates are the ones who most need them, and an increase in rebate amounts for low-income purchasers to expand access to clean vehicles. The experts also broadly agreed that the base rebate amount the CVRP offers should not be increased, and most experts believed the rebate amount should be reduced as clean vehicles reach price parity with gasoline-powered vehicles.

The experts offered a variety of other policy suggestions to change the CVRP. These included increasing the rebate amount for vehicles with a larger range in electric-only mode, further decreasing the recently-enacted income limit while further increasing the rebate for low-income purchasers, and expanding the program to encourage the purchase of used clean vehicles. The first two policy suggestions involve changes to the existing rebate program. CARB may wish to take into consideration a change in the way it determines which vehicles are eligible for specific levels of rebates. Manufacturers have an incentive to create cars that meet the minimum

requirements to qualify for a certain level of rebate, and after they reach that level, they may not focus on further improving the technology that makes the vehicle clean. Specifically, manufacturers currently do not receive an additional incentive from the CVRP for creating a plug-in hybrid with a larger “battery-only” range (the distance a vehicle may drive on battery power alone before it switches to gasoline for power). In fact, they likely face an incentive not to extend the battery-only range, as that requires a larger battery which in turn increases vehicle cost. CARB currently offers a flat \$1,500 rebate for all plug-in hybrid vehicles. To encourage additional innovation in this market, CARB may wish to set lower rebates for vehicles with a low battery-only range, and a higher rebate for vehicles with a larger battery-only range. Similarly, CARB may wish to increase rebates for low and moderate-income purchasers to further raise accessibility to clean vehicles. Establishing a rebate for the sale of used clean vehicles would be a larger policy shift, and would require more political will than the other two policy changes.

#### *Changes to the States Carpool Access Stickers*

Each of the experts I interviewed identified access to carpool lanes as a strong incentive for many consumers to purchase clean vehicles. For many commuters, access to the carpool lane may save valuable time during the morning and evening commute. Until December 2015, the state offered carpool access stickers to certified pure zero-emission vehicles as well as vehicles that met state certification as a transitional zero emission vehicles. In December 2015, the state reached its predetermined limit for the number of stickers available for transitional zero emission vehicles, and stickers are now available only for certified pure zero-emission vehicles (California Air Resources Board, 2016).

With the expiration of the access to stickers for transitional zero emission vehicles, California has an opportunity to change how it offers stickers to these vehicles. The state has reached its maximum number of stickers before and extended this program three times already, so

it may very well choose to do so again (Cobb, 2015). The state may opt to only offer the stickers to vehicles that meet certain requirements, such as a minimum electric-only range or charging speed. These additional standards would encourage manufacturers to improve their technology to ensure that their vehicles qualify.

### **Limitations of My Research and Suggestions for Future Research**

As noted above and in Chapter 4, one of the primary weaknesses of my quantitative analysis is the negative association it finds in the linear form between the number of CVRP-eligible vehicles and sales of clean vehicles. This result was likely due to omitted variable bias, because my quantitative analysis only used three variables. I would have liked to include several additional variables in my analysis, but time and data constraints prevented me from doing so. Below, I discuss additional variables future researchers may want to consider.

The dependent variable in my analysis is the raw number of rebates that the CVRP issued in a given week. As the experts noted in my qualitative analysis, it would make the analysis much stronger to identify the proportion of new car sales that were clean vehicles for the dependent variable, as opposed to the raw number. The concern here is that sales of both clean vehicles and gasoline-powered vehicles rise or fall more or less in tandem. An approach that captures the proportion of new car sales that are clean vehicles would take this fact into account and capture how clean vehicle sales compare to the rest of the new car market. If the CVRP is expanded to include used vehicles, future researchers will want to explore what factors affect the sale of used clean vehicles and compare them to the factors affecting the sales of new clean vehicles. Researchers may also wish to use data from Colorado, which allows tax credits for used vehicles for which the credit has not already been claimed (Voelcker, 2015).

One expert suggested that although the CVRP issued rebates for luxury vehicles such as the Tesla Model S, the consumers purchasing these expensive vehicles are likely not doing so due

to the presence of the rebate. Future studies may wish to include a price cap on the price of a clean vehicle to attempt to analyze only the clean vehicle sales for which the rebate was likely to have a sizable impact.

