UC Berkeley
Earlier Faculty Research

Title
Environmental Knowledge, Environmental Attitudes, and Vehicle Ownership and Use

Permalink
https://escholarship.org/uc/item/6pv1x9xq

Author
Flamm, Bradley John

Publication Date
2006

eScholarship.org Powered by the California Digital Library
University of California

Environmental Knowledge, Environmental Attitudes, and
Vehicle Ownership and Use

by

Bradley John Flamm

B.A. (University of California, Berkeley) 1984
M.R.P. (Cornell University) 1992

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

City and Regional Planning

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Martin Wachs, Chair
Professor Robert Cervero
Professor Gene Rochlin

Fall 2006

The dissertation of Bradley John Flamm is approved:

Chair ______________________________ Date______________

______________________________ Date______________

______________________________ Date______________

University of California, Berkeley

Fall 2006

Environmental Knowledge, Environmental Attitudes, and
Vehicle Ownership and Use

Copyright 2006

by

Bradley John Flamm

ABSTRACT

Environmental Knowledge, Environmental Attitudes, and
Vehicle Ownership and Use

by

Bradley John Flamm

Doctor of Philosophy in City and Regional Planning

University of California, Berkeley

Professor Martin Wachs, Chair

Since the 1970s, significant majorities of Americans say they support protecting the natural environment, even if it involves some economic cost. Yet almost every year since the 1970s Americans have driven farther than the year before, owned more vehicles, used them for a larger percentage of all trips, and shared them with other passengers less often. Vehicles today are much cleaner and more fuel efficient than in the recent past, but many of the potential environmental benefits are offset by higher consumption. This dissertation explores this apparent contradiction by analyzing the relations between environmental knowledge, environmental attitudes, and vehicle ownership and use. The research relies on quantitative analysis of responses from 1,506 Sacramento, California area residents to a 37-question knowledge-attitudes-behavior survey (39.6% response rate). Hypotheses were tested concerning the bi-directional effects of environmental knowledge and environmental attitudes on each other and on number of household vehicles, fuel efficiency of household vehicles, estimated annual household miles driven, and estimated annual household fuel consumption.

Difference of means analyses, multiple regression equations, and structural equation modeling reveal that 1) respondents with pro-environmental attitudes know more about the environmental impacts of vehicle ownership and use, 2) the households of knowledgeable respondents own more fuel efficient vehicles and use less fuel, 3) the households of pro-environment respondents own fewer and more fuel efficient vehicles, drive them less, and consume less fuel, 4) vehicle ownership and use inversely affect environmental attitudes, but to a lesser extent than attitudes affect vehicle ownership and use, and 5) many respondents perceive constraints to making their vehicle ownership and use reflect their knowledge and attitudes.

These findings suggest that public education and social marketing campaigns focusing on the majority of Americans with pro-environmental attitudes, combined with policies to reduce barriers to less resource-intensive vehicle ownership and use, could encourage greater demand for more fuel efficient vehicles and lower levels of vehicle ownership and miles driven. They also highlight the research importance of effective survey design, appropriate measurement of latent variables, and the inclusion of knowledge and attitudinal variables in some travel and environmental behavior studies.

Dedication

To Esther, Maya, and Theo

Table of Contents

LIST OF FIGURES

List of Tables

LIST OF APPENDICES

ACKNOWLEDGEMENTS

Writing this dissertation has been a mix of long stretches of solitary work—just me, my laptop, and a pile of surveys, articles, and books—punctuated by meetings and calls and encounters in which the generosity, thoughtfulness, and insights of mentors, colleagues, friends, and family have kept me on track, pointed me in new directions, or simply recharged my intellectual, professional, and emotional batteries.

My thanks go first to my dissertation committee chair, Professor Martin Wachs, who has consistently supported, guided, challenged, and helped me through this project. The other two members of my dissertation committee, Professor Robert Cervero and Professor Gene Rochlin, also contributed greatly to my work with their advice and questions and thoughtfulness. They all put a great deal of time and effort into helping me define my topic, plan a strong research methodology, conduct the data collection and analysis, and write it all up in this document. I have learned a great deal from each of them, from their teaching and research, and from their commitment to their students.

I am grateful to other professors who have contributed to my success. Professor Elizabeth Deakin chaired my inside field exam, encouraged me to think creatively and rigorously about the questions that interest me, and supported my applications for the financial support that made this possible. Professor Tim Duane graciously served on my oral exam committee, Professor John Landis met with me on several key occasions and was a model of an academic who puts students first, Professor Daniel Kammen helped me through my outside field requirements, Professor Michael Teitz gave me encouragement and helpful advice, Professor Susan Handy made time to advise me on several difficult analytical choices, Professor Lee Kaskutas taught me about effective survey design and implementation, and Professor Enda McGovern read my early proposals and gave me helpful references and lots of friendly encouragement.

I am grateful for the financial support for this dissertation that came from the U.S. Department of Transportation's Dwight David Eisenhower Graduate Transportation Fellowship program and the University of California Transportation Center's Dissertation Research Grant program.

The logistics and administration of attending a doctoral program and managing a dissertation research project have not always been straightforward and I am grateful for the generous help, encouragement, and friendship of many UC Berkeley staff: Kaye Bock, Andres Alvarez, Pat Ramirez, and Malla Hadley of the Department of City and Regional Planning; Norine Shima, Kay Stevenson, and Phyllis Orrick of the Institute of Transportation Studies; Eunice Park and Michael Harvey of the University of California Transportation Center; and Carey Pelton of the Institute of Urban and Regional Development. Rita Evans of the Institute of Transportation Studies Library and Deborah Sommer of the Environmental Design Library have both provided excellent help in navigating the resources of libraries here and on other campuses.

UC Berkeley provides several excellent resources to graduate students implementing surveys and analyzing the resulting data. Bradley Luen of the Department of Statistics spent many a session discussing the statistical techniques I relied on. Robert H. Lee and Thomas Piazza of the Survey Research Center met with me several times to help with my survey design and analysis.

Three groups of colleagues inspired and challenged me in writing groups that helped keep me on track. They have been among my toughest, but most supportive readers and I thank them for that: Rachel Berney, Victoria Chanse, Amy Harris, Neil Hrushwy, Yasuyuki Motoyama, Victor Polanco, and Pitch Pongsawat.

A large number of transportation planners, activists, and other professionals lent me a hand on many occasions by discussing survey design proposals, finding useful data sets, and critiquing my assumptions and arguments: Howard Maier of the Northeast Ohio Areawide Coordinating Agency, Stephen Finnegan of the Automobile Club of Southern California, David Beach of EcoCity Cleveland, Greta Vohlers of the Sacramento Regional Transit District, Gordon Garry and Robert McCrary of the Sacramento Area Council of Governments, John Holtzclaw and Robert Solotar of the Sierra Club, Larry Bye of Field Research Corporation, and Janet Hapson of the Oak Ridge National Laboratory.

The one thousand, five hundred and six anonymous respondents who helped me out with their answers to the survey did me a great service. It goes without saying that this dissertation would not have been possible without their giving me their time and thoughtful responses and I'm grateful to them for that.

Many other colleagues, friends, family, and neighbors have helped me out with large and small pieces of this project, from thinking through arguments to stuffing survey envelopes (8,000 of them!). They have all generously given me one of the most important things a graduate student working on a dissertation needs: moral support. Many thanks to them all: Idalina Baptista, Veronica Carrizales, Mike Duncan, Bill Eisenstein, Christopher Ferrell, Karen Frick, Todd Goldman, Aaron Golub, Junhee Kang, Lewison Lem Lee, Jonathan Mason, Noreen McDonald, Larry and Rita Murillo, Gregory Newmark, Madhukar and Nitika Pai, Sungjin Park, Lynn Purkey, Gerardo Sandoval, Gian-Claudia Sciara, Matthew Taecker, Asha Weinstein, Aaron Taecker-Wyss, Joseph Taecker-Wyss, John Thomas, Rana Tomaira, and Marianne Wyss. My parents-in-law, Hans and Edith Wyss, have consistently encouraged me with their support and their enthusiasm. And my parents, Carla and Daniel Flamm, instilled a love of learning in me and have supported it in countless ways over the years.

Finally, I am grateful to my wife, Esther Wyss-Flamm, who has been with me through the thick and thin of these years of doctoral study and whose love, support, curiosity, and care have helped me get to this point. And to my children, Maya and Theo, who have given me fresh eyes and helped me keep a clear perspective.

CHAPTER 1. INTRODUCTION

In the summer of 2003, a two year long series of arson attacks on car dealerships intensified in a wave of incidents in southern California, New Mexico, Pennsylvania, and elsewhere. The attacks were attributed to members of the Environmental Liberation Front and, in each case, the targets of the vandals were large all-terrain and sports utility vehicles, such as Ford Explorers and General Motors Hummers. Fortunately, nobody was hurt or killed, but the property damage ran into the millions of dollars.

The attacks received national and international attention, including a report by a San Francisco Bay Area radio station from a Hummer dealership in Los Gatos. The purpose was to gauge local reaction to the attacks from people who owned vehicles that would be considered potential targets should the attacks spread to northern California.

One Hummer owner interviewed for the story made a very interesting comment that piqued my interest in the topic that would become the subject of this research project: the relationships between environmental knowledge, environmental attitudes, and vehicle ownership and use. She said she believed it was "possible to own a Hummer and be environmentally conscious. 'I think all cars use a lot of gas and if you just drive it in a safe manner you could economize with the amount of gas you have'" (KCBS/AP 2003).

The woman was correct in saying that it is possible to drive a Hummer and be environmentally conscious at the same time. People have many reasons for choosing the vehicles they own and their environmental attitudes may be only one of many factors that go into their decisions. And she was absolutely right in asserting that the way in which a vehicle is driven can make a large difference in its fuel efficiency. Driving at the speed limit on highways (instead of going with a flow of traffic that may be 10 to 15 miles per hour higher), keeping tires properly inflated, using the right grade of oil, changing air filters when needed, and combining trips can save 20% or more in fuel use, depending upon the vehicle and the conditions under which it is normally operated.

But her implication that owning a Hummer could be as environmentally responsible as owning other types of vehicles was both odd and incorrect. Hummers weigh more than 8,500 pounds, exempting them from U.S. Environmental Protection Agency fuel efficiency requirements and the stricter pollutant emissions standards that passenger cars are subject to. While a Hummer can be operated in ways that are more or less environmentally responsible, it can never be operated in a way which is as efficient or emits as few pollutants as just about any passenger car on the market, not to mention any but the very largest of SUVs. It simply cannot be done.

I was intrigued by the combination of pro-environmental attitudes, accurate assertions, and erroneous implications wrapped up in a short quote. Here was a woman who apparently owned a gas-guzzling vehicle, suggested she considered herself an environmentalist, and knew that driving efficiently makes a difference in fuel economy. Yet she still seemed to believe that a Hummer could be as environmentally responsible as any other vehicle.

What was going on here? Was she alone in holding this intriguing mix of beliefs? Or were her opinions about vehicles and the environment shared by other vehicle owners?

Certainly, her apparent pro-environmental attitudes are common. National surveys have demonstrated for decades that most Americans hold pro-environmental attitudes. At the same time, consumption of transportation—the number of vehicles owned, the amount they are driven, the frequency with which people ride together—has risen steadily, year in and year out for decades. What precisely are the relationships between knowledge of the environmental impacts of owning and using vehicles, attitudes toward the natural environment, and vehicle ownership and use?

As I considered these questions and began reading previous studies about environmental attitudes and travel behavior, I learned that the questions had never been addressed thoroughly, either by psychologists or travel behavior researchers. There were many who argued that, despite the pro-environmental beliefs of many Americans, people are simply not ready to make sacrifices—such as buying smaller vehicles than they would otherwise select or driving less and taking public transit more often—for benefits that accrue to society at large (Lave 1998). In the field of marketing, some researchers concluded that "For most automobile shoppers in the U.S., environmental pluses and minuses rate somewhere below the number and location of cup holders in the hierarchy of reasons to buy a particular vehicle" (Los Angeles Times, 29 March 2000, quoted in Kurani and Turrentine 2002). But there was little empirical evidence to back up these claims in terms of the specific relationship between environmental attitudes and vehicle ownership and use. No one had conducted a study specifically designed to address the issue.

To fill this gap, I decided to design a survey that would test the hypotheses that environmental knowledge and environmental attitudes *do* affect the number and types of vehicles households own, how much household members drive them, and, consequently, how much motor fuel they consume annually. I expanded the hypotheses to include a test of the link between environmental knowledge and environmental attitudes, an exploration into the possibility that behavior affects knowledge and attitudes in a mutually reinforcing, "bi-directional" manner, and an examination of people's perceptions of the constraints they face in making their vehicle ownership and use more fuel efficient and less polluting. This dissertation is the result of my efforts.

Before describing details of how I designed and implemented this study, some background information is useful. To understand why these questions are important, I review important recent trends in vehicle pollutant emissions and fuel efficiency, key indicators of travel behavior, and Americans' attitudes toward the natural environment.

Cleaner cars and pro-environmental attitudes

Over the past 35 years Americans have made extraordinary strides in reducing many of the aggregate and per capita environmental impacts of their vehicle ownership and use. National emissions from private vehicles of all "criteria pollutants"—those that the U.S. Environmental Protection Agency is required to regulate by the federal Clean Air Act and Clean Air Act Amendments—have been significantly reduced over the past three decades. National carbon monoxide (CO) emissions from all light duty gasoline vehicles (cars, pickup trucks, sports utility vehicles, mini-vans, and vans) dropped 71% between 1970 and 2002 from 119 million short tons (58% of all national carbon monoxide emissions from all sources) to 34 million short tons (31% of all national carbon monoxide emissions from all sources). Nitrogen oxides (NOx) emissions fell 75% over the same time period; volatile organic compounds (VOC) emissions decreased 90%; particulate matter (PM-10) emissions fell 79%; sulfur dioxide (SO_2) emissions dropped 27%; and lead emissions have all but completely disappeared because of the element's removal from gasoline (U.S. Environmental Protection Agency 2005). Most vehicles are so much cleaner that analysts can argue “a modern, properly functioning passenger car produces roughly 1% of the health-threatening pollution emitted by a car built in the 1960s” (Greene 2004, p. 285).

Pollutant emissions technologies (for example, catalytic converters) and reformulations of gasoline have been critical to this success, as has the rising fuel economy of cars, light duty trucks, and heavy duty trucks. In 1970, all passenger cars on the road averaged 13.5 miles per gallon; by 2002, that figure had risen to 22.1 mpg. The average 2002 vehicle, therefore, would have emitted 39% less pollutants per mile driven than a 1970 vehicle, even without improvements in pollution technologies and fuels. The fuel economy of two-axle, four-tire truck (a category that includes vans, pickup trucks, and SUVs) made similar gains over the same time period, increasing from 10.0 mpg to 17.6 mpg (Davis and Diegel 2004, Tables 4.1 and 4.2).

Public support for making cars and trucks cleaner and more fuel efficient has been strong, a reflection of Americans’ long-held pro-environmental attitudes. For more than three decades, U.S. survey respondents have consistently said that they believe stricter laws and regulations to protect the natural environment are worth the economic costs incurred.[1] What began in the mid-1970s as a strong plurality of people who were willing to pay some economic costs in order to protect the environment, rose to solid majorities of 55% to 65% by the late 1980s (see Figure 1.1 below), a level that has been maintained since then (Hand and Macheski 2003). Kempton *et al.* (1995) summarize evidence from more than 25 years of studies by concluding that:

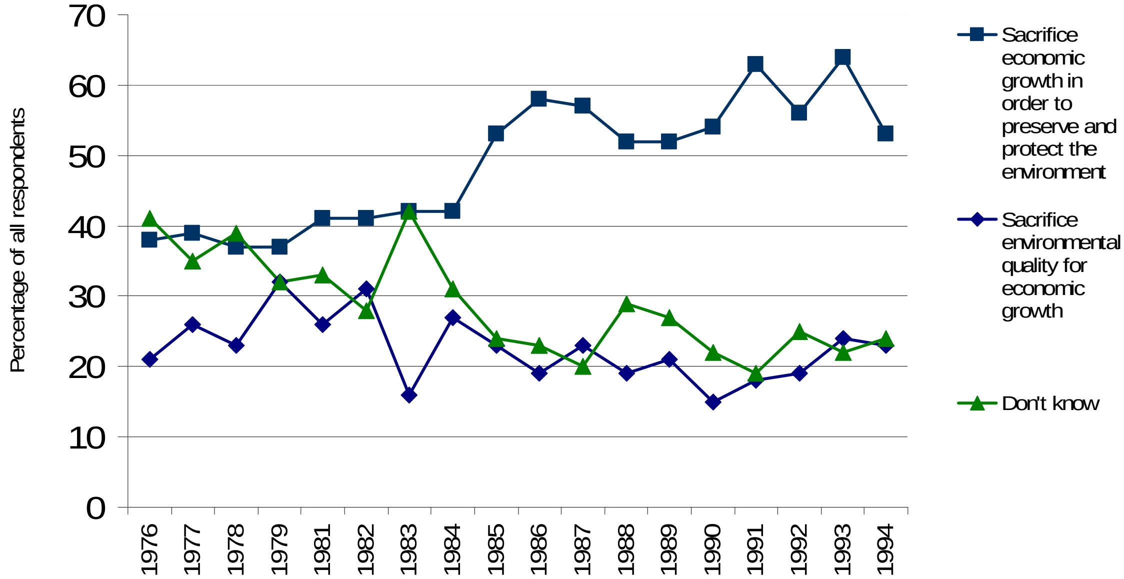
---

[1] This was in answer to a now classic choice of two statements that survey takers give to respondents: “Do you believe that stricter environmental laws and regulations cost too many jobs and hurt the economy? or Do you believe that stricter environmental laws and regulations are worth the cost?”

> "Americans have become significantly more proenvironmental since the sixties, and especially since 1980; their environmentalism goes deeper than just opinion or attitude to core values and fundamental beliefs about the world; and their environmentalism affects market and voting behavior." (p. 4)

With such widespread support for the environment, it seems reasonable to expect that Americans would support cleaner fuels and vehicle pollution control and fuel-efficiency technologies, even if they increase the costs of vehicles and fuel.

Figure 1.1: Americans' environmental attitudes, 1976 to 1994



Source: *Cambridge Reports* trend data, cited in Hand and Macheski, 2003

Going beyond technological efforts to clean up vehicle emissions and make vehicles more fuel efficient by changing travel behavior patterns could reduce the environmental impacts of transportation even more. Owning fewer vehicles, driving less, taking transit, walking or bicycling more, and car- and van-pooling: all of these actions would reduce consumption of resources and emissions of pollutants because fewer private passenger vehicles would be manufactured and those that were built would be used more efficiently. So might these high levels of pro-environmental attitudes also suggest a willingness on the part of the American people (at least those responding that protection of the natural environment is worth the economic costs required) to modify some of their behaviors to realize even greater environmental benefits?

Rising consumption of vehicles and travel

The answer to this question appears to be "no." There is no evidence, at least at the aggregate level, for pro-environmental behavioral change in vehicle ownership and use during the past thirty years. The extraordinary accomplishments in pollution reduction from vehicle ownership and use appear to have all come from technological changes, not changes in Americans' behavior.[2,3] From 1970 to 2002, while vehicles became cleaner and fuel efficiency was increasing, Americans' per-capita "consumption" of travel, as measured by the most commonly used travel behavior indicators (vehicle-miles traveled, passenger-miles traveled, occupancy rates, mode choice, and vehicle ownership per capita), has steadily increased almost every year above the previous year's level (see Figure 1.2 below).

For example,

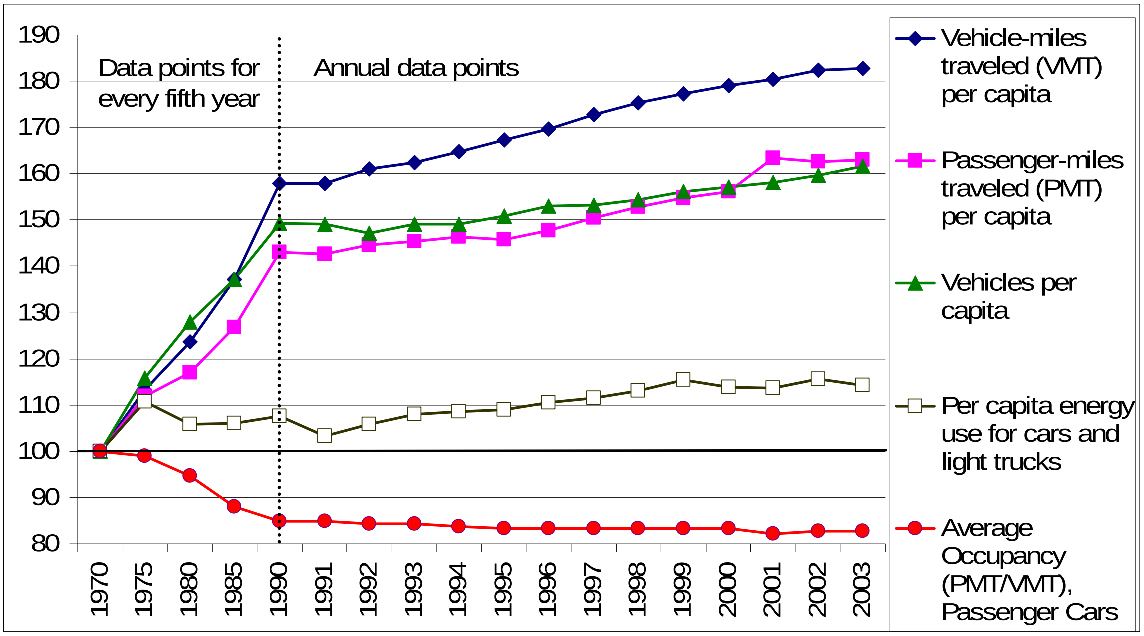
- **Americans own more vehicles**. The national fleet of vehicles rose from about 100 million in 1970 to over 220 million in 2002, with per capita vehicle ownership rising from 0.48 to 0.77, an increase of 59% (Davis and Diegel 2004, Tables 3.3 and 8.2).

---

[2] A comparable situation exists with motor vehicle death rates where declining numbers of deaths are attributed to technological advances that have made vehicles safer, not to better driving (i.e., safer behavior) on the part of motorists (see Insurance Institute for Highway Safety 2006).

[3] Some analysts argue that consumer preferences have prevented technology from contributing as much as it could to reducing the environmental impacts of transportation. "Consumer preferences for large, powerful vehicles and the array of sometimes contradictory regulations have inhibited greater progress" in building "green" vehicles, according to Maclean and Lave (2003, p. 5445).

Figure 1.2: Key travel behavior indicators show rising levels of consumption



- **Fuel efficiency gains have stalled, in large part due to Americans' preference for larger, less fuel efficient vehicles**. While the twenty-four year period between 1978 and 2002 witnessed a 24% increase in car and light truck fleet fuel economy (from 20.1 mpg in 1978 to 25.0 mpg in 2002), fleet fuel economy peaked in 1987 at 26.2 mpg. Since then the rising share of larger, heavier, less fuel efficient light trucks in the total fleet (from 9.8% in 1979 to 50.1% in 2003) has gradually pulled the overall fleet average down (National Highway Traffic Safety Administration 2004).
- **Americans use vehicles to travel longer distances**. 1970 vehicle-miles per capita of 5,440 rose 82% to 9,903 by 2002 (Davis and Diegel 2004, Table 8.2) and passenger-miles per capita increased 62% from 9,958 to 16,193 (calculated from population statistics in U.S. Census Bureau 2004, p. 7; U.S. Department of Transportation Bureau of Transportation Statistics 2005, Table 1-37).

- **Americans share travel less often with others**. Passenger-miles per vehicle-mile in passenger cars (a measure of vehicle occupancy) has fallen 17% from 1.91 in 1970 to 1.58 in 2002 (calculated from Federal Highway Administration 1997, Table VM-201 and updates; U.S. Department of Transportation Bureau of Transportation Statistics 2005, Table 1-37). Shrinking average household size in the U.S., from 3.21 people in 1969 to 2.58 in 2001, and reductions in car-pool commuting are two contributing factors to this change (U.S. Census Bureau 2003).
- **Americans use private vehicles for more of their travel than ever before**, with shared and non-motorized forms of transportation being used for a smaller proportion of trips than in the past. For example, the percentage of workers commuting alone by private vehicle grew from 64.4% in 1980 to 76.3% in 2000. During the same time period, workers who carpooled decreased from 19.7% to 11.2%, workers using all forms of public transportation dropped from 6.4% to 5.2%, workers using bicycles to get to work fell from 0.5% to 0.4%, and workers walking to work dwindled from 5.6% to 2.7% (Davis and Diegel 2004, Table 8.14).

One result of these behavioral trends is that, even though cars are now much more energy efficient than they were, Americans consume more energy driving today than they did thirty years ago. In 1970, per capita energy use from light duty vehicles was 48.9

million Btu (British thermal units), but by 2002 it had risen 15% to 56.1 million (calculated from Davis and Diegel 2004, Table 2.6; U.S. Census Bureau 2004, p. 7).[4]

Environmental and quality of life impacts of rising consumption

Much of the potential gain in reduced emissions and fuel use is thus being offset by rising levels of consumption. In fact, the consumption of resources for transportation is the single most harmful consumer activity in terms of four of seven categories of environmental impacts assessed by the Union of Concerned Scientists: greenhouse gas emissions, common air pollution emissions, toxic air pollution emissions, and toxic water pollutant emissions (Brower *et al.* 1999, p. 248).[5] This unfortunate status for Americans' travel behavior is most directly tied to the number and types of vehicles Americans own and the amount they drive them. These, in turn, exacerbate the most vexing transportation problems facing planners, elected officials, citizens, and residents: air quality, greenhouse gas emissions, environmental impacts of infrastructure construction and vehicle manufacture and disposal, and traffic congestion.

Despite technological advances, air quality is poor in many American metropolitan regions to the point where the health of some people, particularly those susceptible to respiratory diseases, is negatively impacted (McConnell *et al.* 2002). This is due in large part to the regional impacts of NOx, VOC, PM, and SO_2 emissions from

---

[4] Total transportation energy use per capita rose even faster—25% over the same time period from 75 to 94 million BTUs—because air travel increased substantially.

[5] The study's authors concluded that the average American household's environmental impacts from transportation accounted for 32% of its total contribution to global warming, 28% of its contribution to common air pollution, 51% of its contribution to toxic air pollution, 23% of its contribution to toxic water pollution, 7% of its contribution to common water pollution, 2% of its contribution to habitat alterations due to water use, and 15% of its contribution to habitat alteration due to land use (see Table A.4, pages 234 to 240). Private vehicles were responsible for 85% to 94% of the average household's environmental impact from all forms of transportation (air travel, recreational vehicles, rail, transit, and marine travel accounted for the remaining portions).

private vehicles and heavy duty trucks. For example, 474 counties—in which almost 160 million Americans resided—were in non-attainment for the 8-hour ozone standards in April, 2005.[6] Atlanta, Denver, Los Angeles, and Houston—all cities with large concentrations of people and the vehicles they own and use—face serious challenges to meeting current minimum air quality standards set by the U.S. Environmental Protection Agency.[7] So, although individual vehicles emit vastly fewer pollutants than they did just a few decades ago, the large population increases in these regions and the even larger increases in the number of vehicles and miles driven have offset some of the environmental gains that might have been realized.

Greenhouse gas emissions from the use of light duty vehicles (primarily carbon dioxide, an unregulated emission directly related to the quantity of fuel combusted) grew 19% between 1990 and 2002, representing 20% of total U.S. carbon emissions from fossil fuel combustion (Davis and Diegel 2004, Table 11.05). The transportation sector as a whole (including all modes: rail, air, water, and personal and commercial vehicles) accounted for 32% of all U.S. carbon emissions in 2002, larger than any other sector, residential, commercial, or industrial (Davis and Diegel 2004, Table 11.04). The U.S. transportation sector is thus the single largest national sectoral source of greenhouse gas emissions in the world.

And traffic congestion continues to rise in hours of delay caused to commuters. This is the result of rising demand for roadway space (primarily due to rising population and increasing numbers of commuters using single-occupancy vehicles) in an

---

[6] See the U.S. EPA's online Green Book at http://www.epa.gov/oar/oaqps/greenbk/.

[7] These cities could have met earlier standards. The standards are stricter today because the U.S. EPA, in order to protect human health and the natural environment, has tightened them as knowledge of the public health impacts of air pollution has deepened.

environment of restricted supply of roadway space. While the impact of traffic congestion on the natural environment is difficult to quantify (vehicles operate less efficiently and emit more pollutants per mile when stuck in traffic, but persistent congestion in a region may motivate more commuters to take transit, walk, or bicycle), its impact on the quality of life is clearer. The Texas Transportation Institute's annual study of congestion in U.S. metropolitan areas concludes that the average American peak hour traveler experiences 47 hours of delay per year due to congestion, up from an average of 16 hours of delay per year in 1982, while the number of urban areas with more than 20 hours of delay per peak hour traveler rose from 5 to 51 over the same time period (Schrank and Lomax 2005, p. 1).

A final important environmental impact related to vehicle ownership and use is the amount of resources required to build and operate the fleets of cars and light duty trucks that Americans rely on and the infrastructure required to use them. Researchers who have conducted life-cycle energy analyses of passenger vehicles estimate that over a quarter of all energy consumption and greenhouse gas emissions and over half of toxic pollutant emissions attributable to the average vehicle come from manufacturing, servicing, and disposal, with most of the impacts coming from the manufacturing phase (Maclean and Lave 1998, 2003). Building and maintaining a roadway infrastructure contributes to even greater energy consumption and greenhouse gas emissions on a per-vehicle basis (Lenzen 1999).

Even were far cleaner propulsion systems invented and commercialized for the fleet of passenger vehicles—electric motors and hydrogen fuel cells, for example—and sustainable forms of electricity generation and hydrogen production developed, vast quantities of energy and resources will still be required to manufacture vehicles and roadway infrastructure. While it is possible to envision a future system of cleaner and far more fuel efficient vehicles which could reduce pollutant emissions and greenhouse gas emissions (at least from vehicle tailpipes), the environmental impacts of vehicle ownership and use would remain significant and traffic congestion would endure as a challenge to quality of life in many metropolitan regions.

Demographic and economic changes over the past thirty years can explain some of the increases in vehicle ownership, miles driven, and traffic congestion. The national population grew 61% between 1960 and 2003, from 181 million people to 291 million (U.S. Census Bureau 2004), while, because of decreasing average household size, the number of households increased by 111%, from 53 million to 111 million (U.S. Census Bureau 2003). Women have steadily increased their labor force participation rate over the past 35 years. Incomes have risen, permitting the purchase of more, more powerful, and larger vehicles. Oil prices have been at historically low levels for most of this period. And land use patterns in most metropolitan areas have become more dispersed, making shared and non-motorized modes of transportation more difficult to employ. While these trends explain some of the rising levels in vehicle ownership and use, the concurrent rise in pro-environmental attitudes is striking.

Are environmental attitudes and vehicle ownership and use related?

Why do we observe high levels of stated support for protecting the environment at the same time most travel behavior indicators show growing levels of consumption? Is there any connection between environmental attitudes and travel behavior and, more specifically, between environmental attitudes and vehicle ownership and use? Do people with pro-environmental attitudes own fewer and more fuel efficient vehicles and do they drive them less than individuals without pro-environmental attitudes? Is there a clear line of causality from attitudes to behavior, or does behavior also influence attitudes? Finally, two related questions should be considered: what role does knowledge of environmental impacts of vehicle ownership and use play in vehicle ownership and use decisions and is such knowledge related to pro-environmental attitudes?

This research project was designed to address these questions by exploring relationships at the household level between environmental knowledge, environmental attitudes, and vehicle ownership and use, controlling for differences in demographic and socio-economic conditions. The conceptual basis on which the analysis is conducted draws on psychological models of relationships between attitudes and behavior, including the theory of planned behavior (Ajzen and Fishbein 1980) and the health belief model (see Forward 1994). By incorporating standard demographic and socio-economic variables that have long been used to explore vehicle ownership and use—household size, income, level of education, and others—with measures of environmental knowledge and environmental attitudes, it may be possible to understand more clearly what influence, if any, knowledge and attitudes have on vehicle ownership and use.

It is important to be clear about how knowledge, attitudes, and behavior are defined for the purposes of this research project. Knowledge refers specifically to an accurate understanding of the issue under consideration, that is, the environmental impacts of vehicle ownership and use. An attitude is defined as “a disposition to respond favorably or unfavorably to an object, person, institution, or event" (Ajzen 2001).[8] The relevant attitudes for this study concern respondents' preferences concerning laws and policies to protect the natural environment. Finally, the specific behaviors of interest, measured at the household level, are: 1) number of vehicles owned, 2) types of vehicles owned, as measured by fuel efficiency, 3) estimated annual miles driven, and 4) estimated annual fuel consumption.

The principal research method employed is the statistical analysis of responses to a knowledge-attitudes-behavior (KAB) questionnaire administered in the Sacramento, California metropolitan region in April, 2005. Four thousand households were selected using a two-step sampling method of proportional, stratified selection of 50 U.S. Census Bureau block groups (from the 1,199 block groups in the Sacramento Area Council of Governments planning area), followed by random selection of households for which addresses were available from a commercial database marketing firm. Usable responses were received from 1,506 households, yielding an overall response rate of 39.57% when 194 undeliverable surveys were subtracted from the 4,000 distributed.

Understanding better how environmental knowledge and environmental attitudes relate to vehicle ownership and use may provide important insights into how planners and policy makers can address challenges related to traffic congestion, air quality, energy consumption, and greenhouse gas emissions more effectively. By studying relationships between knowledge, attitudes, and vehicle ownership and use, we may be able to identify strategies for weakening or removing some of the barriers and constraints to less resource- and energy-intensive vehicle ownership and use. What is more, it may be

[8] Ajzen argues that where attitudes are directed at abstractions, such as freedom, honesty, and security, they are better referred to as "values."

possible to broaden the range of projects, programs, and policies that transportation planners can employ to include those which motivate more environmentally conscious vehicle ownership and use.

Such initiatives might include those that make it easier for pro-environmental vehicle owners to align their attitudes with their behavior, such as car- and ride-sharing programs, and the design and support of more responsive, comfortable, convenient transit systems. Providing incentives for owning fewer and more fuel efficient vehicles with, for example, feebate and parking cash-out programs might also facilitate behavior that more closely matches pro-environmental attitudes. Motorists whose knowledge of the environmental impacts of vehicle ownership and use is low may be encouraged to reduce the environmental impacts of their vehicle ownership and use (whether they profess pro-environmental attitudes or not) through public information, social marketing, and travel feedback programs. These policy recommendations will be discussed in the final chapter of this dissertation.

Structure of the dissertation

Following this introductory chapter, I describe in Chapter 2 the analytical framework used to conduct this research and the previous literature that informs it. Relevant studies in the fields of travel behavior, vehicle ownership, and environmental behavior are summarized and discussed. Following this discussion, the research questions and study hypotheses are specified.

In Chapter 3 I explain the study methodology, the sampling method, and the survey design and distribution used to collect the data necessary to conduct the analysis. I describe how I developed, pre-tested, revised, and distributed an original survey of 37 questions (34 closed- and three open-ended questions) covering demographic, vehicle ownership and use, environmental knowledge, and environmental attitudes variables.

Chapter 4 is devoted to a discussion of survey response, descriptive statistics of the sample population, and the distribution of respondents' environmental knowledge and environmental attitudes. I also describe how I developed a set of analytical weights (used in all of the statistical analyses reported on in Chapter 5), required because of sampling and non-responses biases in the data set. Finally, I explain the steps taken to create scales of environmental knowledge and environmental attitudes and my efforts to screen the data set and correct for missing data, skewness and kurtosis, and the presence of outliers.

In Chapter 5 I describe my first set of principal findings that, in large part, confirm the hypotheses detailed in Chapter 2. Environmental knowledge and environmental attitudes are strongly related to each other, as hypothesized. Environmental knowledge proves to have a significant relationship in the expected direction with one outcome variable: average fuel economy of household vehicle ownership. Environmental attitudes, on the other hand, demonstrate significant relationships in the expected direction with all four outcome variables: number of vehicles owned, types of vehicles owned, annual miles driven, and estimated annual fuel consumption. These findings are supported both by differences of means analyses, using t-tests and analysis of variance, and by sequential multiple regression analyses which I used to control for respondent-level, household-level, and physical environment factors.

Chapter 6 is devoted to the findings of the structural equation model developed specifically to explore directions of causality among knowledge, attitudes, and behavior variables. I conclude that there is bi-directionality between environmental attitudes and behavior, as defined by the four indicators of vehicle ownership and use, although the level of causality appears to be stronger for attitudes' impact on behavior than for behavior's impact on attitudes. No evidence was found for a bi-directional relationship between environmental knowledge and behavior; knowledge has an effect on two measures of vehicle ownership and use, but none of the indicators of vehicle ownership and use have a statistically significant impact on environmental knowledge.

Finally, in Chapter 7 I do three things. I review the major findings of this study concerning the relationships between environmental knowledge, environmental attitudes, and vehicle ownership and use. Then I discuss the constraints that respondents feel they face in more directly aligning their attitudes and their actions by summarizing responses to the final three open-ended survey questions. And finally, I conclude the chapter by describing policy and research recommendations supported by the results of this study.

CHAPTER 2. LITERATURE REVIEW AND RESEARCH APPROACH

In this chapter I describe my analytical approach to studying the questions posed in the previous chapter. I start by reviewing several branches of travel behavior literature—vehicle ownership and use, attitudes as predictors of travel behavior, and the role of knowledge in travel behavior studies—as well as theoretical models of behavior that include attitudinal and knowledge variables. This provides the background and justification for the conceptual model developed to guide the analysis, which I describe in detail. Finally, I end the chapter with a description of the specific research questions and hypotheses tested.

Previous research on attitudes and travel behavior linkages

Vehicle ownership and use has long been studied by economists, planners, and other social scientists interested in understanding the determinants, patterns, and likely trends of vehicle ownership and use at the international, national, sub-national, and household levels. In this section of the chapter I summarize the research approaches that have informed these studies and their major findings, then examine the role that attitudes, particularly environmental attitudes, and knowledge have played in understanding travel behavior, in general, and vehicle ownership and use in particular.

Determinants of vehicle ownership and use

Researchers have relied on numerous approaches, methods, and models in their efforts to understand travel demand, travel behavior, and the demand for vehicles. The most traditional approach has been an economic one, in which the concepts of derived demand and utility maximization have proven particularly useful in modeling travel demand. From this perspective, travel is a good that is desired, not for itself, but as a means of access to other goods and experiences. In this sense, the demand for travel is derived by more direct needs and desires for food, household goods, medical attention, employment, communities of worship, and time with friends: goods and experiences that often are not accessible directly adjacent to one's own residence.

Those who have this derived demand for travel (effectively everyone, directly or indirectly) are assumed to want to maximize the utility of travel by minimizing—to a point—the cost of obtaining it, in terms of both money and time. "To a point," because researchers have concluded that individuals throughout the world generally do not try to limit their travel to the absolute minimum—i.e., to reduce it to no travel whatsoever—but, rather, allocate their time and money resources within a roughly constant travel time budget (Schafer 2000). These studies indicate that as incomes rise so too does distance traveled, even though travel time remains relatively constant. Interestingly, this appears to be true regardless of geographic, national, and cultural contexts. People generally accomplish this by substituting costlier, faster, and more resource- and energy-intensive modes of transportation for cheaper, slower, less resource- and energy-intensive modes (i.e. private vehicles substitute for public or non-motorized forms of travel).

Some researchers argue that such travel time budgets (TTBs) are more variable than the aggregate figures suggest. Mokhtarian and Salomon (2001), for example, believe that there is an "unobserved desired TTB, which varies by attitudes, personality traits, demographic variables, mode, and purpose" (p. 716). But the basic concept—that people set travel time budgets and seek to maximize their utility of travel within them—remains unchallenged.

This theoretical approach based on derived demand and utility maximization has ample empirical support in studies of vehicle ownership and use. Researchers from Lave (1977), Train (1982), and Mannering (1985) to Schimek (1996), Dargay (1997), Ingram and Liu (1999), and Pickrell (1999) have found that household income, household size, and costs of vehicle ownership and use are all strong predictors of household vehicle ownership. Cameron *et al.* (2004) summed up this body of research with the conclusion that "the worldwide increase in urban mobility since 1960 has been the direct result of increased affluence and the consequent greater accessibility of private motor vehicles" (p. 287).[9]

Other variables have also been linked to vehicle ownership and use. Holtzclaw *et al.* (2002) found that, in addition to household income and size, residential density and transit access had significant impacts on travel demand and number of vehicles owned. And demographic variables, such as levels of education, age, residential location type, race, and ethnicity have also been shown to be associated with vehicle ownership and use and mode choices. John Pucher and colleagues, in a series of articles analyzing the Nationwide Personal Transportation Survey (substantially redesigned in 2001 and renamed the National Household Travel Survey) describe the differences in automobile ownership and travel behavior of various groups of Americans (Pucher *et al.* 1998; Pucher and Renne 2003; Pucher and Williams 1992). The most recent of these articles, for example, documents that per person trips and miles traveled per day both increase with household income, as does vehicle ownership.

[9] They caution, however, that the income-vehicle ownership link is not deterministic; some metropolitan regions around the world have used urban and transportation planning policies to influence the rates of growth in vehicle ownership and the travel patterns and modal splits of regional populations.

The large literature on household vehicle ownership and use provides useful models for studying these indicators, but the variables that have proven most highly correlated with them—household income, household size, costs of car ownership, and residential population density—do not address attitudes and knowledge, two constructs that this study seeks to understand. So, I need to examine additional branches of the travel behavior literature.

