Title

Transportation and the Environment: Essays on Technology, Infrastructure, and Policy

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Publication Date

2009-09-01

University of California Transportation Center
UCTC Dissertation No. 155

Transportation and the Environment: Essays on Technology, Infrastructure, and Policy

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University of California, Irvine
2009

UNIVERSITY OF CALIFORNIA
IRVINE

Transportation and the Environment: Essays on Technology, Infrastructure, and Policy

DISSERTATION

Submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Transportation Science

by

Mana Sangkapichai

Dissertation Committee:
Professor Jean-Daniel Saphores, Chair
Professor Michael McNally
Professor Oladele A. Ogunseitan
Professor William Recker

2009

The dissertation of Mana Sangkapichai
is approved and is acceptable in quality and form for
publication on microfilm and in digital formats:

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2009

DEDICATION

To My Mother

The Greatest Woman in My Life

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ACKNOWLEDGEMENTS

I would like to express my sincere gratitude and deepest appreciation to my advisor, Professor Jean-Daniel Saphores, for his patience, inspiration and dedication throughout the process of pursing my degree. It would not have been possible without his guidance and exceptional mentorship.

I would like to thank my committee members, Professor Michael McNally, Professor Oladele Ogunseitan, and Professor William Recker for their support and guidance.

I would like to thank my friends and colleagues at the University of California, Irvine Institute of Transportation Studies who have made my "ITS experience" such a memorable one.

In addition, the support from University of California Transportation Center in the form of a fellowship is gratefully acknowledged

Lastly, I reserve my heartfelt appreciation to my wife, for her incredible patience and unconditional support. She always found a way to cheer me up, even when I had doubts. This accomplishment would be insignificant if I did not have her to share it with.

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ABSTRACT OF THE DISSERTATION

TRANSPORTATION AND THE ENVIRONMENT:

ESSAYS ON TECHNOLOGY, INFRASTRUCTURE, AND POLICY

BY

MANA SANGKAPICHAI

Doctor of Philosophy in Transportation Science

University of California, Irvine, 2009

Professor Jean-Daniel Saphores, Chair

With soaring oil prices and growing concerns for global warming, there is increasing interest in the environmental performance of transportation systems. This dissertation contributes to this growing literature through three independent yet related projects essays that deal with transportation technology, infrastructure, and policy.

My first essay analyzes the increasing interest for hybrid cars by Californians based on a statewide phone survey conducted in July of 2004 by the Public Policy Institute of California (PPIC) using discrete choice models. Results suggest that the possibility for single drivers to use hybrid vehicles in HOV lanes is more important than short term concerns for air pollution, support for energy efficiency policies, long term concerns for global warming, education, and income. This suggests that programs designed to improve the environmental performance of individual vehicles need to rely

on tangible benefits for drivers; to make a difference, they cannot rely on environmental beliefs alone.

The second essay is concerned with assessments of Travel Demand Management (TDM) policies, which have been used to deal with congestion, air pollution, and now global warming. I compare two TDM programs: Rule 2202 (the on-road motor vehicle mitigation options in southern California) and the Commute Trip Reduction Program (CTR) in Washington State. My results show that after 2002, the impacts of Rule 2202 are mixed. Commuters' modal choices are affected by worksite characteristics but only two (out of six) basic strategies affect the change in average vehicle ridership (AVR). Moreover, the level of subsidies appears to play an important role in commuting behavior. In Washington State, location has an impact on AVR and combinations of location and employee duties influence the single occupancy vehicle index. Details of the CTR and its relative success suggest that there is room for improving Rule 2202 by making it friendlier to businesses and more effective.

Finally, I examine the health impacts of NO_x (nitrogen oxides) and PM (particulate matter) generated by trains moving freight through the Alameda Corridor to and from the Ports of Los Angeles and Long Beach. After estimating baseline emissions for 2005, I examine two scenarios: in the first one, I assume that all long-haul and switching locomotives are upgraded to Tier 2 (from Tier 1); in the second scenario, all Tier 2 locomotives operating in the study area are replaced with cleaner, Tier 3 locomotives. I find that mortality from PM exposure accounts for the largest component of health impacts, with 2005 annual costs from excess mortality in excess of $40 million. A shift to Tier 2 locomotives would save approximately half of these costs while the benefits of shifting from Tier 2 to Tier 3 locomotives would be much smaller. To my knowledge, this is the first comprehensive assessment of the health impacts of freight train transportation in a busy freight corridor.

CHAPTER 1 INTRODUCTION

The benefits of modern transportation systems are often taken for granted although they underlay our economic system, shape are cities, and more generally, mold our way of life. But modern transportation also comes with massive externalities. In particular, concerns about the environmental impacts of our use of motor vehicles have been steadily building up over the last two decades, especially regarding their contribution to air pollution and climate change.

Transportation is a major contributor of greenhouse gases that drive climate change. Americans have the highest rate of vehicle ownership in the world, with more than 250 million motor vehicles (1). They drive approximately 3 trillion vehicle miles annually, and burn more than 175 billion gallons of gasoline each year (1), which each generates 19.4 pounds of CO_2 (2). And while the entire transportation sector accounts for one third of all U.S. greenhouse gas emissions, all motor vehicles comprise more than 80% of that sector's emissions (3, 5). Goods movement should not be forgotten: according to the U.S. Environmental Protection Agency (EPA) Inventory of Greenhouse Gas Emissions and Sinks, emissions from domestic freight sources increased by 58 percent between 1990 and 2005 – over twice the growth rate of U.S. passenger transportation sources and over 3.5 times more than the increase in GHGs from all U.S. sources (16 percent).

Moreover, in spite of significant progress since the 1960s, air quality is still a significant concern across the U.S., nearly two decades after the Clean Air Act was last amended. Many major metropolitan regions have been designated nonattainment for persistently exceeding limits established by the U.S. EPA for one or more of the six criteria pollutants (O_3, CO, NO_2, SO_2, PM, and Pb) with ozone and particulate matter (PM) of particular concern because of their potential health impacts (6).

The complexity of the links between transportation, global warming, the health impacts of air pollution, politics, and public policy, has led to much controversy. A number of different policies have been proposed and/or implemented, including, for example, mandating better fuel efficiency (the CAFE standards); using economic instruments (to manage externalities, price freeways and urban parking, and create a market for carbon emissions); funding alternative fuel vehicle technologies; developing public transportation; or trying to "manage" the demand for transportation (for example via transportation demand management (TDM) programs). However, results so far have been mostly insufficient and often disappointing.

California is playing a special role in the US fight against air pollution and global warming. First, because of particularly severe air pollution in Southern California and its pre-existing standards, California has special dispensation from the federal government to promulgate its own automobile emissions standards; other states may choose to follow either the national standard or the stricter California standards. Second, in September of 2006, AB 32 was signed into law in California. It is the first comprehensive program that requires a verifiable reduction of greenhouse gas emissions. Its goal is to reduce California's greenhouse gas emissions by 25 percent by 2020 using a mix of regulations and market mechanisms. Mandatory caps kick in by 2012 for significant sources and become progressively more stringent to meet the 2020 goals (7).

In this context, this dissertation addresses three facets of the complex linkage between transportation and the environment, and it makes contributions through three independent yet related essays that deal with transportation technology, infrastructure, and policy. I focus on California because of this state's special role in the fight against global warming and air pollution.

My first two essays deal with a central claim of a recent book by Dan Sperling and Deborah Gordon (8), who argue that "people, acting as consumers, travelers, voters, and investors, are central to all strategies to reduce oil use and (our) carbon footprints" and that it is essential for Americans to adjust their behavior (Chapter 6, page 151).

More specifically, my first essay analyzes Californians' stated demand for hybrid cars, a technology that has the potential of significantly improving gas mileage and of reducing air pollution in congested conditions. My analysis relies on a statewide phone survey conducted in July of 2004 by the Public Policy Institute of California (PPIC). I develop several ordered models, including an extension of the ordered probit/logit models, to explain the respondents' stated interest in hybrid cars. Results indicate that the possibility for hybrid vehicles to use HOV lanes is a key factor for explaining Californian's interest for hybrid vehicles; relying on their environment concerns is not enough to insure the widespread adoption of clean vehicles.

My second essay deals with two transportation demand management (TDM) programs: Rule 2202 in Southern California and the Commute Trip Reduction Program (CTR) in Washington State. TDM programs are an important tool for reducing air pollution and decreasing congestion (9), yet they have been quite unpopular in Southern California. First, I update the work by Giuliano, Hwang and Wachs on the performance of Regulation XV's employee trip reduction strategies; Regulation XV was superseded by Rule 2202 in December 1995. I then compare the performance of Rule 2202 with that of Washington State's CTR program. I find that the CTR program is doing much better than Rule 2202 in terms of average vehicle ridership (AVR), although these good results are partly due to factors specific to King County, by far the largest county covered by the CTR program. I also examine the impact of worksite location, size, and industry on both AVR and mode choice. My results suggest that TDM programs can be made to work effectively to increase AVR.

In the third essay, I focus on the environmental impacts of freight transportation, which is often overlooked in discussions about transportation and the environment. I use recently developed tools to examine the health impacts of NO_x and PM generated by trains and trucks moving freight from/to Ports of Los Angeles and Long Beach (also known as San Pedro Bay Ports, or SPBP), through the Alameda Corridor. Results show seasonal effects and complex spatial dispersion patterns in the dispersion of both PM and NOx, which are driven by changing meteorological directions. I also find that mortality from PM exposure accounts for the largest part of health impacts, with health costs in excess of $40 million annually. A shift from Tier 1 to Tier 2 locomotives, which would reduce NOx and PM emissions by 26% and 52% respectively, would save approximately half of these annual health costs but the benefits of shifting from Tier 2 to Tier 3 locomotives (resulting in further reductions of 38% for NOx and 23% for PM) would be much smaller. To my knowledge, this is the first study of the health impacts of train operations in a major transportation corridor.

In summary, this dissertation takes an in-depth look at three facts of the nexus between transportation and the environment. Policymakers are actively engaged in developing new policies and regulations to clean-up the environmental performance of transportation systems. In order to be effective, these policies need to be informed by a thorough understanding of people's attitudes and of the health impacts of pollution resulting from transportation.

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CHAPTER 2 WHY ARE CALIFORNIANS INTERESTED IN HYBRID CARS?

INTRODUCTION

Over the last thirty years, motor vehicles have become a lot cleaner thanks to stringent emission standards, clean fuel programs, technological innovations stimulated by regulations, a greater awareness of the health impacts of air pollution from motor vehicles, and gasoline price increases. For example, the California Air Resources Board (CARB) estimates that between 1975 and 2005 on-road motor vehicle emissions of Reactive Organic Gas (ROG) emissions fell just over 80%, while NOx emissions decreased by 38%. One notable exception, however, is a 37% increase in particle matter (PM) emissions over the same period. During this time, the state's population increased by more than 67% and total annual vehicle miles travels soared by almost 250% (1).

Based on data for 2002 to 2004, ozone and particulate matter (PM) are of concern for air quality. Seven of the top fifteen areas that exceed the national 8-hours standard of 0.08 parts per million (PPM) are located in California. Worse, the Los Angeles South Coast Air Basin and San Joaquin Valley areas ranked first and second respectively (2). Moreover, most Californians still live in air basins where PM_{10} and $PM_{2.5}$ concentrations violate state standards. PM poses serious problems because of its complex nature, as the level and chemical make-up of ambient PM varies widely from one area to another. In some areas, PM levels depend on seasonal activity: for example, dry windy conditions cause elevated PM concentrations, making it more difficult to be in compliance with air quality standards.

One important tool for reducing traffic congestion and for improving air quality is HOV lanes (see Figure 2.1). In 2004, there were 1,112 miles of HOV lanes on the California highway system, with another 1,045 miles proposed by 2030 (3). Unfortunately, this expansion is unlikely to be sufficient to reduce congestion and improve air quality. Indeed, California's population is projected to grow by over 30% by 2020 but the capacity of the state highway system is unlikely to keep up with this growth. According to the 2005 Urban Mobility Report from the Texas Transportation Institute, among urban area over 3 million population, the Los Angeles – Long Beach – Santa Ana area and San Francisco – Oakland led the nation for annual travel delay per traveler in 2003 with 93 and 72 hours, respectively.

A number of factors contribute to worsening congestion and air quality. According to the California Department of Transportation, in recent years, the annual change in the state's vehicle miles traveled (VMT) outgrew population growth close to 2 to 1 (3). This rapid growth in VMT is a function of a number of factors including increases in auto ownership, household mobility, and commuting distance. In addition, as auto ownership has increased, average vehicle occupancy (AVO), defined as the number of people arriving at a worksite divided by the number of vehicles arriving at that worksite, has decreased. This has put an even higher number of cars on the road relative to the population. The AVO for work trips in California is expected to remain around 1.09, which is low compared to the country's average of 1.57 (4).