Future studies may also wish to utilize the additional data that the CVRP collects when issuing rebates. These data include information regarding recipients' income, education level, rationale for purchasing a clean vehicle, and geographic location. These data may be helpful for studies regarding the presence of a "neighbor effect" for clean vehicles, in which an individual is more likely to purchase a good when a member of his or her peer group has purchased it. I was not able to include these factors in my analysis due to a lack of time. The additional data may also help determine which consumers the CVRP helps the most, so the state may be able to better target the program to them. Finally, the survey data may help determine which of the households purchasing clean vehicles have a second vehicle, and which are purchasing a clean vehicle to be their only household vehicle. This information could help gauge whether consumers are approaching clean vehicles as a true replacement for gasoline-powered vehicles, or as a supplementary vehicle only.

### **Concluding Comments**

California is a national leader in taking steps to reduce its GHG emissions. Because emissions from the transportation sector accounted for 37 percent of the state's emissions in 2013 – more than any other sector – the state must take action to reduce the carbon footprint from this sector if it is to reach its ambitious targets for reducing its GHG emissions (California Environmental Protection Agency, 2015). In 2013, nearly half of the nation's plug-in electric vehicles were sold in California, and sales have increased since then (Energy Information Administration, 2014). Still, the state lags behind the sales needed to reach its goal. This thesis offers an analysis of what factors may be leading to an increase in sales of clean vehicles,



suggests policy changes the state may want to explore to increase clean vehicle sales, and identifies additional topics for research that may help policymakers make more informed decisions about how to encourage the transition to clean vehicles.

## APPENDIX A

## INTERVIEW QUESTIONS:

- 1) What has your involvement been with California's effort to transition to clean vehicles in general and the Clean Vehicle Rebate Program in particular?
- 2) What do you believe are the three biggest factors slowing down consumers' transition to clean vehicles? What are the biggest factors encouraging the transition?
- 3) What more do you think the State of California can or should do to encourage consumers to purchase clean vehicles?
- 4) Even with the rebates from the Clean Vehicle Rebate Program, many clean vehicles remain unaffordable or impractical for Californians. What changes, if any, should be made to the Clean Vehicle Rebate Program to increase its efficacy? Should the rebate be increased or decreased, or income restrictions tightened further?
- 5) With newer, less expensive, and more versatile clean vehicles hitting the market in the coming years (e.g., the Chevrolet Volt and the Tesla Model 3), will the Clean Vehicle Rebate Program remain necessary in coming years?
- 6) Outside of the financial incentives offered through the Clean Vehicle Rebate Program, what California programs or policies do you believe have had the greatest impact on encouraging the transition to clean vehicles?
- 7) In 2014, California's cap and trade system expanded to include transportation fuels, effectively adding about a dime to the cost of a gallon of gasoline. Do you think the addition of transportation fuels to the cap and trade system will have a significant impact on California's transition to clean vehicles?
- 8) My initial regression analysis found that the only factor that had a significant effect on the purchase of clean vehicles was the unemployment rate, which served as a proxy for

the economy. When the unemployment rate decreased, presumably the economy improved and the purchase of clean vehicles increased. This finding indicates that the rebates offered through the Clean Vehicle Rebate Program, gasoline prices, and the number of vehicles available in the program were not significant factors in increasing the sales of clean vehicles. Do you find this result surprising? What factors do you think may be at play in why an improving economy, but no other variables, was significant?

- 9) Access to the carpool lane has been a major consideration for many consumers when purchasing a clean vehicle. How important do you feel the carpool access stickers have been in incentivizing clean vehicle purchases compared to other factors?
- 10) Research has shown that part of the motivation behind consumers' decisions to purchase green products is the desire to publicly exhibit an environmentally consciousness to others. How large a factor do you believe the desire to "be seen being green" plays in consumers' decision to purchase clean vehicles?

## APPENDIX B

## INFORMED CONSENT FORM

You are invited to participate in a research study approved by the institutional review board which will involve quantitative and qualitative analysis seeking to identify the factors influencing consumers to purchase fuel efficient vehicles. The principal investor, Damien Mimnaugh, is a student in the Master of Public Policy and Administration program at California State University, Sacramento.

Your participation in this project is voluntary. Even after you agree to participate, you may decide to leave the study at any time.

The purpose of this research is to identify factors that influence consumers to purchase clean vehicles. If you decide to participate, you will be asked to participate in a interview lasting between 15 and 30 minutes about your experience in the field of clean vehicles. Risks associated with this study are not anticipated to be greater than those risks encountered in daily life. If you have any questions about your rights as a participant in a research project please call the Office of Research Affairs, California State University, Sacramento, (916) 278-5674, or email [irb@csus.edu](mailto:irb@csus.edu).

Your signature below and your participation in this study indicates that you have read and understand the information provided above.