Attitudes as predictors of travel behavior

Why have researchers included attitudes as predictor variables in some travel behavior analyses? They have done so because attitudes influence decisions in ways that may not be entirely rational, adding a new concept with potential for greater explanatory power to traditional studies of travel behavior. Rationality—the idea that individuals make informed decisions based upon careful consideration of the choices they perceive—is an important assumption in utility maximization theory. But an individual's likes and dislikes—his or her "disposition to respond favorably or unfavorably to an object, person, institution, or event," as Ajzen (2001) defines attitudes—may lead to vehicle ownership decisions that confound or contradict expectations based on the theory of utility maximization. Attitudes may even lead to broader decisions about how, or even if, to travel from point A to point B. In this sub-section, I describe how attitudinal factors have been incorporated in travel behavior research, in general, and vehicle ownership and use studies, more specifically.

Attitudes are key predictors in what is known as the behavioral approach to travel demand research. Researchers using this approach draw on psychological and sociological concepts of how and why individuals make decisions about how they travel, when, with whom, by what modes, and how often. Studies of travel demand management (Wachs 1991), the impact of the built and physical environments on travel behavior (Cervero 2002; Cervero and Kockelman 1997; Cervero and Radisch 1996), and lifestyles (Choo and Mokhtarian 2002; Krizek and Waddell 2002) also fall within this body of research.

Kitamura *et al.* (1997) argue that attitudes have only rarely been used in analyses of travel demand, for a variety of reasons.

> "Among the most important reasons are the various difficulties encountered when measuring and forecasting attitudes. Also important is the view that attitudes are, like travel behavior itself, elements that are to be explained, but not to be used to explain behavior. In fact there are competing hypotheses regarding the relationship between attitudes and behavior: attitudes are formed through experience as a result of behavior; attitudes prompt certain types of behavior; and interactive, two-way relationships exist between attitudes and behavior" (p. 149).

To study attitudes-travel behavior relationships in more detail, they asked respondents residing in five neighborhoods of the San Francisco Bay Area (N=1,380) to consider thirty-nine statements representing attitudes toward various aspects of urban life. Their responses were factor analyzed, resulting in the identification of eight principal types of attitudes: pro-environment, pro-transit, suburbanite, automotive mobility, time pressure, urban villager, TCM (support for transportation control measures), and workaholic. The results of their analysis, which included measures of the physical environment and socio-economic variables, led them to conclude that attitudes were more powerful predictors of behavior than physical environment characteristics were. "In particular, the number of trips by travel mode and modal split are both strongly associated with factors that represent individuals' attitudes toward the environment, public transit, automotive mobility, urban forms, and time" (p. 154). Handy *et al.* (2005), in a study of eight neighborhoods in the Sacramento and San Francisco Bay Area metropolitan regions, came to a similar conclusion that the influence of the built environment on travel behavior (commute, non-work, and walking trips, vehicle ownership, and miles driven per week) almost disappears after controlling for attitudes, except when using a quasi-longitudinal approach, where both attitudes and built environment prove significant.

Golob and Hensher (1998) studied the impact of attitudes toward climate change and policies aimed at reducing greenhouse gas emissions on two types of travel behavior: commuters' mode choice (solo driving or public transit) and the use of compressed work weeks. They found that individuals who did not perceive climate change as a serious threat were more likely to be solo drivers. They were less willing to reduce their vehicle mileage, but were willing, in general, to use compressed work week schedules. Individuals with a strong commitment to the environment were more likely to use public transit, but there was evidence that the behavior influenced the attitude more strongly than the attitude influenced the behavior.

More directly relevant to this study, some researchers have used groups of attitudes, including environmental attitudes, in exploring vehicle type choice—an important factor in studying vehicle ownership and use. Choo and Mokhtarian (2002), for example, confirmed the importance of such attitudes in a study of vehicle type choices based on a survey of a sample of residents in three neighborhoods of the San Francisco Bay Area. They modeled vehicle type choice (defined as the type of the vehicle that a respondent drives most frequently) by considering groups of dependent variables representing objective mobility, subjective mobility, travel liking, attitudes, personality, lifestyle, and demographics. They identified attitudes from responses to thirty-two questions which fell into six categories: travel dislike, pro-environmental solutions, commute benefit, travel freedom, travel stress, and pro-high density. They used a multinomial logit model which achieved a ρ^2 value of the 0.177 (i.e., the model explains 17.7% of the information in the data, a figure comparable to similar studies they cited), and included two of their six attitudinal measures: travel dislike and pro-high density. The study had several limitations, including its focus on only the vehicle driven most frequently (other vehicles in the household were disregarded), but the study confirmed that attitudinal variables can play an important role in predicting some aspects of vehicle ownership.

Knowledge in travel behavior research

While attitudinal variables have been included in many studies, researchers have only rarely examined the role of knowledge in vehicle ownership and use decisions. Nevertheless, in the broader field of travel behavior, knowledge has been an important consideration in recent years when exploring the determinants of mode choice. While the studies to be discussed below are not directly relevant to this dissertation research, they remain important for their consistent finding that when levels of knowledge directly relevant to the behavior of interest change behavior too often changes.

Australian researchers and transportation planners have explicitly worked to foster voluntary changes in travel behavior through various initiatives. To do this, they have used several approaches, all based upon providing travelers with information about shared modes of transportation and, in some of the projects, specific environmental impacts of various travel modes.

For example, Rose and Ampt (2001) conducted research into individuals' ability to voluntarily reduce their use of personal vehicles. They hypothesized that by providing commuters with detailed information about the environmental impacts of personal vehicle use and the alternatives available to travelers in their communities some of their subjects would combine more personal trips and take public transportation for some of them. Through the program they called "Travel Blending," 100 households in the Adelaide metropolitan region of Australia were provided with this targeted information and advice. The result: a "10% reduction in car driver kilometres and a slightly higher percentage reduction in car driver trips and total hours spent in the car" (p. 109). Over time, the results of travel blending programs seemed to be sustained and, in some cases, further reductions in the use of vehicles was observed (Taylor and Ampt 2003).

Brog (1998) conducted similar research, using a program dubbed "Indimark" (for Individualized Marketing) that educated travelers on both the environmental impacts of the use of private vehicles and the practical alternatives that could be used. His initial assumption was that "information about the alternative of using public transit is insufficient and that the perception of these alternatives—even if they are recognized—is that they are worse than they really are" (p. 116). He concluded that the program effectively led to significant reductions in vehicle use and corresponding increases in public transit use. Taylor and Ampt (2003) reported that follow-up studies found the reductions in auto use attributed to IndiMark programs were not only sustained over time, but became more pronounced "yielding an additional 3% reduction in VKT (a 17% reduction in VKT from the initial situation)" (p. 170).

Not all efforts to use knowledge in this way have resulted in the same findings. Researchers in Japan (Fujii and Taniguchi 2005) concluded that the provision of knowledge to their sample population was less important to changing a household's mix of travel modes than was the encouragement to plan trips more pro-actively. This raises questions about the source of the behavior change in travel mode studies. In both the Travel Blending and Indimark programs subjects increased their environmental knowledge *and* their practical knowledge about the local public transit systems at the same time they also received incentives, such as no-cost bus passes, to modify their travel behaviors. It is, therefore, unclear to what extent higher levels of environmental knowledge affected behavior. Nevertheless, these studies suggest that, at least in some circumstances, knowledge can play a role in affecting some types of travel behavior.

Bringing knowledge, attitudes and travel behavior together

In conducting this literature search, I was able to identify only two articles that examined the specific relationships of interest in this study: environmental knowledge, environmental attitudes, and the environmental impacts of travel behavior. Swedish researchers Nilsson and Küller (2000) studied the environmental knowledge, environmental attitudes, and travel behavior of samples of citizens and public officials in the town of Lund (population 71,000). Using information from 422 respondents (51% of 827 distributed surveys), they measured travel behavior by annual driving distance, frequency of trips, choice of travel mode, and level of acceptance of potential traffic restrictions. They concluded that "environmental attitudes were more potent than factual knowledge in promoting pro-environmental travel behaviour," (p. 229) that is, attitudes explained more of the variation in behavior than knowledge did. Attitudes' impact on frequency of trips, travel mode, and acceptance of travel restrictions policies was significant, but not large, being much less important than demographic and economic attributes in explaining behavior, as defined by the researchers. The impact of knowledge was only significant on one variable—acceptance of travel restrictions policies—and only minimally so.

Researchers in New Zealand (Walton *et al.* 2004) addressed the relationships between environmental concern (a construct similar to environmental attitudes), environmental knowledge, and travel mode choice by distributing a survey to three groups of commuters: train and bus commuters, private motor vehicle commuters, and a subset of the second group, smoky vehicle commuters. Their sample included responses from 566 commuters, which they used to test two travel behavior-related hypotheses: 1) train and bus commuters have higher levels of environmental concern and knowledge than commuters who use private vehicles and 2) smoky vehicle drivers have lower levels of environmental concern and knowledge than do other private vehicle commuters. In both cases, they found no significant relationship; smoky vehicle drivers were no less environmentally concerned or knowledgeable than other private vehicle commuters and public transport users were no more concerned or knowledgeable than other commuters. They concluded that "environmental concern… [was] independent of behaviour exhibited by the commuting samples in New Zealand" (p. 338).

In the case of both of these studies, environmental knowledge was found to have a minimal or insignificant impact on the measures of travel behavior the researchers focused on. Nevertheless, Nilsson and Küller argued in their conclusion that "[d]espite the weak link between factual knowledge and pro-environmental behaviour, knowledge must be an operand in establishing environmental concern and should not be neglected" (p. 229). This is so because of the central role knowledge plays in many theoretical models of attitude-behavior relations and for both intuitive and practical reasons when vehicle ownership and use are considered. Intuitively, it is unlikely that an individual with pro-environmental attitudes could make vehicle ownership and use decisions that were effective in reducing environmental impacts without knowledge of how owning and using vehicles affect the environment. And practically, a decision by an individual with pro-environmental attitudes to reduce the environmental impacts of personal vehicle ownership and use requires an ability to assess vehicles by class, emissions, and fuel efficiency.

Yet, as we have seen, only limited research has addressed the direct relationships between environmental knowledge, environmental attitudes, and travel behavior and vehicle ownership and use. While growing literatures on sustainable transportation (Committee for a Study on Transportation and a Sustainable Environment 1997, 1997; Deakin 2001; OECD Project on Environmentally Sustainable Transport 2000; World Bank 1996) and the social costs of transportation (Delucchi 2000, 1997; Murphy and Delucchi 1998) have documented the environmental impacts of transportation and travel behavior, I had to turn to the field of psychology for models to analyze environmental behavior related to transportation choices and the role of environmental knowledge and environmental attitudes.

Theories of attitudes and behavior linkages

The specific relationships I study in this research project are indicators of environmental behavior: actions that we expect reflect, at least in part, individuals' attitudes toward and knowledge of the environmental impacts of owning and using personal vehicles. Consequently, it is helpful to review the definition of "environmental behavior" before considering the theoretical concepts that contribute to this study's analytical framework.

Environmental behavior

Researchers have struggled to define what they mean by environmental behavior and to settle on the appropriate term for it: ecologically-oriented behavior, environmentally significant behavior, environmentally conscious behavior, pro-environmental behavior, environmentally sustainable behavior, and environmentally benign behavior have all been used to refer to the same concept. Stern (2000) defines it this way: "Environmentally significant behavior can reasonably be defined by its impact: the extent to which it changes the availability of materials or energy from the environment or alters the structure and dynamics of ecosystems or the biosphere itself" (p. 408). But he notes that many researchers have given it a different definition by focusing on the actor's intentions toward, rather than the tangible impacts of, a given behavior.

Gatersleben *et al.* (2002) are critical of the majority of researchers who have explicitly or implicitly studied only those behaviors based on the latter definition.

> "[I]t is often assumed they enable us to make valid distinctions between those who are more and those who are less environmentally harmful. However, this may not always be a valid conclusion. Although the actual environmental impact of people who indicate they behave more proenvironmentally is likely to be somewhat lower, common social science measures of proenvironmental behavior (based on popular notions of environmentally significant behavior) are often only weakly related to the actual environmental impact of people's behavior" (p. 336).

If the actual impact on the environment is considered important, therefore, the impact-focused definition is preferable, for it requires measurement of environmental effects in a way that permits empirical comparisons between behaviors.

Our understanding of how common such pro-environmental attitudes are and their determinants has improved significantly in the recent past. Many researchers argue that these attitudes are based upon an inherent human affinity for nature, what E. O. Wilson called “biophilia,” a concept explored and expanded upon by academics such as Stephen Kellert (1997). Other researchers investigating the origins of pro-environmental attitudes have concluded that they are not based on a single factor, but are multi-dimensional. For example, Kempton *et al.* (1995) argue that environmental attitudes draw on religious and ethical values, pragmatic and anthropocentric orientations, and biocentric beliefs that all living organisms have rights to exist and survive (p. 87). Dunlap *et al.* (2000) identified a different set of determinants of environmental values, concluding that beliefs about the balance of nature, limits to growth, and man's dominance over nature are three key facets of environmental attitudes, reinforcing the idea that they can be traced to multiple beliefs and values.

As environmental attitudes have grown stronger, the question as to what determines environmental behavior has become increasingly important, as a large and growing literature attests. Several researchers have examined simple associations between environmental behavior and demographic and socioeconomic characteristics of individuals and households. Owens *et al.* (2000), for example, found strong, positive associations of annual household income, home-ownership status, and level of education with recycling efficiency.

Most researchers, however, are interested more in *why* people engage in environmental behavior rather than simply in which groups of people behave in this way. Consequently, researchers have focused more energy on exploring motivational and attitudinal factors. The results have been inconsistent, with some studies finding strong relationships and others finding little or no relationship. Hini *et al.* (1995) argue that the effect of environmental attitudes on behavior is weak, at best, and "when attitudes are measured as they commonly are, their predictive ability is unlikely to be higher than about 30%, and could be much lower" (p. 29).

What is more, when assessing previous studies of the impact of environmental attitudes on various types of behavior, Gatersleben *et al.* (2002) found that "environmental attitudes are most strongly related to behaviors that do not have a high impact on people's daily lives (e.g. waste management, political behavior, food purchase...) than to behaviors with a high psychological and financial impact (e.g. transport and energy use...)" (p. 338). Vehicle ownership and use, the subject of this research project, falls into the latter category.

Other researchers have hypothesized that habitual, repetitive behaviors respond less directly to attitudes and/or knowledge about a behavior. Verplanken *et al.* (1997) found that attitudes have a stronger influence on behaviors that are not habitual and that more information is sought out by an individual when novel, non-habitual circumstances occur, presumably increasing knowledge. Weak links between attitudes and behavior are, therefore, expected when habits are strong and frequent, such as often occurs in daily commute behavior. In contrast, Bamberg *et al.* (2003) found that "choice of travel mode is largely a reasoned decision; that this decision can be affected by interventions that produce change in attitudes, subjective norms, and perceptions of behavioral control; and that past travel choice contributes to the prediction of later behavior only if circumstances remain relatively stable" (p. 175). The findings of these two studies suggest that habits can exert a powerful influence on behavior—people will continue to drive, use transit or bicycle to work if they have habitually done so—but that changes in knowledge or the use of some intervention that encourages the individual to reconsider his or her behavior *can* influence future behavior.

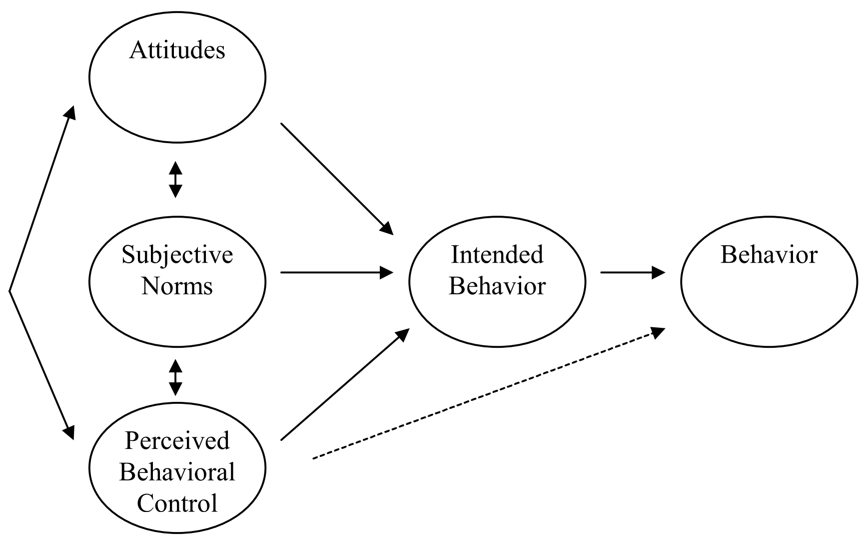
Psychological models linking attitudes and behavior

Psychologists have long sought to understand behavior by examining beliefs, values, concerns, and attitudes. In the course of doing so, they have developed numerous theories and models. The validity and predictive power of such conceptual models has been debated at length, because studies that apply these models empirically have produced mixed results. It appears that there is strong evidence to support a significant relationship between attitudes and behavior (though rarely convincing evidence of a causal link), but it is a link that often depends upon the situational context.

The best known, most frequently applied model is called the *Theory of Planned Behavior* which suggests that, to a large degree, human actions can be explained by understanding human attitudes, of which environmental attitudes are just one type. Icek Ajzen, widely credited with developing the theory (1988), argued that attitudes toward a given behavior, subjective norms about that behavior (or the social expectations of individuals concerning the behavior), and perceived level of control over the behavior all contribute to behavioral intentions. Those behavioral intentions combine with an individual's perceptions of control to produce the actual behavior (see Figure 2.1 below).

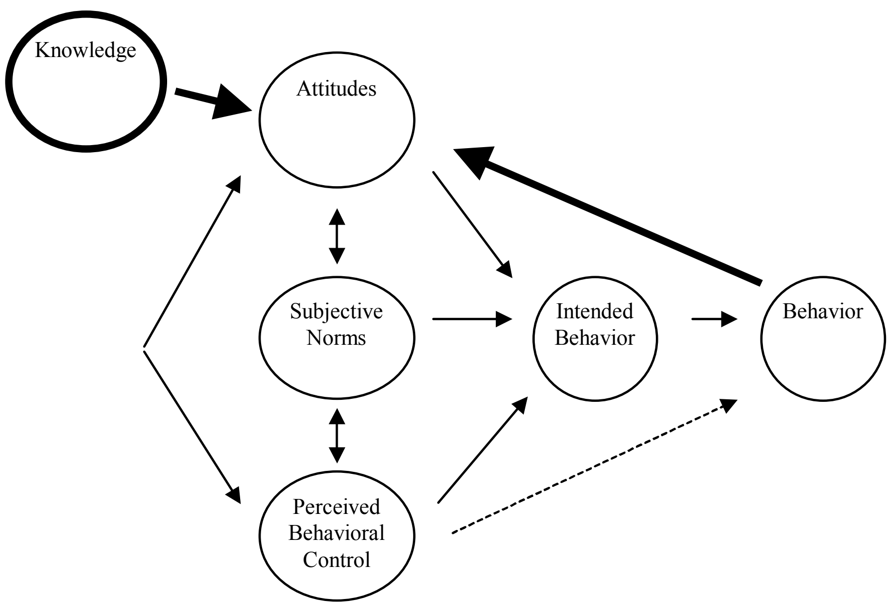
Perceptions of control and constraints on an individual's control are particularly important. They depend, in large part, on the opportunities and constraints (both real and perceived) that individuals are subject to. In the case of vehicle ownership and use, for example, some commuters may have a preference for transit or non-motorized modes of transportation or believe that they should take transit, bike, or walk because of their environmental beliefs and attitudes. But acting on those preferences may be extremely difficult if significant constraints exist. In many cases home destinations are not served by transit or responsibilities to others (such as children who must be picked up and dropped off at childcare facilities or employers who require extensive travel during working hours) preclude any form of commuting other than personal vehicle.

Figure 2.1: Icek Ajzen's Theory of Planned Behavior



Many researchers have refined and modified Ajzen's *Theory of Planned Behavior* by examining additional variables that contribute to behavior or additional relationships between those variables included in the original design (see Figure 2.2 below). For example, it is possible that individuals adapt their attitudes to their behavior, rather than adapting their behavior to their attitudes, particularly when a behavior seems obligatory in some way. When conceived of this way, the relationship between behavior and attitudes is bi-directional. Golob and Hensher (1998), for example, in examining the relationships between attitudes toward climate change and travel behavior, found that behaviors influenced attitudes more strongly than attitudes influenced behaviors.

Figure 2.2: Modifications to the Theory of Planned Behavior



Knowledge-Attitudes-Behavior models

Another important modification to the *Theory of Planned Behavior* concerns the inclusion of knowledge as a variable. Though psychologists often consider knowledge a necessary precursor to attitudes, it is not explicitly included in Ajzen's original model. Researchers such as Kaiser *et al.* (1999) have made it an integral part of their adapted theory of planned behavior. "Because attitude includes not just the evaluation of a certain outcome but also the estimation of the likelihood of this outcome, salient information or factual knowledge is a necessary precondition for any attitude," they write (p. 3). This provides the theoretical grounding for the use of a conceptual model that combines knowledge, attitudes, and behavior (often referred to as a KAB model) in a single framework.

It is important to note, however, that there are varying assumptions concerning how important knowledge is in predicting behavior. There are some who assume that increases in knowledge concerning a particular behavior (or about the "problem" to which the behavior is associated) will lead to changes in behavior. But findings on this point are mixed. Grob (1995), for example, found that "... the most important effects on environmental behaviour come from personal-philosophical values…. The weakest effect was due to factual environmental awareness, contrary to general opinion" (p. 215). Hines *et al.* (1986/87), on the other hand, reported that "[t]he positive correlation coefficient indicates that those individuals with greater knowledge of environmental issues and/or knowledge of how to take action on those issues were more likely to have reported engaging in responsible environmental behaviors than were those who did not possess this knowledge" (p. 2). They acknowledged, however, that there remained great "uncertainty involved in the prediction of environmental behavior" (p. 8).

Very few researchers have brought travel behavior, environmental behavior, and KAB studies together to explore the relationships I want to understand better through this study. Several have addressed knowledge-attitudes-behavior linkages in relation to travel behavior in a more general sense. Two separate studies, for example, have looked at pedestrian behavior as affected by knowledge and attitudes about pedestrian traffic regulations (Moyano Díaz 2002; Yagil 2000). Others have considered driving and commuting behavior as one type of many potential ecologically-oriented behaviors

(Gatersleben *et al.* 2002). Still others have looked at the effects of knowledge and attitudes on seat-belt use (Harré *et al.* 2000) and driving under the influence of alcohol (Kayser *et al.* 1995) by using knowledge-attitudes-behavior analyses. Only the aforementioned research projects by Nilsson and Küller and by Walton *et al.*, however, have explicitly combined environmental knowledge, environmental attitudes, and travel behavior, leaving the nature of these relationships still largely unexplored.

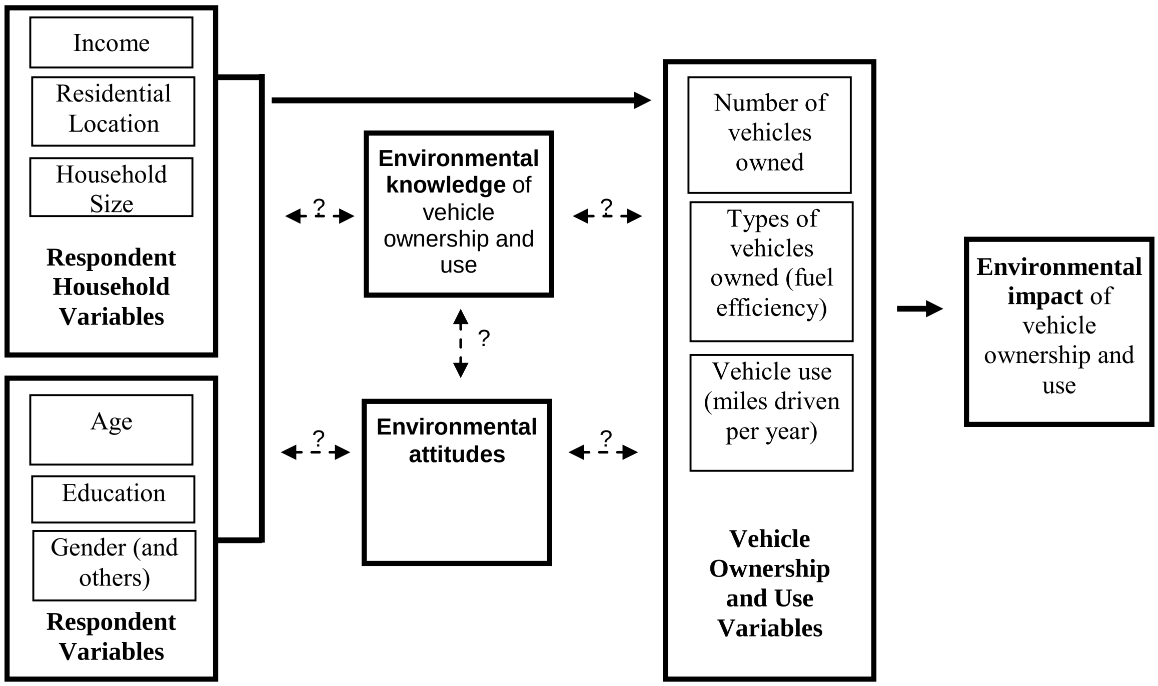
Analytical framework

In this research project, I analyzed the relationships between environmental knowledge, environmental attitudes, three vehicle ownership and use variables (number of household vehicles, average fuel efficiency of household vehicles, and estimated annual household miles driven) and an estimate of fuel consumption related to household vehicle ownership and use (a proxy for environmental impact). The goal has been to understand the degree to which higher levels of environmental knowledge and pro-environmental attitudes may be associated with lower energy and environmental impacts of vehicle ownership and use.

The analysis relied on primary cross-sectional data obtained in a KAB (knowledge-attitudes-behavior) survey administered to a random sample of respondents in the Sacramento, California metropolitan region.

The conceptual framework underlying this research is illustrated in Figure 2.3 below. The nature of the relationships between individual and household demographic and socio-economic variables and vehicle ownership and use—previously demonstrated to be strong—is depicted with solid lines. Dashed lines, on the other hand, indicate that the degree to which environmental attitudes and environmental knowledge affect both socio-economic and demographic variables and vehicle ownership and use is less well understood.

Figure 2.3: Conceptual model of the study



Research questions and hypotheses

The principal question that this research seeks to answer is the following: **Is the environmental impact of a household's vehicle ownership and use affected by levels of household members' environmental knowledge and environmental attitudes?** In other words, do high levels of environmental knowledge and pro-environmental attitudes influence vehicle ownership and use in ways that reduce environmental impacts? By learning the answer to this question, we may have a more thorough understanding of the factors that influence household decisions about how many and what types of vehicles to own, how much to use them, and, consequently, how much motor fuel to consume. If successful, that more complete conception of household vehicle ownership and use could improve the predictive ability of travel behavior models and help develop policies and programs to address transportation planning challenges related to air quality, energy consumption, and traffic congestion.

This question is researchable, but relatively broad, so four more detailed sets of questions will help explore this issue:

- Are environmental knowledge and environmental attitudes positively related? Are people who are more knowledgeable about the environmental impacts of vehicle ownership and use more likely to have strong pro-environmental attitudes and vice-versa? Or are environmental attitudes and environmental knowledge independent of each other?
- Is the environmental impact of vehicle ownership and use different for households represented by individuals with high and low levels of environmental knowledge? How does knowledge about the environmental impacts of vehicle ownership and use affect ownership and use choices? Do individuals with more accurate knowledge of environmental impacts make choices that affect their household's consumption of energy and natural resources?
- Is the environmental impact of vehicle ownership and use different for people with high versus low levels of pro-environmental attitudes? How do environmental attitudes affect household vehicle ownership and use? Do people with high levels of pro-environmental attitudes make choices that reduce their household's consumption of energy and natural resources?

- If relationships between environmental knowledge and vehicle ownership and use, on the one hand, and pro-environmental attitudes and vehicle ownership and use, on the other, are weak—that is, if we observe that vehicle ownership and use has little or no correlation with either environmental knowledge or pro-environmental attitudes—what accounts for people's failure to alter their most resource-intensive behavior in ways that reflect their environmental knowledge and attitudes?

These questions can be expressed in five principal hypotheses and eight sub-hypotheses that this research project will address:

Hypothesis 1: Knowledge of the environmental impacts of vehicle ownership and use is positively related to pro-environmental attitudes.

Hypothesis 2: Knowledge of the environmental impacts of vehicle ownership and use is related to less resource-intensive household vehicle ownership and use. Therefore, all else being equal:

2a) High levels of knowledge of the environmental impacts of vehicle ownership and use are related to <u>lower vehicle ownership</u>.

2b) High levels of knowledge of the environmental impacts of vehicle ownership and use are related to <u>ownership of more fuel efficient vehicles</u>.

2c) High levels of knowledge of the environmental impacts of vehicle ownership and use are related to <u>driving fewer miles annually</u>.

2d) High levels of knowledge of the environmental impacts of vehicle ownership and use are related to lower fuel consumption related to household vehicle ownership and use.

Hypothesis 3: Higher levels of pro-environmental attitudes are related to less resource-intensive household vehicle ownership and use. Therefore, all else being equal:

3a) Pro-environmental attitudes are related to lower vehicle ownership.

3b) Pro-environmental attitudes are related to ownership of more fuel efficient vehicles.

3c) Pro-environmental attitudes are related to driving fewer miles annually.

3d) Pro-environmental attitudes are related to lower fuel consumption related to household vehicle ownership and use.

Hypothesis 4: There are mutually reinforcing, bi-directional relationships between knowledge, attitudes, and behavior, such that vehicle ownership and use affect environmental knowledge and environmental attitudes at the same time environmental knowledge and environmental attitudes affect vehicle ownership and use.

Hypothesis 5: Real and perceived economic, political, and social constraints contribute to low levels of perceived behavioral control over the environmental impacts of personal vehicle ownership and use.

CHAPTER 3. SURVEY DESIGN AND DISTRIBUTION

My goal of measuring individuals' environmental attitudes and environmental knowledge in a manner that permits direct linkages to actual behavior required the distribution of an original survey, as no pre-existing data sets existed that contained all of the variables of interest. For reasons of expense and feasibility, a mail-out survey within the geographic boundaries of a single metropolitan area was chosen as the most practical survey type. I asked respondents to reply to questions concerning their environmental knowledge, environmental attitudes, and vehicle ownership and use, as well as questions concerning their household's size, income, residence type, and other demographic and socio-economic characteristics.

Study area

After considering a statewide survey, I rejected the idea as too costly. To conduct the survey throughout California would have required the purchase of more addresses than would be needed, and at a very high financial cost that did not fit within my research budget (see Appendix A). Though the results of a statewide survey would have been representative of a larger geographic area, a metropolitan region was a reasonable compromise between expense and geographic range, and sufficient for the purpose of testing the hypotheses.

I chose the Sacramento, California metropolitan region for several important reasons. It is a large, growing region with a mix of urban, suburban, and rural sub-regions. Its population is diverse and on most key demographic and transportation-related variables it falls somewhere between Californian and national values (see Table 3.1 below). In addition, the local Metropolitan Planning Organization, the Sacramento Area

Council of Governments (SACOG), has publicly accessible databases that facilitated the completion of several important pre-survey distribution analyses and may permit useful follow-up analyses to be conducted.

Table 3.1: Demographic and transportation statistics for the Sacramento PMSA, California, and the United States, 2000[10]

	Sacramento CA PMSA	California	United States
Demographic			
Male	48.6%	49.5%	48.8%
Female	51.4%	50.5%	51.2%
Caucasian	71.4%	67.9%	77.3%
African American	7.6%	6.3%	11.9%
Asian	9.3%	11.3%	3.8%
Hispanic	14.4%	32.6%	12.6%
Native born	87.1%	74.1%	88.9%
College degree (associate degree or higher)	35.6%	34.8%	31.5%
Registered Democrats	39.17% (SACOG, Feb. 2005)	43.04% (Feb. 2005)	36.90%
Registered Republicans	39.28% (SACOG, Feb. 2005)	34.49% (Feb. 2005)	36.20%
Population Density per sq. mile (metro areas)	352.7	354.0	320.2
Housing Units Density per sq. mile (metro areas)	140.4	126.9	128.7
Transportation			
Commute by drive-alone car, truck or van	75.7%	72.3%	76.3%
Commute by public transportation	2.3%	5.4%	5.2%
Commute by walking	2.5%	2.8%	2.7%
Work at home	3.5%	3.6%	3.2%
Mean travel time to work	25.7 minutes	26.7 minutes	24.4 minutes
HH owns no vehicles	5.9%	8.1%	9.4%
HH owns 1 vehicle	34.9%	33.8%	33.8%
HH owns 2 vehicles	39.5%	38.5%	38.5%
HH own 3+ vehicles	19.7%	19.6%	18.3%

[10] Data referenced here are from the U.S. Census bureau's 2000 census and are available in tables for the Sacramento PMSA, California, and the United States on the Internet at http://www.census.gov/acs/www/Products/Profiles/Chg/2001/SS01/. Political affiliation statistics are available at http://www.ss.ca.gov/elections/ror/county_02_10_05.pdf and at http://www.rasmussenreports.com/Summary%20of%20Party%20Weight.htm. Population and housing unit density data are from U.S. Census Bureau, Census 2000 Summary File 1 available at http://factfinder.census.gov/servlet/GCTSubjectShowTablesServlet?_lang=en&_ts=177612073062.

The Sacramento region, covering most of 6 counties with a combined population of approximately 1.9 million residents, is a relatively young urban area, having been settled by Westerners shortly before the California gold rush of 1849. Its urban form reflects its substantial growth following widespread adoption of the automobile as a principal means of transportation: population densities are generally low (0.55 people per acre for the entire metro region),[11] the roadway network is extensive (2.71 miles of roadway system centerline miles per 1,000 Sacramento area residents, compared to an average of 2.35 miles per 1,000 people in the other eight major metro areas of California), transit use is low (22.36 annual unlinked passenger trips per Sacramento area resident, compared to 50.80 in the other eight major metro areas of California and 56.18 in all 85 major metro areas of the U.S.),[12] and land uses are separated and spread out. Nevertheless, several moderately dense urban centers (having an average of 8 or more residents per gross acre) exist in the region that are home to about 3% of the region's population (1% live within neighborhoods of 12 or more residents per acre). A relatively extensive network of bus, paratransit, and light rail public transportation serves these areas and neighboring, less densely populated suburban communities.

Survey design

Care was taken in developing the survey to 1) minimize the potential for social desirability or researcher preferences to influence respondents' answers,[13] 2) ensure

---

[11] U.S. Census Bureau, Census 2000 Summary File 1 available at http://factfinder.census.gov/servlet/GCTSubjectShow TablesServlet?_lang=en&_ts=177612073062.

[12] Roadway density and transit use figures calculated from data available at the Texas Transportation Institute's 2005 Urban Mobility Study Internet Web site at http://mobility.tamu.edu/ums/congestion_data/. Figures are for 2003.

[13] This is an important issue as my family owns a Honda Civic Hybrid, we generally drive less than 10,000 miles per year, and we use public transit and non-motorized forms of transportation regularly.

anonymity and confidentiality (no identifying information was requested or recorded),[14] 3) keep time necessary to complete the survey short, and 4) maintain measurement correspondence, so that, for example, the environmental knowledge tested corresponds with the respondent behavior of interest, i.e., vehicle ownership and use. Don Dillman's *Mail and Internet Surveys: The Tailored Design Method* (2000) provided the framework for this research project in the following areas: writing questions, designing the printed survey, and developing a distribution and follow-up contact strategy to ensure the desired design criteria could be met and to obtain as high a response rate as possible.

I developed an original survey to obtain responses concerning five principal categories of information: environmental knowledge of the impacts of vehicle ownership and use, environmental attitudes, demographic variables relating to the respondent and the respondent's household, household vehicle ownership and use, and constraints to cleaner and more fuel efficient vehicle ownership and use (see summary in Table 3.2 below). A copy of the survey as it was mailed to the targeted population is found in Appendix C.

Table 3.2: Survey components

Environmental knowledge variables	Environmental attitudes variables	Demographic variables	Vehicle ownership and use variables	Constraints variables
7 questions about respondent knowledge of the environmental impacts of vehicle ownership and use	3 questions about respondent attitudes toward tradeoffs b/w the natural environment and the economy	12 questions about the respondent and the respondent's household	12 questions about number, types, and use of household vehicles	3 open-ended questions about constraints to reducing environ-mental impacts of vehicle owner-ship and use

[14] Because anonymity was guaranteed—respondents were all adults and not institutionalized—and the contents of the survey did not include sensitive or controversial questions, an exemption was obtained from the UC Berkeley Committee for the Protection of Human Subjects on February 3, 2005 (see Appendix B).

Environmental knowledge questions

No standard set of questions exists to measure an individual's knowledge of the environmental impacts of vehicle ownership and use. Two groups of researchers have developed sets of environmental knowledge questions, but neither was appropriate to use for the purposes of this study. Walton *et al.* (2004) wrote a 31-item scale to test understanding of "vehicle emissions, pollutants, and health risks associated with emissions" (p. 336), while Nilsson and Küller (2000) used eight questions: "three multiple-choice questions about traffic noise, air pollution and accidents…" and five questions dealing with "global aspects of pollution" (p. 215). The first set of questions was too long for the purposes of this study. The second set of questions, because it emphasized global aspects of pollution, did not adhere to the principle of measurement correspondence; that is, the questions did not focus on knowledge individuals would need to have about the environmental impacts of vehicle ownership and use in order to effectively make choices that reflect pro-environmental attitudes.

Consequently, I developed an original set of seven environmental knowledge questions for this survey. In writing the questions, I identified the knowledge a person with pro-environmental attitudes would have or seek out if he or she wanted to reduce the environmental impacts of his or her vehicle ownership and use. Therefore, the questions included in the survey measured whether respondents knew that vehicles remain a significant source of air pollution, that the air pollutants emitted by vehicles contribute to public health problems, that vehicles are a major source of greenhouse gas emissions, that manufacturing vehicles causes significant environmental impacts, and that fuel economy and emissions standards are different for passenger cars and light-duty trucks.

The seven statements that comprise the environmental knowledge questions are these:

1. All cars, mini-vans, vans, pickups, and SUVS pollute about the same amount for each mile driven.

    False: Vehicles vary both between categories and within categories in terms of how much polluting emissions they generate.[15]

2. Cars, mini-vans, vans, pickups, and SUVS are not an important source of air pollution any more.

    False: Although cars individually are much cleaner today than they were before strict emissions regulations were enacted, collectively vehicles are still responsible for significant amounts of pollution.[16]

3. Cars, mini-vans, vans, pickups, and SUVS are an important source of the gases that many scientists believe are warming Earth's climate.

    True: Gases that most scientists believe are warming Earth's climate include carbon dioxide (CO_2), which is an unregulated emission from combustion occurring in vehicle engines. In the US, 17% of all CO_2 emissions come from cars and light duty vehicles.[17]

---

[15] For example, within the category of 2005 model family sedans, grams per mile of NOx emissions range from 0.20 for the Pontiac Grand Prix to 0.07 for the conventional Mitsubishi Lancer and 0.03 to 0.01 for the Toyota Prius. Estimated annual greenhouse gas emissions for the same vehicles are 8.7 tons, 6.1 tons, and 3.4 tons. (Source: the U.S. Department of Energy's vehicle fuel economy Web site at http://www.fueleconomy.gov.)

[16] In 2002 in the United States, cars and light duty vehicles were responsible for 25% of national emissions of VOCs, 52% of carbon monoxide emissions, and 16% of NOx emissions. See U.S. Environmental Protection Agency's National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data available at http://www.epa.gov/ttn/chief/trends/trends02/trendsreportallpollutants 07182005.zip.

[17] See Davis and Diegel 2006, Tables 2.01 and 2.06.

4. Government rules allow mini-vans, vans, pick-ups, and SUVs to pollute more than passenger cars, for every gallon of gas used.

   True: Even setting aside fuel economy considerations, passenger cars are held to higher standards for emissions of the following pollutants: SO_2, NO_x, Pb, CO, PM, and VOCs.[18]

5. Government rules require mini-vans, vans, pick-ups, and SUVs to meet the same miles-per-gallon standards as passenger cars.

   False: Passenger cars are held to higher fuel economy standards than light duty vehicles are. In 2005, the fuel economy standard for passenger cars was 27.5 miles per gallon; for light duty vehicles it was 21.0. Vehicles with a gross vehicle weight rating of over 8,500 pounds—such as the Chevrolet Silverado 2500 and the Ford Excursion—are not required to meet any fuel economy standards (see National Highway Traffic Safety Administration 2004).

6. Manufacturing a new passenger car, mini-van, van, pickup, or SUV is a major source of pollution and energy use even before it is driven out of the factory for the first time.

   True: Manufacturing a new vehicle requires large amounts of energy and the extraction and refining of tons of raw materials to create the metals, plastics, electronics, synthetic rubbers, and other materials that go into

[18] The smallest light duty vehicles have met the same emissions standards as passenger cars, but "[m]ost SUVs and pickups, and all vans, [have been] permitted to emit 29% to 47% more carbon monoxide (CO) and 75% to 175% more nitrogen oxides (NOx) than passenger cars" (Yacobucci 2004, p. 5). The U.S. EPA's "Tier 2" standards, adopted in February 2000, will require all cars and light duty vehicles to meet the same standards, but not until Model Year 2009.

assembling new vehicles. Analyses estimate that about a quarter of the lifetime energy requirements attributable to a vehicle is required to manufacture, service, and dispose of it, with most of this coming from the manufacturing phase. Over half of the more than 14,700 pounds of hazardous wastes per vehicle lifetime attributable to manufacture and use comes from the manufacturing phase (see Maclean and Lave 1998 for more detail on this topic).