As a result, the effectiveness of HOV lanes, in already congested highway system, has been questioned. According to the Legislative Analyst's Office, the performance of California's HOV lanes is mixed (5). First, California's HOV lanes carry on average of 2,518 persons per hour during peak hours, which is only two-third of their capacity. Second, although HOV lanes may induce people to carpool, the statewide impacts on AVO are still unknown. Finally, the contribution of HOV lanes to improving air quality also remains unclear. In fact some argue that HOV lanes worsen congestion by forcing single occupant vehicles (SOVs) to crowd together in mixed-flow lanes, while adjacent HOV lanes may remain underutilized (5). This so-called "empty lane syndrome" has led critics to conclude that there should be a better use for apparent HOV lanes excess capacity.

As part of a comprehensive strategy to further improve air quality, state and federal authorities have embraced hybrid electric vehicles because they generate much lower emissions with a power and range similar to that of gasoline vehicles. Many consumers appear interested in hybrid vehicles, especially after the recent increase in gasoline prices and growing concerns for global warming. According to the Associated Press (6), hybrid vehicles accounted for 1.5 percent of all U.S. vehicle sales in 2006 (254,545 units), with 42.8% of registrations for the Toyota's Prius alone. Although 2006 Prius sales increased 28% over 2005, their growth rate is slowing down. This may be partly due to the $2,000 to $4,000 premium a hybrid vehicle commands over its conventional counterpart. Until recently, this premium was partly offset by federal tax credits. However, Toyota (the market leader for hybrids) hit the legal production limit 60,000 vehicles last summer, which caused the tax credit per car to shrink 50% to $1,575 on October 1st, 2006.

Without this tax incentive, the economics of hybrids is much less attractive, In fact, Edmund.com (7) argues that "hybrids don't stack up economically compared to similar cars that use only gas and hybrid buyers are probably paying more unless buyers drive much more than 15,000 miles a year or gas price exceed $5.60 a gallon".

To make HEV more attractive, California allowed in 2004 solo occupancy of qualified hybrids in HOV lanes. The California law, AB2628, applies to hybrid vehicles that meet advanced technology-partial zero emission vehicle (AT PZEV) standards and achieve at least 45 miles per gallon (mpg). This limits HOV lanes access to reduce the risk of congesting them. To enforce these provisions, eligible vehicles have to carry "Clean Air Vehicle decals" similar to those currently available for electric, LPG, and compressed natural gas vehicles, which have been allowed in HOV lanes with solo occupancy since 1999 under AB71.

AB 2628's provisions were scheduled to expire on January 1, 2008. However, AB 2600, which took effect on January 1, 2007, extended the sunset date to January 1, 2011 for the cleanest, most fuel-efficient vehicles to use high HOV lanes without meeting the minimum occupancy requirement and it authorized an additional 10,000 clean air decals for hybrid electric vehicles.

LITERATURE REVIEW

Economists have long been interested in explaining vehicle type choice. I review here some key papers to get an overview of the tools used and of the variables considered.

This literature has mostly examined two types of decisions: purchasing a new vehicle or keeping an existing one. Since the mid 1970s, two types of disaggregated choice model have primarily been used: multinomial logit (e.g., see (8), (9), (10), or (11)), and nested logit (e.g., see (12), (13), (14), (15), (16), or (17)). More recent work, however, has relied on more flexible models such as mixed logits (e.g., see (18)), and some authors have combined stated and revealed preferences (e.g., see (19)).

Most of these studies strive to explain consumer choice based on vehicle characteristics (e.g., operating cost or fuel efficiency), household characteristics (household size, income, or number of vehicles, for example), characteristics of the main driver (such as age, gender, or education), or brand loyalty (20). Models for vehicle holding have also considered vehicle age and transaction costs. An excellent summary of some of these key papers can be found in Choo and Mokhtarian (21).

Several of these papers explore consumer preferences for alternative fuel vehicles based on stated preferences. In an early paper, Train (22) estimates the market share for several non-gasoline vehicles for 2000 and 2025. In their seminal work on ordered logit models, Beggs, Cardell and Hausman (23) find that the demand for electric vehicles is low because of their limited range; this finding is confirmed by Calfee (24) and Greene (25). More generally, the literature has also explored preferences for fuel efficient vehicles (e.g., see (26) or (27)).

However, as highlighted in (21), there are still very few published studies that account for lifestyle, personality, or beliefs in the decision to buy a new vehicle. In an early paper, Murtaugh and Gladwin (28) propose an anthropological approach, centered on the decision maker, for modeling the decision to select a vehicle. They report that buyers are influenced by their opinions about the manufacturer, the dealer, or information received from friends and relatives. In general, buyers give a much higher priority to performance and safety than to fuel efficiency, although this factor is more important for a second car.

The most relevant paper for our work, however, is Choo and Mokhtarian (21). The purpose of their study is to relate attitudes, lifestyle, and personality to vehicle choice. Using data from a 1998 mail survey of San Francisco Bay area residents, they develop a disaggregated choice model of vehicle type based on variables obtained by factor analysis as well as typical demographic variables. They find that vehicle type groups (except the mid-sized car group) have distinct characteristics with respect to these factors. Moreover, their empirical results support the contention that travel attitudes, lifestyle, and personality are important to vehicle type choice. This is also a starting point of our study, and like them, I do not estimate a standard discrete choice model.

Since our analyses rely on stated preferences (SP) for hybrid cars and not on observed behavior, which would have been difficult because there were still relatively few hybrid vehicles in 2004, it is useful to briefly discuss advantages and limitations of stated preferences data.

In the economics literature, SP methods, such as contingent valuation or contingent ranking, have been criticized because they rely on hypothetical questions to elicit preferences without guarantee that respondents will act consistently with their answers (29). The alternative, however, which is to rely on observed behavior (revealed preferences, RP), is not without problems either: first, it cannot elicit preferences about new goods, services, or policies and second, it yields observations only on a limited range of behaviors from which it may be impossible to identify the impacts of various factors that affect choice (30).

A number of economic studies test the consistency of stated preferences with behavior. Evidence is mixed. Loomis (31) compares SP data with actual trip data; he finds that SP about intended trips under alternative quality levels are valid and reliable indicators of actual behavior. More recently, Loureiro, McCluskey, and Mittelhammer (32) compare data from an economic experiment with actual purchase decisions to test whether hypothetical willingness-to-pay is an effective predictor of actual behavior. They find that consumers who state a willingness to pay a premium are more likely to actually buy eco-labeled apples. However, when Loomis *et al.* (33) compare an open-ended question with an actual market outcome for an art print, they reject the hypothesis that revealed and stated willingness to pay are equal.

Most studies comparing revealed and stated preferences rely on laboratory experiments rather than on actual data. Cummings, Harrison, and Rutström (34) compare purchasing behaviors for three consumer goods using economic experiments and dichotomous choice (DC) contingent valuation (CV) questions. They report that the proportion of stated yes responses exceeds the proportion of actual purchases. These results are confirmed by Cummings et al.'s (35) study of hypothetical donations for a ‘‘good cause”: they conclude that subjects answering a hypothetical CV question don't behave the same way in an experimental situation.

On the other hand, Johannesson, Liljas, and Johansson (36) find that "definitely sure" yes responses provide a lower bound for actual willingness to pay. They conjecture that the difference between hypothetical and real responses found in (35) study may be due to how respondents perceived the questions they were asked.

The link between stated preferences and behavior has also received much attention in the environmental psychology literature, but associated evidence is not clear cut either. Several theories have been proposed to explain pro-environmental behaviors

(PEB), including Schwartz's Norm Activation model that emphasizes the role of altruism (37, 38); the Theory of Reasoned Action (39, 40); and the Theory of Planned Behavior (41). These papers have spawned a large literature which suggests that behavior is guided by broad goals, conceptualized as more abstract attitudes or values.

In support of this argument, a number of environmental psychology papers find that values (e.g., (42), (43), (44)) and environmental concern (e.g., (45), (46), (47)) are motivational antecedents of environmentally friendly behavior. Studies on personal responsibility also found that affective factors such as guilt, indignation about insufficient nature conservation, and interest in nature may prompt ecological behavior (48).

Some authors have argued that environmentally friendly choices are in fact made on an activity-to-activity basis and do not reflect a "general conservation stance" ((49) or (50)). More recent studies find, however, that different environmentally beneficial behaviors are in fact correlated (e.g., (51), (52)), which contradicts the claim above. A recent paper by Thøgersen and Ölander (53), which analyzes correlations between recycling, buying organic foods, and using public transport or bicycling, provides evidence in favor of common motivational causes for environmentally beneficial choices. They claim that previous papers found no common basis for environmentally behavior because they did not properly control for the background characteristics of their respondents.

DATA AND METHODOLOGY

Data analyzed in this study were not collected to estimate a vehicle choice model. Instead, they come from a July 2004 survey conducted on behalf of the Public Policy Institute of California (PPIC; http://www.ppic.org/main/home.asp). During this multilingual phone survey (English, Spanish, Chinese, Korean, and Vietnamese), 2505 adult California residents were interviewed about their perceptions of regional and statewide environmental conditions, and their preferences for various state and national environmental policies. According to PPIC, this was at the time the most comprehensive survey on state environmental conditions and policies.

Of direct interest to this study, one survey question asked respondents "For your next automobile, would you seriously consider purchasing or leasing a vehicle powered by a hybrid gas and electric engine?" Six possible answers are reported: 1) "Yes", 2) "No", 3) "Already have a hybrid, 4) "Don't drive", 5) "Don't know", and 6) "Refused." Since I am interested in understanding why Californians are considering buying a hybrid vehicle, I excluded respondents who already have a hybrid (21 respondents) or who do not drive (52 respondents). I also excluded the two people who refused to answer this question. This left me with three possible answers ("Yes", "Don't know," and "No"), which I interpret as three different levels of interest for hybrid vehicles.

A starting hypothesis of our work is that environmental attitudes and beliefs play an important role in people's decision to consider buying a hybrid vehicle given the premium commanded by hybrid vehicles. I thus include in our models variables reflecting our respondents' environmental beliefs and attitudes, in addition to their socio-economic characteristics. Unfortunately, not all our respondents answered these questions so I have 1907 responses (out of 2,505) to work with. Of these, 971 respondents (51%) stated they would seriously consider a hybrid vehicle, 314 (16%) did not, and the other 622 respondents (33%) did not know. See (54) for detailed answers to all survey questions.

A summary of answers to key demographic and socio-economic variables for our final sample is presented in Table 2.1. In general, based on the 2000 Census, our respondents cover the whole spectrum of characteristics for important variables compared to the California population. However, our respondents are typically slightly older and better educated than Californians, and they are more likely to have children under 18 in their household. They are also more likely to have a middle class income, as people with a lower (<$20,000) and a higher (>$100,000) annual income are under-represented. Although the gender ratio of our respondents is pretty good, Asians and Hispanics are under-represented. Finally, our respondents are more likely to bike and walk to work and slightly less likely to drive there alone.

Principal Component Analysis

To summarize twenty five survey questions on environmental attitudes and behaviors, I rely on Principal Components Analysis (PCA). PCA is a technique for simplifying a dataset, by extracting a set of factors calculated by linear combinations from a set of variables (55). The technique allows identifying patterns in the data and characteristics that contribute most to the variance of answers to our questions (56, 57). To simplify the interpretation of our factors, I use the Promax rotation, which rotates the axis corresponding to each question in order to help eliminate questions that contribute little to each factor. Promax is effective even if the underlying questions are highly correlated (58). I also normalize our factors to be between 0 and 1.

To assess the adequacy of our factors, I first check for the appropriate level of intercorrelation between our variables using Bartlett's test for sphericity. Intercorrelations need to be high enough to limit the number of factors, but not too high to avoid multicollinearity; I rely on the Kaiser-Meyer-Olkin (KMO) statistic to detect this problem. For PCA to work well, the Bartlett test should reject the hypothesis that the correlation matrix is the identity matrix and the KMO should be greater than 0.6 (KMO ranges between 0 and 1). I also use Cronbach's alpha to measure the reliability of our factors; Cronbach's alpha will generally increase with the correlations between the underlying questions. Its maximum value is 1 and a value of at least 0.6 is desirable.