Signature

Date

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APPENDIX C

SUMMARY OF INTERVIEW RESULTS

<b>Respondent Background</b>	<b>Factors encouraging the purchase of clean vehicles in California</b>	<b>Factors discouraging the purchase of clean vehicles in California</b>	<b>Additional steps California should take to promote clean vehicles</b>	<b>Changes the state should make to the CVRP</b>
<p>Consultant to clean vehicle association, former legislator, clean vehicle rebate recipient</p>	<ul style="list-style-type: none"> <li>• The clean vehicle rebate program</li> <li>• Consumers’ desire to reduce their impact on the environment</li> <li>• Clean vehicle attributes such as convenience and performance)</li> <li>• Carpool lane access</li> </ul>	<ul style="list-style-type: none"> <li>• Lack of consumer information creating about range anxiety and concern about charging</li> <li>• Lack of appropriate vehicle types</li> <li>• Affordability</li> </ul>	<ul style="list-style-type: none"> <li>• Break down the information gap for consumers about clean vehicles</li> <li>• Tighten the rules for carpool stickers by allowing only vehicles with a minimum range in electric-only mode</li> </ul>	<ul style="list-style-type: none"> <li>• Increase the rebate for cars that cars with a larger battery pack and incentivize further technology improvement. Vehicles with smaller battery packs reduce consumer concern about range anxiety</li> </ul>
<p>Academic researcher studying consumer responses to clean vehicles and alternative fuel vehicles</p>	<ul style="list-style-type: none"> <li>• Clean vehicle attributes (handling &amp; performance)</li> <li>• Publicity and awareness due to the recent Tesla 3 launch</li> <li>• Carpool lane access</li> <li>• State support for charging infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>• Low awareness that clean vehicles exists</li> <li>• Limited knowledge of how clean vehicles work &amp; limited hands-on experience</li> <li>• Range and fueling/charging speed</li> </ul>	<ul style="list-style-type: none"> <li>• Further promote awareness of clean vehicles through investments in experiential and educational events</li> </ul>	<ul style="list-style-type: none"> <li>• Higher rebates are not needed</li> <li>• The CVRP should be phased out over time as clean vehicles become more cost competitive</li> </ul>
<p>Academic researcher evaluating policies aimed at encouraging clean vehicle purchases</p>	<ul style="list-style-type: none"> <li>• Clean vehicle rebate program</li> <li>• Government subsidies for charging stations</li> <li>• Carpool lane sticker program</li> </ul>	<ul style="list-style-type: none"> <li>• Lack of consumer knowledge of benefits of clean vehicles</li> <li>• Difficulty of vehicle charging hard in multifamily housing</li> </ul>	<ul style="list-style-type: none"> <li>• Examine which programs supporting clean vehicles work the best and further support them</li> </ul>	<ul style="list-style-type: none"> <li>• Expand the CVRP to used clean vehicles</li> <li>• The CVRP will become less important over time as clean vehicles become more</li> </ul>

				cost competitive
Legislative Director for a member of the California Legislature	<ul style="list-style-type: none"> <li>• Consumer desire to reduce their impact on the environment</li> <li>• A larger number of clean vehicle options than ever</li> <li>• Clean vehicles have become a status symbol for the wealthy</li> <li>• Carpool lanes, especially in Los Angeles and the Bay Area</li> </ul>	<ul style="list-style-type: none"> <li>• Low gas prices</li> <li>• Limited range of battery electric vehicles</li> </ul>	<ul style="list-style-type: none"> <li>• Develop programs to support the used clean vehicle market</li> </ul>	<ul style="list-style-type: none"> <li>• Further reduce the income limit</li> <li>• Further increase the rebate for low and moderate-income consumers</li> </ul>
Project director at a nonprofit supporting the growth of the clean transportation technologies	<ul style="list-style-type: none"> <li>• Access to the carpool lane</li> <li>• Access to preferential parking</li> <li>• Clean vehicle attributes, specifically the quiet ride</li> <li>• Availability of charging at workplace</li> </ul>	<ul style="list-style-type: none"> <li>• Lack of knowledge by the public</li> <li>• High cost of clean vehicles</li> <li>• Difficulty of convincing consumers to change habits</li> <li>• Consumers are unclear of the benefits of clean vehicles</li> </ul>	<ul style="list-style-type: none"> <li>• Increase incentives for clean vehicles, such as parking, access to toll roads or otherwise restricted areas</li> <li>• State support for car-sharing or ridesharing programs to increase consumer experience with clean vehicles</li> </ul>	<ul style="list-style-type: none"> <li>• Phase out the CRVP over time</li> </ul>

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