7. Exhaust from cars, mini-vans, vans, pickups, and SUVs is an important source of the pollution that causes asthma and makes asthma attacks worse.

   True: Vehicle emissions are major contributors to ground-level ozone formation which has been found to cause and exacerbate the effects of asthma and other respiratory diseases (see, for example, McConnell *et al.* 2002).

Respondents were asked to answer the questions as True, Probably True, Probably False, or False; a "do not know" option was not included. The "probably" choices allowed respondents to answer questions they have a belief or hunch about, even if they do not have detailed information or complete confidence in their opinion. This was an important option to include, as many decisions made by consumers, policy-makers, and others are made only with partial or imperfect information.

Environmental attitude questions

Three pairs of statements were used to elicit respondents' attitudes toward protecting the natural environment:

Question #1: a) Stricter environmental laws and regulations cost too many jobs and hurt the economy, or b) Stricter environmental laws and regulations are worth the cost.

Question #2: a) People like me will have to make major lifestyle changes to solve today's environmental problems, or b) People like me will have to make few or no lifestyle changes to solve today's environmental problems.

Question #3: a) Development of U.S. energy supplies—such as oil, gas, and coal—should be given priority, even if the environment suffers to some extent, or b) Protection of the environment should be given priority, even at the risk of limiting the amount of energy supplies—such as oil, gas, and coal—which the U.S. produces.

Questions like these have been posed by many different polling organizations over the past three decades. The specific wording of these questions came from surveys recently administered by the Public Policy Institute of California (2003; 2005).

Before settling on these three questions, I considered other sets of more detailed questions concerning environmental attitudes for inclusion in the survey. For example, I used the New Ecological Paradigm Scale (NEPS), a set of 15 questions that elicits opinions on the balance of nature, limits to growth, and human domination of nature (see Dunlap *et al.* 2000), for the pre-test version of the questionnaire. The questions were considered difficult to answer by several pre-test respondents. For this reason, and because it was necessary to keep the average length of time required for survey completion to a minimum, I chose to use the simpler three questions included in the final version of the survey.

Demographic questions

Demographic information concerning the respondent (age, gender, ethnicity, Hispanic or not, highest level of education, membership in an environmental organization, and membership in the California Automobile Association) and the respondent's household (number of household members, number aged 16 or older, number licensed to drive, type of housing, and household income) were obtained through twelve questions. Most of these variables are ones commonly used in vehicle ownership research (income, education, household size, etc.) and have strong correlations with number and types of vehicles owned.

Vehicle ownership and use questions

The details of respondent households' vehicle ownership and use were explored with a series of twelve questions concerning commuting habit, number of household vehicles owned, and the details of up to three vehicles: year, make, model, trim level, transmission type, wheel drive, means of obtaining the vehicle, length of ownership, fuel, and estimated miles driven annually.[19]

Self-reported annual mileage can, in some cases, be a poor estimator of actual mileage driven. But several studies suggest that self-reported mileage driven can be a

[19] An additional set of questions concerning operation and maintenance of household vehicles in ways that conserve fuel and resources (e.g., keeping the correct air pressure in vehicle tires and driving on highways at or below posted maximum speeds) was developed and pre-tested. For reasons of space, however, and the fact that these questions were not as central to the study objectives as were ownership and miles driven per year, this set of questions was eliminated from the final version of the survey. Follow up research efforts may incorporate such questions, however, as they are one more way in which household members may compensate for the environmental impacts of other aspects of their vehicle ownership and use.

reasonably accurate reflection of actual mileage driven. Grob, for example, found that "subjects' self-reports of kilometres driven and rate of purchasing passes for public transport did not differ from the official statistics" (1995, p. 219). And Davis and Diegel (2006, Table 8.13) found that when self-reported mileage was compared to actual mileage obtained through odometer readings in the 1995 NPTS (National Personal Transportation Survey) and the 2000 NHTS (National Household Travel Survey), the variation was small; self-reported mileage was 3% higher than odometer readings in the NPTS and 7% lower in the NHTS.

Environmental constraints questions

Finally, three short open-ended questions addressed the constraints that prevent (or that respondents perceive to prevent) owning fewer vehicles, more fuel efficient vehicles, and driving vehicles fewer miles annually. These questions were open-ended because the number of possible constraints to more environmentally responsible behavior is very large: employment opportunities and limitations, residential location possibilities, family responsibilities, consumer preferences, school and day-care schedules, social expectations, community commitments, recreational activities, transit system availability and quality, urban design and built environment, and other factors can all limit or be perceived to limit a respondent's ability or willingness to reduce the environmental impact of household vehicle ownership and use. By asking respondents to identify those constraints they feel are most important, I avoided the necessity of asking dozens of questions related to possible constraints. The inclusion of open-ended questions also permitted a qualitative analysis to be conducted which may provide insights into future research directions.

Data entry and completion

Data entry was accomplished with the assistance of six data entry clerks who have relevant experience working with the University of California Transportation Center (UCTC). I developed a codebook prior to the commencement of data entry (see Appendix D) and each data entry clerk was trained in the proper techniques. I created three codes for missing or unclear responses: multiple responses to a single question were coded -9, missing responses were coded -8, and irrelevant variables (for example, the vehicle ownership and use variables in the case of zero-vehicle households) were coded -7.

Microsoft Excel was used for this stage of the project because of its flexibility and ease in providing validation of reliable data entry. I set ranges of permissible values for each variable, locks on data entry in cells outside of the appropriate range were established, and double entry, using two separate worksheets, and comparison of the first round of data entry to the second, was used to identify discrepancies. Data entry clerks commenced data entry work in June, 2005 and completed their work approximately two months later.

In addition to the data collected from respondents with the 34 closed-ended questions and three open-ended question, I appended fourteen variables to the record for each respondent, including U.S. EPA vehicle category and fuel economy ratings for each model year 1985 or later vehicle and a block group-level walkability measure called "pedestrian environment factor," developed by SACOG. Several variables to be used in the analysis also had to be calculated, such as average fuel efficiency of household vehicles, estimated annual miles driven for vehicles owned less than a year, total estimated annual household miles driven, and estimated annual household fuel consumption attributable to vehicle ownership and use. See Appendix E for details of these added and calculated variables.

Sampling method

A two-stage sampling method was used to select 4,000 targeted respondents. First, I chose 50 U.S. Census Bureau-defined block groups by using proportional stratified random sampling from all block groups in the six-county planning area for the Sacramento Council of Governments (SACOG).[20] The 1,199 block groups were stratified based on the average number of vehicles per household members aged 16 and older, as reported in the 2000 decennial census. Such stratification ensured that potential respondents would be included from areas characterized by all levels—low to high—of average household vehicle ownership, an important attribute given the centrality of number of vehicles owned in this study's conceptual model and hypotheses.

Table 3.3: Proportional, stratified random selection of block groups

Range of average household ownership of vehicles per household member aged 16 and older	# of block groups	Population 16 and older	Population 16 and older percentage	# block groups to select (rounded)
0.01 – 0.42	23	28,128	1.97%	1
0.42 – 0.69	176	185,488	12.98%	7
0.69 – 0.85	326	401,180	28.07%	14
0.85 – 1.01	479	607,859	42.53%	21
1.01 – 1.53	195	206,473	14.45%	7
	1,199	**1,429,128**	**100%**	**50**

Using ArcGIS software to categorize block groups based on the "natural breaks" method, I combined the 1,199 block groups into five groups. Then, based on the proportion of the overall population aged 16 and older in each category of block groups, I identified the appropriate number of block groups to randomly select from within each

[20] The SACOG planning area includes all of Sacramento, Yolo, Yuba, and Sutter counties, and all areas of El Dorado and Placer counties outside of the Lake Tahoe basin.

category (see Table 3.3 above). Random numbers were generated using the random sequence function at http://www.random.org and used to select target block groups.

The second stage involved random sampling of approximately every seventh household from all households within the selected 50 block groups for which addresses were available through a commercial database company (29,067 addresses from AccuData America), leading to a final sample of 4,000 households.[21]

Survey distribution

The distribution method for the survey was based upon recommendations in *Mail and Internet Surveys: The Tailored Design Method* (Dillman 2000). Dillman emphasizes survey design features and distribution techniques that convey to survey recipients the value of the study and of their participation in it. These features include careful attention to survey question wording, appealing graphic design, repeated communications, the use of a small incentive—distributed without obligation to participate[22]—and the use of first class postage, rather than bulk mail distribution. I conservatively estimated that, using this method of survey distribution, a response rate of 25% would be achieved, so a total distribution of 4,000 surveys was needed in order to obtain 1,000 completed surveys.[23]

---

[21] AccuData America's database of addresses is compiled from directories maintained by telephone companies, credit reporting agencies, county assessors, and other sources. The company's 29,067 addresses for the 50 selected block groups represents 98% of the 29,808 households enumerated in the 2000 census. On a block group by block group basis, however, AccuData America's coverage ranged from 34% of the number of households identified in the census to 411%. This introduction of sampling bias was unavoidable, as other commercial database companies consulted were able to provide less than half the number of addresses for the selected block groups with similar variations in coverage. For information about AccuData America, see http://www.accudata.com.

[22] A small amount of money given before completion of a survey and without obligation is a form of social exchange that has been found to motivate higher survey completion rates than larger amounts given only upon completion (see Dillman 2000).

[23] Power calculations were difficult to make with a large degree of confidence given the lack of similar analyses completed in the past. Nevertheless, a two-tailed power calculation was completed, assuming normal distributions and equal variances for two groups of respondents (categorized into those with low

Because 15.8% of Sacramento area residents are of Hispanic origin, according to the 2000 census, I hired a translator to translate the survey into Spanish. The expense of distributing both English-language and Spanish-language surveys to every recipient was prohibitive, so a notice in Spanish was placed on the cover of the English-language version of the survey with a telephone number to call, if a respondent wanted to receive a copy of the Spanish-language version in the mail. No requests for the Spanish-language version of the survey were received.

The survey was distributed in late April 2005, accompanied by a cover letter, a $1 bill, and a return, postage-paid envelope. This was one week after a notification had been mailed to all 4,000 potential respondents and one week before a reminder postcard was distributed (copies of the notification letter, cover letter, and reminder postcard can be found in Appendices G, H, and I). Recipients were instructed to ask the household member aged 18 or older whose birthday occurred most recently (a criterion used to randomize respondents within households) to complete the survey.

Survey response

Of the 4,000 surveys distributed, 194 were returned by the U.S. Postal Service as undeliverable. Of the 3, 806 deliverable surveys, 1,559 responses were received for a total response rate of 40.96%. Of these, 22 envelopes were returned without surveys and 31 envelopes contained blank surveys. Thus, 1,506 responses contained usable data, 39.57% of the total deliverable surveys.

---

and high levels of pro-environmental attitudes), a significance level of 0.05 and a power setting of 0.90. The resulting sample size indicated was 1,052 (see Appendix F for details).

This response rate compares favorably to other mail-out surveys completed for travel behavior research in the United States and abroad, being higher than many, but not all, response rates for similar studies. For example, Choo and Mokhtarian (2002) obtained a 23% response rate for a survey of 1,904 residents in three neighborhoods of the San Francisco Bay Area. Cao *et al.* (2006) received a response rate of about 25% for the distribution of 6,746 surveys in eight northern California neighborhoods. And Noblet *et al.* (2006), in a two-round statewide survey of Maine motorists, obtained response rates of 60% and 64%. Some travel behavior mail-out surveys conducted in other countries appear to elicit higher response rates. While Jakobsson *et al.* (2000), using a sample of 524 randomly selected car owners living in Greater Göteborg, Sweden, received a response rate of 33%, Nilsson and Küller (2000) obtained a response rate of 51%, Polk (2003) a response rate of 61%, and Walton *et al.* (2004) a response rate of 50%.[24]

[24] The Walton *et al.* data set, however, included both surveys distributed by mail and in person. The authors report the overall response rate of 50% and acknowledge that there was a "higher rate for those who were handed surveys" (p. 336), without providing specific figures.

CHAPTER 4: DATA AND DATA VALIDITY

With a larger-than-expected response rate of almost 40%, the survey generated a data set of 1,506 cases. Such a large data set provides a valuable resource for studying the questions posed in this research project, but also creates challenges to ensuring the internal validity of the analysis. In addition, with so many cases, reaching statistical significance is more likely than with a smaller data set, but assessing the meaningfulness of the results accordingly becomes more difficult.

I begin this chapter with a description of the sample, its size, geographical variation, and basic descriptive statistics. Possible sources of error and bias are identified, followed by explanations of steps taken to correct for these: the development of a set of weights based on sampling, non-response, and post-stratification adjustments, the development and testing of scales of environmental knowledge and environmental attitudes, and corrections for minor violations of standard statistical analysis assumptions.

All statistical analysis in this study was conducted using SPSS software (version 13.0 for Windows), except for the structural equation modeling detailed in Chapter 6, which was conducted using AMOS software (version 5.0.1). I used two principal texts for reference and statistical analysis advice: *SPSS Survival Manual* (Pallant 2001) and *Using Multivariate Statistics* (Tabachnick and Fidell 2001).

Survey response

The response rate of 39.57% was significantly higher than the expected response rate of 25%, upon which the initial desired sample size was determined. The overall number of usable responses was, therefore, 50% larger than power analysis indicated would be needed. On a neighborhood-by-neighborhood basis, the response rate varied considerably, however, ranging from 21% of deliverable surveys in neighborhood #46 (an unincorporated area of Placer County near the city of Auburn) to 67% in a downtown Sacramento neighborhood, though no specific pattern to the rates of response was evident. The response rates per stratum of vehicle ownership, upon which the random selection of block groups was based, were all very close, ranging from 37.7% to 42.9% (see Table 4.1 below).

Table 4.1: Response rate per vehicle ownership category

Vehicle ownership per capita (16 and older)	Vehicle ownership category	Response rate
0.01 – 0.42	1	42.9%
0.42 – 0.69	2	42.0%
0.69 – 0.85	3	37.7%
0.85 – 1.01	4	42.2%
1.01 – 1.53	5	39.9%

Description of the respondents and their households

Basic descriptive statistics and frequencies of responses to fourteen demographic questions are presented in Table 4.2 below. The respondents were, on average:

- older than the population as a whole (they had an average age of 51),
- well educated (more than 50% had a bachelor’s degree or higher),
- relatively wealthy (they had household incomes of $50,000 or more per year and owned their own homes),
- racially fairly homogeneous (more than three-quarters were of European ancestry), and
- more likely to be men than women (53.32% were male).

Table 4.2: Key respondent and household characteristics of the final sample (N=1,506), unweighted analysis

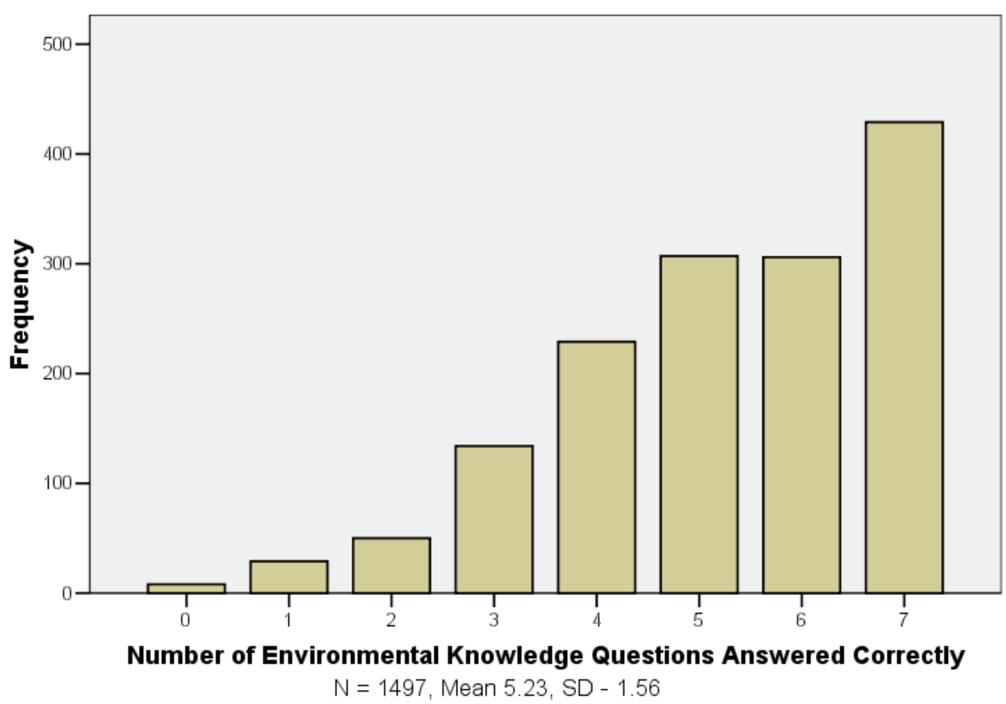
Respondent Characteristics					
	Number responses	% of responses			
Gender (N=1,476)			**Age (N=1,441)**		
Male	787	53.32%	Average	51.35	
Female	689	46.68%	Standard Deviation	15.31	
Hispanic/Latino Origin (N=1,438)			**Commute Type (N=1,416)**		
Yes	115	8.00%	Drove Myself	935	66.01%
No	1,323	92.00%	Carpool or Vanpool	49	3.46%
			Took Public Transport	43	3.03%
Member of AAA (N=1,497)			Walked	17	1.20%
Yes	865	57.78%	Bicycled	13	0.92%
No	632	42.22%	Did not commute, worked at home	50	3.60%
Member of Environmental Org. (N=1,493)			Did not commute, unemployed or retired	292	20.59%
Yes	140	9.38%	Other	17	1.20%
No	1,353	90.62%			
Highest Level of Education (N=1,473)			**Race (N=1,417)**		
Less than high school	14	0.95%	White alone	1,079	76.15%
Some high school	21	1.43%	Black or Afr Amer alone	38	2.68%
High school or GED	328	22.27%	American Indian or Alaska Native alone	11	0.78%
Assoc. degree or tech trg	358	24.30%	Asian alone	95	6.70%
Bachelor degree	446	30.28%	Native Hawaiian or Other Pacific Islander alone	14	0.99%
Graduate college degree (Masters, Prof., or Ph.D.)	306	20.77%	Some other race alone	41	2.89%
			Two or more races	139	9.81%

Respondent Household Characteristics					
Number of household members (N=1,498)			**Number of household members aged 16 and older (N=1,493)**		
Average	2.59		Average	2.05	
Standard Deviation	1.44		Standard Deviation	0.89	
Number of household licensed drivers (N=1,491)			**Number of Vehicles (N=1,478)**		
Average	1.91		Average	2.08	
Standard Deviation	0.82		Standard Deviation	1.03	
			0 Vehicles	37	2.50%
Household Income (N=1,365)			1 Vehicle	380	27.51%
Less than $20,000	85	6.23%	2 Vehicles	663	44.86%
$20,000 to $29,999	112	8.21%	3 Vehicles	277	18.74%
$30,000 to $39,999	100	7.33%	4 or more Vehicles	121	6.39%
$40,000 to $49,999	131	9.59%			
$50,000 to $74,999	326	23.88%	**Residency (N=1,497)**		
$75,000 to $124,999	399	29.23%	Own	1,220	81.50%
$125,000 to $199,999	149	10.92%	Rent	263	17.57%
$200,000 or more	63	4.62%	Other (unspecified)	14	0.93%

Environmental knowledge of the sample population

I measured environmental knowledge using an index constructed from responses to seven questions about vehicle emissions, the public health impacts of emissions, vehicle contributions to greenhouse gas emissions, the environmental impacts of vehicle manufacturing, and differing fuel economy and emissions standards for passenger cars and light-duty trucks (mini-vans, vans, pickup trucks, and sports utility vehicles). Respondents could select one of four responses to each of the seven questions: true, probably true, probably false, or false. Three of the questions were negatively worded (the correct answer was "false") and four were positively worded. There was no option to reply "don't know," though instructions to the survey indicated that respondents should feel free to not respond to any question they did not want to answer. Between 77 and 113 responses were left blank for each of the seven questions.

Figure 4.1: Number of environmental knowledge questions answered correctly



Respondents in the sample were, in general, knowledgeable about the environmental impacts of vehicle ownership and use. On average, they answered 5.23 of the seven questions correctly (SD=1.56), with 29% of respondents answering seven of the seven questions correctly (see Figure 4.1 above and Table 4.3 below). Question #2, which asked whether cars and light duty vehicles remain an important source of pollutant emissions, elicited the largest percentage of correct responses: 90.9%, while Question #4, comparing pollutant emissions standards for passenger cars to light duty vehicles, proved

Table 4.3: Responses to environmental knowledge questions, unweighted analysis

	Correct Answer	Incorrect Answer	Certain	Uncertain
Question #1: All cars, mini-vans, vans, pickups, and SUVS pollute about the same amount for each mile driven.	78.0%	22.0%	57.4%	42.6%
Question #2: Cars, mini-vans, vans, pickups, and SUVS are not an important source of air pollution any more.	90.9%	9.1%	70.6%	29.4%
Question #3: Cars, mini-vans, vans, pickups, and SUVS are an important source of the gases that many scientists believe are warming Earth's climate.	82.6%	17.4%	49.3%	50.7%
Question #4: Government rules allow mini-vans, vans, pick-ups, and SUVs to pollute more than passenger cars, for every gallon of gas used.	58.8%	41.2%	36.0%	64.0%
Question #5: Government rules require mini-vans, vans, pick-ups, and SUVs to meet the same miles-per-gallon standards as passenger cars.	74.1%	25.9%	46.5%	53.5%
Question #6: Manufacturing a new passenger car, mini-van, van, pickup, or SUV is a major source of pollution and energy use even before it is driven out of the factory for the first time.	68.8%	31.2%	30.9%	69.1%
Question #7: Exhaust from cars, mini-vans, vans, pickups, and SUVs is an important source of the pollution that causes asthma and makes asthma attacks worse.	80.1%	19.9%	41.5%	58.5%

to be the most difficult question, with 41.2% of respondents answering incorrectly that such regulations were the same for the two categories of vehicles. Respondents were most certain about the answer to Question #2: less than a third (29.4%) answered using the "probably" options. In response to Question #6, which asked if manufacturing a new vehicle was a major source of pollution and energy consumption, on the other hand, over two-thirds of respondents (69.1%) were uncertain of their response.

Environmental attitudes of the sample population

To measure environmental attitudes, respondents were asked to "select the statement that most closely matches your opinion" from three pairs of statements. For those respondents who answered each of these questions,

- 70.6% indicated that protecting the environment is worth the economic costs that stricter environmental laws and regulations may require (29.4% indicated the contrary);
- 54.7% said they believe people like them will have to make major lifestyle changes to solve today's environmental problems (45.3 % said they do not believe they will have to do so); and
- 60.6% believe protection of the environment should be given priority, even at the risk of limiting the amount of energy supplies produced in the United States (39.4% of respondents felt energy production should be given priority).[25]

The breakdown of "pro" and "anti" environmental responses is very similar to the results of a 2002 survey (Public Policy Institute of California 2002) that posed the same questions (see Table 4.4 below), except for Question #3, concerning the environmental

[25] Note that these questions imply that there is, by necessity, a tradeoff between a strong economy and protection of the natural environment. Many people question this assumption, including seventeen respondents who voluntarily added comments next to these questions criticizing the limited way in which they addressed the issue. Even environmental organizations and labor unions have rejected the idea that protecting the natural environment and preserving jobs are mutually exclusive (see, for example, the "Blue Green Alliance" of the Sierra Club and the United Steelworkers of America at http://www.bluegreen alliance.com).

costs of developing U.S. energy supplies. The discrepancy between this survey's findings and the results of the 2002 Public Policy Institute of California survey is likely to reflect, at least in part, the relative cost of a gallon of gasoline at the two points in time. In late May and early June of 2002, when the PPIC survey was conducted, gasoline on the west coast of the U.S. cost approximately $1.43 a gallon. In April of 2005, when respondents received this survey, gasoline cost an average of $2.40 per gallon on the west coast after having increased more than $0.50 per gallon in the space of the preceding three months.[26]

Table 4.4: Responses to environmental attitudes questions, unweighted analysis

		This survey	2002 PPIC survey
Question #1:	a) Stricter environmental laws and regulations cost too many jobs and hurt the economy.	29.4%	32.6%
	b) Stricter environmental laws and regulations are worth the cost.	70.6%	67.4%
Question #2:	a) People like me will have to make major lifestyle changes to solve today's environmental problems.	54.7%	54.6%
	b) People like me will have to make few or no lifestyle changes to solve today's environmental problems.	45.3%	45.4%
Question #3:	a) Development of U.S. energy supplies – such as oil, gas, and coal – should be given priority, even if the environment suffers to some extent.	39.4%	30.9%
	b) Protection of the environment should be given priority, even at the risk of limiting the amount of energy supplies – such as oil, gas, and coal – which the U.S. produces.	60.6%	69.1%

Sampling- and non-response biases

While the response rate was significantly higher than expected, sixty percent of survey recipients failed to respond, raising the question of whether this sample is fully representative of the universe of potential respondents. By comparing the demographic

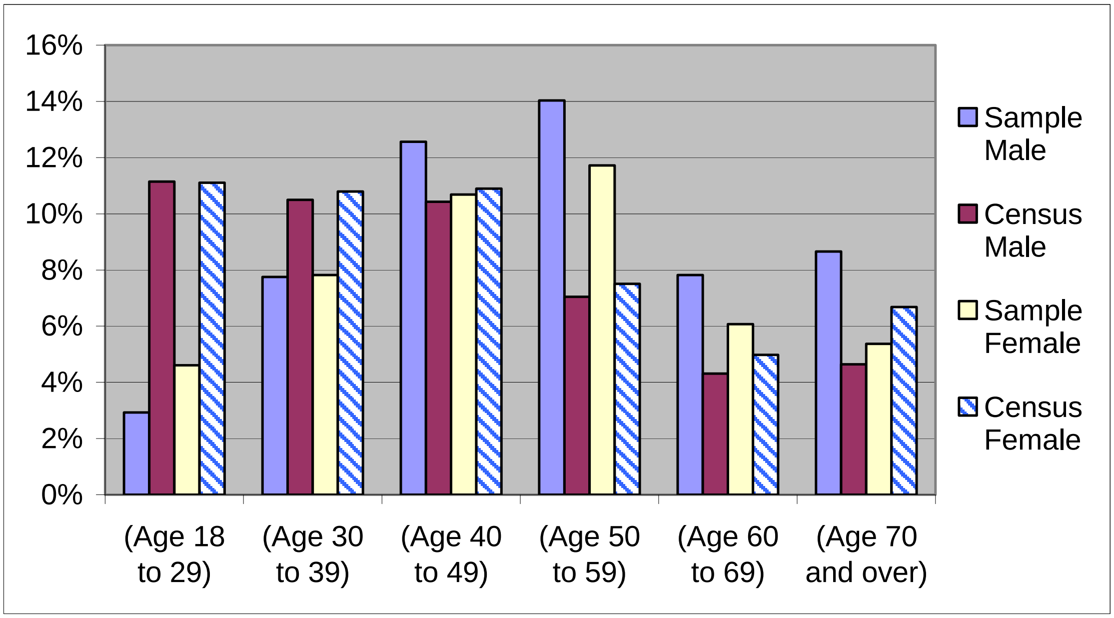
[26] For gasoline prices during the past 15 years, see the data set available from the U.S. Energy Information Agency at http://www.eia.doe.gov/oil_gas/petroleum/data_publications/wrgp/mogas_history.html.

characteristics of the sample to characteristics of the overall population in the SACOG planning area in 2000, as assessed from data in the 2000 U.S. Census, I found that this sample is wealthier, more racially homogeneous, and older than the population as a whole. For example,

- Survey respondents are overrepresented in every household income category of $50,000 or more and underrepresented in categories of less than $50,000.
- Sample respondents are overrepresented in every category of vehicle ownership of 2 or more vehicles and underrepresented in owners of zero cars (1.7% compared to an area average of 7.8%) and one car (18.0% compared to an area average of 34.4%).
- The sample is overrepresented in homeowners (81.5% compared to an area average of 61.2%), and underrepresented in renters (17.6% compared to an area average of 38. 8%).
- Sample respondents are overrepresented in race categories of white (76.1% compared to area average of 69.5%) and two or more races (9.8% compared to area average of 5.6%) and underrepresented in all other race categories.
- The sample is underrepresented in Hispanics, with just 9.2% of the sample household population (only 8.0% of respondents are of Hispanic origin, but average household size is larger for Hispanic respondents than for non-Hispanic respondents), compared to an area average of 15.7%.
- Sample respondents are overrepresented in every age category 40 years and older and underrepresented in every age category under 40 years (see Figure 4.2 below).

- The sample is overrepresented in males aged 18 and over (53.3% compared to an area average of 48.1%), and, thus, underrepresented in females aged 18 and over (46.7% compared to an area average of 51.9%).

Figure 4.2: Comparison of sample respondents (by age and gender) to 2000 census, unweighted data

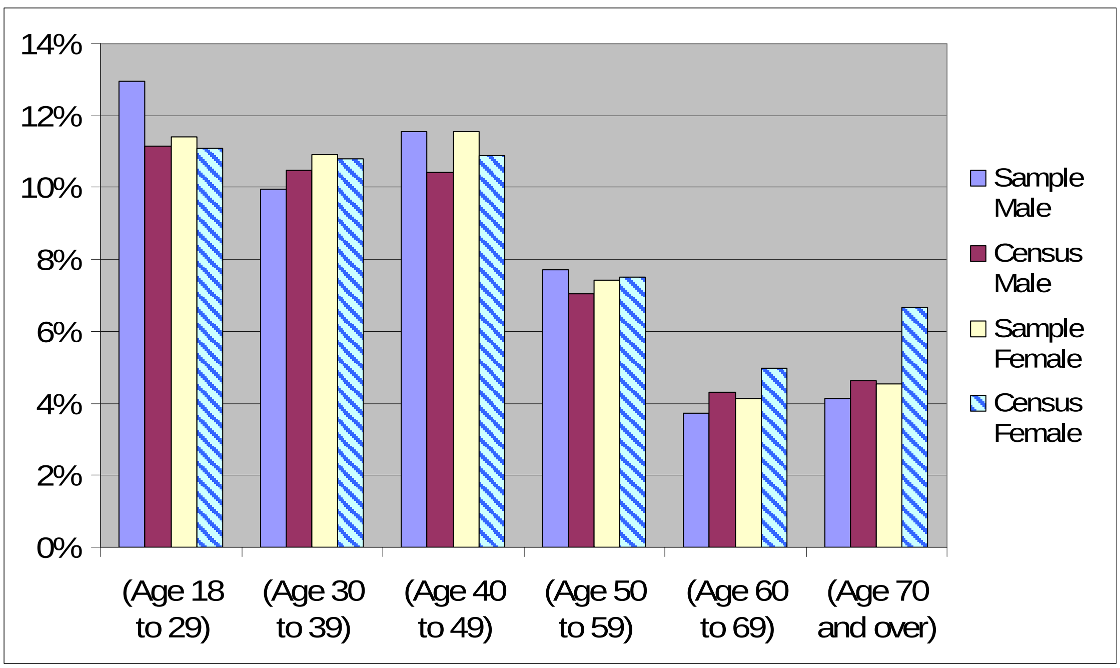


Development of a set of analytical weights

The differences between the sample population and the overall population of the six-county SACOG planning area indicate that generalizations from the sample may be biased. Such differences can be attributed to several factors, including sampling bias and non-response bias. For example, though the survey cover letter indicated how to randomize participation *within* each recipient household—the adult in the household whose birthday occurred most recently was asked to complete the survey, so long as he or she was involved in household vehicle ownership decision-making—it is unknowable to what extent these instructions were followed. To correct for these biases, a set of analytic weights was developed to use in subsequent analyses.

I calculated a separate weight for each record based upon 1) the unequal probability of selection within each household (sampling weight, or *SW*), 2) a non-response adjustment based upon the category of average household vehicle ownership associated with each respondent's residential location (non-response adjustment, or *NRA*), and 3) a post-stratification adjustment based upon divergence of the distribution of age and gender of respondents from that of the overall population in the Sacramento region (post-stratification adjustment, or *PSA*). Details of the calculation of these weights are provided in Appendix J.

Figure 4.3: Comparison of sample respondents (by age and gender) to 2000 census, weighted data



The values of the final set of analytic weights ranged from 0.23 for males in their 50s, from single-adult households, living in vehicle ownership category 4 block groups (all characteristics that are overrepresented in the sample) to 7.91 for males in their 20s, from 4-adult households, living in vehicle ownership category 3 block groups (all characteristics underrepresented in the sample). When age and gender groups were recalculated using the analytic weights, the demographic distribution of the sample much more closely matched the distribution of age and gender groups in the six-county region, as indicated in the 2000 census (see Figure 4.3 above).

Construction of environmental knowledge scales

Two indexes of environmental knowledge were constructed. The first was a simple tally of the number of correct responses to the seven questions and thus ranged from 0 to 7 with an average value (N=1,497) of 5.23 (S.D.=1.56), indicating that the typical respondent could answer about five of the questions knowledgeably (see Figure 4.1 above). The distribution was skewed to the left (skewness=-.705) and was slightly peaked (kurtosis=.051).

The second index was more complicated in its construction. Responses were converted to correct and incorrect values with a 2 for a correct answer, a 1 for a "probably" correct answer, a -1 for a "probably" incorrect answer, and a -2 for an incorrect answer. The values for the second index (N=1,497) ranged from -13 to 14, with an average of 5.81 (S.D.=4.78). This index achieves a more normal distribution of values than did the first index (skewness=-.446), but is more peaked (kurtosis=0.95). Eighteen outliers (values lower than -6) account for some of the negative skewness and can be corrected by collapsing the responses into seven roughly equal groups of respondents.[27]

[27] Such a transformation eliminates the problem of outliers in the data set. By creating a minimum of six or seven groups, it is generally agreed that the transformed variable, though technically ordinal in nature, may be used in statistical analyses as if it were a ratio scale variable. Two other ordinal variables were also used in this manner, though they did not require transformation by regrouping: highest level of respondent education (six categories) and household income range (eight categories). Choo and Mokhtarian (2004) say this about the issue: "Although the five-point subjective mobility and travel liking scales are, strictly speaking, purely ordinal variables, it is common practice to treat such variables as effectively continuous,

The level of skewness is not so high, however, that the variable cannot be used without this transformation.

The validity of the indexes was tested using Cronbach's alpha, with the first scoring 0.55 and the second scoring 0.64. Cronbach's alpha describes how well a set of items measures a single unidimensional latent construct in an internally consistent way (Pallant 2001), in this case, knowledge of the environmental impacts of vehicle ownership and use. There is no single value for Cronbach's alpha which is considered acceptable in the social sciences, but 0.70 is often considered to be the lowest desirable value for a reliable index.[28] As the resulting values from this study are below that threshold, I conducted additional analysis using principal components analysis (PCA) to assess whether the seven questions are measuring two or more constructs, instead of a single construct. While PCA does suggest that two components are being measured with these seven questions—a component related to knowledge of the environmental impacts of all types of personal vehicles and a component related to knowledge of the differences in environmental impacts of cars versus light duty vehicles—the resulting two indices are no more valid in terms of Cronbach's alpha analysis (see Appendix K for details). Therefore, in this study, I have emphasized the second full index of all seven questions in the statistical analyses, both because its Cronbach's alpha value is higher than that of the

---

i.e. ratio-scaled, by assigning them equally-spaced integer values, combining them into composite scales through simple addition or more complex approaches such as factor analysis, and so on…" (p. 211).

[28] There does not, however, appear to be strong adherence to a minimum Cronbach's alpha value in the literature. For comparison, Nilsson and Küller (2000) used an index of environmental knowledge that achieved an alpha of only 0.44 and relied on various indices of attitudes that had alpha values ranging from 0.35 to 0.63. Polk (2003) used several indices that reflected Cronbach's alpha levels of 0.63 to 0.87. And Collins and Chambers (2005) used four indexes of beliefs that had Cronbach's alpha values ranging from 0.53 to 0.76.

first index (approaching the generally accepted standard of 0.70) and because its distribution is closer to normal.

Construction of environmental attitudes scales

Indexes were also constructed for environmental attitudes using responses to the three environmental attitudes questions and the question regarding membership in an environmental organization. Values for the first scale, which was based only on the three attitude questions, ranged from 0 to 3, with an average of 1.83 (N=1471, SD=1.01). Cronbach's alpha for this index was 0.48, suggesting it is not effectively measuring a single unidimensional latent construct (environmental attitudes).

The second index—comprising the three attitudinal questions described above and the environmental organization membership question—was analyzed, but the scale reliability was even poorer (Cronbach's alpha of .46). Given the poor reliability of each of these scores, most of the analyses conducted for this study use the single dichotomous variable of environmental question #1, the long-used question concerning a respondent's preference between protecting the environment or minimizing economic costs.

Data screening

The statistical analyses used to obtain answers to the questions posed in this research project impose assumptions about the data set and its variables. These include sufficient sample size, independence of observations, that any missing values are random in nature (i.e., that there is not a pattern to the distribution of missing values), that values are normally distributed, relationships are linear in nature, that the variance of residuals is homoscedastic, and that there are no extreme outliers. This data set does not meet all of these assumptions with regard to every variable and every set of variables. For example, although assumptions concerning sample size and independence of observations were met, missing values for the household income variable were non-random (respondents who did not respond to that question had significantly lower levels of environmental knowledge and environmental attitudes than respondents who did give an answer). In addition, the four key outcome variables—number of household vehicles, average fuel efficiency of household vehicles, estimated annual household miles driven, and estimated annual household fuel consumption—all had large numbers of outlier values. The steps that I took to correct for these violations of assumptions are described in more detail in Appendix L.

CHAPTER 5: KNOWLEDGE, ATTITUDES, AND VEHICLE OWNERSHIP AND USE

To explore the relationships between the various indicators of knowledge, attitudes, and behavior, I relied upon standard tools of statistical analysis, including correlation analysis, difference of means tests (using both t-tests and analysis of variance) and sequential multiple regression. In this chapter I describe the analyses that verify many, but not all, of the testable hypotheses of this study.

Three main findings emerge:

1) Environmental knowledge and environmental attitudes are strongly related in the expected direction, that is, respondents who indicate that protecting the natural environment is important to them know more about the environmental impacts of vehicle ownership and use.
2) Environmental knowledge is significantly related to only one measure of vehicle ownership and use: types of household vehicles, as measured by average fuel efficiency. This relationship confirms the relevant hypothesis: the households of respondents who know more about the environmental impacts of vehicle ownership and use own, on average, more fuel efficient vehicles.
3) Environmental attitudes are related in the hypothesized direction to all four measures of vehicle ownership and use considered in this study. That is, the households of respondents who indicate that protecting the natural environment is a priority own fewer and more fuel efficient vehicles, drive them less, and, therefore, consume less fuel annually than do the households of respondents who indicate that protecting economic growth and jobs is more important.

Following this introduction, this chapter is organized into three sections. The first is a discussion of the bi-variate correlation analysis conducted to understand basic relationships between environmental knowledge, environmental attitudes, and socio-economic and demographic variables. In the second section, I describe the differences of means analyses I conducted (t-tests and ANOVA) to assess hypotheses 1 (concerning environmental knowledge and attitudes), 2 (concerning environmental knowledge and vehicle ownership and use), and 3 (concerning environmental attitudes and vehicle ownership and use). Finally, in the third section, I delve more deeply into the relationships of knowledge and attitudes to vehicle ownership and use by describing sequential multiple regression analyses used to evaluate the impacts of environmental knowledge and environmental attitudes on vehicle ownership and use, after having controlled for key socio-economic and demographic variables.

Knowledge, attitudes, and socio-economic / demographic variables

Are there significant relationships among the various bi-variate measures of environmental knowledge, environmental attitudes, socio-economic status and demographic characteristics? If so, how strong are those relationships? The answers to these questions are important for two reasons. First, they help identify significant and revealing connections between pairs of key variables. For example, do women have stronger pro-environmental attitudes than men? Are respondents with more formal education better informed of the environmental impacts of vehicle ownership and use? Is there a relationship between type of residency and environmental attitudes or knowledge? The results of simple bi-variate correlation analyses will help answer these questions and suggest whether or not such intervening variables may be critical to subsequent analyses.

In addition, such analysis is an important step in screening the data for potential occurrences of multi-collinearity, where relationships between pairs of independent variables may be so strong as to create problems in using some statistical tools.

Spearman's rank order correlation analysis (rho) was conducted using fourteen demographic and socio-economic variables, one measure of environmental knowledge (index B, which ranges from -14 to 14, being based on both certainty and accuracy of responses) and two measures of environmental attitudes (responses to environmental attitudes question #1 and index A, which ranges from 0 to 3 and combines results of responses to the three environmental attitudes questions). The results, presented in Table 5.1 below, indicate twenty four statistically significant bi-variate relations, but only those amongst environmental knowledge and the two measures of environmental attitudes have coefficients of determination indicating more than four percent of shared variance.[29] So, although the data set is sufficiently large to reveal statistically significant relationships, few indicate a large enough measure of shared variance to be particularly meaningful.

Hypothesis 1 states that "Knowledge of the environmental impacts of vehicle ownership and use is positively related to pro-environmental attitudes." Correlation analysis indicates that knowledge and attitudes are, indeed, significantly related to each other in the expected, positive, direction (at the .01, two-tailed level). Environmental knowledge (index B) is related to environmental attitudes (question #1) with a Spearman's rank order correlation of 0.252, indicating shared variance of 6.34%, and to environmental attitudes (index A) with a Spearman's correlation of 0.289, indicating shared variance of 8.36%. I explore this finding of support for hypothesis 1 and the

[29] Shared variance is calculated by squaring the Spearman's correlation coefficient value and expressing the result as a percentage.

relationship between environmental knowledge and environmental attitudes in more depth later in this chapter.