Ordered Models

To explain our respondents' interest in hybrid cars, I consider heteroskedastic ordered choice models (59). To introduce these models, it is convenient to define a latent dependent variable y^* that is related to our observed dependent variable y by:

$$y_i = \begin{cases} 1 = \text{interested in hybrids, if } \tau_0 \equiv -\infty < y_i^* \le \tau_1, \\ 2 = \text{indifferent, } \quad\quad\quad\;\; \text{if } \tau_1 < y_i^* \le \tau_2, \\ 3 = \text{not interested, } \quad\quad\;\; \text{if } \tau_2 < y_i^* < \tau_3 \equiv +\infty. \end{cases} \quad (1)$$

In the above, τ_1 and $\tau_2 > \tau_1$ are unknown thresholds. The observed dependent variable y_i thus indicates in what interval y_i^* falls into. Then, for i=1,…,N, where N is the number of valid responses considered, I assume that y_i^* is linearly related to x_i, a vector of explanatory variables, by

$$y_i^* = x_i^{'}\beta + \varepsilon_i. \tag{2}$$

For model identification, Equation (2) has no intercept. In Equation (2), β is a vector of unknown parameters, and the ε_is are independently distributed errors, with zero mean and variance σ_i^2. If heteroskedasticity is present, σ_i is assumed to depend on z_i, a vector of explanatory variables (a subset of x_i), and a vector of unknown coefficients γ as follows:

$$\sigma_i = \exp\left(\gamma^{'} z_i\right). \tag{3}$$

This functional form guarantees that σ_i is strictly positive. If F denotes the cumulative distribution function of ε_i, the probability of outcome $j \in \{1,2,3\}$ is

$$\Pr(y_i = j) = F\left(\frac{\tau_j - x_i^{'}\beta}{\sigma_i}\right) - F\left(\frac{\tau_{j-1} - x_i^{'}\beta}{\sigma_i}\right), \tag{4}$$

with $F(\tau_0 - x_i^{'}\beta) = 0$ and $F(\tau_2 - x_i^{'}\beta) = 1$. Our model parameters ($\beta$, γ, τ_1 and τ_2) can then be estimated by maximizing the log-likelihood function:

$$\mathcal{L}(\beta, \gamma, \tau_1, \tau_2 \mid x_i) = \sum_{i=1}^{n} \sum_{j=1}^{m} y_{ij} \ln\left[F\left(\frac{\tau_j - x_i^{'}\beta}{\exp\left(\gamma^{'} z_i\right)}\right) - F\left(\frac{\tau_{j-1} - x_i^{'}\beta}{\exp\left(\gamma^{'} z_i\right)}\right)\right]. \tag{5}$$

If $F(.)$ is the distribution of the standard logistic function (zero mean and variance $\pi^2/3$) and if there is no heteroskedasticity (i.e., if $\sigma_i = \sigma$), then Equation (1)-(4) describe an ordered logit model (60). If heteroskedasticity is present, however, it is important to model it because estimators of (β, γ, τ_1 and τ_2) would otherwise be biased and inconsistent (59). This would lead to meaningless estimates of our unknown coefficients.

To assess the statistical validity of our models, I conducted a number of tests. First, I tested for the exclusion of relevant variables using a linktest, which is commonly used after logit models. A linktest uses the predicted value and its square as the predictors to rebuild the model. Unless the model is completely misspecified, the predicted value should be statistically significant, but not its square. If the latter is significant, then the linktest fails. This usually means that either relevant variable(s) have been omitted or that our functional form is inadequate.

Second, I tested for the significance of various interaction terms and of third order polynomial of our PCA factors; I assessed their statistical significance using likelihood ratio tests. I also report information measures to compare non-nested models (60).

Finally, I used sensitivity analysis to analyze the impact of both discrete and continuous variables on stated preferences for hybrids.

RESULTS AND DISCUSSION

Principal Component Analysis

Results of our principal component analysis are presented in Table 2.2, which includes the text of each question entering our factors. The 25 survey questions were condensed into seven factors. The two factors that assess the economic performance of California, and synthesize opinions about traffic and housing are not statistically significant so I do not consider them any further.

The first significant factor, denoted by F1, summarizes opinions about 1) the role of government for protecting the environment (at both the state and federal level); 2) prioritizing the economy over the environment; and 3) the future of air quality in the state. F1 explains 49.3% of the variance in four questions; its Cronbach alpha is 0.610 with a KMO value of 0.646 and a highly significant Bartlett test ($p < 0.0001$). The second factor, denoted by F2, reflects support for finding more oil, either by drilling in federally protected areas or off the California Coast. Conversely, our third factor (F3) measures support for energy efficiency policies. It is based on five questions dealing with attitude toward solar power, renewable energy, hydrogen-fuel cell, improved fuel efficiency in automobiles, and increased energy efficiency. F2 and F3 jointly explain 48.8% of the variance in answers to their seven questions; their Cronbach's alpha is 0.564, which is low, with a KMO equal to 0.631, and again a highly significant ($p < 0.0001$) Bartlett test. The last two factors are also related. F4 summarize concern about air pollution and its health impacts. F5, aggregates beliefs about global warming, the need to act quickly to curb it, and support for policies designed to curb global warming. These policies include requiring all automakers to reduce the GHG of all new cars starting in 2009, adding $6 to the vehicle license fee for new cars to finance replacing the engines of older diesel buses, and requiring all trucks to meet federal air pollution standards. F4 and F5 account for 51.4% of the variance in answers to their seven questions. Cronbach's alpha for F4 and F5 is 0.642 with a KMO of 0.665, and again a highly significant Bartlett test ($p < 0.0001$).

Estimated Models

After obtaining the factors, I estimated ordered choice models with and without heteroskedasticity. Results for the best models are presented in Table 2.3. Before discussing these, let summarize briefly some specification test results to gain some confidence in the results.

Model Testing

As explained in the methodology section, I conducted an extensive series of tests and diagnostics to detect possible interactions and functional form misspecification. The statistically significant independent variables for the best ordered logit model and the best heteroskedastic ordered logit model are presented in Table 2.1. Both models predict approximately 75% of the observed choices, which is reasonable. They also pass "linktest" in Stata, which tests for the exclusion of relevant variables, so they are not obviously misspecified.

In addition, for the best ordered logit model, a Wald test is conducted of the independence of irrelevant alternatives (IIA). I followed the procedure recommended by Brant (62, 63), and fortunately, no violation was detected, which again suggests that the best ordered logit model is not misspecified.

Ordered Logit Model

Let now discuss results from the ordered Logit model. Statistically significant explanatory variables include education (at less than college education levels), annual income (except less than $20,000 and between $60,000 and $80,000), race (Caucasian), age (25-34 years old), but also beliefs about energy, the environment, and air quality (factors F1 through F5), as well as expectations about the permanence of gasoline price increases.

It also makes sense to see a variable that tells about the impact of gas prices on the amount of driving. In the light of (21), I interpret the variable about owning or leasing an SUV as an indication of lifestyle. Interestingly, our two variables related to HOV lanes (the possibility of driving hybrids in HOV lanes and living in a county adjacent to a county with HOV lanes) are also statistically significant. There are also significant interaction terms between age, ethnicity, the use of HOV lanes, energy related beliefs and environmental beliefs.

From these results, I infer that Californians' interest for hybrids is partly motivated by their beliefs related to energy, air pollution, and health, partly by hardships caused by increases in the price of gas, but also by the prospect of being able to drive hybrid vehicles with single occupancy in HOV lanes. Gender is not significant, which may seem surprising because women more often than men adopt more pro-environmental attitudes (64). Likewise, population density and the type of vehicle people drive (with the exception of SUVs) are not statistically significant. I interpret this as a sign of the fairly wide appeal of hybrid vehicles.

Our main interest here is to understand the impact of explanatory variables on the stated interest for hybrid vehicles. However, in a non-linear model, the impact of an explanatory variable cannot be understood by simply looking at the coefficients presented in Table 2.3. For that purpose, we need to conduct a sensitivity analysis.

The first step is to select a baseline respondent for whom I calculate baseline probabilities and then change one variable at a time while holding all other variables at their baseline value while monitoring how the probability of being in different categories changes (63).

. My baseline respondent is a non-Caucasian, Non-Hispanic person, between 35 and 64 years old, who does not own an SUV. He/she has less than a college education, with an annual income between \$60,000 and \$80,000. Moreover, he/she believe that allowing hybrid in HOV lanes is a bad idea, and he/she does not live in a county adjacent to a county with HOV lanes. If he/she does not expect the 2004 increase in gas price to be permanent, he/she did not drive less when gas prices increased.

Following Long (60), I then proceed differently for discrete and for continuous variables. For discrete variables, one variable is changed at a time while holding all other variables at their baseline value and recording the change in the probability of observing each level of interest for hybrids. Results are presented in Table 2.4. Although statistically significant, the impact of age is modest. Being between 25 and 34 increases slightly (1.5%) the probability of being interested in hybrids; this may reflect a slightly larger inclination to adopt new technologies. Conversely, being 65 or older has a small opposite effect. Interestingly, income has a non linear effect: low income (<\$20,000) and the core of middle income (\$60,000 to \$100,000) households show the most interest for hybrids. I speculate that the former may be more affected by soaring gas prices, while the latter may be more motivated by environmental attitudes. For income, respondent whose income is between \$20,000 and \$60,000 seem less interested while respondents who are wealthier are not really interested in hybrids. These attitudes are likely related to education, which turns out to be an important driving force here; for example, people with a college education are 20% more likely to be interested in hybrids (compared to our baseline). Ethnicity is also relevant: both Caucasians and Hispanic/Latinos state more interest (12%) in hybrids than Asians or African Americans.

Likewise, lifestyle matters: people who don't own or lease an SUV are 9.7% more likely to show interest in hybrids. As expected, a similar response (+9.1%) is observed from those who believe that the 2004 gas price increases are permanent. On the other hand, people who don't have to drive less when gas price more expensive are 6% less likely to show interest in hybrids.

The most important variable after education, however, is the possibility of driving hybrid vehicles with solo occupancy in HOV lanes: people who agree with this measure are 15.8% more likely to be interested in hybrids. This interest is further reinforced (+7.3%) for respondents who live in counties adjacent to counties with HOV lanes, whom I regard as the people with the longest commuting times. The maximum combined effect of HOV lanes therefore results in a 23.1% boost in interest for hybrids.

To investigate the importance of continuous variables (the five factors used in our model), I study numerically how they impact the probability for the baseline respondent to be interested in F1 ("satisfaction with doing enough for environment"). With a higher satisfaction with doing enough for environment, the probability of interest for hybrid drops approximately 13% (see Figure 2.2).

Figure 2.2 to Figure 2.6 present the change in predicted probability that a respondent is interested in hybrid vehicles as a function of F1 ("Satisfaction with doing enough for the environment"), F2 ("Support for finding more oil"), F3 ("For energy efficiency"), F4 ("Air pollution and health concerns"), and F5 ("Global warming concerns"), respectively. F4 appears more influential, but not quite as much as F2, F3, and F5. F3 especially stands out: when it increases from 0 to 1, the probability of a positive interest for hybrids goes from 0.12 to 0.49, while the probability of a negative response drops from 0.84 to 0.44. This suggests that Californians' stated interest in hybrids is also strongly driven by their beliefs about energy use and its environmental consequences.

Heteroskedastic Ordered Model

Let us now briefly discuss our best heteroskedastic ordered logit model (right column of Table 2.3). Based on the AIC (Akaike's Information Criterion) and BIC (Bayesian Information Criteria) goodness of fit measures at the bottom of Table 2.3, our best heteroskedastic ordered logit model is superior to our best ordered logit model because it minimizes both of these measures. But how do these two models differ?

Our heteroskedastic ordered logit model generally confirms the results above (right column of Table 2.3), but not without a few noteworthy differences. First, the binary variables for households with an annual income between \$80,000 and \$100,000 and for households who did not disclose their income become statistically significant, which suggests that caution is necessary when interpreting the impact of income on interest for hybrids. Second, only African Americans now stand out as the group less likely to embrace hybrids. Third, gender and "owning a full size vehicle" also become statistically significant; they appear in the variance function, and so does "Did not cut back significantly on driving."

To understand the quantitative effect of these differences, we conduct another sensitivity analysis (see Table 5). It reveals several differences compared to the simpler ordered logit model. First, households with an annual income between \$80,000 and \$100,000 are now less likely to be interested in hybrids, just as with households who kept their income private. This suggests that the ordered logit model may overstate the support for hybrids. Second, the support for hybrids related to the use of HOV lanes is stronger: the maximum combined effect of HOV lanes now results in a 29.7% boost in interest for hybrids. Finally, among our continuous variables, F4 ("Air pollution and health concerns") now has an almost insignificant effect on interest in hybrids, which suggests that Californians only weakly link motor vehicles and air quality.

Figure 2.7 to Figure 2.11 present the change in predicted probability that a respondent is interested in hybrid vehicles as a function of F1 ("Satisfaction with doing enough for the environment"), F2 ("Finding more oil"), F3 ("For energy efficiency"), F4 ("Air pollution and health concerns"), and F5 ("Concerns about global warming"), respectively, for the heteroskedastic ordered logit model. Their interpretation is similar to the interpretation of Figure 2.2 to Figure 2.6.

CONCLUSIONS

In this chapter, ordered logit models were developed to explain Californians' interest in hybrid vehicles based on a 2004 statewide phone survey conducted by the Public Policy Institute of California. I used principal components analysis to synthesize in seven factors the answers to 25 questions that probed our respondents' beliefs about energy and the environment. Five of these factors are statistically significant, and at least three strongly influence the respondents' stated interest for hybrids. I also conducted a series of tests to gain confidence in my results and I detected no misspecification.

I found that Californians' interest for hybrids is motivated by concerns about global warming, the environment, increases in the price of gasoline and the desire to escape congestion. In fact, the prospect of using HOV lanes with solo occupancy seems a very important consideration for many of the respondents; this consideration is statistically higher for respondents who live next to counties with HOV lanes, and who are more likely to be long distance commuters. Its practical impact on the congestion of HOV lanes still remains to be determined, and it may not be sustainable as the California population continues to grow. It seems, however, that it may motivate many Californians to seriously consider purchasing a hybrid vehicle. In order to further stimulate innovation, it would be wise to periodically revisit the attribution of HOV lanes extra capacity as new technologies become available, such as "clean" diesel cars by 2009-2010 and fuel cell vehicles in the longer term.

The weakness of the air quality and health factor (F4) in the preferred model (a heteroskedastic ordered logit) suggests that Californians may not make a strong connection between their choice for motor vehicle transportation and poor air quality, especially in Southern California. Policies targeting better fuel efficiency and alternative energies may therefore want to play up this link in order to gain popularity.

More generally, results reinforce the findings of Choo and Mokhtarian (21) about the usefulness of including measures of beliefs and environmental attitudes (as well as lifestyle and mobility factors) in vehicle type choice models.

From a policy point of view, the decision to open apparently under-used HOV lanes to hybrid electric vehicles with solo occupancy for a limited period of time, as was done in California, makes sense for several reasons. First, it helped offset the extra cost of hybrid electric vehicles to households at no extra cost for the state budget, which is perennially under stress, while taking advantage of the under-used (according to the

Legislative Analyst's Office, 2000) capacity of HOV lanes. Second, making these clean vehicles more attractive gave more Californian drivers a chance to discover and appreciate them, and it helped alleviate air pollution. In addition, this policy gave innovative manufacturers an added incentive to develop hybrid vehicle technology while the price of oil was still relatively low, at least compared to 2008 prices.

This study has some limitations. Our survey data, which was collected for other purposes, did not have information on all the vehicles in a household, their detailed characteristics, or household mobility needs. We also lacked data about people's knowledge of tax incentives and parking privileges for hybrids, although the latter were not as common in 2004 as they are now. Second, our dataset reflects perception about an early generation of hybrid vehicles, which had significant performance limitations compared to similar non-hybrid cars. These limitations have been sharply reduced in the second generation of hybrid vehicles, so motivations for considering hybrid vehicles and the accuracy of perceptions about their performance are likely to be different today.

Future research could consider impacts of policy related, such as tax incentives for hybrids as well as parking privileges. In addition, in the context of increasing concerns for air pollution and especially global warming, people's decision to buy cleaner vehicles should be studied in other states and countries. This and the inclusion of belief and lifestyle variables in vehicle type choice models are left for future research.

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Table 2.1 Demographic Characteristics of Survey Respondents

Characteristic	Survey Respondents [California Population]
Age	18-24: 10.0% [13.4%]; 25-34: 19.7% [19.7%]; 35-44: 21.9% [21.2%]; 45-54: 19.7% [18.4%]; 55-64: 15.7% [12.3%]; 65 and over: 12.5% [14.9%]; Refused: 0.5%.
Children under 18 in Household	Yes: 44.6% [38.8%]; No: 54.9% [61.2%]; Refused/don't know: 0.5%.
Education	Some high school: 10.1% [19.6%]; High school graduate: 20.9% [21.6%]; Some college: 25.2% [21.9%]; College graduate: 27.9% [26.5%]; Post graduate: 15.2% [10.4%]; Refused: 0.7%.
Employment Status	Full-time employed:56.2% [60%]; Employed part-time:14.3%; Not employed: 27.0%; Disabled: 1.8%; Refused: 0.8%.
Household Income	<$20,000: 14.3% [18.1%]; $20,000-$40,000: 20.2% [21.1%]; $40,000-$60,000: 17.8% [17.6%]; $60,000-$80,000: 14.3% [$60,000-$75,000:10.3%]; $80,000-$100,000: 9.9% [$75,000-$100,000: 12.2%]; >$100,000: 17.7% [20.6%]; Refused: 5.9%.
Gender	Male: 49.3% [49.9%]; Female: 50.7% [51.1%].
Race/Ethnicity	Asian: 6.8% [11.6%]; African-American: 6.2% [6.0%]; Caucasian: 58.3% [44.6%]; Hispanic: 24.0% [34.8%]; Other: 4.7% [2.9%].
Commute to work	Drive alone: 72.0% [75.4%]; Carpool: 12.4% [11.3%]; Public bus/transit: 4.2% [4.8%]; Walk/bike: 5.1% [2.3%]; Work at home: 4.6% [4.4%]; Other: 1.3% [1.8%]; Refused: 0.3%.
Own or Lease an SUV	Yes: 24.3% [30%]; No: 75.2% [70%]; Refused: 0.5%.

Note: Some categories do not sum to 100% due to rounding; numbers in parenthesis indicate California statistics.

Data sources:

- gender, race, and age: California Department of Finance (www.dof.ca.gov/HTML/DEMOGRAP/Data/RaceEthnic/Population-00-04/documents/California.xls).
- Education, employment status, income, children under 18, commute to work: U.S. Census Bureau, 2004 American Community Survey (factfinder.census.gov/servlet/DatasetMainPageServlet?_program=ACS&_lang=en&_ts=143547961449).
- SUV ownership: www.census.gov/prod/ec02/viusff/ec02tvff-ca.pdf.

Age data were adjusted to account only for people 18 and over; in 2004, 26.5% of Californians were less than 18 years old.

Table 2.2 Principal Components Analysis Results

Factors and Survey Items	Normalized Factor Loadings
F1 (Economy over environment/air quality)	
1. "How much optimism do you have that we will have better air quality in California 20 years from now than we do today?" (0=Hardly any; 1=Some; or 2=A great deal)	0.067
2. "In general, which one of these statements is closest to your view: (0=) Protection of the environment should be given priority, even at the risk of curbing economic growth; (1=) Both equally; or (2=) Economic growth should be given priority, even if the environment suffers to some extent?"	0.129
3. "Overall, do you think that the federal government is doing (0=) not enough; (1=) just enough; or (2=) more than enough to protect the environment in the United States?"	0.154
4. "Overall, do you think that the state government is doing (0=) not enough; (1=) just enough; or (2=) more than enough to protect the environment in California?"	0.150
F2 (For finding more oil)	
1. "How about allowing more oil drilling off the California coast?" (0=Bad idea; 1=Don't know; 2=Good idea).	0.255
2. "How about allowing new oil drilling in federally-protected areas such as the Alaskan wilderness?" (0=Bad idea; 1=Don't know; 2=Good idea).	0.258
F3 (For energy efficiency)	
1. "What about the goal of having 15 percent of NEW homes in California run at least partially on SOLAR power starting in 2006?" (0=Bad idea; 1=Don't know; 2=Good idea).	0.108
2. "What about doubling the use of renewable energy, such as wind and solar power, over the next ten years from 10% of all California power today to 20%?" (0=Bad idea; 1=Don't know; 2=Good idea).	0.106
3. "What about a plan to have California lead the nation in the development of hydrogen-fuel cell technology by building a hydrogen highway with 200 hydrogen fueling stations by 2010?" (0=Bad idea; 1=Don't know; 2=Good idea).	0.095
4. "How about requiring automakers to significantly improve the fuel efficiency of cars sold in this country?" (0=Bad idea; 1=Don't know; 2=Good idea).	0.080
5. "How about setting the objective that all the western states increase their energy efficiency by 20 percent by 2020?" (0=Bad idea; 1=Don't know; 2=Good idea).	0.111
F4 (Air pollution and health concerns)	
1. "Is air pollution a big problem, somewhat of a problem, or not a problem in your region?" (0=Not a problem; 1=Somewhat of a problem; 2=A big problem).	0.251
2. "How serious a health threat is air pollution in your region to you and your	0.249

immediate family--do you think that it is a very serious, somewhat serious, or not too serious a health threat?” (0=Not too serious; 1=Somewhat serious; 2=Very serious).	
F5 (Global warming concerns)	
1. “Do you believe the theory that increased carbon dioxide and other gases released into the atmosphere will, if unchecked, lead to global warming?” (0=No; 1=Unsure; 2=No)	0.129
2. “Do you think it is necessary to take steps to counter the effects of global warming RIGHT AWAY, or isn't it necessary to take steps yet?” (0=Later; 1=Unsure; 2=Now)	0.130
3. “What about the state law that requires all automakers to further reduce the emissions of greenhouse gases from new cars in California by 2009? Do you support or oppose this law?” (0=Oppose; 1=Unsure; 2=Support)	0.113
4. “What about adding $6 to the vehicle license fee for NEW cars and exempting new cars from smog checks for the first six years in order to pay for a state program to put cleaner engines in older diesel buses, trucks, and other equipment--do you think this is a good idea or a bad idea?” (0=No; 1=Unsure; 2=Yes)	0.070
5. “What about requiring ALL TRUCKS that deliver goods into California, including trucks from Mexico, to meet federal air pollution standards--do you think this is a good idea or a bad idea?” (0=No; 1=Unsure; 2=Yes)	0.059

Notes:

To calculate a factor from our survey data, simply sum up the numerical score of each constituent question weighted by the corresponding factor loading shown in the last column above. The sum of each set of weights (factor loadings) equals 0.5 since the answer to each question is comprised between 0 and 2. This normalizes the value of each factor between 0 and 1.

A higher value of F1 suggests that a respondent believes I am already doing too much for the environment as well as air quality; he/she prioritizes the economy over the environment and air quality.

For F2, a higher value indicates greater support for finding more oil; for F3, it shows instead more support for energy efficiency policies.

A higher value for F4 indicates greater concern for air pollution and health; for F5, it indicates greater concern about global warming and support for policies to reduce greenhouse gas emissions.

Table 2.3 Ordered Logit and Heteroskedastic Ordered Logit Regression Results

Variables	Ordered Logit Coefficients (SE)	Heteroskedastic Ordered Logit Coefficients (SE)
Choice Function		
Age 25-34	2.063 (0.641)*	1.302 (0.469)*
Some college education	-0.765 (0.156)*	-0.558 (0.133)*
College graduate	-0.809 (0.157)*	-0.573 (0.132)*
Professional	-0.626 (0.195)*	-0.538 (0.171)*
$20,000-$40,000 annual income	0.264 (0.154)	0.352 (0.123)*
$40,000-$60,000 annual income	0.398 (0.159)	0.422 (0.141)*
$80,000-$100,000 annual income		0.369 (0.186)
$100,000+ annual income	0.316 (0.17)	0.387 (0.151)*
Refused to disclose income		0.475 (0.186)*
Caucasian/white/non-Hispanic	-0.346 (0.137)	
Black/African American		0.285 (0.157)
Doesn't own/lease an SUV	-0.391 (0.131)*	-0.279 (0.103)*
Believes gas price increases are permanent	-0.370 (0.114)*	-0.328 (0.09)*
Did not drive less when gas prices increased	0.255 (0.119)	
Allowing hybrids in HOV lanes is a bad idea	0.638 (0.136)*	0.499 (0.114)*
Lives in county adjacent to county with HOV lanes	-0.296 (0.166)	-0.312 (0.137)
F1 (Economy over environment/air quality)	0.566 (0.264)	
F3 (For energy efficiency)	-2.363 (0.342)*	-2.023 (0.335)*
F4 (Air pollution and health concerns)	-0.606 (0.188)*	
F5 (Global warming concerns)	-0.715 (0.259)*	-0.656 (0.226)*
F2 (For finding more oil) × F3 (For energy efficiency)	0.899 (0.184)*	0.645 (0.148)*
Age 25-34 × F3 (For energy efficiency)	-2.541 (0.778)*	-1.649 (0.592)*
Age 55-64 × No answer about hybrids in HOV lanes	1.193 (0.552)	
Age 65 or older × No support for hybrids in HOV lanes	-0.666 (0.323)	-0.525 (0.264)
Age 65 or older × F3 (For energy efficiency)	0.823 (0.223)*	0.614 (0.192)*
Hispanic/Latino × F2 (For finding more oil)	-1.082 (0.249)*	-0.446 (0.180)
F3 (For energy efficiency) × No answer about hybrids in HOV lanes		0.555 (0.210)*
Variance Function		
Female		-0.270 (0.093)*
Owns a full-size vehicle		0.322 (0.181)
F4 (Air pollution and health concerns)		-0.514 (0.144)*
Did not cut back significantly on driving × F1 (Economy over environment/air quality)		0.637 (0.238)*
Thresholds		
τ_1	-2.028 (0.382)	-1.523 (0.303)
τ_2	-1.736 (0.381)	-1.287 (0.291)

Notes: Number of observations = 1907. All estimated coefficients shown above are statistically significant at 10%; * indicates significance at 1%.