Table 5.1: Spearman's Rank Order Correlation values for key bi-variate relationships, weighted analysis

		Environ-mental Knowledge (Index B)	**Environ-mental Attitudes (Q. #1)**	**Environ-mental Attitudes (Index A)**
Env K Index B (Measure ranging from -14 to 14)	Correlation Coeffic N			
Env A Q #1 Value (0=Pro-Economy; 1=Pro-Environment)	Correlation Coeffic N	**0.252**** 1,447		
Env A Index A (Measure ranging from 0 to 3)	Correlation Coeffic N	**0.289**** 1,479	**0.679**** 1,448	
Member of AAA (1=Yes; 2=No)	Correlation Coeffic N	0.018 1,500	-0.003 1,441	-0.010 1,473
Number Household Members	Correlation Coeffic N	**-0.062*** 1,498	**-0.063*** 1,440	-0.013 1,472
Number Household Members 16 or Older	Correlation Coeffic N	**-0.080**** 1,491	**-0.072**** 1,435	-0.026 1,465
Number Household Licensed Drivers	Correlation Coeffic N	**-0.055*** 1,486	**-0.081**** 1,427	-0.030 1,459
Number Household Members Under 16	Correlation Coeffic N	-0.01 1,488	0.01 1,432	0.03 1,462
Member Env Org Value (1=Yes; 2=No)	Correlation Coeffic N	**0.164**** 1,489	**0.126**** 1,430	**0.154**** 1,462
Highest Level of Education (Ordinal Measure from 1 to 6)	Correlation Coeffic N	**0.199**** 1,474	**0.070**** 1,417	0.041 1,447
Income Range (Ordinal Measure from 1 to 8)	Correlation Coeffic N	**0.080**** 1,380	-0.017 1,335	-0.016 1,360
Hispanic (1=Yes; 2=No)	Correlation Coeffic N	0.051 1,442	-0.016 1,389	-0.008 1,418
Age	Correlation Coeffic N	-0.039 1,438	0.020 1,384	**-0.077**** 1,413
Gender (1=Male; 2=Female)	Correlation Coeffic N	**-0.127**** 1,477	**0.134**** 1,423	**0.133**** 1,452
Homeowner (1=Yes; 2=No)	Correlation Coeffic N	-0.024 1,489	**-0.111**** 1,430	**-0.094**** 1,462
SOV Commuter (1=Yes; 2=No)	Correlation Coeffic N	-0.024 1,130	**-0.067*** 1,085	-0.045 1,110
Commuter (1=Yes; 2=No)	Correlation Coeffic N	0.036 1,507	**-0.059*** 1,448	**0.062*** 1,480

*=statistically significant at the .95 level; **=statistically significant at the .99 level

Environmental attitudes question #1 and environmental attitudes index A show a much higher Spearman's rank order correlation (of 0.679, indicating 46.15% of shared variance), as is expected, given that question #1 is one of three components of environmental attitudes index A. Problems associated with singularity—i.e., redundancy due to one variable being a combination of one or more other variables within a single analysis—will prevent inclusion of both environmental attitudes question #1 and environmental attitudes index A in multi-variate regression analyses reported below.

There are statistically significant bi-variate relations between environmental knowledge and four of the demographic and socio-economic indicators: a) number of household members, b) number of household members aged 16 or older, c) number of household licensed drivers, d) membership in an environmental organization, e) respondent highest level of education, f) household income, and g) gender. Respondents from smaller households (with fewer total members, members aged 16 and older, and members who are licensed drivers), who are members of organizations such as the Audubon Society and the Sierra Club, have higher levels of education, have higher household incomes, or are male know more about the environmental impacts of owning and using vehicles. The values of the *Spearman's* correlations, however, are all low, with the highest being 0.199 (highest level of education with environmental knowledge). Correspondingly, the coefficients of determination—which indicate the percentage of shared variance between two variables—are all very low, none rising above 3.96% (0.199 squared). So, although these seven bi-variate relations rise to the level of statistical significance, the strengths of the relationships are so low as to be relatively unimportant.

In addition, fourteen bivariate relationships between one or both of the two measures of environmental attitudes and nine of the demographic and socio-economic status variables are statistically significant. Only five of these—for the variables related to membership in an environmental organization, gender, and homeownership—have *Spearman's* correlations values larger than 0.100. Those who are members of an environmental organization are likely to have higher levels of pro-environmental attitudes. Women are statistically more likely to have higher levels of pro-environmental attitudes and homeowners are statistically more likely to have lower levels of pro-environmental attitudes. But, as with the environmental knowledge bivariate relationships, all of these correlations are very small, none indicating more than 2.37% of shared variance.

Though not included in Table 5.1, bivariate correlations amongst the socio-economic and demographic variables were assessed to determine whether any correlations were strong enough to raise concerns of multi-collinearity in subsequent analyses. When variables are highly correlated (with Spearman's Rank Order Correlation values of 0.70 and above), logical and statistical problems arise (Tabachnick and Fidell 2001). Three of the bi-variate relationships in this analysis reach that level, but not surprisingly, they are relationships *among* the four household membership variables:

- Number of household members related to number of household members aged 16 and older has a Spearman's correlation of .737, indicating 54.32% of shared variance.
- Number of household members aged 16 and older related to number of household licensed drivers has a Spearman's correlation of .857, indicating 73.44% of shared variance.
- Number of household members related to number of household members under age 16 has a Spearman's correlation of .712, indicating 50.69% shared variance.

Only two other bivariate correlations share more than 10% of variance: income with highest level of education (Spearman's correlation of .424, indicating 17.98% of shared variance) and income with homeownership (Spearman's correlation of .448, indicating 20.07% of shared variance). Careful consideration is necessary if the four measures of household membership are to be included in a single statistical analysis, but none of the other bivariate relationships among the socio-economic and demographic indicators reach a level of correlation that would raise concerns about multi-collinearity.

Difference of means analyses

Spearman's rank order correlation analysis reveals some interesting, statistically significant relationships between environmental knowledge, environmental attitudes, and various measures of socio-economic status and demographic characteristics, but it is not the appropriate technique for confirming or refuting the first three hypotheses of this study. For that purpose, it was useful to begin by using standard independent-samples t-tests and analysis of variance (ANOVA) to explore the differences in mean values of the four principal outcome variables (number of household vehicles, average fuel efficiency of household vehicles, estimated annual household miles driven, and estimated annual household fuel consumption), when divided into groups of respondents according to levels of environmental knowledge and environmental attitudes. This permitted me to identify statistically significant differences at the aggregate level, where they existed, before conducting multiple regression analysis to control for possibly intervening variables.

In this section, therefore, I examine three key relationships that directly address the first three study hypotheses, seeking to establish whether, at the level of groups of respondents, significant differences are observable in four key components of vehicle ownership and use.

Environmental knowledge and environmental attitudes

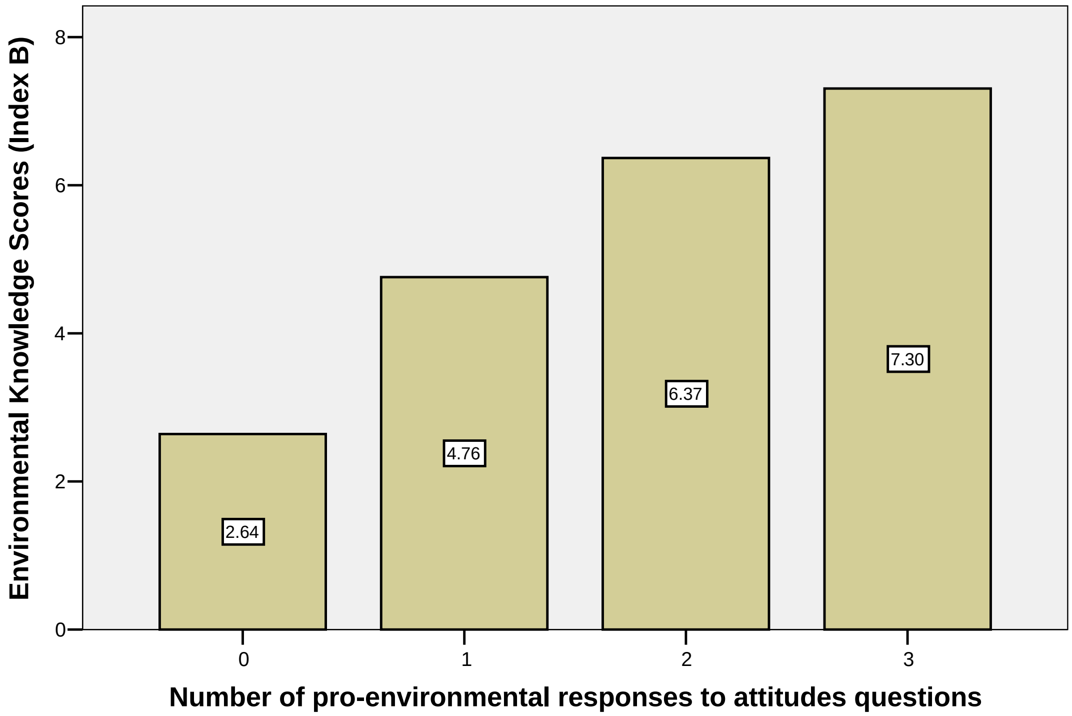
With the correlation analysis described above I identified a statistically significant relationship between environmental knowledge and environmental attitudes, providing some evidence to confirm hypothesis 1 that "Knowledge of the environmental impacts of vehicle ownership and use is positively related to pro-environmental attitudes." I used a one-way between-groups analysis of variance[30] to explore this question in more detail by relating changes in levels of knowledge of the environmental impacts of vehicle ownership and use (index B) to levels of environmental attitudes measured using index A (values range from 0 to 3).[31] There was a statistically significant difference at the $p<.01$ level in environmental knowledge for the four categories of environmental attitudes [$F(3, 1466)=54.81$, $p=.01$]. The differences in average levels of environmental knowledge were quite large, increasing significantly from a score of 2.64 on the environmental knowledge index B for those who answered none of the three attitudes questions with a pro-environmental response, to 7.30 for those who answered all of the questions in a pro-

[30] "One-way between-groups analysis of variance is used when you have one independent (grouping) variable with three or more levels (groups) and one dependent continuous variable. The 'one-way' part of the title indicates there is only one independent variable, and 'between-groups' means that you have different subjects or cases in each of the groups," (Pallant 2001, p. 187).

[31] As explained in Chapter 4, Cronbach's alpha analysis of environmental attitudes index A did not yield a high value, raising questions about the utility of using it in subsequent analyses. I use it here because index A remains an intuitively straightforward index in that it indicates the number of environmental attitudes questions respondents answered in a pro-environmental way, from 0, in which no such questions were answered in the pro-environmental way, to 3, in which all three were.

environmental way (see Figure 5.1 below). The effect size, calculated using eta squared, was 0.10 (a medium to large effect, according to Cohen, cited in Pallant 2001). [32,33]

Figure 5.1: Average environmental knowledge scores for respondents with four levels of environmental attitudes



This analysis provides convincing evidence that environmental knowledge is positively associated with pro-environmental attitudes: pro-environment respondents know significantly more about the environmental impacts of owning and using vehicles than do pro-economic growth respondents. I cannot say, at this point, if this relationship

[32] Eta-squared is calculated using the formula $t^2 / t^2 + (N_1 + N_2 - 2)$ and provides an indication of the magnitude of differences between the groups by representing "the proportion of variance in the dependent variable that is explained by the independent (group) variable" (Pallant 2001, p. 180). Cohen (1988, cited in Pallant 2001) identifies these values for interpreting eta-squared: .01=small effect; .06=moderate effect; and .14=large effect.

[33] When the analysis is conducted using a t-test based on only the response to environmental attitudes question #1 (the indicator of environmental attitudes that will be used throughout the rest of this study) and environmental knowledge index B, a comparable result emerges: there was a significant difference in scores for those who did not respond in the pro-environmental way (M=3.83, SD=5.07), and those who did (M=6.71, SD=4.40; t(733.17)=-10.29, p=.000.

is causal. But whether there is a directional relationship or not—with higher knowledge leading respondents to hold pro-environmental attitudes or respondents' pro-environmental attitudes causing them to become more knowledgeable about the environmental impacts of vehicle ownership and use—the link between the two variables is clear and strong.

Knowledge, attitudes, and vehicle ownership and use

To test the basic propositions put forth in the second and third hypotheses—that higher levels of environmental knowledge and pro-environmental attitudes are positively related to less resource-intensive vehicle ownership and use choices—difference-of-means analyses were conducted using standard t-tests and analysis of variance (ANOVA). The vehicle ownership and use variables of interest are 1) number of household vehicles, 2) types of vehicles owned, as measured by average fuel efficiency,[34] 3) estimated annual household miles driven, and 4) estimated annual household fuel consumption related to the ownership and use of vehicles.

Vehicle ownership and use behavior is complex, so I include these four separate vehicle ownership and use variables in the analysis. Within a household, individuals may have varying needs and desires related to vehicle ownership and use and environmental knowledge and attitudes may only influence, or be expressed in, one or some of the various types of behavior and by one or more of the members of a household. For example, employment opportunities and locations may require each driving age household member to commute by personal vehicle (even if one or more of them would

[34] Fuel economy data come from the United States Environmental Protection Agency (USEPA) combined miles-per-gallon ratings available online at www.fueleconomy.gov. The data are only available for vehicles weighing under 8,500 pounds and manufactured in 1985 or later. Fuel economy data for vehicles manufactured in 1985 or later weighing more than 8,500 pounds was estimated at 12 miles per gallon.

prefer not to own so many vehicles or to drive so much), but some compensating behavior related to environmental knowledge and attitudes may be expressed in the types of vehicles owned (for example, smaller, more fuel efficient vehicles).

In these differences of means analyses, I explore number of household vehicles, estimated annual household miles driven, and estimated annual household fuel consumption variables in four ways: for the entire household, per household member (children and adults), per household member aged 16 and older, and per household licensed driver. The purpose of analyzing these three variables using four different measurements is to consider the household as a unit and then to control for household size in three ways that reflect the number of all household members, the number of household members old enough to legally drive a vehicle (those 16 and older), and the number of household members who actually hold drivers' licenses (some people aged 16 and older are unable or choose not to drive).[35] At this stage, my purpose is to identify whether there are significant differences in the average values of each variable of interest for respondents with different levels of environmental knowledge and attitudes. Significant differences do exist, as is described immediately below, so analyses to control for age, income, education, and other important demographic and socio-economic variables with multiple regression equations were conducted, with the results described later in the chapter.

[35] Though there may be a relationship between average fuel efficiency of vehicles and household size (larger families may buy larger vehicles that generally get lower miles per gallon than do smaller vehicles), it makes no logical sense to divide average fuel efficiency of household vehicles by number of household members, those aged 16 and older, and those licensed to drive. Consequently, for analysis of average fuel economy of household vehicles, no additional calculations per household members are made.

Environmental knowledge and vehicle ownership and use

The next four sub-sections consider relationships between environmental knowledge and the four indicators of vehicle ownership and use discussed above. Analysis of variance (ANOVA) was used to assess each relationship, based upon a seven-category regrouping of environmental knowledge (index B). By collapsing environmental knowledge into seven groups (instead of using the continuous twenty-eight separate values in the range between -13 and 14 that the final data set exhibited), extremely low values[36] are collapsed into the group of respondents with the lowest environmental knowledge and the resulting categories can be given more intuitive labels of "very low" to "very high" levels of environmental knowledge.

Environmental knowledge and number of vehicles owned

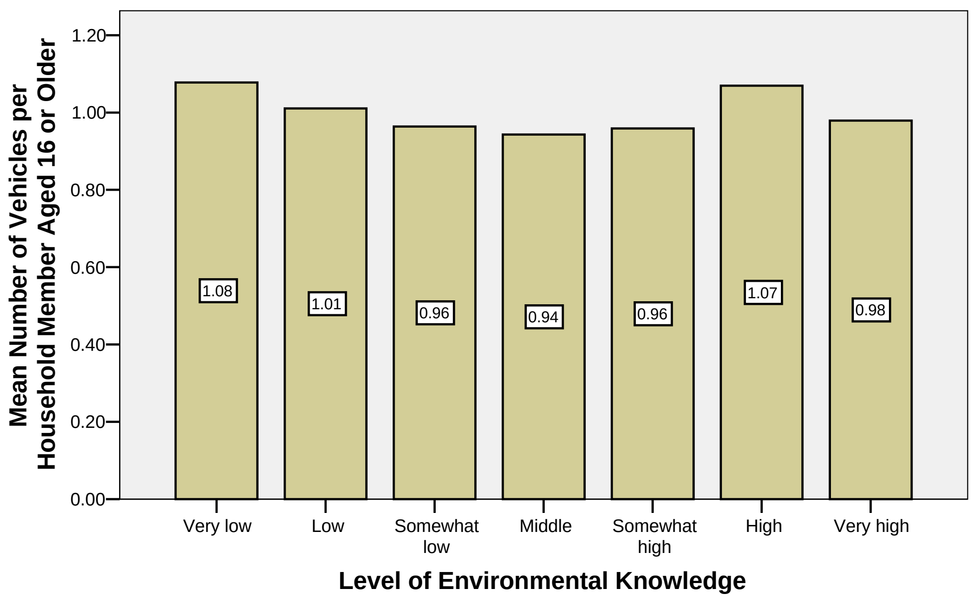
Hypothesis 2a states that "High levels of knowledge of the environmental impacts of vehicle ownership and use are related to lower vehicle ownership." To assess whether the data collected in this survey confirms or rejects this hypothesis, I conducted a one-way between-groups analysis of variance to explore relationships between increasing levels of environmental knowledge on number of vehicles owned per household.[37] In this and all subsequent analyses, the set of analytic weights developed to correct for sampling and non-response biases (see discussion in chapter 4) was used.

Results indicate significant differences at the $p<.01$ level in number of vehicles owned per household member aged 16 and older [$F(6, 1442)=3.471$, $p=.002$] for respondents categorized by level of environmental knowledge (no statistical differences

[36] All values below -6 for this variable were so uncommon as to be considered outliers.
[37] The original, untrimmed values for number of household vehicles were used in this analysis, rather than the trimmed values that set respondents with six or more vehicles to "5". These results were compared to those from the analysis using the trimmed values and they are the same.

in means for the other three variables were identified[38]). Despite reaching statistical significance, however, the calculated effect size was small (eta-squared=0.01, a "small" strength of association, according to Cohen's guidelines, cited in Pallant 2001). What is more, the differences in mean values followed a pattern which did not confirm the hypothesis that higher levels of environmental knowledge would be associated with lower levels of vehicle ownership. Post-hoc comparisons using the Tukey HSD[39] test indicated that the significant differences in mean scores for vehicles owned per household member aged 16 and older (see Figure 5.2 below) were only to be found between middle levels of knowledge (M=0.94, SD=0.40) and very low (M=1.08, SD=0.48) and high (but not very high) levels of knowledge (M=1.07, SD=0.39).

Figure 5.2: Results of analysis of variance for vehicles per household member aged 16 or older grouped on levels of environmental knowledge



[38] While the results indicate that vehicles per household licensed driver is also significant—p=.017—a test for homogeneity of variance for this variable demonstrates a violation of this assumption. In such cases, a more stringent p value of $p<.01$ is recommended (see Tabachnik and Fidell, 2001, p. 80) and, in this case, the more stringent significance level is not met.
[39] HSD stands for "Honestly Significant Difference."

The differences are relatively large: groups of respondents with very low and high levels of environmental knowledge averaged 14.89% and 13.83% more vehicles per household member aged 16 and older than did respondents with middle levels of knowledge. But the fact that the lowest level of vehicle ownership is identified with respondents possessing middle levels of environmental knowledge does not conform to the hypothesis and suggests no obvious conclusion. It is possible that number of vehicles owned per household member aged 16 and older and environmental knowledge may both correlate with other variables, such as income and level of education, suggesting that it is worthwhile to control for such variables using multi-variate regression techniques in a subsequent step, as was done and is reported on below.

Environmental knowledge and fuel efficiency of household vehicles

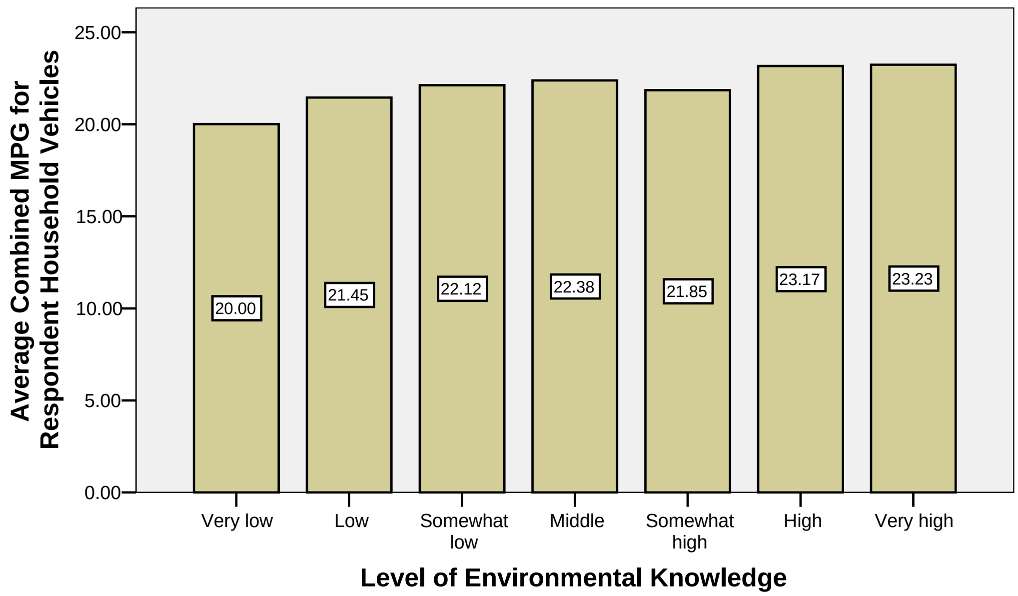
Hypothesis 2b states that "High levels of knowledge of the environmental impacts of vehicle ownership and use are related to ownership of more fuel efficient vehicles." As with the previous question, I used a one-way between-groups analysis of variance to explore this question. The one analytical difference in this case is that I used a dummy variable to limit analysis to those respondents whose vehicle ownership permitted consideration of complete and accurate data.[40]

Results indicate significant differences at the $p<.01$ level in average fuel economy of household vehicles [$F(6, 978)=8.987$, $p=.001$] for respondents categorized by level of environmental knowledge (see Figure 5.3 above) with a moderate effect size (eta-squared=0.05). Post-hoc comparisons using the Tukey HSD test indicated significant

[40] This dummy variable limited analysis to those respondents who owned three or fewer vehicles which were manufactured in 1985 or later (the period for which USEPA data are available for USEPA-tested city, highway and combined fuel economies). These respondents comprised 70% of the unweighted sample (1,052 cases out of 1,506) and 66% of the weighted sample (990 cases out of 1,506).

differences in mean scores for average fuel efficiency of household vehicles for seven of the twenty-one pairs of comparisons, rising from very low and low levels of environmental knowledge (respectively M=20.00, SD=3.79 and M=21.45, SD=3.58) to high and very high levels (respectively M=23.17, SD=4.65 and M=23.23, SD=4.97).

Figure 5.3: Results of analysis of variance for vehicle fuel efficiency grouped on levels of environmental knowledge



The differences are relatively large: as a group, the respondents with very high levels of environmental knowledge own vehicles that are 16.14% more fuel efficient than are the vehicles owned by the group of respondents with very low levels of environmental knowledge (see Figure 5.3 above). This confirms the hypothesis that as levels of knowledge of the environmental impacts of vehicle ownership rise, so too does the average fuel efficiency of household vehicles owned.

Environmental knowledge and annual miles driven

I tested hypothesis 2c ("High levels of knowledge of the environmental impacts of vehicle ownership and use are related to driving fewer miles annually") by using one-way between-groups analysis, but I had to resolve a problem with the data before I could do so. The values for self-reported annual miles of driving per household required transformation because of the presence of a large number of outliers (the same was true for the annual miles of driving per household member, per household member aged 16 and older, and per household licensed driver, as these were calculated using the value for annual miles of driving per household). The problem originated, at least in part, in some confusion concerning the survey instructions for vehicles owned less than one year. These instructions stated that "If you have owned or used it [vehicle #1, #2, or #3] *less than one year*, indicate how many miles you have driven it so far."[41] When I made the calculations to estimate annual miles from such self-reported mileage, however, I obtained excessively high values in many cases. I used SPSS EXPLORE to identify outliers in each of the four annual miles outcome variables and "trimmed" them to the highest non-outlier value.[42]

Results indicate no significant differences at the $p<.05$ level in any of the estimated annual miles variables.[43] The hypothesis is rejected and I cannot conclude that

[41] Italics were used in the survey to highlight the circumstances for which the instructions were relevant.
[42] An alternative solution to this problem was also assessed. A new dummy variable was created to identify the one hundred and nine cases with outlier values, then used to limit analysis to only those cases which were not outliers. This alternative had the benefit of avoiding changes in the original data values, but eliminated a large number of cases that were not random in nature (difference of means analyses indicated that the group of outlier cases had statistically significant lower levels of environmental knowledge and pro-environmental attitudes). At any rate, the results of ANOVA using this dummy variable to split the analysis were comparable to the analysis described here.
[43] While SPSS analysis of variance determined a significance level of 0.018 for estimated annual miles driven per household, the distribution of values violated the assumption of homogeneity of variance

environmental knowledge bears a significant relation to annual miles driven, measured as those attributed to an entire household or to any subset of a household's members. Regardless of a respondent's level of environmental knowledge, amounts of driving per household and per household member are approximately the same.

Environmental knowledge and fuel consumption

Like hypothesis 2c, hypothesis 2d ("High levels of knowledge of the environmental impacts of vehicle ownership and use are related to lower fuel consumption related to household vehicle ownership and use") is rejected after conducting analysis of variance.[44] Results indicate no significant differences at the $p<.05$ level in any of the estimated annual fuel consumption variables. F-values range from 0.666 [$F(6, 845)=0.666$, $p=.678$] for estimated annual household fuel consumption in gallons to 1.475 [$F(6, 844)=1.475$, $p=.184$] for estimated annual fuel consumption in gallons per household member. Consequently, it cannot be concluded that environmental knowledge bears a significant relationship to estimated annual fuel consumption, measured as that attributed to an entire household or to a subset of a household's members.

Environmental attitudes and vehicle ownership and use

In the next four sub-sections I consider the relationships between environmental attitudes and the four indicators of vehicle ownership and use considered in the

---

(Levene statistic (6, 1351)=5.301, $p<.000$), requiring a stricter level of 0.01 be used in determining statistical significance, a level that was not reached.

[44] This question was tested using a dummy variable that restricted analysis to those cases for which mileage variables were not outliers and all data necessary to calculate complete average fuel efficiency of household vehicles, conditions necessary to calculate accurate estimates of annual household fuel consumption. Nine hundred and fifty one (unweighted) cases were available for this analysis, while four hundred and ninety one cases (sixty four cases were missing mileage data and could not be used).

environmental knowledge analysis conducted above. I used t-tests to assess each relationship, based upon the dichotomous variable of environmental attitudes question #1, asking respondents whether they believe environmental laws and regulations cost too many jobs and hurt the economy or are worth such costs.

Environmental attitudes and number of household vehicles

To test hypothesis 3a ("Pro-environmental attitudes are related to lower vehicle ownership"), I conducted an independent-samples t-test to compare average number of vehicles (per household, household member, household member aged 16 and older, and household licensed driver) for respondents with pro-environmental attitudes and respondents with pro-economic growth attitudes. Significant differences were found for each of the four number of household vehicles variables (see Table 5.2 below) with, in every case, the average number of vehicles owned by the households of pro-environmental respondents being lower than for households of those who said environmental laws and regulations cost too many jobs and hurt the economy.

Table 5.2: Results for t-tests, number of household vehicles grouped by environmental attitudes

	Environmental laws and regulations cost too many jobs / hurt economy	Environmental laws and regulations are worth the cost	t(df), significance	eta-squared
Number of Vehicles per Household (N=1404)	2.56	2.23 (12.89% less)	**t(709)=5.026, p=.000**	.02
Vehicles per Household Member (N=1397)	0.87	0.81 (6.58% less)	**t(1395)=2.362, p=.018**	.00
Vehicles per Household Member Aged 16 or Older (N=1391)	1.04	0.98 (6.52% less)	**t(1389)=2.813, p=.005**	.01
Vehicles per Household Licensed Driver (N=1389)	1.13	1.05 (6.66% less)	**t(1387)=3.073, p=.002**	.01

Analysis therefore confirmed hypothesis 3a: respondents with pro-environmental attitudes own fewer vehicles than respondents who believe the economic costs of environmental laws and regulations are too high. Note, however, that the eta-squared values were all small, indicating that, despite the statistically significant differences in the aggregate, the predictive power of these differences is very low at the level of the individual respondent.

Environmental attitudes and fuel efficiency of vehicles owned

An independent-samples t-test of hypothesis 3b ("Pro-environmental attitudes are related to ownership of more fuel efficient vehicles") confirmed that there is a significant difference in average fuel efficiency of household vehicles for respondents with pro-economic growth attitudes (M=20.84, SD=3.94), and pro-environmental attitudes (M=22.47, SD=4.37; t(950)=-5.294, p=.000). The average fuel efficiency of vehicles owned by the latter group is 7.8% higher than for the former group. All else being equal, then, of two households driving the same number of miles, the "pro-environmental" household would use 7.3% less fuel than the household represented by a respondent who did not answer the question in a pro-environmental way. For every 10,000 miles driven, this equals a difference of 34.8 gallons of fuel consumed and approximately 680 pounds of carbon-dioxide emissions.[45] The magnitude in difference of means was small to moderate (eta squared=.03), however, indicating that the predictive power of the relationship at the level of the individual respondent is not great.

[45] A gallon of gasoline contains approximately 5.5 pounds of carbon (and 0.8 pounds of hydrogen) which combine with oxygen from the air to create carbon-dioxide (one carbon atom with an atomic weight of 12 plus two oxygen atoms with an atomic weight of 22 each), for a total weight of CO_2 emissions of about 20 pounds. See http://www.fueleconomy.gov/feg/co2.shtml for a more detailed explanation.

Environmental attitudes and annual miles driven

T-test analysis confirmed hypothesis 3c ("Pro-environmental attitudes are related to driving fewer miles annually") with statistically significant differences in estimated annual household miles driven for households of pro-environment and pro-economic growth respondents.[46] For annual miles driven per household, the households of respondents who selected the pro-environmental statement (M=24,977, SD=15,422) drove, on average, 17.6% fewer miles than did the households of respondents who did not select the pro-environmental statement (M=30,317, SD=16,586; t(672)=5.416, p=.000).

Table 5.3: Results for t-tests, estimated annual household miles driven grouped by environmental attitudes

	Environmental laws and regulations cost too many jobs / hurt economy	Environmental laws and regulations are worth the cost	t(df), significance	eta-squared
Annual miles driven per household, trimmed values (N=1311)	30,317	24,977 (17.61% less)	**t(672)=5.416, p=.000**	.02
Annual miles driven per Household Member, trimmed values (N=1308)	9,930	8,794 (11.44% less)	**t(1306)=3.344, p=.001**	.01
Annual miles driven per Household Member Aged 16 or Older, trimmed values (N=1304)	12,236	10,798 (11.75% less)	**t(1302)=3.626, p=.000**	.01
Annual miles driven per Household Licensed Driver, trimmed values (N=1286)	13,350	11,661 (12.65% less)	**t(1284)=4.031, p=.000**	.01

The other three annual miles variables also showed statistically significant differences at the p=.001 level, with, in each case, the group of respondents who answered in the pro-environmental way driving, on average, at least 11.4% fewer miles than respondents who

[46] I used trimmed values of estimated annual household miles driven (and estimated annual miles driven per household member, household member aged 16 and older, and household licensed driver) for the reasons explained above in the discussion of Hypothesis 2c.

did not answer in the pro-environmental way (see Table 5.3 below). The magnitude of differences in the means for these variables, as measured by eta-squared, however, was again quite small.

Environmental attitudes and fuel consumption

In using t-tests to analyze the relationship of environmental attitudes to estimated annual household fuel consumption, I found statistically significant differences for each of the four indicators, confirming hypothesis 3d: "Pro-environmental attitudes are related to lower fuel consumption related to household vehicle ownership and use."[47] The households of pro-environmental respondents consumed, on average, 16.9% fewer gallons of fuel (M=982, SD=631) than the households of pro-economic growth respondents (M=1,182, SD=678; t(824)=3.857, p=.000). See Table 5.4 below.

Table 5.4: Results for t-tests, estimated annual household fuel consumption grouped by environmental attitudes

	Environmental laws and regulations cost too many jobs / hurt economy	Environmental laws and regulations are worth the cost	t(df), significance	eta-squared
Annual estimated fuel consumption per household, in gallons (N=826)	1182	982 (16.92% less)	**t(824)=3.857, p=.000**	.02
Annual estimated fuel consumption per Household Member, in gallons (N=826)	433	371 (14.32% less)	**t(824)=3.207, p=.001**	.01
Annual estimated fuel consumption per Household Member Aged 16 or Older, in gallons (N=826)	563	463 (17.76% less)	**t(824)=4.281, p=.000**	.02
Annual estimated fuel consumption per Household Licensed Driver, in gallons (N=826)	594	493 (17.00% less)	**t(824)=4.222, p=.000**	.02

[47] The same dummy variable used in assessing Hypothesis 2d above was used in this analysis in order to restrict consideration to cases for which mileage variables were not outliers and all data necessary to calculate complete average fuel efficiency of household vehicles (conditions necessary to calculate accurate estimates of annual household fuel consumption) were available.

Findings of significance were comparable for each of the other three indicators (estimated annual fuel consumption per: household member, household member aged 16 and older, and household licensed driver), with the difference in levels of consumption ranging from 14.3% to 17.8% less fuel consumption by members of households of pro-environmental respondents than by members of households of pro-economic growth respondents. The magnitude of differences in the means, as measured by eta-squared, however, was again generally small.

Summary of differences of means analyses

Difference of means analyses using analysis of variance and independent-samples t-tests confirm five of the eight components of hypotheses 2 and 3. Knowledge of the environmental impacts of vehicle ownership and use exhibited two statistically significant relationships, only one of which confirmed a study hypothesis. The first significant relationship was with number of vehicles per household member aged 16 and older, with the critical difference lying between the group of respondents with a middle level of environmental knowledge (they have the lowest level of vehicle ownership) and the groups of respondents with the very lowest and high levels of environmental knowledge, who owned more vehicles, on average. The conclusion appears to be that some environmental knowledge, but not too much, is related to lower levels of vehicle ownership, a finding that does not confirm hypothesis 2a and the idea that more knowledge would lead to lower levels of ownership.

The second statistically significant relationship for environmental knowledge, however, is not only stronger, but confirmed one of the study's hypotheses. The households of respondents who have higher levels of knowledge of the environmental impacts of vehicle ownership and use owned more fuel efficient vehicles, as measured by the average fuel efficiency of all household vehicles. There is a 16.1% difference in average combined miles-per-gallon ratings of vehicles owned by those who have the lowest knowledge (on average, 20.0 miles per gallon) and the highest (on average, 23.2 miles per gallon).

Environmental attitudes on the other hand—as measured by responses to the single, “classic” question concerning priorities, protection of the environment or of jobs and economic growth—had statistically significant relationships with each of the four measures of vehicle ownership and use, confirming all of the hypotheses related to environmental attitudes. The households of pro-environmental respondents owned fewer vehicles (6.7% fewer per household licensed driver), more fuel efficient vehicles (7.8% higher average combined mpg), drove them fewer miles on an annual basis (12.7% fewer per household licensed driver), and consumed fewer gallons of fuel per year in owning and running them (17.0% fewer per household licensed driver).

The strengths of association of the statistically significant relationships, however, were generally quite small. With one exception, eta-squared values were never larger than 0.03, indicating that the predictive power of these relationships at the level of the individual household is low. So although the differences in means at the aggregate level were significant and relatively large, which is an important finding, an individual respondent’s levels of environmental knowledge and environmental attitudes were unlikely to help much in predicting his or her household’s actual vehicle ownership and use. The one exception to this conclusion is the relationship between environmental knowledge and average fuel efficiency of household vehicles. In this case, with an eta-squared value of 0.05, the strength of association was stronger and, thus, the predictive power of an individual respondent's level of environmental knowledge was higher in regards to his or her household's average vehicle fuel efficiency.

Table 5.5: Summary of findings for knowledge, attitudes, and vehicle ownership and use, differences of means analyses

	Environmental Knowledge	**Environmental Attitudes**
Number of Household Vehicles	**Significant** for one of four outcome variables (small effect size of 0.01).	**Significant** for four of four outcome variables (small effect sizes ranging from 0.01 to 0.02).
	Does not confirm hypothesis 2a	Confirms hypothesis 3a
Average Fuel Efficiency of Household Vehicles	**Significant**, with a medium effect size (0.05).	**Significant**, with a small to medium effect size of 0.03.
	Confirms hypothesis 2b	Confirms hypothesis 3b
Estimated Annual Household Miles Driven	Insignificant for four of four outcome variables.	**Significant** for four of four outcome variables (small effect sizes of 0.01 and 0.02).
	Does not confirm hypothesis 2c	Confirms hypothesis 3c
Estimated Annual Household Fuel Consumption	Insignificant for four of four outcome variables.	**Significant** for four of four outcome variables (effect sizes range from 0.01 to 0.02).
	Does not confirm hypothesis 2d	Confirms hypothesis 3d

This first set of analyses, however, has not controlled for any other variables that may influence household vehicle ownership and use, except for household membership, in the case of the per household member, per household member aged 16 and older, and per household licensed driver variables. In the next stage of analysis, I use multiple regression to control for variables at the household level (such as income), respondent level (highest level of education and age, for example), and variables representing qualities of the physical environment (residential population density and a measure of neighborhood pedestrian friendliness).

Multiple regression analysis

To analyze the influence of environmental knowledge and environmental attitudes on the study's four indicators of household vehicle ownership and use, while controlling for common socio-economic, demographic, and physical environmental variables, I developed four multiple regression equations[48] (see Table 5.6 below). Each equation is based on the household as the unit of analysis, and shares the same set of independent variables, except for the first equation, which examines number of vehicles owned per household. The independent variables are grouped into sets of household, respondent, physical environment, and environmental knowledge and attitudes variables.

- Household variables: 1) number of licensed drivers in the household (i.e., the number of household members who might want or need to own or use a vehicle), 2) the number of household members under age 16 (i.e., the number of household members who cannot legally drive a vehicle, but who may create a want or need for the services of a household vehicle), 3) household income, and 4) number of household vehicles available.
- Respondent variables: 1) respondent age, in years, 2) highest level of education, and 3) whether or not the respondent commutes to a job using a single-occupancy vehicle.
- Physical environment variables: 1) population density per gross acre (calculated using US Census Bureau data for block group population and size, in acres, excluding water bodies) and 2) pedestrian environment factor, a scale measure,

[48] Yagil (2000) and Nilsson and Küller (2000) both used regression analysis to study the influence of attitudes and knowledge on travel behaviors for similar analytical purposes.

ranging from 7 to 11, developed by SACOG[49] using three categories of variables—density and land uses, urban form, and availability of sidewalks—with higher values indicating more walkable and bikeable block groups.

Table 5.6: Descriptions of multiple regression models with lists of variables

	Number of HH Vehicles	**Fuel Efficiency of HH Vehicles**	**Estimated Annual HH Miles Driven**	**Estimated Annual HH Fuel Consumption**
Dependent Variable	Q2_HH_Vehs	T_T5_OMPS (Trimmed Values)	T_T2_Miles (Trimmed Values)	T_C1_ FuelHH (Trimmed Values)
Analytic Weights	✓	✓	✓	✓
Split	None (N= 1,474)	S1_OMPG[50] (Valid N= 990)	None (N= 1,364)	S1_OMPG (Valid N= 990)
Household Variables				
Number of Household Licensed Drivers (Q2_hh_vehs)[51]	✓	✓	✓	✓
Number of Household Members Under Age 16 (A40_hh_15)		✓	✓	✓
Household Income (Q30_inco)	✓	✓	✓	✓
Number of Household Vehicles (Q2_vehs)		✓	✓	✓
Respondent Variables				
Respondent Age (Q33_age)	✓	✓	✓	✓
Respondent Highest Level of Education (Q29_edu)	✓	✓	✓	✓
Single Occupancy Vehicle Commuter (D13_SOV)	✓	✓	✓	✓
Physical Environment Variables				
Population Density (A5_popdn)	✓	✓	✓	✓
Pedestrian Env Factor (A6_pef)	✓	✓	✓	✓
Environment Knowledge and Attitudes				
Environmental Knowledge (I2_ekb)	✓	✓	✓	✓
Environmental Attitudes (Q20_eaq1)	✓	✓	✓	✓

[49] SACOG Senior Planner/Modeler Robert McCrary provided me with the data for this variable in March, 2006.
[50] This dummy variable permits analysis to be limited to those cases in which complete data is available for the fuel efficiency of all of a household's vehicles. This restricts analysis to households with three or fewer vehicles, all manufactured in or after 1985, when standardized USEPA fuel efficiency data became available.
[51] The naming convention for data base variables is the following: Q variables are directly input values from responses to survey questions, A variables are added data values (for example, population density from the US Census Bureau and pedestrian environment factor from SACOG), D variables are dummy variables created from other variables, I variables are indexes created from two or more other variables, and T variables are transformations of other variables, usually for the purpose of trimming outlier values, or grouping continuous variables into ranges of values.