Ordered Logit: Log-Likelihood = -1159.527. Chi-square (23 degree of freedom) = 406.17; the corresponding p-value is $\leq$ 0.0001. Pseudo R^2=0.149; AIC=2369.06; BIC=2507.89.

Heteroskedastic Ordered Logit: Log-Likelihood = -1147.554. Chi-square (26 degree of freedom) = 568.20; the corresponding p-value is $\leq$ 0.0001. Pseudo R^2=0.158; AIC=2351.11; BIC=2506.60.

Table 2.4 Sensitivity analysis of discrete variable in the Ordered Logit Regression Model

Discrete Variable	Discrete Change	"Yes"	"Don't know"	"No"
Baseline		0.413	0.072	0.515
Age 25-34	No -> Yes	0.015	0.000	-0.015
Age 65 or older	No -> Yes	-0.005	0.000	0.006
Some college education	No -> Yes	0.189	-0.005	-0.184
College graduate	No -> Yes	0.200	-0.005	-0.194
Professional	No -> Yes	0.155	-0.002	-0.153
$20,000-$40,000 income group	No -> Yes	-0.062	-0.003	0.065
$40,000-$60,000 income group	No -> Yes	-0.092	-0.005	0.098
$100,000 and more income group	No -> Yes	-0.074	-0.004	0.078
Caucasian	No -> Yes	0.085	0.000	-0.086
Hispanic or Latino	No -> Yes	0.122	-0.001	-0.121
Does not own/lease a SUV	No -> Yes	0.097	0.000	-0.097
Believes gas price increases are permanent	No -> Yes	0.091	0.000	-0.092
Did not drive less when gas prices increased	No -> Yes	-0.060	-0.003	0.063
Allowing hybrids in HOV lanes is a bad idea	Yes -> No	0.158	-0.002	-0.156
Lives in county adjacent to county with HOV lanes	No -> Yes	0.073	0.001	-0.074

Note: Our baseline respondent is a non-Caucasian, Non-Hispanic person, aged less than 24 or between 35 and 64. He/she has less than a college education, with an annual income under $20,000 or between $60,000 and $100,000. Moreover, he/she owns an SUV, he/she believes that allowing hybrid in HOV lanes is a bad idea, and he/she does not live in a county adjacent to a county with HOV lanes. Moreover, he/she does not believe that gas prices increased permanently in 2004, so he/she did not drive less when gas prices increased.

Table 2.5 Sensitivity analysis for discrete variables in the Heteroskedastic Ordered Logit Regression Model

Discrete Variable	Discrete Change	"Yes"	"Don't know"	"No"
Baseline		0.481	0.088	0.430
Age 25-34	No -> Yes	0.029	-0.001	-0.028
Age 65 or older	No -> Yes	0.004	0.000	-0.004
Some college education	No -> Yes	0.201	-0.017	-0.184
College graduate	No -> Yes	0.206	-0.017	-0.188
Professional	No -> Yes	0.194	-0.016	-0.179
$20,000-$40,000 income group	No -> Yes	-0.128	-0.004	0.132
$40,000-$60,000 income group	No -> Yes	-0.152	-0.006	0.157
$80,000-$100,000 income group	No -> Yes	-0.134	-0.004	0.138
$100,000+ income group	No -> Yes	-0.140	-0.005	0.145
Refuses to disclose income	No -> Yes	-0.169	-0.008	0.177
Black/African American	No -> Yes	-0.105	-0.002	0.107
Female	Yes -> No	0.004	-0.021	0.016
Believe gas price increase permanent	No -> Yes	0.122	-0.007	-0.115
Owns a full-size vehicle	No -> Yes	0.005	-0.024	0.019
Doesn't own/lease a SUV	No -> Yes	0.104	-0.006	-0.099
Allowing hybrids in HOV lanes is a bad idea	Yes -> No	0.181	-0.014	-0.167
Lives in county adjacent to county with HOV lanes	No -> Yes	0.116	-0.007	-0.110

Note: Our baseline respondent is a female, non-African American, either less than 24 years old or between 35 and 64 years old. She has less than a college education and her annual income is either under $20,000 or between $60,000 and $80,000. She does not believe that gas price increases are permanent and she owns neither a full-size vehicle nor an SUV. She believes that allowing hybrids in HOV lanes is a bad idea, and she does not live in a county adjacent to a county with HOV lanes.

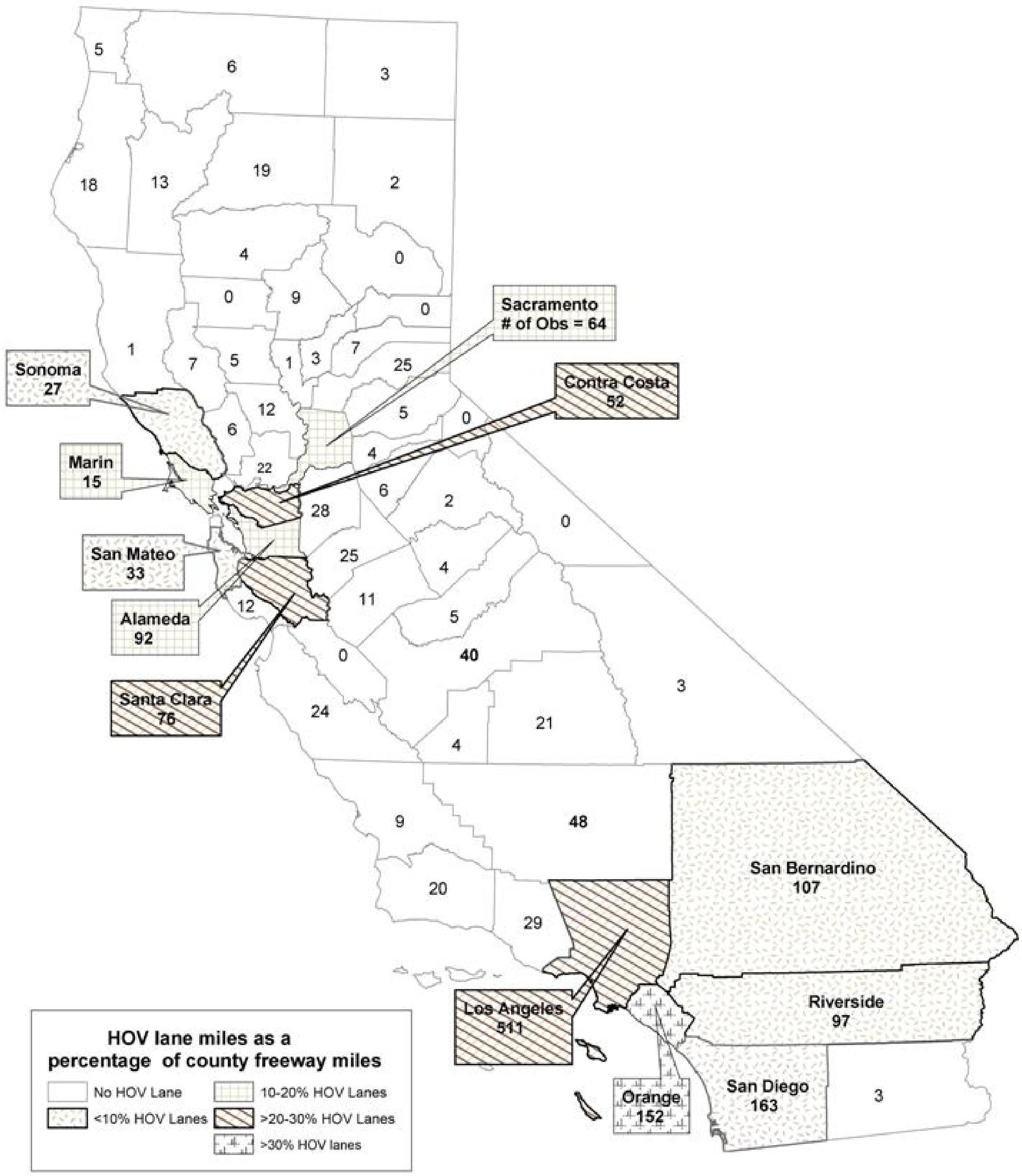

Figure 2.1 HOV lanes in California.

Note: the number below the name of a county is the number of survey respondents.

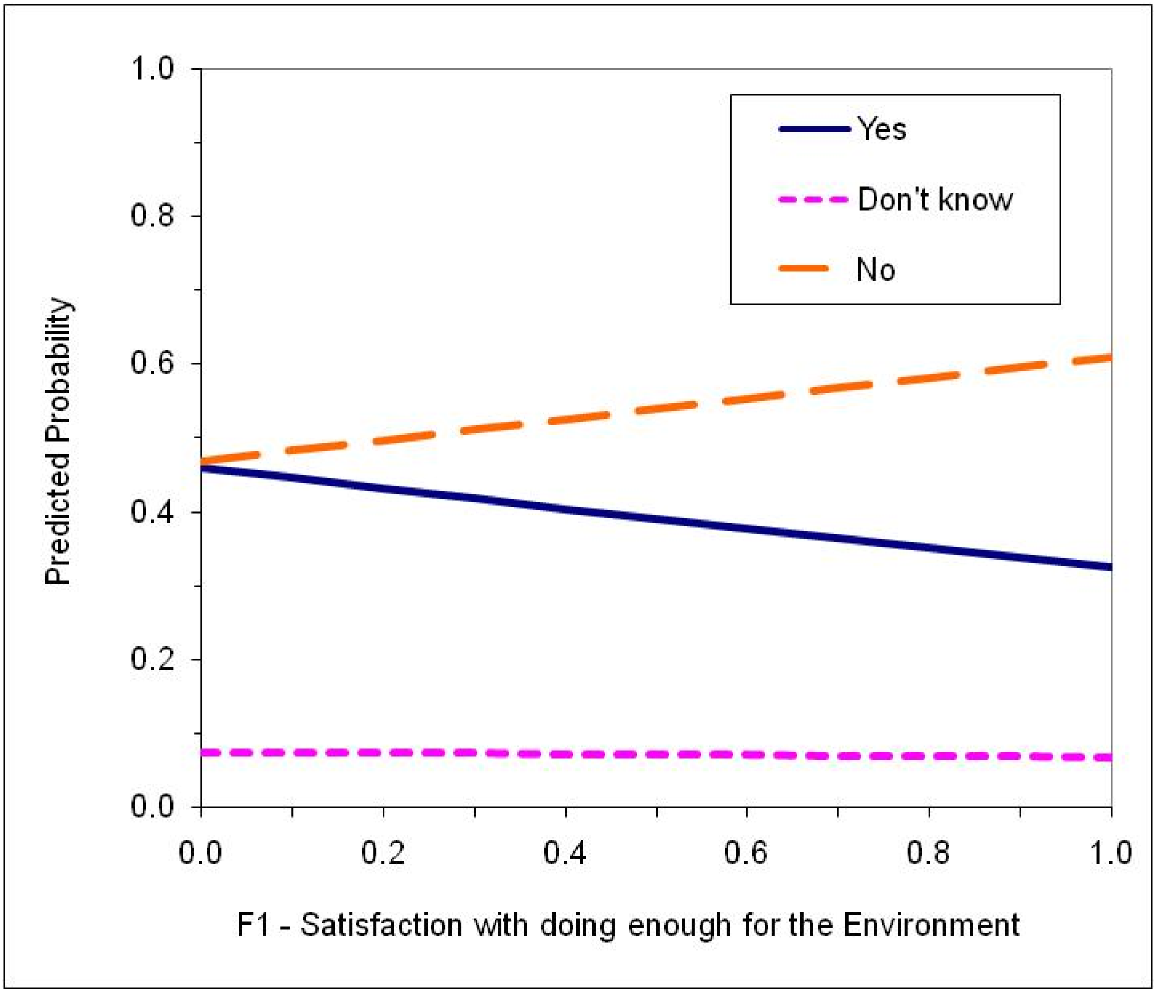

Figure 2.2 Predicted probability of interest for hybrid vehicles versus F1.