- Environmental knowledge and attitudes variables: 1) Index B of environmental knowledge (ranging in value from -13 to 14, based upon correctness and level of certainty of responses to seven environmental knowledge questions) and 2) response to environmental attitudes question #1.

I did not include number of children under age 16 in the first model estimating number of household vehicles, because their presence in a family would not be a reason for purchasing *additional* vehicles, as children cannot legally drive one. This variable is included in the other three equations along with number of household licensed drivers,[52] however, because their presence in a household may encourage buying *larger* vehicles for space and / or safety reasons (thus lowering the average combined fuel efficiency of the household's vehicles) and driving *more miles* to travel to places of children's activities, thus requiring higher levels of fuel consumption. In addition, number of vehicles, though a logical and theoretically sound variable to be included in the second, third, and fourth models, is the dependent variable in the first, so cannot be an independent variable in this equation at the same time.

I chose sequential multiple regression analysis (also called hierarchical regression analysis) to determine whether the addition of environmental knowledge and attitudes variables to sets of household-level, respondent-level, and physical environment variables would improve estimation of the four outcome variables. I did this for two reasons. First, it allowed me to enter groups of variables into the equation in the expected order of

[52] While several bi-variate relations amongst the four household members variables are strong enough to suggest that problems of multi-collinearity would arise with their shared inclusion in a single multiple regression equation (for example, number of household members aged 16 and older and number of household licensed drivers has a Spearman's correlation of .857), number of household licensed drivers and number of household members under age 16 have a Spearman's correlation of only .084. This is statistically significant at the .01, two-tailed level, but is not high enough to raise concerns of multi-collinearity.

greatest influence. Household income and household size have been found to be influential variables in past studies of vehicle ownership and use, respondent-level variables a bit less significant, and physical environment variables even less so. Second, sequential multiple regression analysis provided the most rigorous test of the influence of environmental knowledge and environmental attitudes by controlling for all other likely predictors *before* their entry into the model. Analysis was performed using SPSS REGRESSION and SPSS FREQUENCIES for evaluation of assumptions and the set of analytic weights, described in Chapter 4, were applied to all four models.

I constructed each model in a manner similar to this first model which predicts number of household vehicles:

$$Y' = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + B_6X_6 + B_7X_7 + B_8X_8 + B_9X_9$$

where

Y= Number of household vehicles (Q2_vehs)
X_1=Number of household members licensed to drive (Q27_hh_ld)
X_2=Household income (Q30_inco)*
X_3=Age of respondent (Q33_age)
X_4=Respondent highest level of education (Q29_edu)*
X_5=Dummy variable for SOV commuters and non-SOV commuters (D13_SOV)
X_6=Population Density of Respondent's Residential Block Group (A5_popdn)
X_7=PEF, Pedestrian environment factor (A6_pef)*
X_8=Environmental knowledge concerning impacts of vehicle ownership and use of the respondent (I2_ekb)*
X_9=Environmental attitudes of the respondent (Q20_eaq1)

* ordinal variable

Table 5.7 below displays the unstandardized regression coefficients (B), the standardized regression coefficients (β), the semipartial correlations (sr_i^2), the intercept and R, R^2, and adjusted R^2 after entry of all independent variables for all four equations. I describe the results of this analysis in the following sub-sections.

Number of household vehicles

This model, based upon the hypothesized influence of nine independent variables, was effective in predicting number of household vehicles with a reasonable degree of accuracy. After step 4, when all independent variables were entered into the equation, R^2=.511, indicating that these variables explained 51.1% of the variation in number of household vehicles. R was significantly different from zero at the end of each step, except for step 3 when the physical environment variables were entered into the equation (neither population density nor pedestrian environment factor proved to significantly affect number of household vehicles, so this step's insignificance was expected).

The final model included four statistically significant variables: number of household licensed drivers, household income, and single-occupancy vehicle commuting (all significant at the .01 level) that were positively related to ownership of more vehicles per household, and environmental attitudes (significant at the .05 level), which reduced vehicle ownership per household. The standardized regression coefficients (β) indicated the relative importance of the four variables to the final equation, with number of household licensed drivers having far and away the largest influence (β=0.64). Income was important in the equation, with a β value of 0.19, and single-occupancy commuter status and environmental attitudes had small, roughly equal impacts, but in opposite directions (respective β values of 0.07 and -0.05). Thus, even after controlling for important demographic and socio-economic variables, environmental attitudes had a statistically significant impact on vehicle ownership at the household level, but it was a small impact of relatively low importance compared to number of household licensed drivers and income.

TABLE 5.7: Summary of Results of Sequential Multiple Regression Models for Four Measures of Vehicle Ownership and Use

	Number of Household Vehicles			Average Combined MPG of Household Vehicles			Annual Miles Driven per Household			Annual Estimated Household Fuel Consumption		
	B (unique)	*β* (incremental)	sr^2	*B* (unique)	*β* (incremental)	sr^2	*B* (unique)	*β* (incremental)	sr^2	*B* (unique)	*β* (incremental)	sr^2
Household Variables												
Number HH Licensed Drivers	0.75**	0.64		0.08	0.02		2376**	0.14		60.34	0.06	
Number HH Members <16				-0.78**	-0.22		385	0.03		22.07	0.03	
Household Income Range	0.11**	0.19		-0.55**	-0.25		955**	0.11		76.38**	0.17	
Number HH Vehicles				0.31	0.05		5293**	0.36		465.27**	0.40	
			Step 1: sr^2 = 0.495			Step 1: sr^2 = 0.086			Step 1: sr^2 = 0.355			Step 1: sr^2 = 0.350
Respondent Variables												
Respondent Age	0.00	-0.02		-0.02*	-0.09		-251**	-0.25		-10.08**	-0.20	
Respo. Highest Level Education	-0.05	-0.05		0.63**	0.18		-165	-0.01		-43.24	-0.06	
Commute SOV (1) or other (2)	0.24**	0.07		-0.44	-0.03		4320	0.08		83.98	0.03	
			Step 2: sr^2 = 0.009			Step 2: sr^2 = 0.048			Step 2: sr^2 = 0.060			Step 2: sr^2 = 0.039
Physical Environment Variables												
Population Density per Acre	-0.01	-0.03		0.19*	0.11		-165	-0.02		-7.91	-0.02	
Pedestrian Environment Factor	-0.01	-0.01		-0.02	-0.01		-948*	-0.08		-51.05	-0.09	
			Step 3: sr^2 = 0.002			Step 3: sr^2 = 0.017			Step 3: sr^2 = 0.009			Step 3: sr^2 = 0.015
Environmental Knowledge and Attitudes Variables												
Enviro. Knowledge	-0.01	-0.03		0.13**	0.16		-132	-0.04		-8.93	-0.06	
Enviro. Attitudes (Question #1)	-0.12*	-0.05		0.86**	0.10		-1747*	-0.05		-251.04**	-0.15	
			Step 4: sr^2 = 0.004			Step 4: sr^2 = 0.041			Step 4: sr^2 = 0.005			Step 4: sr^2 = 0.027
	Intercept = 0.503			Intercept = 20.49			Intercept = 24207			Intercept = 1275		
	R^2 = .511[a]			R^2 = .192[b]			R^2 = .429[c]			R^2 = .432[d]		
	Adjusted R^2 = .506			Adjusted R^2 = .179			Adjusted R^2 = .423			Adjusted R^2 = .423		
	R = .715**			R = .438**			R = .655**			R = .657**		
* p <.05	[a] Unique variability= .499			[b] Unique variability= .181			[c] Unique variability= .224			[d] Unique variability= .163		
** p <.01	Shared variability= .012			Shared variability= .011			Shared variability= .205			Shared variability= .269		

Fuel efficiency of household vehicles

The power of the second model to predict average fuel efficiency of household vehicles[53] was not as high as the first model, but it was able to explain a significant proportion of the variation in this indicator of household vehicle ownership and use. After all variables were entered in the equation, R^2=.192 and R was significantly different from zero at the end of each step, indicating that each group of independent variables added statistically significant predictive power to the model.

In combination, environmental knowledge and attitudes explained more of the variation in average fuel efficiency of household vehicles than did any other single variable. Number of household members under the age of 16, household income range, and age all had strong inverse influences on fuel efficiency, that is, they all contributed to households buying *less* fuel efficient vehicles. Rising levels of population density, environmental knowledge, and environmental attitudes all worked in the opposite direction, leading to the ownership of *more* fuel efficient vehicles.

Annual household miles driven

This model was effective in predicting estimated annual household miles driven[54] with a reasonable degree of accuracy. After step 4, when all independent variables were entered into the equation, R^2=.429, indicating that these variables explained 42.9% of the

[53] The dependent variable was a transformed version of A37_avg_mpg (Average Combined MPG for HH Vehicles) named Average Combined MPG, Trimmed Low and High (T_T5_OMPG). The transformation trimmed extremely low and high average fuel efficiency values to the lowest and highest non-extreme values (as assessed by SPSS FREQUENCIES). Note also that I ran this equation using only those records (N=990) for which I had complete information necessary to calculate average fuel efficiency of household vehicles (that is, the respondent had three or fewer vehicles, none of which were earlier than model year 1985, the earliest year for which U.S. EPA fuel economy data are available).

[54] I used a transformed version of estimated annual household miles driven (O11_am_hh) for this analysis. Extremely high values were trimmed to the highest non-extreme value, and the resulting variable named (T_T2_Miles).

variation in this indicator of vehicle ownership and use. Number of household vehicles, number of household licensed drivers, and household income range all contributed to higher annual household miles of driving (respective β values of 0.36, 0.14, and 0.11). The more vehicles, licensed drivers, and income that were available, the more miles a household was likely to drive each year. Respondent age worked strongly in the opposite direction (β=-0.25), likely reflecting a reduction in miles driven as many people retire from work. Pedestrian environment factor of respondent's residential block group and environmental attitudes also reduced the number of estimated miles driven per year, though the strength of these effects was considerably lower (β values, respectively, of -0.08 and -0.05).[55]

Fuel consumption of household vehicles

This model too proved to be fairly effective, in this case predicting estimated annual fuel consumption.[56] After step 4, when all independent variables were entered into the equation, R^2=.432, indicating that these variables explained 43.2% of the variation in this indicator of vehicle ownership and use. R was significantly different from zero at the end of each step, so each group of variables added some predictive value to the model.

Number of household vehicles and household income range contributed to higher annual fuel consumption (respective β values of 0.40 and 0.17); the more vehicles and

---

[55] It is interesting to note that pedestrian environment factor significantly affected miles driven, but not average vehicle fuel efficiency, while population density hads the opposite effect. Perhaps greater population density affects parking availability, making smaller, more fuel efficient vehicles more desirable, while pedestrian friendly areas encourage more walking, bicycling (and perhaps transit use), reducing the number of miles driven per household. The data set, however, doesn't allow us to confirm or refute these hypotheses.

[56] Again I used a transformed version of estimated annual fuel consumption (O6_fuel_hh) for this analysis. Extremely high values were trimmed to the highest non-extreme value, and the resulting variable named (T_C1_FuelHH). This analysis also relied upon a subset of the entire database (N=990): records for which complete data were available for calculating average fuel efficiency of household vehicles.

income that were available, the more fuel a household was likely to consume each year. Respondent age worked strongly in the opposite direction (β=-0.25), likely reflecting a reduction in miles driven, and thus fuel consumption, as many people retire from work. Environmental attitudes also reduced the estimated amount of fuel consumed per year, with a strength roughly in the same range as the other significant variables (β value=-0.15).

Summary

Findings of the multiple regression analyses, in which sets of household-level, respondent-level, and physical environmental variables were held constant, were largely the same as for the simpler, differences-of-means analyses (see Table 5.8 below). That is, environmental attitudes made a difference in terms of all four vehicle ownership and use variables (number of vehicles owned, types of vehicles, annual miles driven, and fuel consumed) and in the hypothesized directions. Environmental knowledge, on the other hand, only affected types of vehicles owned (measured by fuel efficiency) in the hypothesized direction, but did not affect number of vehicles, amount driven, or fuel consumption.

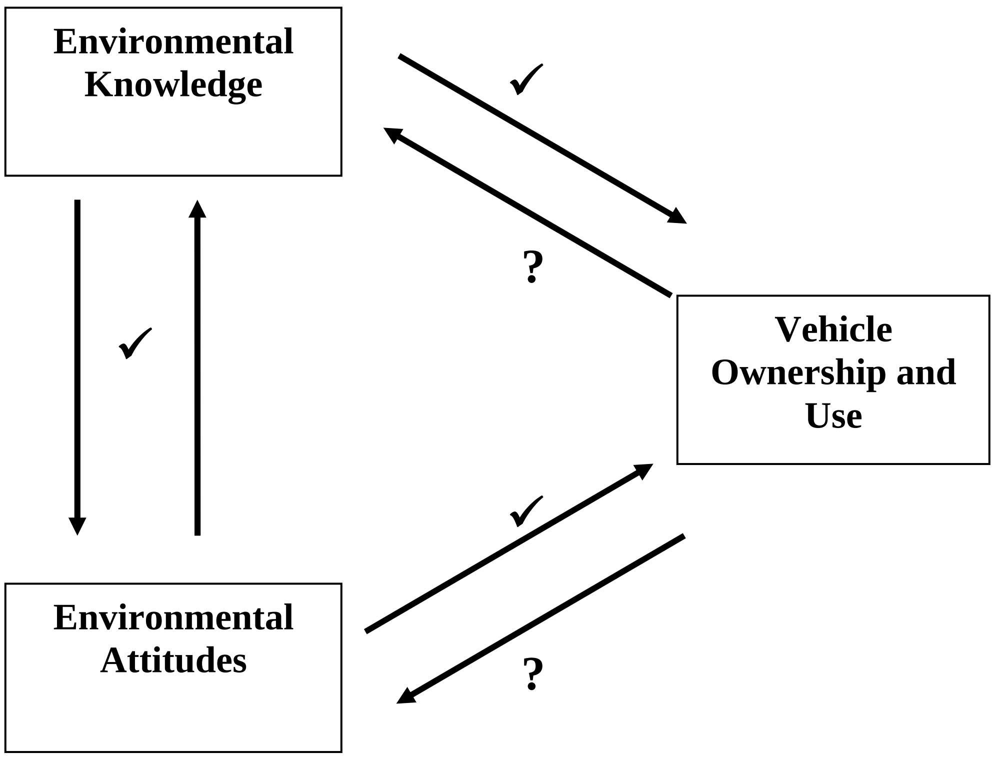
It appears, therefore, that in terms of the environmental impacts of household vehicle ownership and use, it matters more whether one cares about protecting the natural environmental than whether one knows about the environmental impacts of owning and using vehicles. In a sense, the "heart" matters more than the "head" when it comes to people's decisions about how many and what types of vehicles to own, how much to drive personal vehicles, and, consequently, how much fuel is consumed by the household because of its vehicle ownership and use.

Table 5.8: Summary of findings for knowledge, attitudes, and vehicle ownership and use, sequential multiple regression analyses

	Model	**Environ-mental Knowledge**	**Environ-mental Attitudes**
Number of Household Vehicles	R=.715, R^2=.511, F(9, 1058)=122.71, p < .001. 4 significant variables: income (β=.19), number of household licensed drivers (β=.64), SOV commuter (β=.07), and environmental attitudes (β=-.05).	Not Significant.	**Significant** at the p<.05 level.
Average Fuel Efficiency of Household Vehicles	R=.438, R^2=.192, F(11, 698)=15.06, p < .001. 7 significant variables: number of household members under age 16 (β=-.22), household income (β=-.25), respondent age (β=-.09), highest level of education (β=.18), population density (β=.11), environmental knowledge (β=.16), and environmental attitudes (β=.10).	**Significant** at the p<.01 level.	**Significant** at the p<.01 level.
Estimated Annual Household Miles Driven	R=.655, R^2=.429, F(11, 1027)=70.18, p < .001. 6 significant variables: number of household licensed drivers (β=.14), income (β=.11), number of household vehicles education (β=.37), respondent age (β=-.25), pedestrian environment factor (β=-.08), and environmental attitudes (β=-.05).	Not Significant.	**Significant** at the p<.05 level.
Estimated Annual Household Fuel Consumption	R=.657, R^2=.432, F(11, 709)=48.31, p<.001. 4 significant variables: income (β=.17), number of household vehicles (β=.40), respondent age (β=-.20), and environmental attitudes (β=-.15).	Not Significant.	**Significant** at the p<.01 level.

An important issue remains unaddressed, however, that could affect the results of this analysis in important ways. Has the question of directionality been conceived of properly? Is it correct to hypothesize that environmental knowledge and environmental attitudes affect behavior, but are not affected *by* behavior, in turn? Figure 5.4 below illustrates the *bi*-directional relationships that may exist among environmental knowledge, environmental attitudes, and vehicle ownership and use. The following chapter explores this question and presents findings that help answer it.

Figure 5.4: Conceptual diagram of bi-directional relationships among knowledge, attitudes, and behavior



CHAPTER 6: MODELING BI-DIRECTIONALITY IN KAB RELATIONSHIPS

To this point in this study, I have considered environmental knowledge and environmental attitudes predictor variables of vehicle ownership and use. But what if the direction of influence is not uni-directional? What if respondents' environmental knowledge and environmental attitudes are, to some degree, affected by vehicle ownership and use? Could it be that the many decisions involved in buying and driving vehicles lead to changes in what the owner / driver knows about the environmental impacts of vehicles and what he or she feels about protecting the natural environment? In short, could these interrelationships be bi-directional, mutually reinforcing?

There are theoretical and intuitive reasons to believe that this may be the case. Buyers of highly fuel efficient vehicles may learn more about fuel efficiency and pollutant emissions standards *because* they have made that decision. Gasoline-electric hybrids, such as the Toyota Prius and the Honda Civic Hybrid, are marketed as "green" cars and the relative amounts of fuel they consume and pollutants they emit are part of the marketing and sales of such vehicles. The same may be true of other small, fuel efficient vehicles, such as the Ford Focus.[57] A desire to spend less on fuel or to be an early adopter of new technology might lead to stronger pro-environmental attitudes because of positive reinforcement of the idea the owner has made the "right" decision for the environment. And the purchase of a large, fuel-inefficient vehicle—for example, because the owner needs a vehicle that can tow a trailer with a boat or because of safety concerns about other drivers having large vehicles—might lead to a respondent's

[57] This is an interesting area for further research. As recently as the fall of 2003, some car companies hid their environmental light under a bushel, so to speak, by touting the economic benefits of cars like the Ford Focus, instead of the environmental benefits (see, for example, Phillips 2003).

adjusting his or her attitudes in a way that diminishes the perceived importance of protecting the environment. All of these are examples of behaviors that can create "cognitive dissonance," a feeling of anxiety that exists when one's beliefs and one's actions appear to be in opposition, that changes in attitudes and knowledge can lessen.

There is research that suggests, in fact, that individuals *do* adjust their attitudes to match their behavior. Golob (2003) reviews the use of structural equation modeling to study the relationships between attitudes and behavior and finds many studies that come to this conclusion. Tardiff (1977), for example, used a two-stages least squares structural model to study attitudes (toward travel mode choices), behavior (use of a bus for commuting one or more times in the previous month), and several exogenous variables. He found that "the hypothesis that attitudes are a response to behavioral experience is more plausible than the conventional hypothesis that attitudes cause behavior" (p. 403). Like Tardiff, Dobson *et al.* (1978) found that attitudes were affected by behavior, but they also found that attitudes influenced behavior: "behavior and attitudes concurrently cause each other" (p. 351), they concluded, through a mutually reinforcing relationship.

More recent analyses have addressed the relationship between attitudes and behavior, and it is interesting to note that many researchers continue to conceive of attitudes only as predictors of behavior. Kaiser *et al.* (1999) and Moyano Díaz (2002), for example, use structural equation models to conduct their analysis, but do not model feedback loops from behavior to attitudes. When the relationship is hypothesized to be bi-directional, however, findings tend to support the concept of a bi-directional relationship between attitudes and behavior, as in Golob and Hensher's (1998) study of Australian bus and private vehicle commuters' stated preferences concerning behaviors to reduce the environmental impact of transportation. Their results, they argue, "show that public transport use, like solo-driving, is self-sustaining because attitudes that are consistent with choice are reinforced by the choice" (p. 17).

For this study, to test the hypothesis that vehicle ownership and use affect environmental knowledge and environmental attitudes, I used structural equation modeling (SEM) as the appropriate analytical tool. SEM—also called causal analysis or modeling, simultaneous equation modeling, and analysis of covariance—is a powerful technique that permits the simultaneous consideration of one, two, or more multiple regressions, sometimes including latent variables analyzed using confirmatory factor analysis. Feedback loops, the designation of some variables as mediating (or intervening) variables via path analysis, and bi-directionality are all features that can be incorporated into a structural equation model.

It is important to note that SEM is a confirmatory, not an exploratory, technique. The purpose is to determine whether the covariances[58] among a set of variables in a data set reflect the relationships identified in a model based on the researcher's hypothesized set of relationships. As such, a researcher does not set out to prove that a model's structure of relationships is correct, but rather seeks results that fail to disprove such a model. Results in SEM are, therefore, never definitive, but are suggestive of relationships that the data set supports.

Determining the directions of causation among a set of variables is ideally studied using time-series data, but structural equation modeling provides a means of

[58] Because covariances are less stable when estimated from small samples, SEM is ideally a large-sample technique. The data set upon which this study is based, with 1,506 respondents, is sufficiently large to be well suited to SEM analysis.

inferring causality between variables with the use of cross-sectional data, like that used in this data set. This is so when the data have some element of temporal sequencing, as they do in this study. The respondents completed the survey in the spring of 2005, replying to questions that elicited their current knowledge and attitudes toward the environmental impacts of owning and using vehicles, while providing information about vehicles that they and/or members of their household had purchased at some point in the past (the range of responses concerning vehicle ownership was from one month to forty years). Vehicle ownership decisions reflected in the survey, thus, preceded the knowledge and attitudes. But it is unknown whether the current levels of knowledge and attitudes were stable (and had preceded the vehicle ownership decisions) or whether they had changed over time.

Data preparation

The analyses to be undertaken using SEM impose assumptions about the data set and its variables similar to those imposed by the multiple regression analyses described in the previous chapter. These include having a sufficient sample size, independence of observations, that any missing values are random in nature, that values are normally distributed, relationships are linear in nature, that the variance of residuals is homoscedastic, and that there are no extreme outliers. The key data manipulation that was conducted for the regression analyses was retained for this SEM analysis: the trimming of outlier values for several variables, including annual estimated miles driven and average fuel efficiency of household vehicles.

I could not retain for the SEM analysis, however, two important data manipulations that I had used in the regression analyses because of limitations of the software package AMOS 5.0.1.[59] The first concerns the use of analytical weights to correct for sampling and non-response biases and to conduct post-stratification adjustments. While the set of analytical weights that I developed and used in the differences of means and regression analyses was an important part of ensuring the validity of those procedures, AMOS does not support their use, so I did not include them in the SEM analysis.

Second, while SPSS software permits pairwise deletion of cases when data are missing, AMOS does not permit analysis if any record has even a single piece of missing data. The choice for dealing with this limitation was to delete all records with one or more fields of missing data or to substitute mean (or mode) values for missing data where necessary. Because the impact of mean substitution on analytical results was assessed in preparation for the regression analyses and found to have minimal or no effects on analytical results, I made the latter choice for the SEM analysis I conducted. AMOS software has a function that computes mean values for substitution where data are missing and this was used for ten of the variables in the analysis (five exogenous and five endogenous). Because two variables function as dummy variables (environmental attitudes and commute type), mode values were substituted for missing data. See Tables 6.1 and 6.2 below for more details on how missing data were handled.

Model construction

The basic proposition I tested is that there are bi-directional relationships among environmental knowledge, environmental attitudes, and vehicle ownership and use. If this

[59] AMOS is an acronym that stands for **A**nalysis of **Mo**ment **S**tructures. This SEM software package is now an add-on package for the SPSS statistical data analysis software.

proved to be supported by the SEM analysis, statistically significant relationships would be identified that demonstrate that environmental knowledge and environmental attitudes mutually influence each other and both influence, and are influenced by, number of household vehicles owned, average fuel efficiency of household vehicles, and estimated annual household miles driven.

The structural equation model I developed for this analysis was constructed of three elements. First, were three sequential multiple regression equations described in the previous chapter: those estimating 1) number of household vehicles, 2) average fuel efficiency of household vehicles, and 3) estimated annual household miles driven. The second element was a fourth equation that assessed estimated annual household fuel consumption related to vehicle ownership and use. Unlike the equation described in the previous chapter, however, this analysis of the determinants of fuel consumption was based upon the three previous outcome variables, environmental attitudes, and environmental knowledge. Finally, two more equations were estimated to predict values of environmental knowledge and environmental knowledge, as influenced by selected socio-economic and demographic variables and the four measures of vehicle ownership and use.

The equations in the model, therefore, could be conceptually expressed as:

1) Vehs $= f(\text{EK, EA, EX}_{1..x})$

2) AvgOMPG $= f(\text{EK, EA, Vehs, EX}_{1..x})$

3) Miles $= f(\text{EK, EA, Vehs, EX}_{1..x})$

4) Fuel $= f(\text{EK, EA, Vehs, AvgOMPG, Miles})$

5) EK $= f(\text{EA, Vehs, AvgOMPG, Miles, EX}_{1..x})$

6) EA = f(EK, Vehs, AvgOMPG, Miles, $EX_{1..x}$)

where

Vehs = Number of Household Vehicles

AvgOMPG = Average Fuel Efficiency of Household Vehicles

Miles = Estimated Annual Household Miles Driven

Fuel = Estimated Annual Household Fuel Consumption Related to Vehicle Ownership and Use

EK = Environmental Knowledge

EA = Environmental Attitudes

$EX_{1..x}$ = One or more exogenous variables (household level, respondent level, and physical environment)

See Figure 6.1 below for a graphic illustration of these relationships.

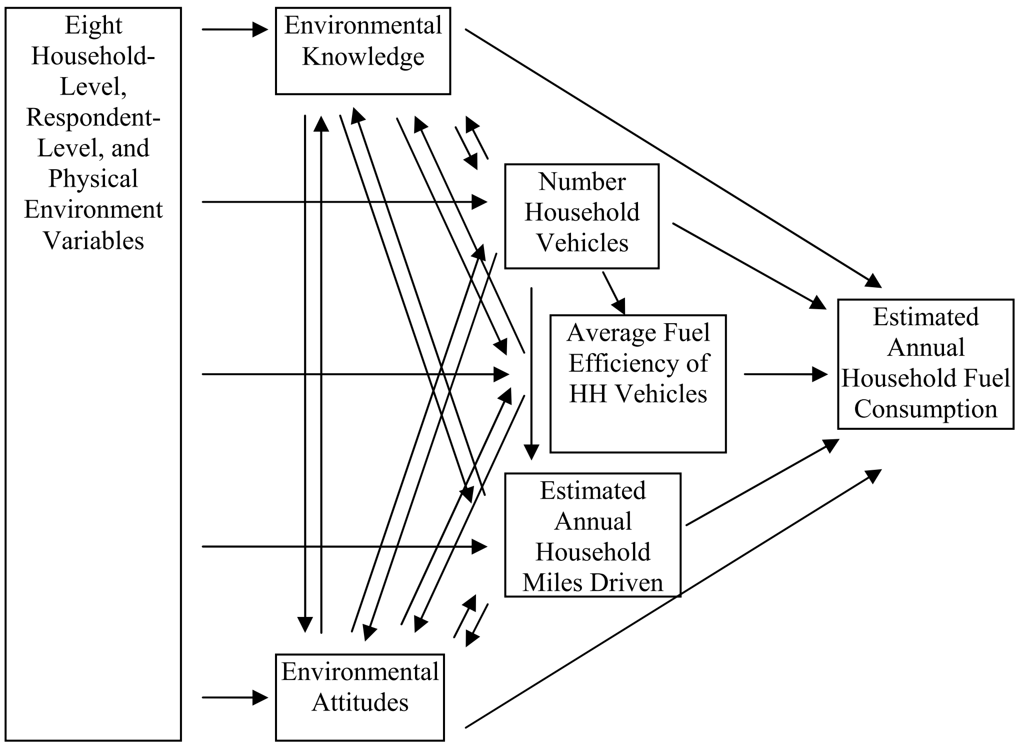
The six variables that are dependent (or endogenous) variables in the above equations all served as intervening variables, as well, except for estimated annual household fuel consumption. The eight household-level, respondent-level, and physical environment variables that were included in the sequential multiple regression equations of the previous chapter were all retained as exogenous variables in this model.[60] See Tables 6.1 and 6.2 below for details of these fourteen variables.

The conceptual model was used to develop the actual structural equation model for analysis. All bi-directional relationships between environmental knowledge,

[60] They are called "exogenous" variables because they are assumed to be of external origin to the model. They are not affected by any other variables in the model and are used only as predictors of the endogenous variables.

environmental attitudes, number of household vehicles, average fuel efficiency of household vehicles, and estimated annual household miles driven were specified.

Figure 6.1: Conceptual diagram of structural equation model



Next, bi-variate relations between the eight exogenous variables and number of household vehicles, average fuel efficiency of household vehicles, and estimated annual household miles driven were specified using the statistically significant relations identified in earlier multiple regression analyses. Then environmental knowledge, environmental attitudes, number of household vehicles, average fuel efficiency of household vehicles, and estimated annual household miles driven were specified as predictor variables of estimated annual fuel consumption related to vehicle ownership and use.

Table 6.1: Endogenous variables in the structural equation model, *N*=1,506

	Mean (S.D.)	Variable Name and Description
Environmental Knowledge	5.85 (4.95)	**I2_ek_b_1**: Environmental knowledge scale B with mean value substituted for missing data.
Environmental Attitudes	1.71 (.444)	**Q20_eaq1_1**: Environmental attitudes question #1 with mode value substituted for missing data.[61] "1" refers to the pro-economy response and "2" refers to the pro-environment response.
Number of Household Vehicles	2.08 (1.02)	**Q2_HH_Vehs_1**: Number of household vehicles with mean value substituted for missing data.
Average Fuel Efficiency of Household Vehicles	21.96 (4.28)	**A37_avg_mpg_1**: Average fuel efficiency of household vehicles (in miles per gallon) with mean value substituted for missing data.
Estimated Annual Household Miles Driven	22,331.82 (14,046.43)	**T_T2_Miles_1**: Estimated annual household miles driven (trimmed values) with mean value substituted for missing data.
Estimated Annual Household Fuel Consumption Related to Vehicle Ownership and Use	1,035.77 (704.82)	**T_C1_FuelHH_1**: Estimated annual household fuel consumption, in gallons (trimmed values), with mean value substituted for missing data.

Finally, selected exogenous variables were specified as predictor variables of environmental knowledge (household income, respondent age, respondent highest level of education, and pedestrian environment factor) and environmental attitudes (household income, respondent age, and pedestrian environment factor).

This first effort at creating a full model with all bi-directional relationships between knowledge, attitudes, and behavior proves to be "unidentified" and could not be estimated. A model is "identified" when it is possible to generate a unique numerical solution for every one of its parameters (Kline 1998; Ullman 2007). To develop a model which could generate valid estimates of covariances, one by one, uni-directional

[61] This variable functions as a dummy variable, and using the mean value, as done with most of the other variables in this analysis, would not have been appropriate. 69.7% of the valid, non-missing responses were "2" for this question (the pro-environment response), indicating that using this as the substituted mode value would lead to the mis-identification of approximately 30% of the 76 missing values (23 responses). This introduction of error into the analysis was only avoidable with the actual deletion of the records of all respondents who failed to respond to this question, an option that was tested, but provided no appreciably different results from using the "mode-substitution" variable.

relationships between vehicle ownership and use variables and environmental knowledge and environmental attitudes were removed from the model until a model was properly identified.

Table 6.2: Exogenous variables in the structural equation model, *N*=1,506

	Mean (S.D.)	Variable Name and Description
Household-Level Variables		
Household Licensed Drivers	1.91 (.812)	**Q27_hh_ld_1**: Number of household licensed drivers with mean value substituted for missing data.
Household Members Under Age 16	.540 (.967)	**A40_hh_15_1**: Number of household members under age 16 with mean value substituted for missing data.
Household Income	4.91 (1.72)	**Q30_inco_1**: Income range, an ordinal variable with eight categories with mean value substituted for missing data.
Respondent-Level Variables		
Respondent Age	51.35 (14.97)	**Q33_age_1**: Respondent age, in years, with mean value substituted for missing data.
Respondent Highest Level of Education	4.44 (1.13)	**Q29_edu_1**: Respondent highest level of education, an ordinal variable with six categories with mean value substituted for missing data.
Respondent Commute Type (SOV or other)		**D13_SOV_1**: Respondent commute type (1=commute by single occupancy vehicle; 0=commute by any other mode or does not commute) with mode value substituted for missing data.[62]
Physical Environment Variables		
Population Density of Residential Location	2.25 (2.17)	**A5_popdn**: Population density of block group in which respondent household resides.
Pedestrian Environment Factor	8.69 (1.29)	**A6_pef**: Pedestrian Environment Factor, a scale ranging from 7 to 11, rising from less to more pedestrian friendly areas, developed by the Sacramento Area Council of Governments.

Four relationships were eliminated to achieve this: 1) estimated annual household fuel consumption to environmental knowledge, 2) estimated annual household fuel consumption to environmental attitudes, 3) number of household vehicles to

[62] I considered using another method of determining likely commute type as a way of assigning dummy values—zero or one—to records with missing data for this variable. The most likely candidate analysis for doing this, however, was age, grouped to distinguish respondents by categories, including those from ages 60 to 69 and over age 70 who are more likely to be retired or not working. But analysis of variance showed that respondents in these age groups identified themselves as single-occupancy vehicle commuters at the rates of 85.8% and 85.9%, the lowest of any age group, but still very high. Consequently, simple mode-value substitution was determined to be the most appropriate analytical choice.

environmental knowledge, and 4) estimated annual household miles driven to environmental knowledge. In addition, four bi-variate relationships between exogenous and endogenous variables were dropped from the model because their critical ratio values[63] were below 1.00 and their inclusion in the model resulted in the generation of negative squared multiple correlation[64] values: household income to environmental knowledge (c.r.=.278), pedestrian environment factor to environmental knowledge (c.r.=-.227), household income to environmental attitudes (c.r.=-.794), and respondent age to environmental attitudes (c.r.=.958). Feedback loops remain in the model, creating bi-directional causal effects and making the overall model a "non-recursive" one. The most complete, identified version of the full model is illustrated in Figure 6.2 below.

Model confirmation

I ran the identified model illustrated above in Figure 6.2 using a maximum likelihood parameter estimation method and it proved to be a stable model, with generally strong goodness-of-fit indicators:[65] $\chi^2(26, N=1,506)=44.213$, $p=.014$, CMIN/DF=1.701, CFI (comparative fit index)=.997, RMSEA (root mean square error of approximation)=.022 (LO 90=.010 and HI 90=.032), AIC (Akaike Information Criterion)=230.21. Its stability index was .032 (values between -1.00 and 1.00 are considered acceptable). The squared multiple correlation values for all endogenous

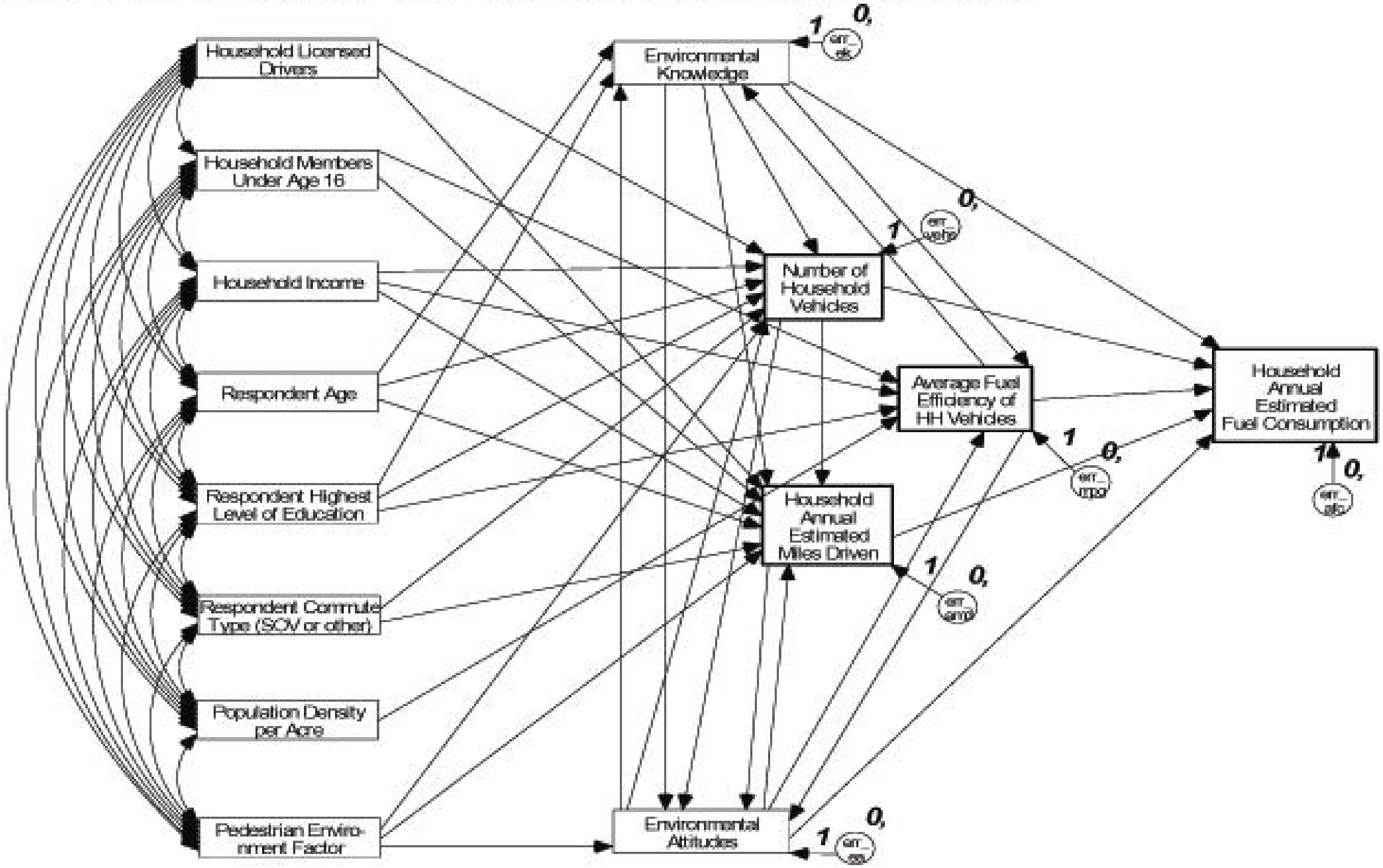
---

[63] The critical ratio for a regression weight is calculated by dividing the regression weight estimate by the estimate of its standard error, providing a value which indicates the number of standard errors above zero.

[64] "A variable's squared multiple correlation is the proportion of its variance that is accounted for by its predictors" (Arbuckle and Wothke 1999, p. 119).

[65] Numerous goodness-of-fit measures are used in assessing the results of structural equation models. No strict boundaries between acceptable and unacceptable are imposed, but, in general, these thresholds are cited as indicating reasonable models: CMIN/DF < 2.0, CFI > .95, RMSEA (including high and low 90% confidence intervals) < .06. The AIC is used as a comparative measure, with smaller values considered better-fitting and more parsimonious when considering competing models. See Ullman (2007), pp. 715-720.

Figure 6.2: Complete set of hypothesized relationships between exogenous and endogenous variables



variables were positive (negative SMC values can be generated by AMOS, but are uninterpretable, according to Ullman 2007).

Post hoc model modifications were performed in an attempt to develop a better fitting, more parsimonious model. Three highly insignificant relationships involving two endogenous variables—environmental attitudes to environmental knowledge (p=.612), environmental knowledge to estimated annual household miles driven (p=.985), and average fuel efficiency of household vehicles to environmental attitudes (p=.745)—were deleted from the model. I retained one other highly insignificant relationship in the model—environmental knowledge to average fuel efficiency of household vehicles (p=.599)—because of its statistical significance in the previously described sequential multiple regression model. The re-estimated model proved to have moderately better goodness-of-fit indicators: $\chi^2(29, N=1,506)=44.743$, p=.031, CMIN/DF=1.543, CFI=.998, RMSEA=.019 (LO 90=.006 and HI 90=.029), AIC=224.74. Its stability index was also slightly better at .029 and all squared multiple correlations were positive.

Because I performed post hoc model modifications, I also calculated correlations between the regression weights of the complete, identified model and those of the final model. The resulting correlation coefficient was $r(41)=.996$, $p < .01$ indicating that the deletion of the three relationships did not alter the parameter estimates.

The model was significantly improved with the deletions of the three parameters mentioned above. The AIC and other goodness-of-fit tests indicated a better-fitting, more parsimonious model and the stability index improved. One additional comparison test was made. Under the hypothesis that the full model was correct, a test of the addition of the three constraints of the final model was run, resulting in a chi-square statistic of 0.531

(44.743 – 44.213) with 3 degrees of freedom (29 – 26). The probability of a chi-square statistic with 3 degrees of freedom exceeding 0.530 was .912. Therefore I could accept the final model as the stronger of the two.

Figure 6.3 below presents the results of the second model. Squared multiple correlations for each endogenous variable are displayed in large bold numbers. Standardized regression coefficients are displayed alongside single-headed arrows, representing direct effects of one variable on another. Twenty two thick lines with bold, italicized numbers identify correlations significant at the < .01 level, four medium lines with italicized numbers identify correlations significant at the < .05 level, and one narrow line with a plain font number identifies a correlation significant at the < .10 level.