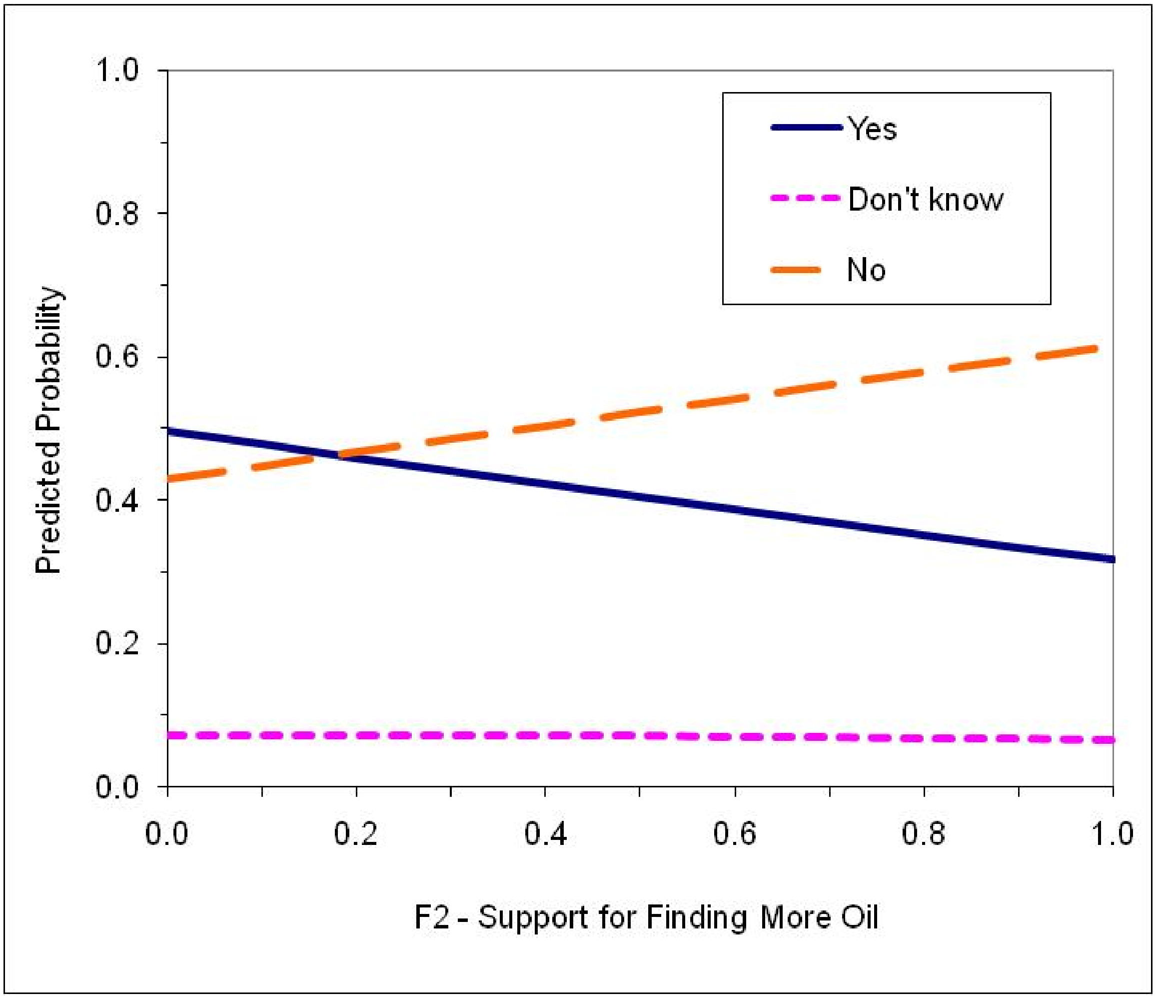

Figure 2.3 Predicted probability of interest for hybrid vehicles versus F2.

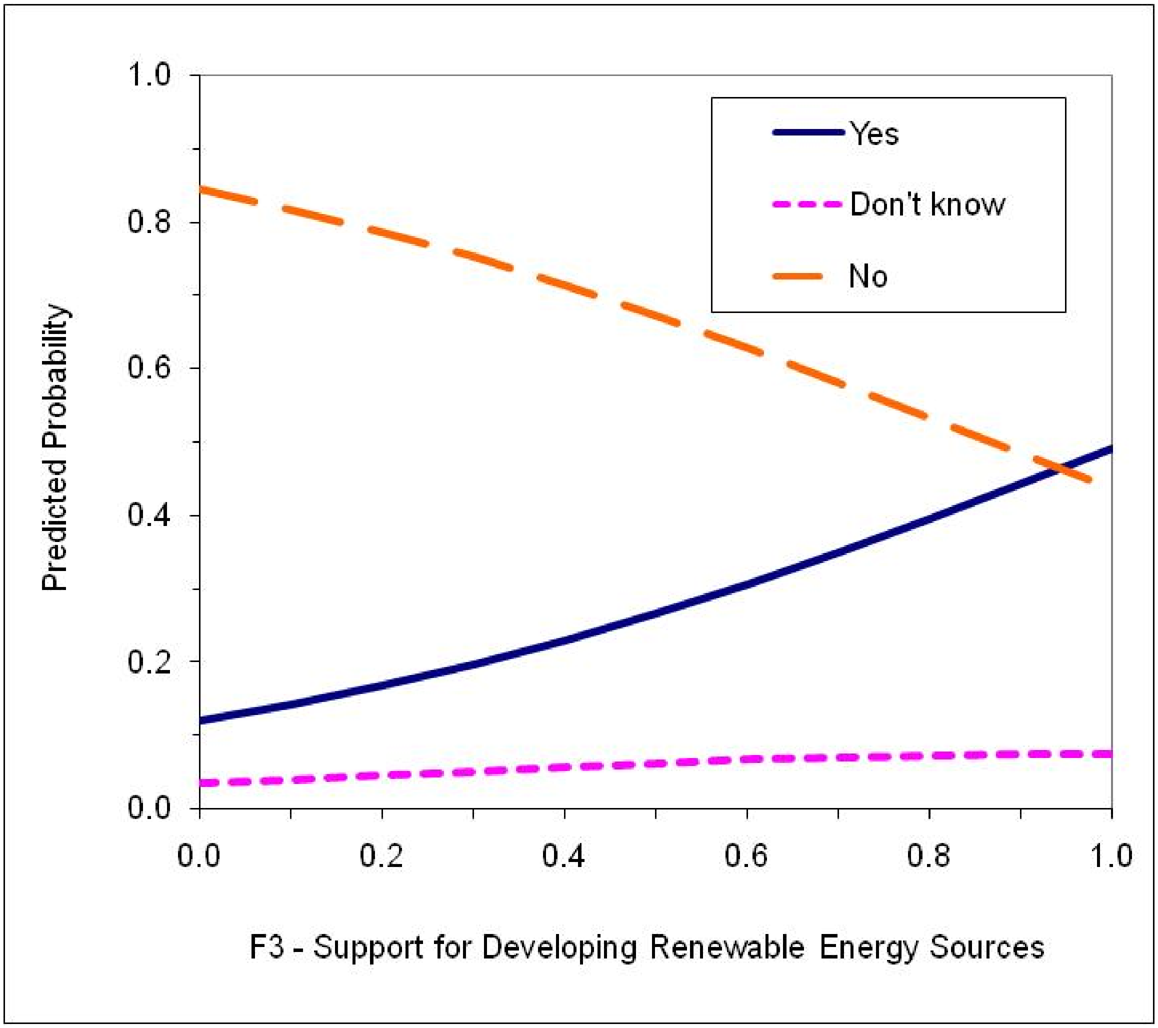

Figure 2.4 Predicted probability of interest for hybrid vehicles versus F3.

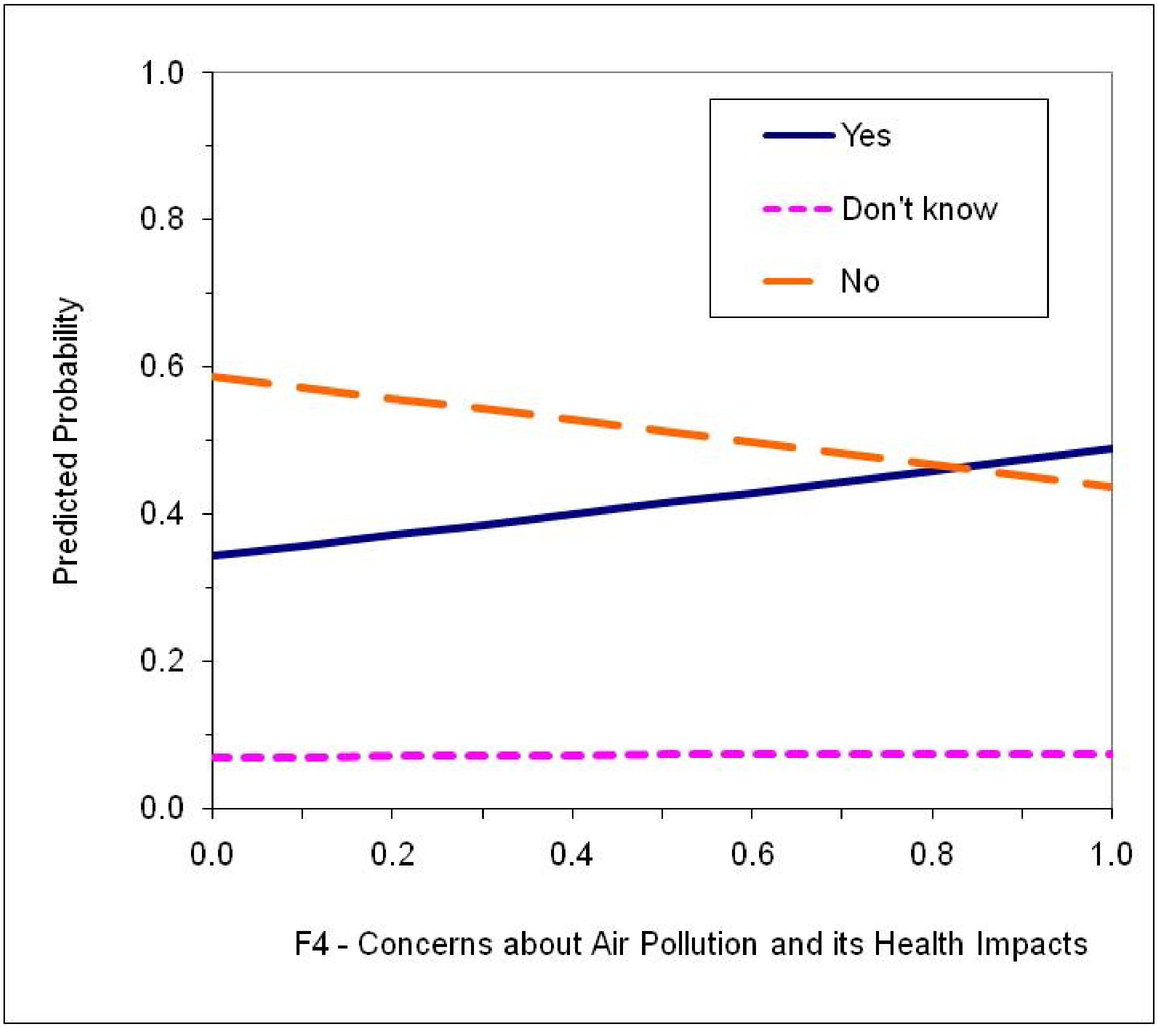

Figure 2.5 Predicted probability of interest for hybrid vehicles versus F4.