Tables 6.3 and 6.4 present the total, direct, and indirect effects of the variables included in the structural equation model, as well as their significance levels. The direct effect between variables is the impact one variable has on another in a linear fashion. The indirect effect between variables is the effect one variable has on another *via* a third, intermediary variable. The direct and indirect effects combine and result in the total effects of one variable on another.

The parameter estimates provided in the Table 6.3 are unstandardized, representing the change in units of outcome variables (the column headings) attributable to one unit changes in the predictor variables (the row headings). The parameter estimates provided in Table 6.4, on the other hand, are standardized, so that when a predictor variable changes by increasing one standard deviation, the outcome variable changes by the proportion of one standard deviation represented in the table.

Findings

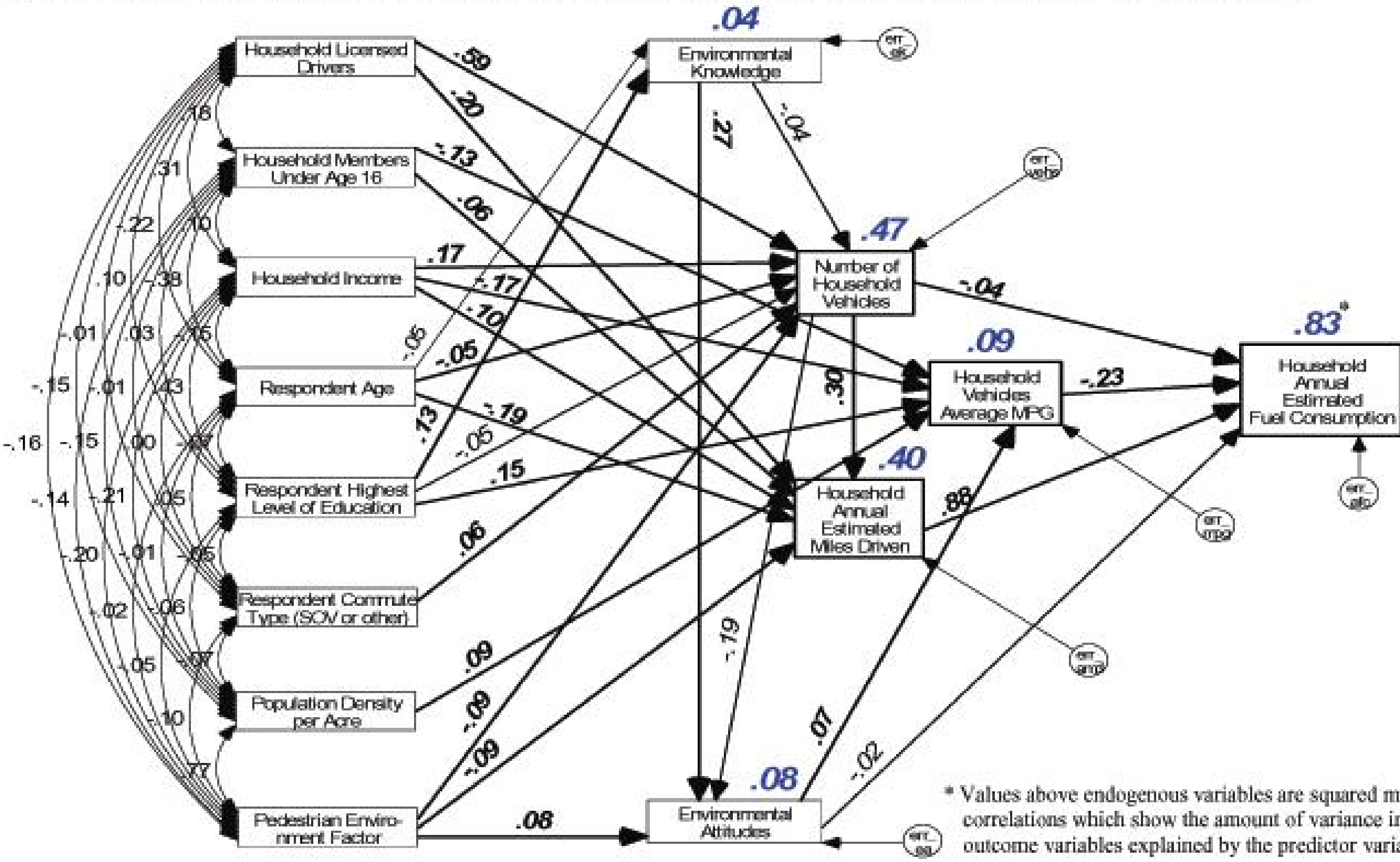
Three principal findings emerge from the analysis. First, the model results suggest that knowledge and attitudes have a far stronger impact on behavior than behavior does on knowledge and attitudes. Second, the parameter estimates for the equations in the structural equation model are very similar to those resulting from the sequential multiple regression equations described in the previous chapter. Third, the ability of the model to estimate levels of environmental knowledge and environmental attitudes is weak.

Bi-directionality among knowledge, attitudes, and behavior

The proposition I tested with this structural equation model is that there are bi-directional relationships among environmental knowledge, environmental attitudes, and four indicators of vehicle ownership and use. While there is some evidence to support this hypothesis, the strengths of the relationships are largely *from* knowledge and attitudes *to* behavior, and not vice-versa. Only in the case of one vehicle ownership and use variable is there any statistically significant impact in the opposite direction. Here are the results that support this conclusion.

Environmental knowledge has statistically significant impacts on three vehicle ownership and use variables: a direct inverse effect on number of household vehicles (as knowledge increases, the number of household vehicles decreases) and indirect effects on average fuel efficiency of household vehicles and estimated annual household fuel consumption (as knowledge increases, fuel efficiency rises and fuel consumption decreases). The mediator variable in the latter two cases is environmental attitudes; environmental knowledge affects fuel efficiency and fuel consumption only indirectly, through the positive impact it has on environmental attitudes.

Figure 6.3: Statistically significant relationships of the final structural equation model (with standardized regression weights)



* Values above endogenous variables are squared multiple correlations which show the amount of variance in the outcome variables explained by the predictor variables.

Table 6.3: Unstandardized total (T), direct (D), and indirect (I) effects of exogenous and endogenous variables

		Enviro Attitudes	Enviro Knowledge	Est. Annual HH Miles Driven	Number of HH Vehicles	Average Fuel Efficiency of HH Vehicles	Est. Annual HH Fuel Consumption
Household Variables							
Number HH Licensed Drivers	T	-0.04**	0.00	6555.42**	0.74***	-0.03**	272.20**
	D	…	…	3377.36**	0.74***	…	…
	I	-0.04**	0.00	3178.05***	-0.01	-0.03**	272.20**
Number HH Members Under Age 16	T	0.00	-0.07	926.78**	0.00	-0.59***	62.83***
	D	…	…	926.42**	…	-0.59***	…
	I	0.00	-0.07	0.36	0.00	0.00	62.83***
Household Income	T	xxx	xxx	1263.17***	0.10**	-0.43**	69.11***
	D	xxx	xxx	826.98***	0.10**	-0.42***	…
	I	xxx	xxx	436.20**	0.00	0.01**	69.11***
Number of HH Vehicles (endogenous)	T	-0.07**	-0.01	4311.35**		-0.05**	166.80**
	D	-0.08**	…	4156.94***		…	-29.19**
	I	0.01	-0.01	154.41*		-0.05	196.00***
Respondent Variables							
Respondent Age	T	xxx	-0.02**	-191.69**	0.00**	0.00	-8.38**
	D	xxx	-0.02**	-179.31***	0.00**	…	…
	I	xxx	0.00*	-12.39*	0.00	0.00	-8.38**
Respondent Highest Level of Education	T	0.02**	0.65***	-261.77**	-0.05**	0.61***	-32.22**
	D	…	0.58***	…	-0.05**	0.57***	…
	I	0.02**	0.07	-261.77**	0.00	0.04	-32.22**
Commute (SOV or other)	T	-0.01	0.00	2645.76**	0.23***	-0.01*	111.44**
	D	…	…	1651.28	0.23**	…	…
	I	-0.01	0.00	994.48***	0.00	-0.01*	111.44**
Physical Environment Variables							
Population Density	T	0.00	0.02	-1.84	0.00	0.17**	-6.51**
	D	…	…	…	…	0.17**	…
	I	0.00	0.02	-1.84	0.00	0.00*	-6.51**
Pedestrian Environment Factor	T	0.03***	xxx	-1360.14***	-0.07**	0.02**	-60.30***
	D	0.03**	xxx	-989.87**	-0.07**	…	…
	I	0.00	xxx	-370.27**	0.00	0.02**	-60.30***
Environmental Knowledge and Attitudes Variables							
Environmental Knowledge	T	0.03**		xxx	-0.01**	0.06	-5.14
	D	0.02**		xxx	-0.01*	0.04	1.90
	I	0.00		xxx	0.00	0.02**	-7.04**
Environmental Attitudes	T		xxx	-2203.04	0.12	0.65**	-162.37*
	D		xxx	-2728.63	0.12	0.65**	-37.82**
	I		xxx	525.60	0.00	-0.01	-124.55*
Other Vehicle Ownership and Use Variables							
Est. Annual HH Miles Driven	T	0.00	0.00		0.00	0.00	0.04***
	D	0.00	…		…	…	0.04***
	I	0.00	0.00		0.00	0.00	0.00
Average Fuel Efficiency of HH Vehicles	T	xxx	0.11	-10.65	0.00		-37.69***
	D	xxx	0.11	…	…		-37.11***
	I	xxx	0.00**	-10.65	0.00		-0.58*

*, **, *** = significance at the 90%, 95%, and 99% levels
xxx = variable constrained to zero in the final model
… = unexamined relationship
[shaded] bi-variate regression significance level of p < .05

Environmental attitudes affect two vehicle ownership and use variables. They directly affect fuel efficiency and directly *and* indirectly (via fuel efficiency) affect fuel consumption. The results suggest that as a respondent's attitudes become more pro-environmental, his or her household is likely to own more fuel efficient vehicles and, consequently, consume fewer gallons of fuel.

Vehicle ownership and use variables, on the other hand, show a statistically significant impact only on environmental attitudes (none of them affect knowledge, either directly or indirectly) and only via the direct impact of number of household vehicles. These results suggest that as respondent households own more vehicles, the household respondent's attitudes become less pro-environmental. This may be evidence that an element of cognitive dissonance is present where respondents recognize that owning more vehicles has environmental impacts in terms of fuel consumption and pollutant emissions. They may, consequently, adjust their attitudes to be less pro-environmental, so that they perceive less of a contradiction between their behavior and their beliefs. Why owning more vehicles would have such an effect on attitudes, while the fuel efficiency of household vehicles, miles driven, and fuel consumption do not, is unclear. It would be worthwhile to explore this question in more detail.

The results of this structural equation modeling analysis—with this data set, using these indicators of knowledge, attitudes, and behavior—suggest, therefore, that there is a small element of bi-directionality in the inter-relationships. The impact of behavior on knowledge, however, appears to be non-existent; that is, the number and types of vehicles that households own, how much they drive them, and how much fuel they consume do not lead to statistically significant changes in levels of knowledge of the environmental impacts of owning and using private vehicles. And the impact of behavior on attitudes is of far lesser importance than is the impact of attitudes on behavior. The relationship is bi-directional, but the two directions are not equal in importance; attitudes are stronger predictors of behavior than behavior is a predictor of attitudes.

Table 6.4: Standardized total (T), direct (D), and indirect (I) effects of exogenous and endogenous variables

		Enviro Attitudes	Enviro Knowledge	Est. Annual HH Miles Driven	Number of HH Vehicles	Average Fuel Efficiency of HH Vehicles	Est. Annual HH Fuel Consumption
Household Variables							
Number HH Licensed Drivers	T	-0.08**	0.00	0.38**	0.59***	-0.01**	0.31**
	D	…	…	0.20**	0.59***	…	…
	I	-0.08**	0.00	0.18***	0.00	-0.01**	0.31**
Number HH Members Under Age 16	T	0.00	-0.01	0.06**	0.00	-0.13***	0.09***
	D	…	…	0.06**	…	-0.13***	…
	I	0.00	-0.01	0.00	0.00	0.00	0.09***
Household Income	T	xxx	xxx	0.16***	0.17**	-0.17***	0.17***
	D	xxx	xxx	0.10***	0.17**	-0.17***	…
	I	xxx	xxx	0.05**	0.00	-0.00**	0.17***
Number of HH Vehicles (endogenous)	T	-0.16**	0.00	0.31**		-0.01**	0.24**
	D	-0.19**	…	0.30***		…	-0.04**
	I	0.03	0.00	0.01*		-0.01**	0.28***
Respondent Variables							
Respondent Age	T	xxx	-0.05**	-0.21**	-0.05**	0.00	-0.18***
	D	xxx	-0.05**	-0.19***	-0.05**	…	…
	I	xxx	0.00*	-0.01*	0.00	0.00	-0.18***
Respondent Highest Level of Education	T	0.05**	0.15***	-0.02**	-0.06**	0.16***	-0.05**
	D	…	0.13***	…	-0.05**	0.15***	…
	I	0.05**	0.02	-0.02**	0.00	0.01	-0.05**
Commute (SOV or other)	T	-0.01	0.00	0.05**	0.06***	0.00*	0.04**
	D	…	…	0.03	0.06**	…	…
	I	-0.01	0.00	0.02***	0.00	0.00*	0.04**
Physical Environment Variables							
Population Density	T	0.00	0.01	0.00	0.00	0.09**	-0.02**
	D	…	…	…	…	0.09**	…
	I	0.00	0.01	0.00	0.00	0.00*	-0.02**
Pedestrian Environment Factor	T	0.09***	xxx	-0.13***	-0.09**	0.01**	-0.11***
	D	0.08**	xxx	-0.09**	-0.09**	…	…
	I	0.01	xxx	-0.03**	0.01	0.01**	-0.11***
Environmental Knowledge and Attitudes Variables							
Environmental Knowledge	T	0.27**		xxx	-0.03**	0.07	-0.04
	D	0.27**		xxx	-0.05*	0.05	0.01
	I	0.00		xxx	0.01	0.02**	-0.05*
Environmental Attitudes	T		xxx	-0.07	0.05	0.07**	-0.10*
	D		xxx	-0.09	0.05	0.07**	-0.02**
	I		xxx	0.02	0.00	0.00	-0.08*
Other Vehicle Ownership and Use Variables							
Est. Annual HH Miles Driven	T	0.09	0.00		0.01	0.01	0.87***
	D	0.09	…		…	…	0.88***
	I	0.00	0.00		0.01	0.01	-0.01
Average Fuel Efficiency of HH Vehicles	T	xxx	0.10	0.00	0.00		-0.23***
	D	xxx	0.10	…	…		-0.23***
	I	xxx	0.00**	0.00	0.00		-0.00*

*, **, *** = significance at the 90%, 95%, and 99% levels
xxx = variable constrained to zero in the final model
… = unexamined relationship

[shaded] bi-variate regression significance level of p < .05

Confirmation of multiple regression analysis

Because the effects of knowledge and attitudes on behavior are strong in the structural equation model, and the opposite does not appear to be so, it is to be expected that the SEM results will be similar to the results of the earlier sequential multiple regression analyses in which I hypothesized only the linear, uni-directional effects of knowledge and attitudes on behavior. This turns out to be the case, as is illustrated in Table 6.5 below. When standardized regression weights from the two types of analyses are assessed side by side, the correlation coefficients are generally high: 0.97 for number of household vehicles, 0.95 for average fuel efficiency of household vehicles, 0.89 for annual estimated household miles driven, and 0.82 for annual estimated household fuel consumption. That the last indicator has the lowest correlation coefficient is not surprising, given that the equations were set up differently in the two analyses: household, respondent, and physical environment variables were directly related to fuel consumption in the multiple regression equation, while they were only indirectly related to fuel consumption in the SEM.

While the overall correlations between standardized regression weights are generally strong, there are some interesting differences that emerge from a more detailed consideration of the two analyses. The regression weights are nearly identical in estimating **number of household vehicles**, except for two indicators: First is a much stronger effect of pedestrian environment factor on number of household vehicles (in the expected, inverse direction) in the structural equation model: as walkability of a neighborhood increases, number of household vehicles decreases. PEF achieves statistical significance in the SEM, which it had not done in the multiple regression equation. Second is a curious change in both level of statistical significance of environmental attitudes (in the SEM, it is no longer significant) and the direction (its sign is positive in the SEM, suggesting that as attitudes become more pro-environmental, household vehicle ownership increases).

Table 6.5: Correlations of the standardized regression weights in the sequential multiple regression (SMR) and structural equation model (SEM) analyses

	# HH Vehicles		Avg Fuel Effic.		Miles Driven		Fuel Consumption	
	SMR	SEM	SMR	SEM	SMR	SEM	SMR	SEM
Household Variables								
Number HH Licensed Drivers	**0.64**	**0.59**	0.02	**-0.01**	**0.14**	**0.38**	0.06	**0.31**
Number HH Members <16	na	na	**-0.22**	**-0.13**	0.03	**0.06**	0.03	**0.09**
Household Income Range	**0.19**	**0.17**	**-0.25**	**-0.17**	**0.11**	**0.16**	**0.17**	**0.17**
Number HH Vehicles	na	na	0.05	**-0.01**	**0.36**	**0.31**	**0.40**	**0.24**
Respondent Variables								
Respondent Age	-0.02	**-0.05**	**-0.09**	0.00	**-0.25**	**-0.21**	**-0.20**	**-0.18**
Respo. Highest Level Education	-0.05	**-0.06**	**0.18**	**0.16**	-0.01	**-0.02**	-0.06	**-0.05**
Commute SOV (1) or other (2)	**0.07**	**0.06**	-0.03	**0.00**	0.08	**0.05**	0.03	**0.04**
Physical Environment Variables								
Population Density per Acre	-0.03	0.00	**0.11**	**0.09**	-0.02	0.00	-0.02	**-0.02**
Pedestrian Environment Factor	-0.01	**-0.09**	-0.01	**0.01**	**-0.08**	**-0.13**	-0.09	**-0.11**
Environmental Knowledge and Attitudes Variables								
Enviro. Knowledge	-0.03	-0.03	**0.16**	0.07	-0.04	0.00	-0.06	-0.04
Enviro. Attitudes (Question #1)	**-0.05**	0.05	**0.10**	**0.07**	**-0.05**	-0.07	**-0.15**	**-0.10**
Other Vehicle Ownership and Use Variables								
Average OMPG	na	0.01	na	na	na	0.00	na	**-0.23**
Miles Driven	na	0.00	na	0.01	na	na	na	**0.87**
Correlation		0.97		0.95		0.89		0.82

Bold = statistically significant at the .05 level (for SEM, refers to *total* effects)

The regression weights for **average fuel efficiency of household vehicles** are also fairly similar in the two analyses, though a few more differences emerge than did with number of household vehicles. Number of household licensed drivers and number of household vehicles achieve statistical significance in the SEM and the weights both change sign to negative, indicating that as these indicators increase, average fuel efficiency decreases. But the relative effects are almost negligible (the β values are -.01).

Number of household members aged under 16 and household income range are strongly, inversely correlated with average fuel efficiency in both analyses: as a household has more family members too young to drive and more income available, it is more likely to own less fuel efficient vehicles. Environmental attitudes are strongly, positively correlated: those with pro-environmental attitudes are more likely to own more fuel efficient vehicles. Surprisingly, the *total* effect of environmental knowledge is not statistically significant in the SEM, whereas it was in the multiple regression analysis. It should be noted, however, that environmental knowledge exhibits a modest statistically significant *indirect* effect (not indicated in Table 6.5) in the expected positive direct. Finally, pedestrian environment factor switches signs (to the expected, positive direction, though at a very small level of impact) and achieves significance in the SEM.

For **estimated annual household miles driven**, the regression weights all share the same signs in the two analyses, but more variables achieve statistical significance in the SEM and the relative levels of effect, as measured by the standardized regression weights, are not all the same. Number of household licensed drivers, for example, becomes the most important predictor of miles driven in the SEM, while number of household vehicles held that position in the multiple regression analysis. This shift is due to an additive impact of the direct and indirect effects (via environmental attitudes) of household licensed drivers on miles driven: the more drivers in a household, the more miles driven, and the more drivers, the less pro-environmental the respondent's attitudes, which in turn also increases miles driven. Neither environmental knowledge nor attitudes are statistically significant in the SEM, whereas attitudes had a small, but statistically significant impact on miles driven (in the expected negative direction) in the multiple regression analysis.

Finally, for **estimated annual household fuel consumption**, the signs of the regression weights are identical for all variables in both analyses, but in the SEM every single variable achieves statistical significance either directly (all mediator variables except environmental knowledge) or indirectly (environmental knowledge and all exogenous variables). The relative impact of variables changes considerably, as well. Number of household licensed drivers has the largest β value (0.31, a positive value, as expected) of all variables in the SEM except for estimated annual household miles driven (in the multiple regression analysis its impact was almost non-existent). Other variables that contribute to higher fuel consumption are number of household members aged under 16, household income, number of household vehicles, and commute type. Variables with negative effects on fuel consumption are respondent age, respondent highest level of education, population density, pedestrian environment factor, and environmental knowledge, and environmental attitudes.

This comparison of the two strategies for analyzing the data set confirms that the overall results are similar, whether using multiple regression or structural equation modeling, but that the relative importance of variables shifts when using the more sophisticated technique of SEM. Five exogenous variables remain basically unchanged in their impacts: household income has a large, statistically significant impact on all four indicators of vehicle ownership and use in both analyses. Number of household vehicles has a large, significant effect on miles driven and fuel consumption and a small effect on average fuel efficiency in both analyses. Population density, commute type, respondent age, and respondent highest level of education all have similar β values in both analyses (though statistical significance levels change).

Three variables take on much greater significance when examined with SEM. Number of household licensed drivers achieves statistical significance in the equations examining all four indicators of vehicle ownership and use (compared to its statistical significance in only two of the multiple regression equations) and has much larger β values for miles driven and fuel consumption. Number of household members under age 16 achieves statistical significance in three equations in the SEM analysis (it did so in only one of the multiple regression equations) and also has larger β values for miles driven and fuel consumption. And pedestrian environment factor achieves significance in all four vehicle ownership and use equations, increasing its β values in three of these.

Environmental knowledge's impact on the indicators of vehicle ownership and use is slightly different. In the multiple regression equations it proved statistically significant only in terms of average fuel efficiency of household vehicles. But in the SEM, its direct impact on fuel efficiency is no longer significant, but it proves to have an indirect, inverse effect on fuel consumption and an indirect positive effect on fuel efficiency of household vehicles. In addition, in the SEM, environmental knowledge has a small, but significant direct inverse relationship with number of household vehicles. In both analyses, environmental knowledge has a small, but significant impact on vehicle ownership and use, but the mechanism by which it has that effect shifts from one analytical technique to the other.

Environmental attitudes' impact on vehicle ownership and use remains statistically significant in the expected direction: the more pro-environment a respondent is, the lower the overall environmental impact of his or her household's vehicle ownership and use. By being specified as both a predictor and an intermediary variable in the SEM analysis, environmental attitudes drop to statistical significance in only two equations (fuel efficiency and fuel consumption) from all four equations in the multiple regression analysis, and its β values drop too, showing a smaller overall impact on the outcome variables when accounting for all other variables and inter-relationships in the system of equations.

Environmental knowledge and environmental attitudes

Only two variables, both exogenous, prove to be statistically significant in predicting environmental knowledge: respondent highest level of education and respondent age. Education level has a positive impact on environmental knowledge, with every unit increase in education corresponding to an increase of 0.65 on the scale of environmental knowledge (see Table 6.3 above). Age, on the other hand, has an inverse relationship, with every year the respondent is older corresponding to a drop in .02 on the scale of environmental knowledge. The standardized parameters (see Table 6.4) indicate that education has an overall effect three times larger than age. But the ability of the variables in this data set to predict levels of environmental knowledge is almost negligible: the squared multiple correlations value is only .04, indicating that only 4% of the variance in level of environmental knowledge is explained with these variables. While this study conceived of environmental knowledge as an exogenous variable from the beginning and, thus, was not designed to identify its determinants, this is still an exceedingly small value and suggests that I should interpret with caution the relative importance of variables that achieve statistical significance.

Five variables are shown to have a statistically significant impact on environmental attitudes. Environmental knowledge and pedestrian environment factor have positive and direct impacts on environmental attitudes, while education has a positive impact on attitudes indirectly through its impact on environmental knowledge. Number of vehicles has a direct negative correlation with environmental attitudes, while number of licensed drivers has an indirect (via number of household vehicles) negative correlation with environmental attitudes. As with environmental knowledge, however, the squared multiple correlations value is low at just .09, and conclusions about these indicators should be made only with caution.

Conclusion

The results of this structural equation model analysis are important for two principal reasons. First, it provides a useful exploration of the directions of causality between knowledge, attitudes, and behavior and suggests that (even while acknowledging the limitations of conducting such analysis with cross-sectional data) there is only modest evidence that vehicle ownership and use has an impact on environmental attitudes. In some respects, therefore, a standard regression approach to the analysis may be sufficient and appropriate to assessing the impact of environmental knowledge and environmental attitudes on vehicle ownership and use. Second, the SEM provides a general confirmation of the results of the previously described sequential multiple regression analysis, while providing more depth in highlighting both the direct and indirect (via intermediary variables) links between key variables.

CHAPTER 7. DISCUSSION AND CONCLUSIONS

I developed this research project in order to answer this question: Is the environmental impact of a household's vehicle ownership and use affected by household members' environmental knowledge and environmental attitudes? The answer to this question is "Yes." Those households represented by respondents with pro-environmental attitudes and greater knowledge of the environmental impacts of owning and using private vehicles *are* making decisions—about how many vehicles to own, about the fuel efficiency of their vehicles, and about how much to drive them—that result in significantly lower fuel and resources consumption. People who care more about protecting the natural environment and who know more about the impacts of cars and light duty vehicles behave differently than do people who do not have pro-environmental attitudes and are less knowledgeable.

In this concluding chapter I describe the major findings of the study. I then highlight some of the responses to the three open-ended survey questions that provide more detail concerning the constraints that prevent respondents from matching their behavior more closely with their attitudes and knowledge. Finally, I consider some of the policy and research implications that are supported by the findings.

Major findings

Using three principal types of statistical analysis—difference of means, sequential multiple regression, and structural equation models—I found that: 1) environmental knowledge is directly related to household ownership of more fuel efficient vehicles and inversely related to estimated annual household fuel consumption, 2) environmental attitudes are directly related to household ownership of more fuel efficient vehicles and inversely related to number of household vehicles, estimated annual household miles driven, and estimated annual household fuel consumption, 3) vehicle ownership and use affect environmental attitudes to a small degree (though much less than attitudes affect vehicle ownership and use), but do not affect environmental knowledge at all, 4) environmental knowledge and environmental attitudes are strongly related, and 5) people perceive barriers to making their vehicle ownership and use more closely reflect their attitudes and knowledge and can identify ways in which car manufacturers and elected officials might facilitate more environmentally responsible vehicle ownership and use decisions.

Knowledge and vehicle ownership and use

Knowledge of the environmental impacts of owning and using private vehicles has an important effect on the average fuel efficiency of household vehicles; the more a respondent knows about these impacts, the more fuel efficient are the vehicles that his or her household owns. This conclusion is supported by all three analyses that were conducted: analysis of variance, sequential multiple regression, and structural equation modeling (in the case of SEM, the influence of knowledge was significant, but indirect, via knowledge's effect on attitudes, which in turn influences fuel efficiency).

The influence of environmental knowledge on other indicators of vehicle ownership and use is less clear and direct. Analysis of variance and sequential multiple regression did not detect any statistically significant effects of knowledge on number of household vehicles owned, annual household miles driven, or annual household fuel consumption. Structural equation modeling, on the other hand, revealed a statistically significant inverse relationship between environmental knowledge and number of household vehicles owned, but its influence paled in comparison to those of number of household members and household income.[66] SEM also revealed a statistically significant (p=.05) indirect inverse effect of environmental knowledge on annual household fuel consumption, but, again, its impact was small compared to other variables.

This finding—that environmental knowledge has its strongest, clearest impact on fuel efficiency of household vehicles while its influence on other vehicle ownership and use variables is small and indirect—supports the argument that benefits to the environment (in the form of reduced consumption of resources) can be most effectively attained by encouraging technological rather than behavioral changes. Those respondents who know more about the environmental impacts of owning and using private vehicles *are* buying more fuel efficient vehicles, but *are not* changing their behavior very much in terms of the number of vehicles they buy or the miles they drive.

Attitudes and vehicle ownership and use

Environmental attitudes have a stronger influence on vehicle ownership and use than does environmental knowledge. T-tests and sequential multiple regression analyses indicated that environmental attitudes have a statistically significant direct impact on average fuel efficiency of household vehicles and a statistically significant inverse effect on number of household vehicles, annual household miles driven, and annual household fuel consumption. SEM analysis confirmed environmental attitudes' influence on average fuel efficiency of household vehicles and annual household fuel consumption, but did not

[66] The standardized beta value for environmental knowledge was -.03, while number of household members and household income had beta values of .59 and .17.

indicate statistically significant effects on number of household vehicles or annual household miles driven.

Unlike environmental knowledge, therefore, there is some evidence that respondents with pro-environmental attitudes are modifying both their travel behavior *and* the technology they use to travel, as measured by the fuel efficiency of the vehicles they drive. By including measures of environmental knowledge and attitudes, the analysis suggests that reductions in fuel consumption and pollutant emissions caused by vehicle ownership and use do not all come from technological changes. Behavioral change can and does lead to reductions in the environmental impacts of transportation and travel behavior, at least for pro-environmental households. This finding is at odds with those who argue that technological changes are responsible for all of the environmental benefits in the transportation sector of recent decades (Dudson 1998; Dunn 1998; Lave 1998).

Households represented by respondents who hold pro-environmental attitudes are making decisions to own fewer vehicles and to drive their vehicles less. How they are doing this is unclear, as I did not include questions in the survey that would get at this issue. They may be taking public transit for more trips, bicycling and walking when they can, trip-chaining more effectively, choosing residential locations that make trips shorter, simply foregoing some trips they might otherwise take, or some combination of these and other strategies. Whatever the reasons, their behavior *is* different than that of respondents who are not pro-environment.

Knowledge, attitudes and behavior

Knowledge and attitudes are strongly related to each other, with those respondents holding pro-environmental attitudes having higher levels of knowledge about the environmental impacts of owning and using vehicles. The analytical techniques that I used in this study did not indicate a specific directionality to this relationship: I do not know whether 1) people develop pro-environmental attitudes because they know more about the environmental impacts of owning and using private vehicles, 2) they become knowledgeable because of their pro-environmental attitudes, or 3) they are knowledgeable and pro-environmental because these characteristics are mutually reinforcing. It is clear, however, that when someone has pro-environmental attitudes, he or she is likely to be knowledgeable about the environmental impacts of owning and using vehicles, and vice-versa.

The effect of knowledge combined with attitudes on vehicle ownership and use is strong in the case of the fuel efficiency of household vehicles, but is not strong for average number of household vehicles or estimated annual household miles driven. That is, there is a significant difference in the effect of environmental knowledge on average vehicle fuel efficiency for the households of respondents with and without pro-environmental attitudes.[67] The households of respondents with pro-economic growth attitudes and low environmental knowledge own vehicles which, on average, are 16% less fuel efficient than the household vehicles of respondents with pro-environmental attitudes and high environmental knowledge (20.02 versus 23.27 mpg.). For the average household in the sample (which estimates annual mileage at 26,577 miles driven) the low

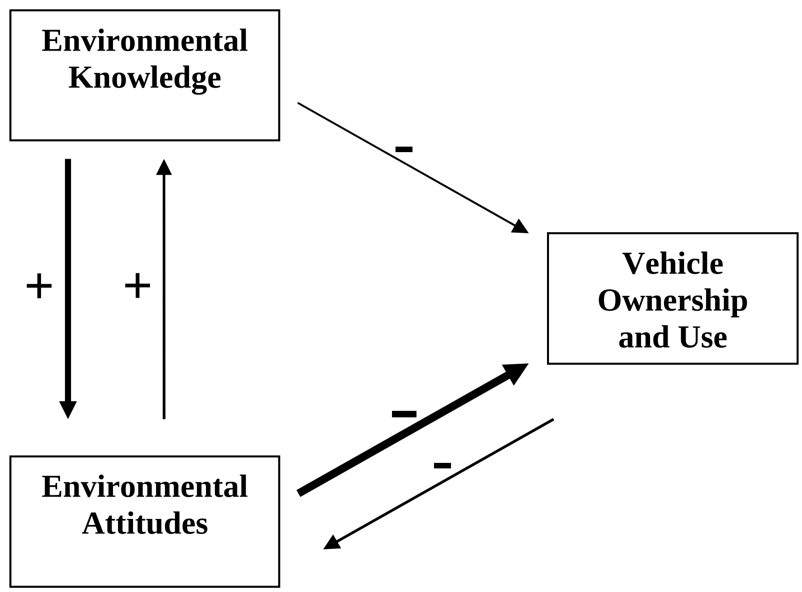
[67] A two-way between-groups analysis of variance was conducted to explore the impact of environmental knowledge and environmental attitudes on average fuel efficiency of household vehicles. Respondents were grouped into three levels of environmental knowledge: low, medium, and high. There was a statistically significant main effect for environmental knowledge [$\underline{F}(2, 1351)=17.13$, $\underline{p}=.000$], for environmental attitudes [$\underline{F}(1, 1351)=25.98$, $\underline{p}=.000$], and for the interaction effect [$\underline{F}(2, 1351)=5.89$, $\underline{p}=.003$], however, the effect sizes were small (respective eta squared values of .02, .03, and .01). Post-hoc comparisons using the Tukey HSD test indicated that the mean scores of average fuel efficiency of household vehicles for those with low, medium, and high levels of environmental knowledge were all significantly different from each other.

environmental attitudes/knowledge respondents consume 185 gallons of motor fuel more than the high environmental attitudes/knowledge respondents, emitting almost two more tons of carbon dioxide per year. Households represented by knowledgeable, pro-environment respondents seem to have both the will (an inclination to accept some costs in order to protect the natural environment) and the necessary information to reduce the environmental impact of their vehicle ownership and use decisions.

By using path analysis in a structural equation model, I was able to test, and largely refute, the hypothesis that vehicle ownership and use have a significant influence on attitudes and behavior. While there was a small statistically significant effect of number of household vehicles on environmental attitudes, none of the other vehicle ownership and use variables influenced environmental attitudes and not one of them affected environmental knowledge. This largely confirms that the original hypotheses, based upon uni-directional relationships *from* attitudes and knowledge *to* vehicle ownership and use, were correctly specified.

The basic relationships between knowledge, attitudes, and behavior are depicted in Figure 7.1 below. Environmental knowledge and attitudes are strongly related, with the impact of knowledge on attitudes being statistically stronger. Both environmental knowledge and environmental attitudes have an inverse relationship with vehicle ownership and use. That is, as pro-environmental attitudes and environmental knowledge increase, number of vehicles owned, miles driven, and fuel consumption decrease (fuel efficiency increases). The stronger effect of attitudes on vehicle ownership and use is indicated by the thicker line. Finally, the small effect of vehicle ownership and use on environmental attitudes is indicated by a thin line.

Figure 7.1: Links between knowledge, attitudes, and vehicle ownership and use



Barriers to stronger links

The links between knowledge, attitudes, and vehicle ownership and use are statistically significant, but relatively small compared to several key demographic and socio-economic variables. Could the links be stronger under different circumstances? Would respondents embrace more fuel efficient technologies and modify their behavior if they could do so more easily? Are there important barriers preventing them from behaving in ways that reflect their attitudes and knowledge more directly?

There are good reasons to expect that this may, in fact, be the case. As described in Chapter 2, the environmental behaviors (i.e., those things people choose to do because they reduce impacts on the environment and consumption of energy and resources) that have the strongest links with environmental attitudes are those that are simple and convenient to do. People are more likely to behave in an environmentally responsible way when there are fewer barriers to doing so. For example, participation in municipal recycling programs that are coordinated with weekly waste disposal services reflects attitudes much more directly than does recycling that requires individuals to make separate trips on their own to recycling facilities (Gatersleben *et al.* 2002).

The open-ended questions at the end of the survey were designed to get at this issue by asking respondents what they feel car companies, elected officials, and people like themselves can do to make owning and using vehicles cleaner and more energy efficient. Comments were wide-ranging, but several common responses to each question were mentioned by large numbers of respondents. They provide insights into how respondents feel about their ability to manage the environmental impacts of their vehicle ownership and use.

First, in response to the question concerning the role of car companies, almost two-thirds of respondents who answered the question[68] mentioned the importance of one or more specific technologies: hybrid electric-gasoline engines, hydrogen fuel cells, electric vehicles, or other alternative fuel technologies.[69] "Devote more money to developing hybrid electric cars, mini-vans, SUV's; produce more hybrids & electrics lowering their cost while producing fewer cars that depend on gas raising their prices," wrote one respondent, while another stated "Build more hybrid cars or hydrogen fuel celled vehicles. But make them in models that are popular like the full-sized SUVs that work best for families." One out of six respondents (181, 17%) said that car companies already have the necessary technology to make vehicles cleaner and more energy

---

[68] Of the 1,506 respondents, 1,057 (70%) provided a substantive answer that said something more than "I don't know," as 54 respondents (4%) wrote. Three hundred and ninety five respondents (26%) left the question blank.

[69] Hybrid technology was the most common answer, mentioned by 333 respondents (32% of those who answered). Six hundred and sixty two respondents (63%) mentioned this and/or another technological improvement.

efficient ("Use existing technology") or could do so by simply making all vehicles smaller and/or less powerful ("Less is more. Make them smaller / lighter across the board, as they are in Europe. Size is relative."). And one in seven respondents (147, 14%) mentioned that cleaner and energy efficient vehicles need to be affordable to buy and maintain, implying that cost is a constraint for them in reducing the environmental impacts of their vehicle ownership and use.

Next, in response to the question about the role of politicians and elected officials, four out of ten respondents who replied (426, 41%)[70] supported government incentives for making vehicles cleaner and more energy efficient ("Tax credits for cleaner burning cars," wrote one respondent, and "Incentives for new technology to improve environments," wrote another) and/or disincentives for making more polluting and less energy efficient vehicles (one respondent said "Like cigarettes, make diesel and gasoline harder to use," and another wrote "disincent[ivize] car makers from continuing to produce 'less clean' vehicles"). These responses were directed at both car companies and buyers.[71] More than a quarter of respondents, however, took a more direct approach and said that government agencies should simply impose regulations requiring car companies to manufacture and/or buyers to buy cleaner and more fuel efficient vehicles. [72] Almost one out of eight respondents who replied to this question (125, 12%) said that government should improve transit services or other alternatives to private vehicles as a way of helping people reduce their reliance on personal vehicles. Like the point made

---

[70] Of the 1,506 respondents, 1,039 gave a usable response to this question (69%).
[71] There was more support for incentives (374, 36%) than for disincentives (87, 8%) and more respondents felt the target of dis/incentives should be buyers (384, 37%), rather than car companies (187, 18%). Note that the percentages do not total to the 41% mentioned above because respondents were able to give multiple answers to each open-ended question.
[72] Respondents focused more on regulating car manufacturers and other business interests, such as oil companies (250, 24%) than on regulating individuals (57, 5%).

above about the cost of fuel efficient vehicles, the suggestion that transit services should be improved can also be interpreted as a constraint that respondents perceive to reducing the environmental impact of vehicle ownership and use.

Finally, in response to the question concerning the role of "individuals like you," respondents had a wide range of ideas. Slightly more respondents answered this question than either of the previous two questions (1,060, 70%), and the single most common answer was to maintain and operate household vehicles in the best shape possible (375, 35%).[73] Other common responses were to buy smaller and/or more fuel efficient vehicles in the future (317, 30%) and to simply decrease the amount of travel or to combine more trips in order to conserve fuel (271, 26%). Another 16% of respondents (173) replied that they could carpool or share vehicles more often, 13% (138) suggested using public transit more, and 8% (89 respondents) said they could walk or ride bicycles more often.

Two percent of respondents (21) said that they could not do anything more than they are currently doing and fifty respondents (5%) directly cited the constraints they felt prevented them from reducing the environmental impact of their vehicle ownership and use. "We live on acreage so walking to stores is impossible. I believe the vehicles we own now get fairly good mileage as the Cadillac gets 25 miles on trips," wrote one respondent, mentioning the large size of her residential property. Several made reference to needing a vehicle because of the size of their families and the transport needs of their

[73] It is unfortunate that I decided for reasons of space and feasibility of the survey to leave out a set of questions concerning vehicle operation and maintenance, another form of behavior related to vehicle ownership and use. Respondents understand the importance of maintaining vehicles in proper working condition and it would have been interesting to see to what extent environmental attitudes and environmental knowledge correlated with this variable.

children, such as one who jokingly wrote “Carpool more. Get rid of the kids or not allow them extracurricular activities (kidding),” and another who explained

> “Well, when our daughter is out of H.S. we will trade in our SUV and get a smaller car. We need our Suburban now as we transport kids, equipment (band and soccer), and 4-H animals and supplies. We need to pull a trailer for cows.”

Employment was another reason for owning less fuel efficient vehicles than respondents might prefer:

> “Unfortunately, the vehicle I drive is a requirement of my employment. I maintain all vehicles I own in top condition. Absent any major changes in manufacturing technology and government regulation that is about all the common person can do at this time.”

Finally, another respondent described how alternatives to private vehicles are difficult to use in the Sacramento region, even for those who wish to do so:

> “#1 would be to decrease driving. The problem with the Sacramento area is that everything is very spread out. If one works downtown, there is a light rail system that goes from outlying areas to the downtown area. Otherwise, public transportation is inadequate. It took my daughter 2 hrs by public transport to get to her high school 10 miles away. I would like to ride my bike to work but I leave work at 10:30 p.m. My son will be riding his bike when he starts H.S. We have been thinking about the Toyota Prius, or getting a used smaller Toyota.”

Three key themes emerge from these responses. First, some respondents are constrained, or feel that they are, by their personal and work circumstances, accessibility of transit, land use patterns, the cost of new vehicles, and other factors from owning fewer and smaller vehicles and driving them less than they currently do.[74] Second, respondents believe car companies and elected officials

[74] I cannot know from the survey responses how serious the constraints cited actually are. It may be that respondents perceive the constraints to be more inflexible than they are or that they are rationalizing decisions that would not change, even if the constraints were removed. It may not matter if the constraints are real or imagined, however, because perceptions and rationalizations influence choices and behavior, just as accurate, factual information does. (This was the concept behind the wording of the seven environmental questions: by having “probably true” and “probably false” choices, I gave respondents the option to express hunches and beliefs that influence their vehicle ownership and use decisions, even when they were uncertain of an answer.)

have a broad range of options for making it easier for vehicle buyers to make choices that reduce the environmental impact of owning and using private vehicles. And third, most respondents feel that technology can and should play a large role in making vehicle ownership and use a more environmentally responsible consumer behavior.

Policy recommendations

I did not design this study to be directly applicable to the work of public policy and transportation planning specialists. The questions I posed and the analysis I conducted were related to basic research questions that only indirectly inform policy debates regarding issues such as traffic congestion, transportation demand management, public transit provision, and infrastructure and transportation services financing. Nevertheless, I believe that there are three important policy recommendations that are supported by these findings.

Increase knowledge of environmental impacts

Respondents' knowledge of the environmental impacts of vehicle ownership and use is, in general, good; on average, they answered 5 of the 7 environmental knowledge questions correctly. Still, even among pro-environmental respondents, 25% answered four or fewer of the seven environmental knowledge questions correctly and 44% of pro-economic growth respondents missed three or more.

The United States Environmental Protection Agency calculates energy efficiency and tons of pollutants emitted per vehicle year, make, and model (except for vehicles weighing over 8,500 pounds) and such information is available online and in new car dealerships. But it is unclear how well the information is actually disseminated and understood: more than three-quarters of respondents knew that passenger cars and light-duty vehicles are subject to different fuel-economy standards, but only 27% were certain that this is the case. And vehicle buyers are targeted every year by multi-billion dollar auto industry advertising campaigns that often obscure the environmental impacts of their products.[75] Because environmental knowledge is significantly associated with the fuel efficiency of household vehicles, there appears to be an opportunity for public education and social marketing campaigns to increase both the accuracy of the information people have and the level of certainty they feel about their understanding of the environmental impacts of vehicle ownership and use. Effectively conducted, these have the potential to encourage greater demand for more fuel efficient vehicles which could lead to reductions in fuel consumption and pollutant emissions.

Might increased knowledge influence the other indicators of vehicle ownership and use: number of household vehicles and household miles driven? It could be the case, at least concerning number of vehicles owned which, in the SEM analysis, had a small but significant inverse relationship with environmental knowledge. (Household miles driven seem less likely to decrease in response to increases in environmental knowledge, as none of the three statistical analyses conducted revealed any relationship whatsoever.)

Consider the large percentage of incorrect responses to the knowledge question concerning the environmental and energy impacts of manufacturing vehicles, an issue that could affect the number of vehicles the members of a household own. Two-thirds of respondents (69%) said that manufacturing a new vehicle is “a major source of pollution

---

[75] There is a large literature on automobile industry history that pays attention to the role of advertising. McShane (1994) and Scharff (1991) provide accounts of the marketing of automobiles in the early years of the industry, while Flink (1988) and Bradsher (2002) review more recent developments in marketing.

and energy use even before it is driven out of the factory for the first time," but only 21% of the sample was certain of this response.[76] Because approximately a quarter of the vehicle lifetime energy consumption and half of the vehicle lifetime hazardous waste generation is attributable to the manufacturing stage (Maclean and Lave 1998), the overall demand that a household creates for new vehicles is extremely important in terms of its overall impacts on the environment. Though responses to this survey cannot confirm it, it is possible that if more people understood the link between the number of vehicles owned and environmental impacts, some households, particularly those whose members hold pro-environmental attitudes, might choose to reduce their impacts on the natural environment by owning fewer vehicles.

Focus on pro-environmental vehicle owners and users

Policy makers and transportation planners should be aware that there is a majority of people whose pro-environmental attitudes influence their vehicle ownership and use decisions and that the combined effect of pro-environmental attitudes and environmental knowledge is particularly strong, especially concerning the fuel efficiency of household vehicles. Planners and policy makers who seek to manage transportation demand by encouraging fewer miles driven, greater use of shared forms of transportation (like public transit, car- and van-pooling, and car-sharing), and reduced vehicle ownership will have a greater impact if they target messages about the environmental benefits of such behavioral changes at the majority of people who value protection of the natural environment. The details of how and when to design and implement public education and

[76] No other question had a lower certain-to-uncertain ratio for correct answers. More respondents answered the question correctly than incorrectly, but few were certain that their response was accurate.

social marketing campaigns are beyond this study's reach,[77] but the finding of a significant link between environmental attitudes and vehicle ownership and use supports the idea that planners and policy makers should see them as potentially useful policy tools.

Reduce barriers to attitudes-behavior correspondence

Finally, the third policy recommendation is to reduce barriers to making decisions that decrease the environmental impacts of vehicle ownership and use. Researchers such as Thompson (2004) have demonstrated that education alone is usually not enough to change behavior. But education combined with facilitation of non-habitual choices, such as the Indimark and Travel Blending programs (Brög 1998; Taylor and Ampt 2003), can encourage behavioral changes. There may also be an indirect value to improving public awareness of the environmental impacts of vehicle ownership and use in terms of support for difficult political positions, such as raising fuel economy standards.[78]

Analysis of the responses to open-ended questions makes it clear that there are important constraints that frustrate many respondents' desire to reduce the environmental impacts of their vehicle ownership and use. Specific circumstances of a household's employment, finances, schooling, home location, transit service availability, and other factors can make reducing the environmental impacts of its vehicle ownership and use difficult, even when one or more members of the household has pro-environmental attitudes. Large numbers of respondents are supportive of technological improvements

---

[77] See Kurani and Turrentine 2002 and McGovern 2005 for examples of more detailed consideration of social marketing's role in transportation planning.

[78] Raising CAFE standards has widespread public support in recent years (Opinion Research Corporation 2005), but has been notoriously difficult to accomplish because of longstanding, effective political opposition.

and can identify actions by car companies and elected officials that would help people make more environmentally responsible vehicle ownership and use decisions. Supporting policies that require more environmentally responsible vehicle purchases (by making improved pollutant control and fuel efficiency technologies mandatory on all new vehicles, for example) and/or facilitate them (such as by providing financial incentives through tax policies or fee-bate programs and making shared and non-motorized forms of transportation easier and more convenient to use) could help narrow the knowledge-attitudes-behavior gaps.

Research recommendations

There are three principal research recommendations that the results of this analysis support. First, they provide additional evidence that surveys designed and implemented using procedures described in Don Dillman's *Mail and Internet Surveys: The Tailored Design Method* (2000) obtain large response rates, making analysis better and more trustworthy. Second, paying close attention to the ways in which key variables are measured pays off in reliable results that more accurately reflect the concepts under study. And finally, they highlight the improved predictive power of travel and environmental behavior models that, where appropriate and relevant, include attitudinal and knowledge variables.

The Tailored Design Method

The response rate for this study was high compared to comparable studies in the fields of transportation and environmental behavior. The higher the response rate, the more likely the results are to be valid and the findings to be generalizable to the study population. I followed the recommendations of Dillman's *Tailored Design Method* and achieved a response rate of nearly 40%. Key elements of this approach are to 1) develop, design, pre-test, and distribute a survey that is visually appealing and simple and fast to complete, 2) provide advance notification of the survey's distribution and a follow-up reminder, 3) communicate with words and other cues that emphasize the importance of the respondents' participation (for example, first class postage on correspondence and personally signing notification and cover letters), and 4) include a small incentive (in this case, a one dollar bill) in advance that is not dependent upon participation in the study.[79] Initial costs were higher with this method (though the cost per completed survey may not have been) and the effort was more time-consuming than using bulk mail rates, a photocopied signature, and an incentive dependent upon completion of the survey, but the high response rate proved the value of following this approach.

Measure knowledge effectively

My success in identifying significant links between knowledge, attitudes, and behavior was due in large part to having measured these variables in detailed and valid ways. In attempting to measure environmental knowledge (a construct that cannot be measured directly), I developed three criteria for ensuring the validity of my work. And in measuring vehicle ownership and use, I ensured that a complex form of behavior was measured in a variety of ways that captures that complexity.

The scale of environmental knowledge that I developed merits some additional comments as it has the potential to be useful in other studies of vehicle ownership and

[79] Dillman recommends one additional effort: to send a second copy of the survey by certified mail to all respondents who have not returned the survey within two weeks of the initial distribution. I did not follow this recommendation because of the high cost of doing so and because my decision to make the responses completely anonymous (I did not place a code on surveys that would allow me to identify specific respondents) would have required sending a second copy of the survey to the entire sample of 4,000, even those respondents who had already completed the survey.

use. I developed the scale from responses to seven simple questions of knowledge that respected three important criteria: 1) the questions tested practical knowledge; 2) they respected the concept of measurement correspondence[80] with the behavior I was interested in; and 3) the results reflected an acceptable level of scale reliability. Though the scale's Cronbach's alpha value (0.64) shows there is room for improvement, it was a higher value than that found for similar scales in many comparable studies (Grob 1995; Nilsson and Küller 2000; Walton *et al.* 2004) and was sufficiently strong to merit inclusion in the analysis. In applying these three criteria, I demonstrated that environmental knowledge has a significant relation to vehicle ownership and use, a connection other researchers had failed to find. Future studies that aim to understand how environmental attitudes influence vehicle ownership and use should include a scale measure of knowledge like this one and researchers addressing other types of travel behaviors influenced by attitudes should consider developing appropriate measures of knowledge.

Better model specification with attitudinal and knowledge variables

Finally, these findings highlight the importance of including attitudinal and knowledge variables in models of transportation and environmental behavior. My sequential multiple regression and structural equation models explained a greater percentage of the variance in outcome vehicle ownership and use variables than they would have without the inclusion of variables measuring knowledge and attitudes. This finding supports the conclusion of Kitamura *et al.* (1997), Cao *et al.* (2006), Choo and

[80] Researchers such as Ajzen and Timko (1986) have applied the concept of measurement correspondence to attitudes and behavior, but I was unable to find any references in the literature to knowledge-behavior measurement correspondence.

Mokhtarian (2002), and other researchers that attitudinal variables can substantially improve the predictive power of some travel behavior models.

While the impacts of knowledge and attitudes on vehicle ownership and use are not as strong as the impacts of other key demographic and socio-economic variables, knowledge and attitudes remain significant in the regression equations and SEM, even after these other variables have been controlled for. This is as I hypothesized, but the findings remain surprising, all the same, given how many competing needs and desires a household balances in making vehicle ownership and use decisions. Perceptions of safety, quality, and dependability are key characteristics that people consider when making vehicle purchase decisions (Gurikova and Davis 2002), while the numbers of people in a household, how many of them are of legal driving age and are licensed to drive, the income a household has available, where home is located (a decision itself dependent upon multiple variables), and other factors all come into play, as well. That environmental knowledge and attitudes remain statistically significant predictors of four separate vehicle ownership and use variables shows that they merit inclusion in appropriate studies of travel behavior and validate the attention I have paid to them in this research project.

REFERENCES

Ajzen, Icek. 1988. *Attitudes, personality, and behavior*. U.S. edition ed. Chicago, IL: Dorsey Press.

———. 2001. Attitudes. In *The Corsini Encyclopedia of Psychology and Behavioral Science*, edited by W. E. Craighead and C. B. Nemeroff. New York, New York: John Wiley & Sons.

Ajzen, Icek, and Martin Fishbein. 1980. *Understanding attitudes and predicting social behavior*. Englewood Cliffs, NJ: Prentice-Hall.

Ajzen, Icek, and Christine Timko. 1986. Correspondence Between Health Attitudes and Behavior. *Basic and Applied Social Psychology* 7 (4):259-276.

Bamberg, Sebastian, Icek Ajzen, and Peter Schmidt. 2003. Choice of Travel Mode in the Theory of Planned Behavior: The Roles of Past Behavior, Habit, and Reasoned Action. *Basic and Applied Social Psychology* 25 (3):175-187.

Bradsher, Keith. 2002. *High and Mighty: SUVs: The World's Most Dangerous Vehicles and How They Got That Way*. New York, New York: PublicAffairs.

Brög, Werner. 1998. Individualized Marketing: Implications for Transportation Demand Management. *Transportation Research Record* (1618):116-121.

Brower, Michael, Warren Leon, and The Union of Concerned Scientists. 1999. *The Consumer's Guide to Effective Environmental Choices: Practical Advice from the Union of Concerned Scientists*. New York: Three Rivers Press.

Cameron, I., T. J. Lyons, and J. R. Kenworthy. 2004. Trends in vehicle kilometres of travel in world cities, 1960-1990: underlying drivers and policy responses. *Transport Policy* 11:287-298.

Cao, Xinyu, Patricia L. Mokhtarian, and Susan L. Handy. 2006. Neighborhood design and vehicle type choice: Evidence from Northern California. *Transportation Research Part D* 11:133-145.

Cervero, Robert. 2002. Built environments and mode choice: toward a normative framework. *Transportation Research Part D* 7 (4):265-284.

Cervero, Robert, and Kara Kockelman. 1997. Travel demand and the 3Ds: density, diversity, and design. *Transportation Research Part D* 2 (3):199-219.

Cervero, Robert, and Carolyn Radisch. 1996. Travel choices in pedestrian versus automobile oriented neighborhoods. *Transport Policy* 3 (3):127-141.

Choo, Sangho, and Patricia Mokhtarian. 2002. The relationship of vehicle type choice to personality, lifestyle, attitudinal, and demographic variables. Davis, CA: Institute of Transportation Studies, University of California at Davis.

Cohen, Jacob. 1988. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale, NJ: Erlbaum Associates.

Collins, Christy M., and Susan M. Chambers. 2005. Psychological and Situational Influences on Commuter-Transport-Mode Choice. *Environment and Behavior* 37 (5):640-661.

Committee for a Study on Transportation and a Sustainable Environment. 1997. Sustainability and Transportation. In *Toward a sustainable future: addressing the long-term effects of motor vehicle transportation on climate and ecology*. Washington D.C.: Transportation Research Board.

———. 1997. Toward a Sustainable Future: Addressing the Long-Term Effects of Motor Vehicle Transportation on Climate and Ecology. Washington D.C.: Transportation Research Board.

Dargay, Joyce, and Dermot Gately. 1997. Vehicle ownership to 2015: implications for energy use and emissions. *Energy Policy* 25 (14-15):1121-1127.

Davis, Stacy C., and Susan W. Diegel. 2004. *Transportation Energy Data Book Edition 24*. Vol. 24. Oak Ridge, Tennessee: Oak Ridge National Laboratory.

———. 2006. *Transportation Energy Data Book: Edition 25*. 25 ed. 25 vols. Vol. 25. Oak Ridge, Tennessee: Oak Ridge National Laboratory.

Deakin, Elizabeth. 2001. Sustainable Development and Sustainable Transportation: Strategies for Economic Prosperity, Environmental Quality, and Equity. Berkeley, CA: University of California Institute of Urban and Regional Development.

Delucchi, Mark. 1997. The annualized social cost of motor-vehicle use in the U.S., 1990-1991: Summary of theory, data, methods and results. Davis, California: Institute of Transportation Studies, University of California.

———. 2000. Should we try to get the prices right? *Access* (16):14-21.

Dillman, Don A. 2000. *Mail and Internet Surveys: The Tailored Design Method*. Second ed. New York: John Wiley & Sons.

Dobson, Ricardo, Frederick Dunbar, Caroline J. Smith, David Reibstein, and Christopher Lovelock. 1978. Structural Models for the Analysis of Traveler Attitude-Behavior Relationships. *Transportation* 7:351-363.

Dudson, Brian. 1998. When cars are clean and clever: A forward-looking view of sustainable and intelligent automobile technologies. *Transportation Quarterly* 52 (3):103-120.

Dunlap, Riley E., Kent D. Van Liere, Angela G. Mertig, and Robert Emmet Jones. 2000. Measuring Endorsement of the New Ecological Paradigm: A Revised NEP Scale. *Journal of Social Issues* 56 (3):425-442.

Dunn, James A. 1998. *Driving Forces: The Automobile, Its Enemies, and the Politics of Mobility*. Washington, D.C.: Brookings Institution Press.

Federal Highway Administration. 1997. Highway Statistics Summary to 1995. Washington, D.C.: U.S. Department of Transportation.

Flink, James J. 1988. *The Automobile Age*. Cambridge, MA: MIT Press.

Forward, Sonja. 1994. Theoretical Models of Attitudes and the Prediction of Drivers' Behaviour. Uppsala, Sweden: Uppsala University Department of Psychology.

Fujii, Satoshi, and Ayako Taniguchi. 2005. Reducing family car-use by providing travel advice or requesting behavioral plans: An experimental analysis of travel feedback programs. *Transportation Research Part D* 10 (5):385-393.

Gatersleben, Birgitta, Linda Steg, and Charles Vlek. 2002. Measurement and Determinants of Environmentally Significant Consumer Behavior. *Environment and Behavior* 34 (3):335-362.

Golob, Thomas F. 2003. Structural equation modeling for travel behavior research. *Transportation Research Part B* 37 (1):1-25.

Golob, Thomas F., and David A. Hensher. 1998. Greenhouse Gas Emissions and Australian Commuters' Attitudes and Behavior Concerning Abatement Policies and Personal Involvement. *Transportation Research Part D* 3 (1):1-18.

Greene, David L. 2004. Transportation and Energy. In *The Geography of Urban Transportation*, edited by S. Hanson and G. Giuliano. New York: The Guilford Press.

Grob, Alexander. 1995. A Structural Model of Environmental Attitudes and Behaviour. *Journal of Environmental Psychology* 15 (3):209-220.

Gurikova, Tatyana, and Stacy C. Davis. 2002. Transportation Energy Survey: Data Book 1.1. Oak Ridge, TN: Oak Ridge National Laboratory, U.S. Department of Energy.

Hand, Carl M., and Ginger Macheski. 2003. Environment-Economy Trade-offs and Forest Environmentalism. *Electronic Green Journal* (18).

Handy, Susan, Xinyu Cao, and Patricia Mokhtarian. 2005. Correlation or causality between the built environment and travel behavior? Evidence from Northern California. *Transportation Research Part D* 10 (6):427-444.

Harré, Niki, Theo Brandt, and Martin Dawe. 2000. The Development of Risky Driving in Adolescence. *Journal of Safety Research* 31 (4):185-194.

Hines, Jody M., Harold R. Hungerford, and Audrey N. Tomera. 1986/87. Analysis and Synthesis of Research on Responsible Environmental Behavior: A Meta-Analysi. *Journal of Environmental Education* 18 (2):1-8.

Hini, Dean, Philip Gendall, and Zane Kearns. 1995. The Link Between Environmental Attitudes and Behaviour. *Marketing Bulletin* 6:22-31.

Holtzclaw, John, Robert Clear, Hank Dittmar, David Goldstein, and Peter Haas. 2002. Location Efficiency: Neighborhood and Socio-Economic Characteristics Determine Auto Ownership and Use -- Studies in Chicago, Los Angeles and San Francisco. *Transportation Planning and Technology* 25 (1):1-27.

Ingram, Gregory K., and Zhi Liu. 1999. Determinants of Motorization and Road Provision. In *Essays in Transportation Economics and Policy*, edited by J. A. Gomez Ibanez, W. B. Tye and C. Winston. Washington, D.C.: Brookings Institution Press.

Insurance Institute for Highway Safety. 2006. Declining Death Rates Due to Safer Vehicles, Not Better Drivers or Improved Roadways. Arlington, VA: Insurance Institute for Highway Safety.

Jakobsson, C., S. Fujii, and T. Garling. 2000. Determinants of private car users' acceptance of road pricing. *Transport Policy* 7 (2):153-158.

Kaiser, Florian G., Sybille Wolfing, and Urs Fuhrer. 1999. Environmental Attitude and Ecological Behaviour. *Journal of Environmental Psychology* 19 (1):1-19.

Kayser, Robin E., Gerard M. Schippers, and Cees P. F. Van Der Staak. 1995. Evaluation of A Dutch Educational "Driving While Intoxicated (DWI)" Prevention Program for Driving Schools. *Journal of Drug Education* 25 (4):379-393.

KCBS/AP. 2003. Los Gatos Hummer owners denounce ELF SUV attacks. USA.

Kellert, Stephen R. 1997. *Kinship to Mastery: Biophilia in Human Evolution and Development*. Washington, DC: Island Press.

Kempton, Willett, James S. Boster, and Jennifer A. Hartley. 1995. *Environmental Values in American Culture*. Cambridge, MA: MIT Press.

Kitamura, Ryuichi, Patricia L. Mokhtarian, and Laura Laidet. 1997. A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area. *Transportation* 24 (2):124-158.

Kline, Rex B. 1998. *Principles and Practice of Structural Equation Modeling*. Edited by D. A. Kenny, *Methodology in the Social Sciences*. New York, New York: The Guilford Press.

Krizek, Kevin J., and Paul Waddell. 2002. Analysis of Lifestyle Choices: Neighborhood Type, Travel Patterns, and Activity Participation. *Transportation Research Record* (1807):119-128.

Kurani, Kenneth S., and Thomas S. Turrentine. 2002. Marketing Clean and Efficient Vehicles: A Review of Social Marketing and Social Science Approaches. Davis, CA: Institute of Transportation Studies, University of California at Davis.

Lave, Charles. 1998. 25 Years of U.S. Energy Policy: Successes, Failures, and Some General Lessons for Public Policy. *Transportation Quarterly* 52 (4):7-13.

Lave, Charles A., and Kenneth Train. 1977. A Disaggregate Model of Auto-Type Choice. Berkeley, CA: Institute of Transportation Studies, University of California.

Lenzen, Manfred. 1999. Total requirements of energy and greenhouse gases for Australian transport. *Transportation Research Part D* 4 (4):265-290.

Maclean, Heather L., and Lester B. Lave. 1998. A Life-Cycle Model of an Automobile. *Environmental Policy Analysis* 32A (13):322 A-330 A.

———. 2003. Life Cycle Assessment of Automobile/Fuel Options. *Environmental Science & Technology* 37 (23):5445-5452.

Mannering, Fred L., and Kenneth Train. 1985. Recent Directions in Automobile Demand Modeling. *Transportation Research, Part B* 19 (4):265-274.

McConnell, Rob, Kiros Berhane, Frank Gilliland, Stephanie J London, Talat Islam, W James Gauderman, Edward Avol, Helene G Margolis, and John M Peters. 2002. Asthma in exercising children exposed to ozone: a cohort study. *The Lancet* 359:386-391.

McGovern, Enda. 2005. Social marketing applications and transportation demand management: An information instrument for the 21st century. *Journal of Public Transportation* 8 (5):1-23.

McShane, Clay. 1994. *Down the Asphalt Path: The Automobile and the American City*. Edited by K. T. Jackson, *Columbia History of Urban Life*. New York, New York: Columbia University Press.

Mokhtarian, Patricia, and Ilan Salomon. 2001. How derived is the demand for travel? some conceptual and measurement considerations. *Transportation Research, Part A* 35 (8):695-719.

Moyano Díaz, Emilio. 2002. Theory of planned behavior and pedestrians' intentions to violate traffic regulations. *Transportation Research, Part F* 5 (3):169-175.

Murphy, James J., and Mark A. Delucchi. 1998. A Review of the Literature on the Social Cost of Motor Vehicle Use in the United States. *Journal of Transportation and Statistics* 1 (1):15-42.

National Highway Traffic Safety Administration. 2004. Automotive Fuel Economy Program Annual Update, Calendar Year 2003. Washington, D.C.: National Highway Traffic Safety Administration of the US Department of Transportation.

Nilsson, Maria, and Rikard Küller. 2000. Travel behaviour and environmental concern. *Transportation Research Part D* 5 (3):211-234.

Noblet, Caroline Lundquist, Mario F. Teisl, and Jonathan Rubin. 2006. Factors affecting consumer assessment of eco-labeled vehicles. *Transportation Research Part D* 11 (6):422.

OECD Project on Environmentally Sustainable Transport. 2000. Environmentally Sustainable Transport: Future, Strategies, and Best Practices.

Opinion Research Corporation. 2005. American Views on Fuel-Efficient Automobiles and a Federal 40 MPG Standard: Summary of Survey Findings. Newton Centre, Massachusetts: Results for America.

Owens, Julie, Sharyn Dickerson, and David L. Macintosh. 2000. Demographic Covariates of Residential Recycling Efficiency. *Environment and Behavior* 32 (5):637-650.

Pallant, Julie. 2001. *SPSS Survival Manual: A Step by Step Guide to Data Analysis Using SPSS for Windows (Versions 10 and 11)*. Philadelphia, Pennsylvania: Open University Press.

Phillips, Braden. 2003. Some Green Machines Swim in the Mainstream. *New York Times*, October 23, 14.

Pickrell, Don, and Paul Schimek. 1999. Growth in Motor Vehicle Ownership and Use: Evidence from the Nationwide Personal Transportation Survey. *Journal of Transportation and Statistics* 2 (1):1-17.

Polk, Merritt. 2003. Are women potentially more accommodating than men to a sustainable transportation system in Sweden? *Transportation Research Part D* 8 (1):75-95.

Public Policy Institute of California. 2002. PPIC Statewide Survey: Special Survey on Californians and the Environment. San Francisco, CA: Public Policy Institute of California.

———. 2003. Special Survey on Californians and the Environment. San Francisco, CA: Public Policy Institute of California.

———. 2005. Special Survey on the Environment. San Francisco, CA: Public Policy Institute of California.

Pucher, John, Tim Evans, and Jeff Wenger. 1998. Socioeconomics of urban travel: evidence from the 1995 NPTS. *Transportation Quarterly* 52 (3):15-33.

Pucher, John, and John L. Renne. 2003. Socioeconomics of Urban Travel: Evidence from the 2001 NHTS. *Transportation Quarterly* 57 (3):49-77.

Pucher, John, and Fred Williams. 1992. Socioeconomic Characteristics of Urban Travelers: Evidence from the 1990 NPTS. *Transportation Quarterly* 46 (4):561-582.

Rose, Geoffrey, and Elizabeth Ampt. 2001. Travel blending: an Australian travel awareness initiative. *Transportation Research Part D* 6 (1):95-110.

Schafer, Andreas. 2000. Regularities in Travel Demand: An International Perspective. *Journal of Transportation and Statistics* 3 (3):1-31.

Scharff, Virginia. 1991. *Taking the Wheel: Women and the Coming of the Motor Age*. Albuquerque, New Mexico: University of New Mexico Press.

Schimek, Paul. 1996. Gasoline and Travel Demand Models Using Time Series and Cross-Section Data from United States. *Transportation Research Record* (1558):83-89.

Schrank, David, and Tim Lomax. 2005. The 2005 Urban Mobility Report. College Station, TX: Texas Transportation Institute.
Stern, Paul C. 2000. Toward a Coherent Theory of Environmentally Significant Behavior. *Journal of Social Issues* 56 (3):407-424.
Tabachnick, Barbara G., and Linda S. Fidell. 2001. *Using Multivariate Statistics*. Fourth ed. Needham Heights, MA: Allyn & Bacon.
Tardiff, Timothy J. 1977. Causal Inferences Involving Transportation Attitudes and Behavior. *Transportation Research* 11 (6):397-404.
Taylor, Michael A. P., and Elizabeth S. Ampt. 2003. Travelling smarter down under: policies for voluntary travel behaviour change in Australia. *Transport Policy* 10 (3):165-177.
Thompson, Robert H. 2004. Overcoming Barriers to Ecologically Sensitive Land Management: Conservation Subdivisions, Green Developments, and the Development of a Land Ethic. *Journal of Planning Education and Research* 24 (2):141-153.
Train, Kenneth, and Michael Lohrer. 1982. Vehicle Ownership and Usage: An Integrated System of Disaggregated Demand Models: California Energy Commission.
U.S. Census Bureau. *Households by Size: 1960 to Present* [Internet Web page in pdf format], June 12, 2003 2003 [cited March 8, 2004. Available from http://www.census.gov/population/socdemo/hh-fam/tabHH-4.pdf.
———. 2004. *Statistical Abstract of the United States: 2004−2005*. 124 ed. Washington D.C.: U.S. Census Bureau.
U.S. Department of Transportation Bureau of Transportation Statistics. 2005. National Transportation Statistics 2005. Washington D.C.: U.S. Department of Transportation.
U.S. Environmental Protection Agency. *National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data*. U.S. Environmental Protection Agency, Posted August, 2005 2005 [cited September 27, 2006. Available from http://www.epa.gov/ttn/chief/trends/trends02/trendsreportallpollutants07182005.zip.
Ullman, Jodie B. 2007. Structural Equation Modeling. In *Using Multivariate Statistics*, edited by B. G. Tabachnick and L. S. Fidell. Boston, MA: Pearson Education, Inc.
Verplanken, Bas, Henk Aarts, and Ad van Knippenberg. 1997. Habit, information acquisition, and the process of making travel mode choices. *European Journal of Social Psychology* 27 (5):539-560.
Wachs, Martin. 1991. Policy Implications of Recent Behavioral Research in Transportation Demand Management. *Journal of Planning Literature* 5 (4):333-341.
Walton, D., J.A. Thomas, and V. Dravitzki. 2004. Commuters' concern for the environment and knowledge of the effects of vehicle emissions. *Transportation Research Part D* 9 (4):335-340.
World Bank. 1996. *Sustainable transport: priorities for policy reform*. Washington, D.C.: World Bank.

Yacobucci, Brent D. 2004. Sport Utility Vehicles, Mini-Vans, and Light Trucks: An Overview of Fuel Economy and Emissions Standards. Washington D.C.: Congressional Research Service of The Library of Congress.

Yagil, D. 2000. Beliefs, motives and situational factors related to pedestrians' self-reported behavior at signal-controlled crossings. *Transportation Research, Part F* 3 (1):1-13.

APPENDIX A: RESEARCH BUDGET

Category	Item	Quantity	Unit Cost	Total Cost
Addresses	Database of addresses	4,000		$294
Notification Letter	Printing	4,000	$0.05	$191
	Envelopes (w/ addresses)	4,000	$0.07	$276
	Labeling	4,000	$0.06	$238
	Postage	4,000	$0.37	$1,480
	Sub-total			*$2,184*
Survey	Translation to Spanish	1	$210.00	$210
	Design			$75
	Printing, survey	4,045	$0.23	$937
	Printing, cover letter	4,000	$0.05	$191
	Envelopes (out, addressed)	4,000	$0.07	$276
	Labeling (out envelopes)	4,000	$0.06	$238
	Envelopes (return, addressed)	4,000	$0.08	$320
	Postage (out)	4,000	$0.37	$1,480
	Postage (return)	4,000	$0.37	$1,480
	Incentive	4,000	$1.00	$4,000
	[undeliverable surveys]	194	-$1.00	-$194
	[returned dollars]	74	-$1.00	-$74
	[returned stamps]	194	-$0.37	-$72
	Sub-total			*$8,866*
Reminder postcard	Printing	3,950	$0.06	$231
	Labels	3,750	$0.01	$39
	Postage	3,800	$0.23	$874
	Sub-total			*$1,144*
Computing	SPSS / AMOS software	1	$107.66	$108
	Endnote software	1	$216.41	$216
	Sub-total			*$324*
Data Entry	Coder hours	198.00	$13.99	$2,770
Total				**$15,582**

APPENDIX B: COMMITTEE FOR THE PROTECTION OF HUMAN SUBJECTS EXEMPTION APPROVAL

UNIVERSITY OF CALIFORNIA, BERKELEY

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

OFFICE FOR PROTECTION
(510) 642-7461 FAX: (510) 643-6272
OF HUMAN SUBJECTS
101 WHEELER HALL, MC: #1340
BERKELEY, CA 94720-1340

Web Site: http://cphs.berkeley.edu
FWA#00006252

February 3, 2005

BRADLEY FLAMM (bflamm@berkeley.edu)
1040 Jackson St., #421
Albany, CA 94706

RE: "Environmental Knowledge, Environmental Attitudes, and the Environmental Impact of Automobile Ownership and Use" Graduate Research – University of California Transportation Center's (UCTC) Doctoral Dissertation Research Grant- City and Regional Planning

Thank you for the statement and request for exemption that you submitted to the Committee for the project referred to above. As described in the statement, your research satisfies the Committee's requirements under Exemption #3, page 4, of CPHS Guidelines of January 1998 (Exemption #2 of the Federal Regulations). Accordingly, the project is exempt from full Committee review provided that there are no changes in the use of human subjects.

Please note that even though your research is exempt from full Committee review, you still have a responsibility to protect your subjects. For example, you should take reasonable steps to obtain their informed consent and to minimize the risks of harm to them.

For our records, the number of the project is 2004-12-28. Please refer to this number in any future correspondence about the project.

If you have any questions about this matter, please contact Beth Mistretta of the OPHS staff at 642-7462; FAX 643-6272; E-Mail bluemist@uclink.berkeley.edu.

Malcolm Potts, M.B., Bchir, Ph.D.
Chair, Committee for the Protection of Human Subjects
Bixby Professor, School of Public Health

MP:mbm

cc: Professor MARTIN WACHS (mwachs@berkeley.edu)
Graduate Assistant
Graduate Division (SID #80629966

APPENDIX C: SURVEY

A Survey About Households, Cars, and the Environment in the Greater Sacramento Metropolitan Region

Versión en español disponible
- Spanish version available -
Si le gustaría completar esta encuesta en español, por favor llame al número de teléfono 510-527-5052 para solicitar la Encuesta sobre hogares, vehículos y medio ambiente. Nosotros le enviaremos a usted una versión en idioma español el día hábil siguiente.

Neighborhood #

NOTE: Surveys were printed with a two digit code—01 to 50—to identify the neighborhood (block group) in which the respondent resides.

We would like to start by asking you a couple of simple questions about how you commute to work and your household's vehicle ownership. **In this survey the word "vehicle" refers to all passenger cars, mini-vans, vans, pickups, and SUVs that your household owns or uses.**

1. How did you commute to work during the past year? If you used several forms of transportation to get to work, indicate the one you used *most often*. (Please circle the number that matches your response.)

Drove myself 1
Carpool or vanpool 2
Took public transportation 3
Walked 4
Bicycled 5
Did not commute, worked at home 6
Did not commute, unemployed or retired 7
Other (please describe):__________________________

2. How many vehicles (including passenger cars, mini-vans, vans, pickups, and SUVs) does your household have available for use? (Please circle the number that matches your response.)

None .... 0 **(If you have no vehicles, SKIP to question 13.)**
One 1
Two 2
Three 3
Four 4
Five 5
Six or more 6

Now we would like to know more about your household's vehicle ownership and use. For each of the cars, mini-vans, vans, pickups, or SUVs that your household owns or uses, please answer the following questions. **If your household has 4 or more vehicles, please answer the questions below for the 3 vehicles that your household drives the *most miles* per year.**

		Vehicle #1	Vehicle #2	Vehicle #3
3.	What is the make of this vehicle? (For example, a *Ford* or *Honda*.)			
4.	What is the model of this vehicle? (For example, a Ford *Explorer* or a Toyota *Corolla*.)			
5.	What is the trim level of this vehicle? (For example, a Ford Explorer comes in several trim levels such as the *XLT*, *XLS Sport*, *or* *Eddie Bauer Edition* and a Toyota Corolla can come in the *CE*, *LE*, *or* *XRS* trim levels.)			
6.	What is the vehicle's model year?			
7.	What type of transmission does this vehicle have?	Automatic .... 1 Manual .... 2 Do not know 3	Automatic .... 1 Manual .... 2 Do not know 3	Automatic .... 1 Manual .... 2 Do not know 3
8.	How did you obtain this vehicle?	Bought new .... 1 Bought used .... 2 Leased .... 3 Gift .... 4 Borrowed .... 5 My employer 6	Bought new .... 1 Bought used .... 2 Leased .... 3 Gift .... 4 Borrowed .... 5 My employer 6	Bought new .... 1 Bought used .... 2 Leased .... 3 Gift .... 4 Borrowed .... 5 My employer 6
9.	How long have you owned or had use of this vehicle?	______ years and ______ months	______ years and ______ months	______ years and ______ months
10.	What type of fuel does this vehicle use?	Gasoline .... 1 Diesel .... 2 Other 3	Gasoline .... 1 Diesel .... 2 Other 3	Gasoline .... 1 Diesel .... 2 Other 3
11.	What type of wheel drive system does this vehicle have?	2 wheel drive .... 1 4 wheel drive .... 2 All wheel drive .... 3 Do not know 4	2 wheel drive .... 1 4 wheel drive .... 2 All wheel drive .... 3 Do not know 4	2 wheel drive .... 1 4 wheel drive .... 2 All wheel drive .... 3 Do not know 4
12.	How many miles does your household drive this vehicle per year? (If you have owned or used it *less than one year*, indicate how many miles you have driven it *so far*.)	__________ miles	__________ miles	__________ miles

The next set of questions concerns your knowledge of some of the environmental effects of vehicle ownership and use. **Please circle the number for each question that corresponds with whether you believe the answer to be *true*, *probably true*, *probably false*, or *false*.**

	True ▼	Probably True ▼	Probably False ▼	False ▼
13. All cars, mini-vans, vans, pickups, and SUVS pollute about the same amount for each mile driven.	1	2	3	4
14. Cars, mini-vans, vans, pickups, and SUVS are not an important source of air pollution any more.	1	2	3	4
15. Cars, mini-vans, vans, pickups, and SUVS are an important source of the gases that many scientists believe are warming Earth's climate.	1	2	3	4
16. Government rules allow mini-vans, vans, pick-ups, and SUVs to pollute more than passenger cars, for every gallon of gas used.	1	2	3	4
17. Government rules require mini-vans, vans, pick-ups, and SUVs to meet the same miles-per-gallon standards as passenger cars.	1	2	3	4
18. Manufacturing a new passenger car, mini-van, van, pickup, or SUV is a major source of pollution and energy use even before it is driven out of the factory for the first time.	1	2	3	4
19. Exhaust from cars, mini-vans, vans, pickups, and SUVs is an important source of the pollution that causes asthma and makes asthma attacks worse.	1	2	3	4

Now we would like to ask you about your thoughts on the environment. **From each pair of statements below, please select the statement that *most closely* matches your opinion by circling the appropriate number.**

20. Stricter environmental laws and regulations cost too many jobs and hurt the economy:.................................1

or

Stricter environmental laws and regulations are worth the cost: 2

21. People like me will have to make major lifestyle changes to solve today's environmental problems:......................1

or

People like me will have to make few or no lifestyle changes to solve today's environmental problems: 2

22. Development of U.S. energy supplies – such as oil, gas, and coal – should be given priority, even if the environment suffers to some extent:.......................... 1

or

Protection of the environment should be given priority, even at the risk of limiting the amount of energy supplies – such as oil, gas, and coal – which the U.S. produces: 2

Now, we would like to ask you a few questions about yourself so that we can compare your answers and opinions with other people's answers and opinions. **Your answers are anonymous and *completely* confidential.**

23. Does your household own or rent your current residence?

Own 1
Rent..2
Other...3

24. Are you a member of the California State Automobile Association (also known as the AAA)?

Yes 1
No..2

25. How many people, *including yourself*, live in your household?

_____ people live in my household

26. How many of the members of your household, *including yourself*, are 16 years or older?

_____ household members are 16 years or older

27. How many people in your household, *including yourself*, hold valid driver's licenses?

_____ licensed drivers live in my household

28. Are you a member of an environmental organization (for example, the Audubon Society, the Sierra Club, or the Nature Conservancy)?

Yes 1
No 2

29. What is the highest level of education you have attained?

Less than high school 1
Some high school 2
High school or GED 3
Associate degree or technical training 4
Bachelor degree 5
Graduate college degree (Masters, Professional, or Doctorate) 6

30. What was your household's approximate or estimated before-tax income in 2004?

Less than $20,000 1
$20,000 to $29,999 2
$30,000 to $39,999 3
$40,000 to $49,999 4
$50,000 to $74,999 5
$75,000 to $124,999 6
$125,000 to $199,999 7
$200,000 or more 8

31. What is your race?

White alone 1
Black or African American alone 2
American Indian or Alaska Native alone 3
Asian alone 4
Native Hawaiian or Other Pacific Islander alone 5
Some other race alone 6
Two or more races 7

32. Are you Spanish/Latino/Hispanic?

Yes 1
No 2

33. What is your age? ______ years

34. What is your gender?

Male 1
Female 2

Finally, we would like to know your ideas about how to make the vehicles we drive more energy efficient and cleaner for the environment.

35. What could car companies (like General Motors, Honda, or Ford) do to make owning and using vehicles cleaner and more energy efficient?

36. What could politicians and government agencies do to make owning and using vehicles cleaner and more energy efficient?

37. What could individuals like you do to make owning and using vehicles cleaner and more energy efficient?

Thank you again for your time and participation!