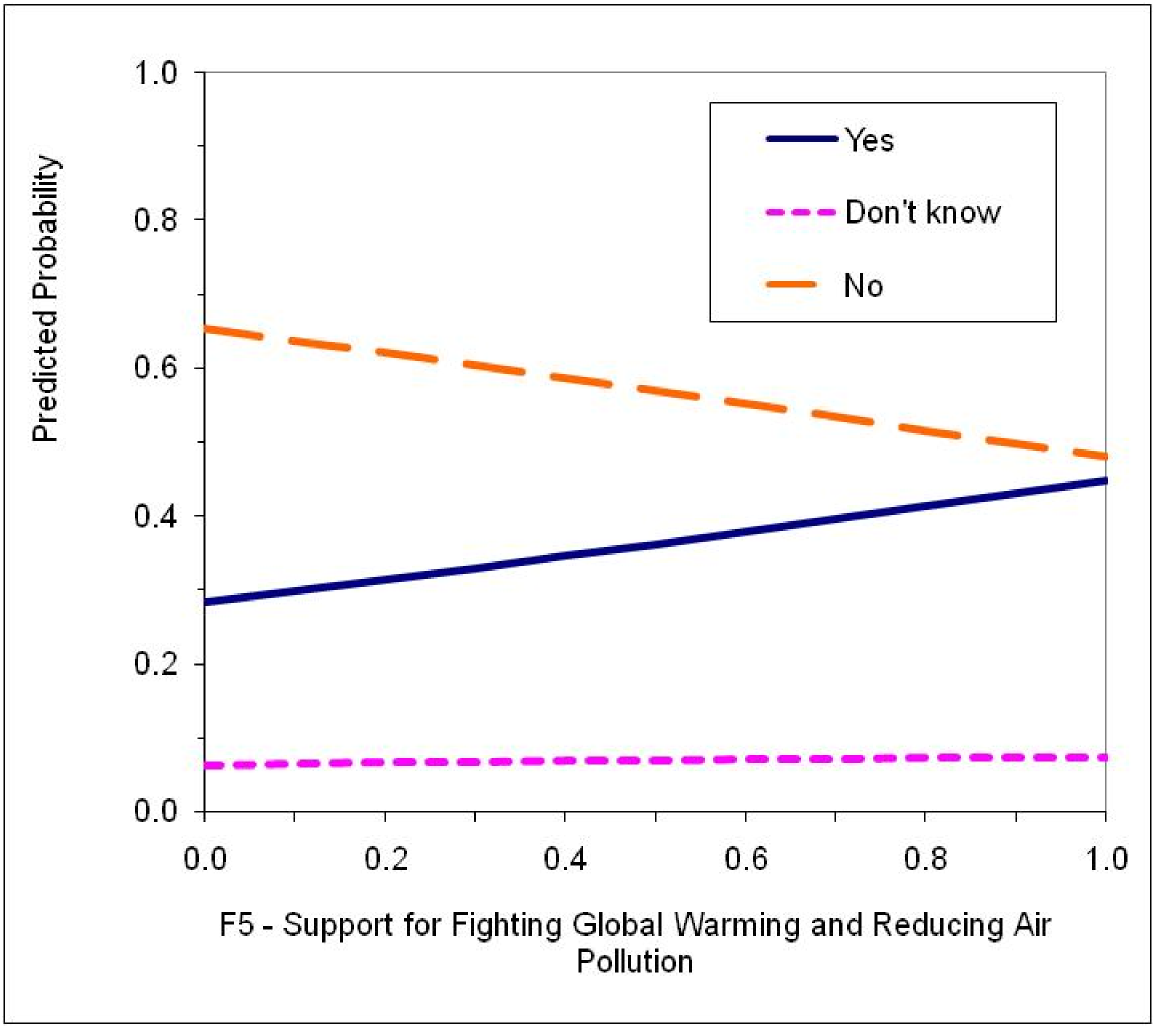

Figure 2.6 Predicted probability of interest for hybrid vehicles versus F5.

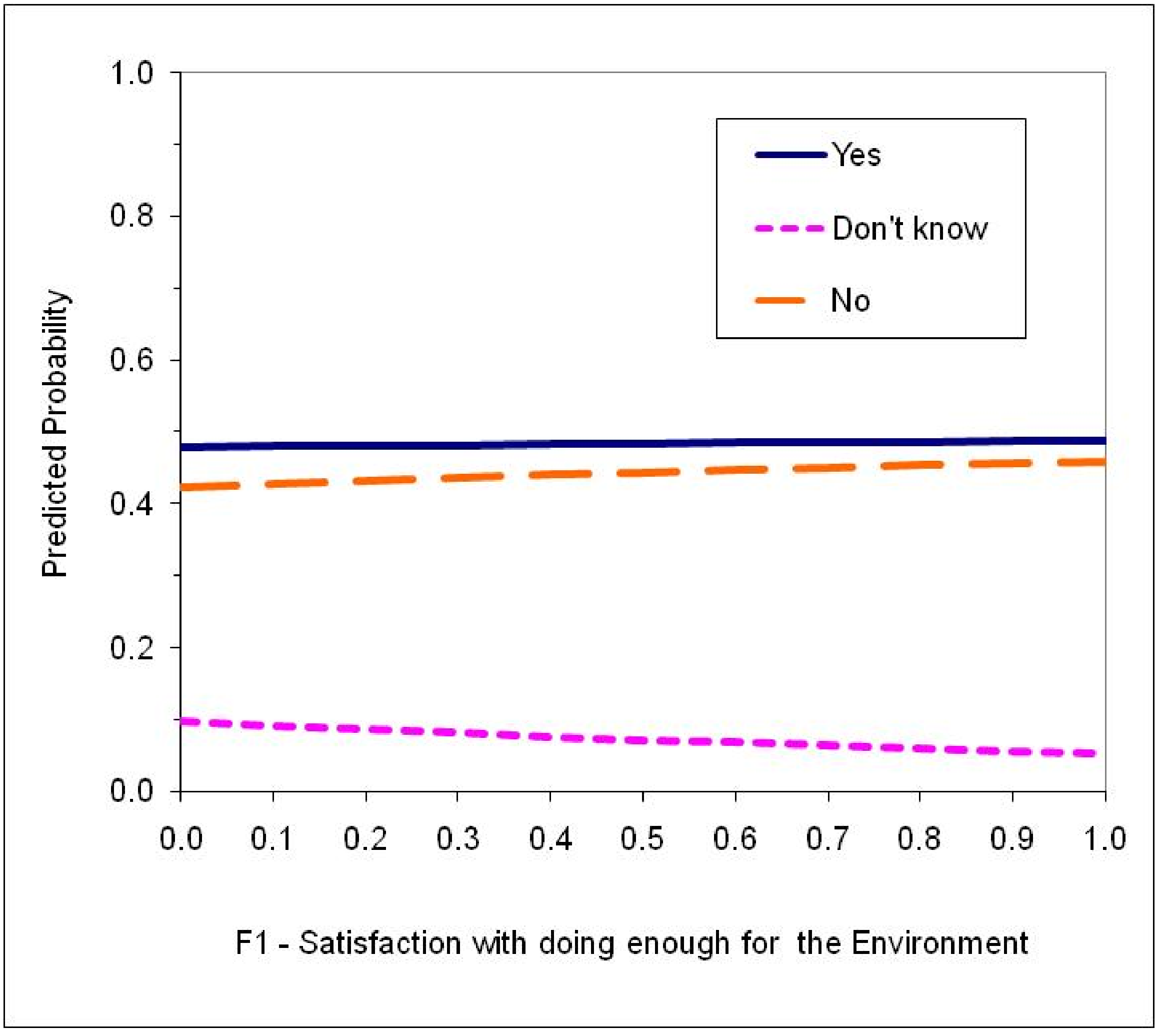

Figure 2.7 Predicted probability of interest for hybrid vehicles versus F1 (Heteroskedastic ordered logit model)

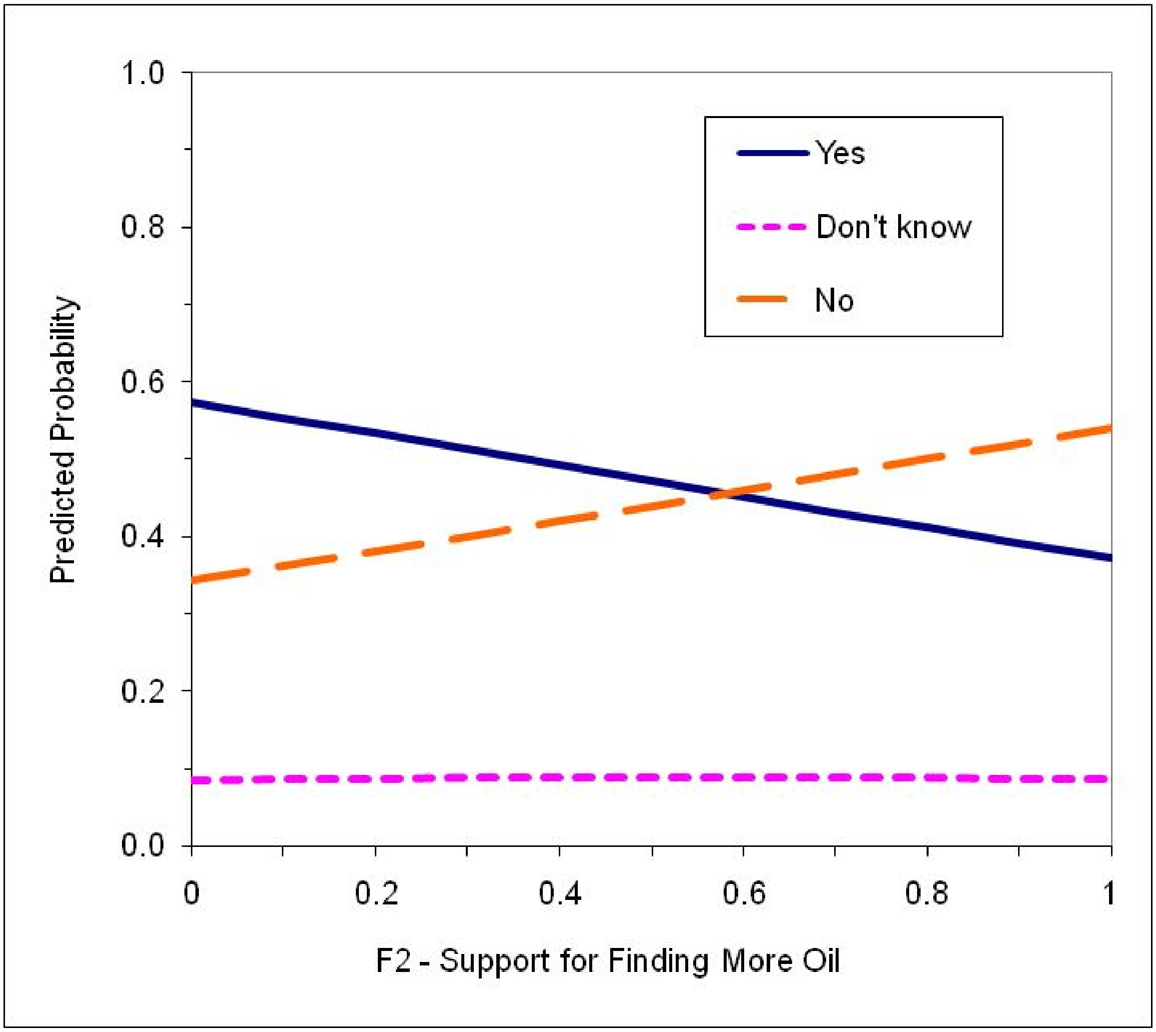

Figure 2.8 Predicted probability of interest for hybrid vehicles versus F2 (Heteroskedastic ordered logit model)