APPENDIX D: DATA ENTRY CODEBOOK

Codebook
for inputting data for

A Survey About Households, Cars, and the Environment in the
Greater Sacramento Metropolitan Region

Bradley Flamm
Ph.D. Candidate
Department of City and Regional Planning
University of California, Berkeley

May and June, 2005

Introduction:

Data from the approximate 1,500 returned surveys of the "Survey About Households, Cars, and the Environment in the Greater Sacramento Metropolitan Region" will be entered in 15 Microsoft **Excel Spreadsheets** named HCE_10001-10100.xls, HCE_10101-10200.xls, etc. (100 returned surveys per spreadsheet).

Each spreadsheet contains **3 worksheets** named "Data Entry 1," "Data Entry 2," and "Validation." The first coder to input data will input all data from each returned survey on worksheet "**Data Entry 1**." The second coder to input data will input data all data for questions #1 to #34 (i.e. the second coder will not input the responses to open-ended questions #35, #36, and #37) on worksheet "**Data Entry 2**."

General notes concerning responses to any question**:**

For those questions that include numbered responses: If the respondent has circled the word, rather than the number that corresponds to the word, input the corresponding number if the meaning is unambiguous. For example, if the respondent circled the word "Walked" in question #1, instead of the number "4", and there are no other marks on the survey for that question, input the number "4."

When multiple responses are given for a question that *should* have a single response only, input "-9," as noted in the coding instructions below *and* note the multiple responses in the Notes column (BR). For example, if the respondent circles both responses 1 and 4 in question #1 (perhaps the respondent both drove alone and bicycled to work and does not want to, or cannot, estimate which mode he/she used most frequently), input -9, but note responses 1 and 4 in column BR.

If the respondent adds a comment to a closed-ended question (#1 to #34), use the "personal comments" column (BS) to input the text of the message and indicate which question it relates to.

Page 1: Cover

The cover of each questionnaire contains a number of variables to input. At a minimum, each questionnaire will have the following, *even in the case that no survey has been returned* (in this case, the information immediately below will have been written on a separate sheet of paper):

Column	Descriptive name	8-letter name	Q #	Notes / description
C	Unique identification number	entry_id	#a	Handwritten (middle bottom cover) code # for this individual survey, from 10001 to over 11400
D	Neighborhood	nghbrhd	#b	Neighborhood code #, printed on survey at bottom right of cover
E	Date survey received	date	#c	Handwritten date received at middle bottom cover
F	No question-naire returned	no_qaire	#d	These are uncommon occurrences, so worksheets have been pre-coded "0," but in the case where a survey has, for example, been returned blank or with the $1 incentive, it is noted in handwriting at the bottom right of the cover. In these cases, change appropriate code from 0 to 1.
G	Blank questionnaire returned	blank	#e	
H	$1 bill returned	dollar	#f	
I	Used own stamp to return	own_stmp	#g	
J	Postmark from outside of Sacramento region	postmark	#h	
K	Respondent affixed own return address	ret_addr	#i	

Two more handwritten codes are found at the bottom middle of each cover: "DI" and "DI2." These are to be filled in by the coders, "DI" by the coder who inputs the data for the first time on worksheet "Data Entry 1" and "DI2" by the coder who inputs the data the second time on worksheet "Data Entry 2."

If the respondent includes comments on the cover, use the "personal comments" column (BS) to input the text of the message and indicate where the message was written.

Page 2

1. How did you commute to work during the past year? If you used several forms of transportation to get to work, indicate the one you used most often. (Please circle the number that matches your response.)

Drove myself	1
Carpool or vanpool	2
Took public transportation	3
Walked	4
Bicycled	5
Did not commute, worked at home	6
Did not commute, unemployed or retired	7
Other (please describe):________________	8
No response	-8
Multiple responses	-9

2. How many vehicles (including passenger cars, mini-vans, vans, pickups, and SUVs) does your household have available for use? (Please circle the number that matches your response.)

None	0 (If you have no vehicles, SKIP to Q# 13.)
One	1
Two	2
Three	3
Four	4
Five	5
Six or more	6
No response	-8
Multiple responses	-9

Questions #3 to #12 can refer to 0, 1, 2 or 3 separate cars and are labeled "vehicle 1" (answers 3a to 12a in columns O to X), "vehicle 2" (answers 3b to 12b in columns Y to AH), and "vehicle 3" (answers 3c to 12c in columns AI to AR). If respondent indicates more cars in response to question #2 than are described by responses to questions #3 to #12, input -8 to indicate responses that should be included, but are not. Columns left blank because the respondent has fewer than 3 cars should also be left blank in the corresponding data columns on the spreadsheet *without* inputting "-8".

3. What is the make of this vehicle? (For example, a Ford or Honda.)

[Input the precise text that respondent uses, unless an abbreviation is well-known and the full name can be substituted. For example, "Chevy" should be input as "Chevrolet."]

4. What is the model of this vehicle?

[Input the precise text that respondent uses.]

5. What is the trim level of this vehicle?

[Input the precise text that respondent uses.]

6. What is the vehicle's model year?

[Input the year that the respondent indicates. If the respondent shortens the year to '05 or '98, input the corresponding year (i.e., 2005 or 1998).]

7. What type of transmission does this vehicle have?

Automatic	1
Manual	2
Do not know	3
No response	-8
Multiple responses	-9

8. How did you obtain this vehicle?

Bought new	1
Bought used	2
Leased	3
Gift	4
Borrowed	5
My employer	6
No response	-8
Multiple responses	-9

9. How long have you owned or had use of this vehicle?

____ years and

____ months

[Input the number of years the respondent indicates. If the respondent includes the number of months, convert the number of months to a decimal point in this way:

# months	decimal	# months	decimal
1	0.08	7	0.58
2	0.17	8	0.67
3	0.25	9	0.75
4	0.33	10	0.83
5	0.42	11	0.92
6	0.50	12	1.00

10. What type of fuel does this vehicle use?

Gasoline	1
Diesel	2
Other	3
No response	-8
Multiple responses	-9

11. What type of wheel drive system does this vehicle have?

2 wheel drive	1
4 wheel drive	2
All wheel drive	3
Do not know	4
No response	-8
Multiple responses	-9

12. How many miles does your household drive this vehicle per year? (If you have owned or used it less than one year, indicate how many miles you have driven it so far.)

___________ miles

[Input the precise number the respondent used. If the respondent has owned the car less than a year and it appears the respondent has estimated annual mileage, instead of miles driven so far, as specified in the question wording (e.g., if they have owned the car for only a month, but indicate 12,000 as the response to this question), make a note of the possible discrepancy in the notes column (BR).]

[If Respondent abbreviates “thousand” with “K” (as in, “10K”), input the number indicated in thousands (i.e., 10,000 for “10K”).]

[If Respondent indicates less than or more than using “<” or “>”, input the number indicated and make a note of the use of the “<” or “>” in the Notes column (column BR).]

Page 3

Use the following coding for responses to questions #13 to #19:

True	1
Probably True	2
Probably False	3
False	4
No response	-8
Multiple responses	-9

13. All cars, mini-vans, vans, pickups, and SUVS pollute about the same amount for each mile driven.

14. Cars, mini-vans, vans, pickups, and SUVS are not an important source of air pollution any more.

15. Cars, mini-vans, vans, pickups, and SUVS are an important source of the gases that many scientists believe are warming Earth's climate.

16. Government rules allow mini-vans, vans, pick-ups, and SUVs to pollute more than passenger cars, for every gallon of gas used.

17. Government rules require mini-vans, vans, pick-ups, and SUVs to meet the same miles-per-gallon standards as passenger cars.

18. Manufacturing a new passenger car, mini-van, van, pickup, or SUV is a major source of pollution and energy use even before it is driven out of the factory for the first time.

19. Exhaust from cars, mini-vans, vans, pickups, and SUVs is an important source of the pollution that causes asthma and makes asthma attacks worse.

Use the following coding for responses to questions #20, #21, and #22:

First sentence	1
Second sentence	2
No response	-8
Multiple responses	-9

20. Stricter environmental laws and regulations cost too many jobs and hurt the economy:
1
or
Stricter environmental laws and regulations are worth the cost:
2

21. People like me will have to make major lifestyle changes to solve today's environmental problems:
1
or
People like me will have to make few or no lifestyle changes to solve today's environmental problems:
2

22. Development of U.S. energy supplies – such as oil, gas, and coal – should be given priority, even if the environment suffers to some extent:
1
or
Protection of the environment should be given priority, even at the risk of limiting the amount of energy supplies – such as oil, gas, and coal – which the U.S. produces: 2

23. Does your household own or rent your current residence?

Own	1
Rent	2
Other	3
No response	-8
Multiple responses	-9

24. Are you a member of the California State Automobile Association (also known as the AAA)?

Yes	1
No	2
No response	-8
Multiple responses	-9

Page 4

25. How many people, including yourself, live in your household?

_____ people live in my household

[Input the number indicated by the respondent. NOTE:"0" is not an acceptable response; if input, change to "1".]

26. How many of the members of your household, including yourself, are 16 years or older?

_____ household members are 16 years or older

[Input the number indicated by the respondent. NOTE:"0" is not an acceptable response; if input, change to "1".]

27. How many people in your household, including yourself, hold valid driver's licenses?

_____ licensed drivers live in my household

[Input the number indicated by the respondent. NOTE:"0" *is* an acceptable response, but may indicate a mistake if previous responses indicate car ownership and use – make a note in column BR, if this appears to be the case.]

28. Are you a member of an environmental organization (for example, the Audubon Society, the Sierra Club, or the Nature Conservancy)?

Yes	1
No	2
No response	-8
Multiple responses	-9

29. What is the highest level of education you have attained?

Less than high school	1
Some high school	2
High school or GED	3
Associate degree or technical training	4
Bachelor degree	5
Graduate college degree (Masters, Professional, or Doctorate)	6
No response	-8
Multiple responses	-9

30. What was your household's approximate or estimated before-tax income in 2004?

Less than $20,000	1
$20,000 to $29,999	2
$30,000 to $39,999	3
$40,000 to $49,999	4
$50,000 to $74,999	5
$75,000 to $124,999	6
$125,000 to $199,999	7
$200,000 or more	8
No response	-8
Multiple responses	-9

31. What is your race?

White alone	1
Black or African American alone	2
American Indian and Alaska Native alone	3
Asian alone	4
Native Hawaiian or Other Pacific Islander alone	5
Some other race alone	6
Two or more races	7
No response	-8
Multiple responses	-9

32. Are you Spanish/Latino/Hispanic?

Yes	1
No	2
No response	-8
Multiple responses	-9

33. What is your age? _______ years

[Input the age in years indicated by the respondent.]

34. What is your gender?

Yes	1
No	2
No response	-8
Multiple responses	-9

35. What could car companies (like General Motors, Honda, or Ford) do to make owning and using vehicles cleaner and more energy efficient?

[**Type in response as closely to the respondent's as possible – i.e., if there are spelling or grammatical mistakes, do not correct them.]**

36. What could politicians and government agencies do to make owning and using vehicles cleaner and more energy efficient?

[**Type in response as closely to the respondent's as possible – i.e., if there are spelling or grammatical mistakes, do not correct them.]**

37. What could individuals like you do to make owning and using vehicles cleaner and more energy efficient?

[Type in response as closely to the respondent's as possible – i.e., if there are spelling or grammatical mistakes, do not correct them.]

[If text is included after the words "Thank you for your time and participation!" and they appear not to be related to question #37, include that text in the "Personal comments" column (BS).]

APPENDIX E: ADDITIONAL DATA VARIABLES

This appendix includes descriptions of variables that were added to the data set during or after respondent answers to questions #1 through #37 were entered. The first set of additional variables was entered during the initial data entry and includes fields indicating whether (=1) or not (=0) the respondent:

1) Returned the survey envelope without a survey (A7_nqre),

2) Returned a blank survey (A8_blank),

3) Returned the incentive $1 bill (A9_dollr),

4) Used his/her own stamp (A10_stmp),

5) Included a return address sticker (A12_rtad),

6) Mailed the return envelope from a location outside of the study area (A11_pmrk).

The next set of variables was added to the data set based upon information obtained from other sources that could be linked to each respondent's survey:

7) Population density of block group in which respondent resides (A5_popdn). Source: calculated using GIS analysis of U.S. Census Bureau data on each block group (total block group population was divided by the result of the total area in acres minus the area covered by water features, such as rivers and lakes).

8) Vehicle ownership category (A3_vehcat). Source: derived from U.S. Census Bureau data and used in selection of 50 study block groups (see description in the *sampling method* section of Chapter 3).

9) A measure of pedestrian environment factor for the respondent's block group (A6_pef). Source: obtained from SACOG.

For each household vehicle for which sufficient information was provided, the following variables were added to the data base:

10) US Environmental Protection Agency (EPA) vehicle class (A16_v1_class, A24_v2_class, and A32_v3_class),

11) US EPA city driving fuel economy (A18_v1_cmpg, A26_v2_cmpg, and A34_v3_cmpg),

12) US EPA highway driving fuel economy (A19_v1_hmpg, A27_v1_hmpg, and A35_v3_hmpg),

13) US EPA combined driving fuel economy (A20_v1_ompg, A28_v2_ompg, and A36_v3_ompg),[81] and

14) A vehicle type code: 1=passenger car, 2=light duty truck, such as a van, mini-van, pickup truck, or sports utility vehicle, or 3=heavy duty truck, that is a vehicle with a gross vehicle weight of over 8,500 pounds (A17_v1_type, A25_v2_type, and A33_v3_type).

To these were added twenty three calculated variables:

15) Vehicles per household member (O1_v_hhm),

[81] Note that for many vehicles it was impossible to know with certainty which of two or more EPA-listed vehicles was the accurate one to use. In most cases, this was due to the fact that the engine displacement was unknown. Though it introduced an element of possible error into the analysis, the best option for proceeding under these circumstances was to assign an averaged value of city, highway, and combined fuel economies, based on the vehicles that a given respondent's vehicle could be (for example, the 2004 Ford Mustang comes in nine separate combinations of transmission type and number of cylinders, with overall fuel economy ranging from 19 to 23 miles per gallon).

16) Vehicles per household member aged 16 years and older (O2_v_16),

17) Vehicles per household licensed driver (O3_v_ld),

18) Estimated annual miles driven per household (O11_am_hh),

19) Estimated annual miles driven per household member (O12_am_hhm),

20) Estimated annual miles driven per household member aged 16 and older (O13_am_16),

21) Estimated annual miles driven per household licensed driver (O14_am_ld), and

22) Estimated annual mileage for each vehicle owned less than a year, calculated by dividing estimated miles driven to date by the percentage of the year elapsed, number of months owned divided by 12, (A15_v1_an_miles, A23_v2_an_miles, A31_v3_an_miles),[82]

23) Dummy variable indicating those respondents who owned one or more vehicles for less than a year (=1) and those respondents who did not own any vehicle for less than a year (=0) (D2_newcars),

24) Average fuel economy of respondent's household vehicles (A37_avg_mpg),

25) Estimated annual household fuel consumption (O6_fuel_hh),

26) Estimated annual household fuel consumption per household member (O7_fuel_hhm),

27) Estimated annual household fuel consumption per household member aged 16 and older (O8_fuel_16),

---

[82] This calculated variable, unfortunately, resulted in a large number of vehicles with unbelievably high estimated annual mileage (some surpassing 200,000), suggesting that some respondents who owned vehicles less than a year had estimated the number of miles they expected to drive the vehicle in the entire first year of ownership. Because it was impossible to distinguish which respondents replied with miles driven to date and which replied with estimated annual mileage, the dummy variable D2_newcars was created.

28) Estimated annual household fuel consumption per household licensed driver (O9_fuel_ld),

29) Dummy variable indicating whether the four estimates of annual fuel consumption are based on complete information (=1) or incomplete information (=0) (S3_Fuel) (when one or more respondent vehicles were too old to have had a USEPA fuel economy rating, the respondent declined to provide vehicle information necessary for identifying USEPA fuel economy ratings, or the respondent declined to provide estimated annual mileage for one or more vehicles, a value of "0" was recorded),

30) Dummy variable indicating whether any data value has been changed in the data entry process from the value indicated by the respondent (D1_changed),[83]

31) A calculated variable, number of household members aged 15 or younger (A40_hh_15),

32) A dummy variable, homeowner (=1) or not (=0), D11_Homeowner,

33) A dummy variable, commuter (=1) or not (=0), D12_Commuter,

34) A dummy variable, single occupancy vehicle commuter (=1) or not (=0), D13_SOV,

35) A dummy variable, D6_Income, used in analyzing respondents who did and did not respond to the income question,

---

[83] For example, some respondents replied that there were no household members aged 16 or older, even though they had responded that there were household members licensed to drive. Because a household member cannot be licensed to drive unless he or she were aged 16 or older, the respondent clearly misread the question as asking for the number of household members under age 16. Where absolutely clear what a respondent intended, as in this case, data values were corrected and a descriptive phrase indicating what change was made was entered into this column.

36) A dummy variable, D7_Race, used in analyzing respondents who did and did not respond to the race question,

37) A dummy variable, S1_OMPG, used for analyses of average fuel efficiency of household vehicles (1=records for which full information on fuel efficiency was available, 0=records for which full information was not available),

38) A dummy variable, S2_Miles, used for analyses of estimated annual household miles driven (1=records for which full information on fuel efficiency was available, 0=records for which full information was not available), and

39-47) Nine additional calculated variables for trimmed values of average fuel efficiency, miles driven, and fuel consumption variables: T_C1_FuelHH, T_C3_AFC_HHM, T_C4_AFC_HH16, T_C5_AFC_HHLD, T_T2_Miles, T_T5_OMPG, T_T6_am_hhm, T_T7_am_16, T_T8_am_ld (see Appendix L, Data Screening, for details of the transformations).

APPENDIX F: POWER ANALYSIS

Two power calculations confirmed an estimate of a necessary sample size of just over 1,000 completed surveys. The first was a test of hypothesis 1a, "Knowledge of the environmental impacts of automobile ownership and use is positively related to the purchase of more fuel efficient automobiles."[84] Assuming that the difference is significant, but small, this power test is based upon an average automobile fuel economy of 21 miles per gallon (combined city and highway driving) for respondents who have a high level of environmental knowledge and an average of 20 miles per gallon for those with a low level of environmental knowledge. The standard deviation is likely to be fairly large and a two-sided test is specified, because it is possible that those with higher levels of environmental knowledge purchase *less* fuel efficient vehicles (if, for example, higher knowledge is associated with higher levels of education and income, such respondents may buy more expensive, larger, less efficient automobiles). Finally, fairly stringent significance and power levels are specified.

Normal Power Calculations for hypothesis 1a (environmental knowledge positively related to purchase of more fuel efficient automobiles)

Normal Distribution 2-Sample Equal Variances

μ_1

The Mean of Population 1: 21

μ_2

The Mean of Population 2: 20

Sigma

Common Standard Deviations for both Populations: 6

Number of Sides

Two sided => H_1: μ_1 not equal μ_2

[84] Please note that the wording and numbering of hypotheses changed before the final version of the dissertation was completed. I retained the original text of this power analysis report, written in October 2 for this Appendix.

```
Significance Level
    The Significance Level of the test or Prob(reject
    Null hypothesis (H0: μ1 =μ2) given it is true): 0.05

Power
    The Power desired for the test or Prob(reject H0 given
    that Ha is true): 0.90
```

Result:

```
N-1: 526.

N-2: 526.>

Total: 1,052
```

The second power calculation tested hypothesis 2b, “Pro-environmental attitudes are positively related to the purchase of fewer cars.” Assuming that the difference is significant, but small, this power test is based upon an average number of automobiles per respondent household licensed driver of 0.95 for respondents who have a higher level of pro-environmental attitudes and an average of 1.00 for those with a lower level of pro-environmental attitudes. The standard deviation is likely to be fairly large and a two-sided test is specified, because it is possible that those with higher levels of environmental knowledge purchase *more* automobiles per household licensed driver (again, higher levels of pro-environmental attitudes might be associated with higher levels of education and income, and so such respondents may buy more automobiles). Finally, fairly stringent significance and power levels are specified.

Normal Power Calculations for hypothesis 2b (environmental attitudes are positively related to the purchase of fewer cars)

```
Normal Distribution 2-Sample Equal Variances
  μ1
      The Mean of Population 1: 0.95
  μ2
      The Mean of Population 2: 1.00
  Sigma
      Common Standard Deviations for both Populations: 0.25
  Number of Sides
```

Two sided => H_1: μ_1 not equal μ_2

Significance Level
The Significance Level of the test or Prob(reject Null hypothesis (H_0: $\mu_1 = \mu_2$) given it is true): 0.05

Power
The Power desired for the test or Prob(reject H_0 given that H_a is true): 0.90

Result:

N-1: 526.

N-2: 526.>

Total: 1,052

APPENDIX G: NOTIFICATION LETTER

UNIVERSITY OF CALIFORNIA, BERKELEY

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

INSTITUTE OF TRANSPORTATION STUDIES
109 McLAUGHLIN HALL, MC 1720
BERKELEY, CA 94720-1720
Phone: 510/642-3585 Fax: 510/643-3955

April 14, 2005

Dear Sacramento Region Resident,

A few days from now you will receive in the mail a request to fill out a brief survey for an important research project being conducted with the assistance of the University of California's Institute for Transportation Studies.

It concerns automobile ownership and use in the greater Sacramento metropolitan region and how the choices residents make about their cars affect the regional transportation system and the environment.

We are writing in advance because we have found many people like to know ahead of time that they will be contacted and asked to help. The study is an important one that is meant to help planners and government agencies better understand the challenges of traffic congestion, parking, air and water quality, and maintaining a high community quality of life.

Thank you for your time and consideration. It's only with the generous help of people like you that our research can be successful.

Sincerely,

Bradley Flamm
Researcher / Ph.D. Candidate

PS: We will be enclosing a small token of appreciation with the questionnaire as a way of saying thank you.

APPENDIX H: SURVEY COVER LETTER

UNIVERSITY OF CALIFORNIA, BERKELEY

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO   SANTA BARBARA • SANTA CRUZ

INSTITUTE OF TRANSPORTATION STUDIES
109 McLAUGHLIN HALL, MC 1720
BERKELEY, CA 94720-1720
Phone: 510/642-3585 Fax: 510/643-3955

April 21, 2005

Dear Sacramento Region Resident,

We are writing to ask your help in completing a study of automobile ownership and use in the greater Sacramento metropolitan region. This study is part of an effort to better understand how area residents make important decisions that affect the regional transportation system and the environment. You were selected to receive this survey as part of a random sample of households in 50 neighborhoods.

A simple, confidential survey. Participation in this survey is completely voluntary and the enclosed 37-question survey should take just about 10 to 15 minutes to fill out. Your answers will be completely anonymous so your confidentiality is guaranteed. All responses will be released only as summaries in which no individual's answers can be identified. Returned surveys will be stored in a secure, locked location. After this project is complete, the data may be used in future research, but the same confidentiality guarantees given here will apply to future storage and use of the materials.

Who should fill out the survey? We ask that one adult member of your household (someone 18 years or older) complete the survey. If there are several adult members in the household, the person filling out the survey should be an adult who helps make decisions about the cars your household owns and uses and whose birthday occurred the most recently. Please answer this survey *whether or not you own or use a car* because every household's responses are valuable for this study.

How to fill out the survey. If you agree to take part in this research, please fill out and return the survey in the enclosed stamped envelope. You may, of course, skip any question that you do not wish to answer.

What benefits and risks are there? There are no expected risks to you from participating in this research, nor is there any direct benefit. We hope, however, that the results will help planners to develop better transportation programs and policies. Your participation will help make the results of our research stronger and more reliable.

Questions or comments? If you have any questions or comments about this study, please feel free to contact me (by telephone at 510-527-5052 or by e-mail at bflamm@berkeley.edu) or the Director of the Institute for Transportation Studies, Professor Martin Wachs, at the mailing address or telephone number printed at the top of this letter or by e-mail at its@its.berkeley.edu.

We have enclosed a small token of appreciation as a way of saying thanks for your help. And if you would like to learn of the results of this research project, after June 1st, 2005, log onto http://www.its.berkeley.edu/research/featuredresearch/sacramentosurvey.html for information on how to receive future updates.

Thank you very much for helping with this important study.

Sincerely,

Bradley Flamm
Researcher / Ph.D. Candidate

APPENDIX I: REMINDER POSTCARD

INSTITUTE OF TRANSPORTATION STUDIES
109 McLAUGHLIN HALL, MC 1720
BERKELEY, CA 94720-1720
Phone: 510/642-3585 Fax: 510/643-3955

April 28, 2005

Dear Sacramento Region Resident,

Last week a survey about automobile ownership in the Sacramento region was mailed to you. Your address was drawn randomly from a list of households in 50 neighborhoods of the greater Sacramento metropolitan area.

If you have already completed and returned the questionnaire, please accept our sincere thanks. If not, please do so today. We are especially grateful for your help because it is by asking people like you to share your opinions that we can better understand how the region's residents make decisions that affect daily travel conditions, the regional transportation system, and the environment.

If you did not receive a survey, or if it was misplaced, please call us at 510-527-5052 or e-mail us at bflamm@berkeley.edu and we will get another one in the mail to you as soon as possible.

APPENDIX J: CALCULATION OF ANALYTICAL WEIGHTS

This appendix provides details of the development of a set of analytical weights used in most of the statistical analyses of this dissertation. Dr. Thomas Piazza of the Survey Research Center met with me on three occasions and provided me with invaluable advice and review of these calculations.

Step 1: **Calculate a sampling weight** (SW) for each record using this formula: k1 * n-eligible (the number of potential respondents within each household), where k1 was calculated by dividing the number of records with data for number of household members aged 16 or older by the sum of household members aged 16 or older in the entire sample: 1,506 / 3,063=<u>0.491675</u>.

Two adjustments had to be made in order to complete this calculation. First, of the 1,506 records, thirteen had missing data for number of household members aged 16 and older and were assigned an n-eligible value of “2” because 2 household members aged 16 and older is the most common number within the sample’s 1,493 respondents who responded to this question (52.5% of the 1,493 records). Second, the range of values for number of household members aged 16 and older for the 1,506 records is 1 to 7, but because only 19 records have values of 5, 6 or 7, they are considered outliers and were consequently “trimmed” to a value of 4, so that the value of 4 actually represents “4 or more”.

Step 2: **Calculate a non-response adjustment** (NRA): based on level of vehicle ownership per household member aged 16 and over (the variable used to proportionally stratify the 1,199 block groups in the 6-county SACOG (Sacramento Area Council of Governments) planning area).

Table J.1: Non-response adjustments for five categories of vehicle ownership

Vehicle ownership per capita (16 and older)	Vehicle ownership category	Response rate	Non-response adjustment
0.01 – 0.42	1	42.86%	2.333
0.41 – 0.69	2	41.96%	2.383
0.69 – 0.85	3	37.66%	2.655
0.85 – 1.01	4	42.23%	2.368
1.01 – 1.53	5	39.87%	2.508
	All	**40.46%**	

Step 3: **Create a combined weight 1**, where SW * NRA is calculated for each record: Resulting combined weight values range from 1.1472 (0.4917 * 2.333) to 5.222 (2.655 * 1.967)

Step 4: **Calculate a post-stratification adjustment** (PSA) based on age and gender distributions of sample respondents (grouped into 6 categories: 18 to 29, 30 to 39, 40 to 49, 50 to 59, 60 to 69, and 70 and older) and the overall population aged 18 and older in the 1,199 block groups of the SACOG (Sacramento Area Council of Governments) 6-county planning region.

Table J.2: Age and gender based post-stratification adjustments

Census	**Group1** (Age 18 to 29)	**Group2** (Age 30 to 39)	**Group3** (Age 40 to 49)	**Group4** (Age 50 to 59)	**Group5** (Age 60 to 69)	**Group6** (Age 70 and over)	Total
Male	153,183	144,179	143,357	96,798	59,215	63,787	660,519
Female	152,590	148,382	149,717	103,168	68,461	91,812	714,130
Total	305,773	292,561	293,074	199,966	127,676	155,599	1,374,649
Sample (unweighted values)							
Male	42	111	180	201	112	124	770
Female	66	112	153	168	87	77	663
Total	108	223	333	369	199	201	1,433
Weight							
Male	3.80	1.35	0.83	0.50	0.55	0.54	0.89
Female	2.41	1.38	1.02	0.64	0.82	1.24	1.12

Weights applied as appropriate to records with both age and gender data available. (Please note that 7 records were missing data for gender, so gender was randomly assigned to these only for the purposes of assigning a post-stratification adjustment for them (that is, the data in the gender field was not changed, but a PSA was assigned as if the record reflected the randomly assigned gender). Randomization of gender was achieved by selecting 7 randomly assigned numbers (a value of 1 for male or 2 for female), using the random integer generator at http://www.random.org/nform.html. In the same way, age groups were assigned to 42 records that were missing age data, but not gender (random integers between 1 and 100 were generated and were matched to one of the six age groups, depending upon their share of the total sample). And finally, 23 records were missing age and gender data, and random integers were obtained in the same way for the purpose of assigning them to age-gender groups.)

Step 5: **Calculate a final weight** using this formula:

SW * NRA * PSA

Step 6: **Calculate k2** using this formula:

k2=(number of records with a non-missing value for final weight) divided by (sum of all non-missing values of **final weight**)=1,506 / 3,779.26=<u>0.39849</u>.

(Note the range of resulting values is 0.233 to 7.911, a difference in scale of 1 to 34.)

Step 7: **Calculate the analytical weight** using this formula:

Final Weight * k2

The final variable was named W1_Weights.

APPENDIX K: PRINCIPAL COMPONENTS ANALYSIS OF ENVIRONMENTAL KNOWLEDGE QUESTIONS

Cronbach's alpha analysis of the environmental knowledge indexes raised the question of whether the seven questions contributing to the indexes were measuring two or more latent constructs, instead of a single latent construct, as was assumed. To explore this possibility, I conducted a principal components analysis, using the seven items in the environmental knowledge index (based on the "b" values ranging from -2 to 2), using SPSS. Prior to performing PCA the suitability of data for factor analysis was assessed, and the data's suitability for PCA was confirmed.[85]

Principal components analysis revealed the presence of two components with eigen values exceeding 1. An inspection of the screeplot revealed a clear break after the second component. To aid in the interpretation of these two components, Varimax rotation was performed. The rotated solution (presented in Table K.1 below) revealed the presence of simple structure, with both components showing a number of strong loadings substantially on one component. The two factor solution explained a total of 52.2% of the variance, with Component 1 contributing 28.9% and Component 2 contributing 23.3%. The two components are grouped into two clear sets of questions, those that concern pollutant emissions and energy impacts attributable to all types of vehicles (component 1) and those questions that concern comparisons of passenger cars to light duty vehicles (component 2).

[85] Inspection of the correlation matrix revealed the presence of 6 coefficients of .3 and above (out of 21 coefficients). The Kaiser-Meyer-Oklin value was .704, exceeding the generally recommended value of .6 and the Bartlett's Test of Sphericity reached statistical significance, both supporting the factorability of the correlation matrix.

Because two sets of questions emerged with this principal components analysis, Cronbach's alpha analyses were conducted to test whether each set of questions represented a more clearly unified latent construct (i.e., knowledge of the environmental impacts of all personal vehicles and knowledge of the environmental impacts of passenger cars compared to light duty vehicles). Had they done so, the results would have suggested using each set of questions separately in subsequent analyses, instead of using all seven questions combined into a single index. However, Cronbach's alpha values for each of the two sets of environmental knowledge questions, using the index A values, only reached values of 0.550 (component 1) and 0.477 (component 2). And for the sets of questions using index B values the Cronbach's alpha levels reached 0.658 (component 1) and 0.530 (component 2).

Table K.1: Principal Components, Environmental Knowledge Questions

Item	Component 1	Component 2
Env K Q #7 Value B	.794	
Env K Q #3 Value B	.774	
Env K Q #6 Value B	.694	
Env K Q #2 Value B	.486	.323
Env K Q #5 Value B		.797
Env K Q #1 Value B		.708
Env K Q #4 Value B		.613
% of variance explained	28.9%	23.3%

Though the Cronbach's alpha level for component 1 using index B values rose to a higher value than did the original environmental knowledge index B for all seven questions, it was only slightly higher and does not represent a sufficiently significant improvement to suggest replacing index B with two separate sets of environmental knowledge questions.

APPENDIX L: DATA SCREENING PROCEDURES

The statistical analyses used to obtain answers to the questions posed in this research project impose assumptions about the data set and its variables. These include sufficient sample size, independence of observations, that any missing values are random in nature (i.e., that there is not a pattern to the distribution of missing values), that values are normally distributed, relationships are linear in nature, that the variance of residuals is homoscedastic, and that there are no extreme outliers. This data set does not meet all of these assumptions with regard to every variable and every set of variables. This appendix describes the extent to which the data set meets each assumption and, in cases where it does not, explains what steps were taken to correct for the discrepancies.

Sample Size

In order to be able to generalize to the two million people living in the 6-county SACOG planning region of El Dorado, Placer, Sacramento, Sutter, Yolo, and Yuba Counties, the sample needs to be of sufficient size to be valid. With 1,506 cases, this data set far exceeds typical rules of thumb, such as that offered in Tabachnick and Fidell (2001, p. 117), [86] and is, therefore, sufficiently large.

Independence of Observations

Each observation must be independent of all others or a serious violation of ordinary least squares assumptions occurs (Pallant 2001). As survey recipients had no ability to know who other recipients of the survey were and only one member of each

[86] $N \geq 50 + 8m$, (where m is the number of independent variables) for testing multiple correlations.

household should have responded to the survey, the observations in this study meet the assumption of independence of observations.

Missing Values

Non-randomly missing values in a data set threaten the generalizability of analytic results and can consequently be very serious. As a general rule of thumb, “if only a few data points, say, 5% or less, are missing in a random pattern from a large data set, the problems are less serious and almost any procedure for handling missing values yields similar results” (Tabachnick and Fidell 2001, p. 59).

Only two of the key demographic variables in the data set are missing more than 5% of responses: race (missing 89 observations, 5.91%) and income (missing 141 cases, 9.36%). To test whether or not these missing values are random or not, dummy variables were created for race and income (0=did not respond to the question; 1=did respond to the question) so that simple t-tests could be conducted to compare the environmental attitudes and environmental knowledge of those who did and did not reply.

In the case of race, no statistically significant differences were detected in either the environmental knowledge of respondents or their environmental attitudes. The average environmental knowledge score for those who did respond to the race question (M=5.82, SD=4.70) was not significantly different from those who did not respond to the question (M=5.54, SD=6.02; t=(87.79)=-.419, p=.676). In terms of environmental attitudes, the mean for those who did respond to the race question (M=1.69, SD=.46) was also not significantly different from those who did not respond (M=1.73, SD=.45; t=(1434)=.572, p=.602).

For income, however, statistical differences did exist. An independent-samples t-test was conducted to compare scores on environmental knowledge and environmental attitudes. The average environmental knowledge score for those who did respond to the race question (M=5.92, SD=4.70) was significantly different from those who did not respond to the question (M=4.60, SD=5.46; t=(145.51)=-2.65, p=.009). In terms of environmental attitudes, the mean for those who did respond to the race question (M=1.70, SD=.46) was also significantly different from those who did not respond (M=1.61, SD=.49; t=(132.30)=-2.04, p=.043).

These results indicate that those who did not respond to the income question differ in a non-random way from those who did respond to it: on average, they demonstrate lower levels of knowledge of the environmental impacts of vehicle ownership and use and lower levels of pro-environmental attitudes. In principle, therefore, the missing data should not be ignored, as they would be if subsequent analyses relied on list-wise or pairwise deletion of cases in which income data were missing.

Strategies for retaining the cases in which non-randomly missing data occur include using mean substitution, multiple regression analysis, expectation maximization, and multiple imputation. Mean substitution is a straightforward approach (in fact, SPSS and AMOS software packages can insert mean values of a variable whenever a data point is missing). However, mean substitution introduces its own element of error (there is no way of knowing if the mean value is accurate or not for those cases with missing data) and it fails to improve the analyses when utilized. Unfortunately, the more sophisticated methods of obtaining values to use for cases in which income is missing prove unproductive (multiple regression analysis) or infeasible with this data set (expectations maximization and multiple imputation). Therefore, despite the fact that it is an imperfect choice, analyses in this study rely on pairwise deletion to eliminate cases in which income data are missing.

Outliers

Several key variables in the data set had very high levels of kurtosis and skewness, notably the outcome variables of number of household vehicles, average fuel efficiency of household vehicles, estimated annual household miles driven, and estimated annual household fuel consumption (see Table L.1 below). These statistics suggest that there may be a significant number of outliers (extreme values that fall outside of a normal distribution) that are contributing to the distribution's peaked and skewed shape.

Table L.1: Descriptive statistics for four indicators of vehicle ownership and use

	N	Min	Max	Mean	S.D.	Skewness		Kurtosis	
Outcome Variables						Statistic	S.E.	Statistic	S.E.
Number HH Vehicles	1478	0	6	2.08	1.03	0.90	0.06	1.58	0.13
Average Combined MPG	1391	12	55.00	21.96	4.46	1.60	0.07	7.55	0.13
Annual Fuel Consumption per HH	1373	0	7,912	1,089	926	2.40	0.07	9.89	0.13
Annual Miles Driven per HH	1371	0	149,143	23,539	18,123	1.93	0.07	6.58	0.13
Outcome Variables Trimmed for Outliers									
Number HH Vehicles, Trimmed	1478	1	5	2.10	0.96	0.90	0.06	0.72	0.13
Average Combined MPG, Trimmed	1391	13	31.96	21.77	3.83	0.31	0.07	-0.14	0.13
AFC per HH, Trimmed	1331	0	4,541	1,036	750	1.14	0.07	1.53	0.13
Annual Miles per HH, Trimmed	1371	0	60,840	22,693	15,163	0.79	0.07	0.10	0.13

In cases where outliers represent actual data points that have a large impact on analysis because they change the shape of the distribution, violating one of the key assumptions of regression analysis, two choices present themselves: eliminate the cases with outlier values, or change the values of variables so that they fall within the range of a normal distribution. For this analysis, I chose to "trim" the outlier values for these skewed and peaked variables. Trimming is accomplished by identifying the low and / or high outlier values and changing them so that they take the lowest (or highest) non-outlier value within the distribution. This retains the ranking of the record, in terms of values for the variable in question, while achieving the goal of obtaining a more normal distribution.

The following variables were, thus, changed in the manners described below. In all cases, SPSS's "Explore" function was used to identify extreme values, then the "Recode" function was used to assign trimmed values to records with outlier values.

For **number of household vehicles** (variable Q2_HH_Vehs), SPSS Explore analysis indicated that household with 6 or more vehicles (14 records) are considered outliers. Q2_HH_Vehs was recoded by changing values indicating 6 or more vehicles to "5." The resulting new variables was named T_T4_NoVehs.

For **average household vehicle fuel efficiency** (variable A37_avg_mpg), extreme values were identified as those below 13 mpg (only a single case, in which the value was 12) or equaling or exceeding 32.0 mpg (48 cases). A37_avg_mpg was recoded with the single record with an average 12 mpg changed to 13 and all records with average mpg values above 32 mpg changed to 32 mpg. The resulting new variable was named T_T5_OMPG.

For **estimated annual household miles driven** (O11_am_hh), the process of trimming values was more complicated. Fifty five cases with values for O11_am_hh over 60,840 were recoded to 60,840. All other values remained as they were (no low values were identified as outliers). This highest value of estimated annual miles driven per household, however, was still an extreme value for households smaller than three people, because calculated values for two or one person households (miles per household member, miles per household member aged 16 and older, and miles per household licensed driver) on a value of 60,840 miles would yield outlier values for these "per person" variables. For records in which outlier values were identified for these variables, trimming was accomplished in this way:

Table L.2: Thresholds for trimming outlier values from three "miles driven" variables

	1 valid person in HH	2 valid people in HH
O12_am_hhm	24,750 miles	49,500 miles
	28 changes	20 changes
O13_am_16	27,800 miles	55,600 miles
	2 changes	6 changes
O14_am_ld	27,000 miles	54,000 miles
	4 changes	4 changes
	34 changes	30 changes
	64 changes	

A total of 109 records, therefore, had annual miles values changed to one of these values: 24,750, 27,000, 27,800, 49,500, 54,000, 55,600, or 60,840 miles. The resulting new variables were named T_T2_Miles (trimmed estimated annual household miles driven), T_T6_am_hhm (trimmed estimated annual miles driven per household member), T_T7_am_16 (trimmed estimated annual miles driven per household member aged 16 and older) and T_T8_am_ld (trimmed estimated annual miles driven per household licensed driver).

Because **estimated annual fuel consumption per household** (O6_fuel_hh) is a calculated variable based upon respondent estimates of mileage for one, two, or three vehicles, it is not possible to recalculate O6_fuel_hh, because trimmed values were calculated for total estimated household miles driven, not for individual vehicles. Therefore, I calculated an estimate of "trimmed" values for fuel consumption per household variable with the following formula:

O6_fuel_hh * (T_T2_Miles / O11_am_hh)

This calculates a percentage correction for overall household miles driven by dividing the trimmed value (for example, 60,840) by the original value for miles (for example, 75,000, as in case 10561), yielding a correction factor of 0.8112. The original estimated annual household fuel consumption of 3122.56 gallons for record number 10561 is thus adjusted to an estimated 2533.02 gallons.[87] The resulting new variable was named T_C1_FuelHH. Similar calculations were applied to O7_fuel_hhm (annual fuel consumption per household member, recalculated and renamed T_C3_AFC_HHM), O8_fuel_16 (annual fuel consumption per household member aged 16 and older, recalculated and renamed T_C4_AFC_HH16) and O9_fuel_ld (annual fuel consumption per household licensed driver, recalculated and renamed T_C5_AFC_HHLD).

[87] Note that this is necessarily a rough estimate because it cannot take into account the differing amounts that households drive each vehicle. In the case of record #10561, the household owns a Honda Civic, a Suzuki Samurai, and a Chevy Silverado Pickup, each of which gets very different miles per gallon.