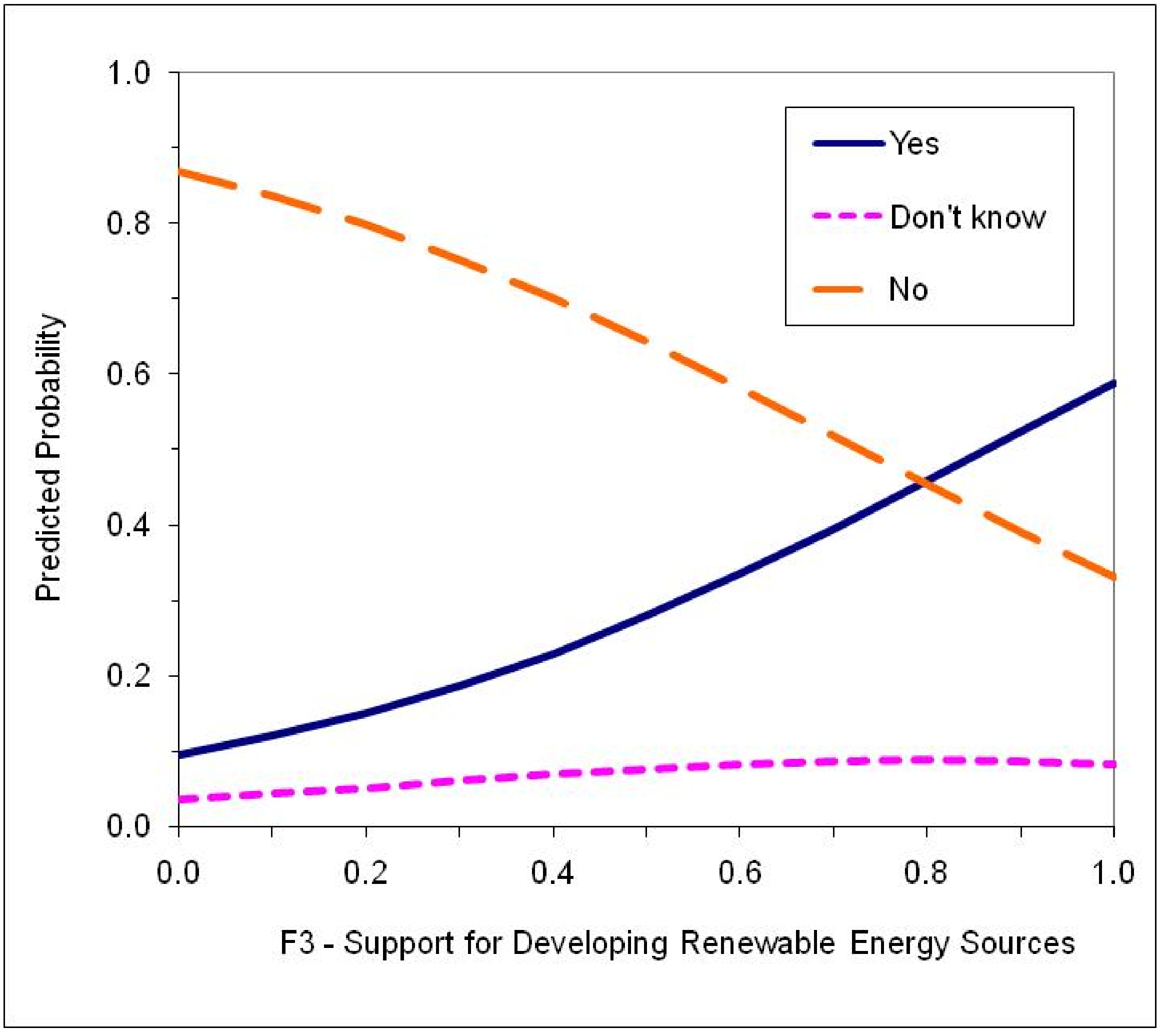

Figure 2.9 Predicted probability of interest for hybrid vehicles versus F3 (Heteroskedastic ordered logit model)

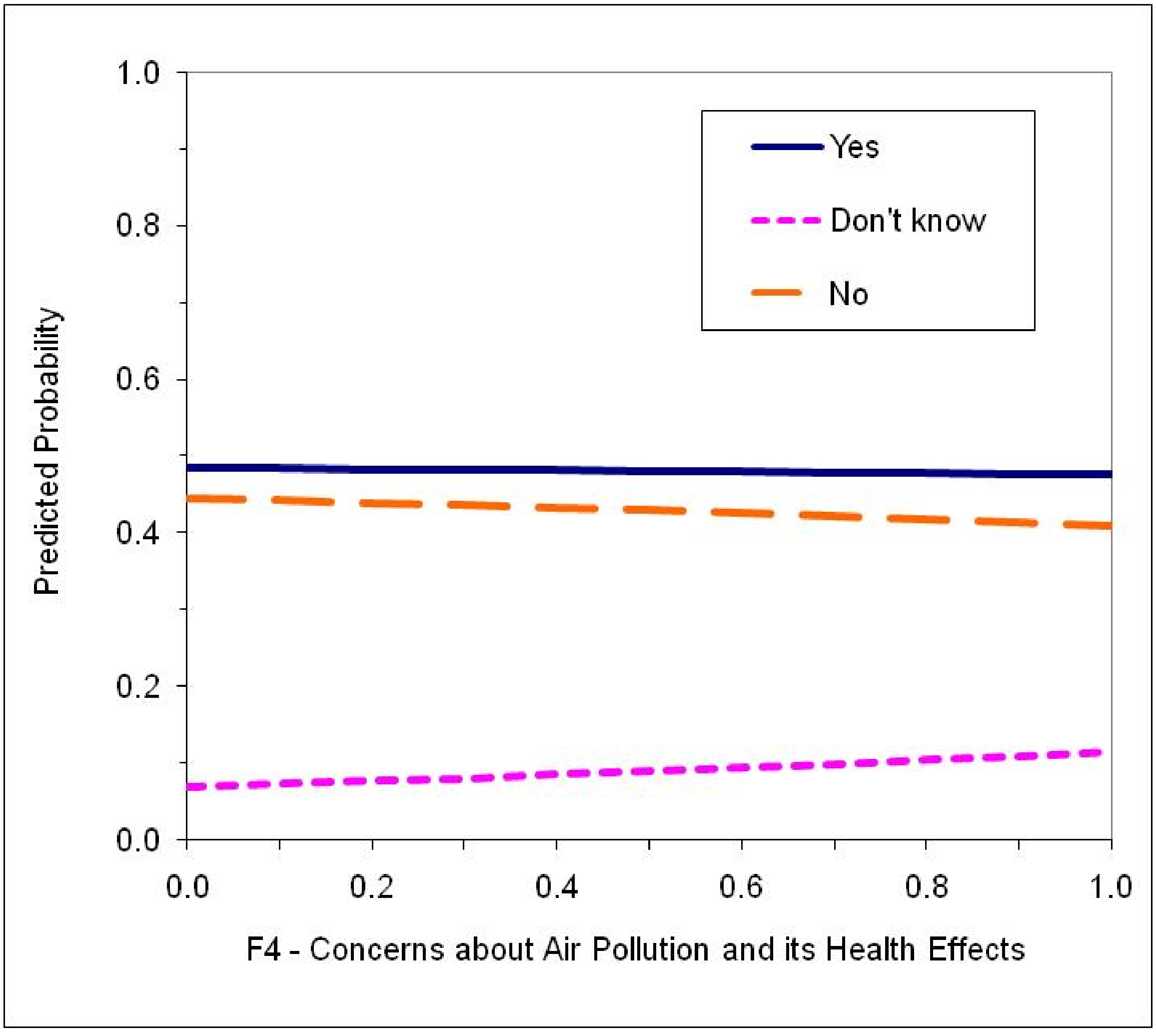

Figure 2.10 Predicted probability of interest for hybrid vehicles versus F4 (Heteroskedastic ordered logit model)

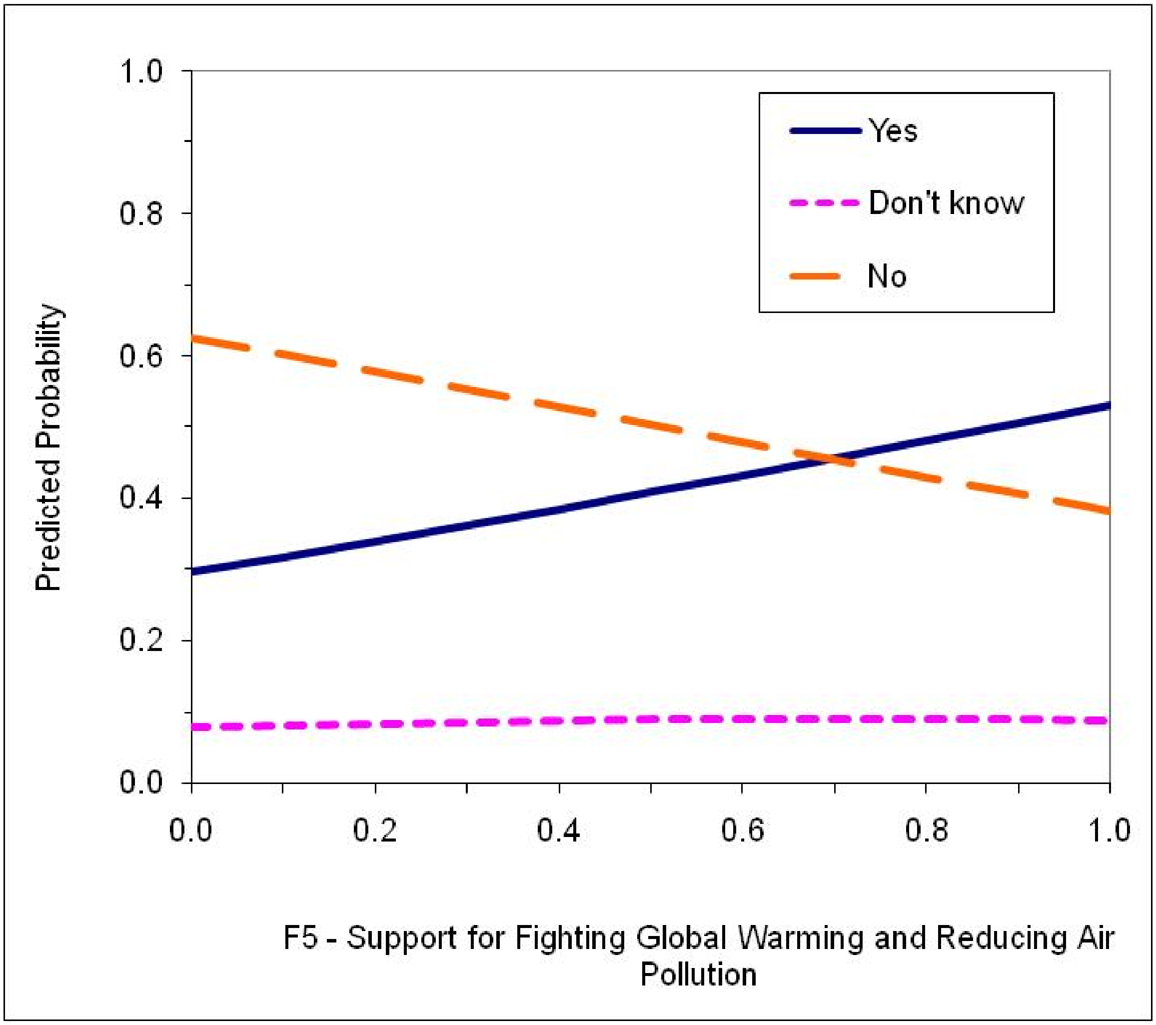

Figure 2.11 Predicted probability of interest for hybrid vehicles versus F5 (Heteroskedastic ordered logit model)

CHAPTER 3 A PRELIMINARY COMPARISON OF TWO TDM PROGRAMS: RULE 2202 IN SOUTHERN CALIFORNIA AND THE WA STATE TRIP REDUCTION PROGRAM

INTRODUCTION

The main purpose of transportation demand management (TDM) programs for worksites is to entice workers to switch from commuting solo by car to higher occupancy modes in order to reduce congestion and abate air pollution. In California, TDM has also emerged as a tool for mitigating climate change as reducing vehicle miles traveled decreases energy use and emissions of greenhouse gases (1).

In the United States, TDM programs have been used since the 1970s with mixed success (2). A number of voluntary and mandatory approaches have been tried, through development agreements, local trip reduction ordinances, and the federal ECO mandate that was part of the 1990 Federal Clean Air Act Amendments. Although the ECO mandate was repealed, many local jurisdictions (see (3)) have kept their ECO measures in place.

In the 1990s, transportation demand management was considered primarily a policy instrument for dealing with urban congestion (4). In Southern California, for example, Regulation XV was introduced in July, 1988 by the South Coast Air Quality Management District's (SCAQMD) to reduce commuting trips during the morning peak period. It targeted all companies in the South Coast Air Basin with 100 or more employees. Each of the approximately 8,000 employers had to submit an annual plan for achieving its designated Average Vehicle Ridership (AVR) goal, which was determined by each firm's geographic location (downtown, central city, or suburb). The plan had to include an annual survey of employees and had to be updated every year (5).

Regulation XV was not popular among a number of legislators and businessmen who were concerned about its costs, so in December of 1995 SCAQMD replaced Regulation XV with Rule 2202, which provides a menu of options for reducing emissions; worksite locations still determine the target AVR. On January 1, 1997, political pressure succeeded in increasing the threshold level for required employer participation from 100 to 250 employees.

Ever since Regulation XV, TDM in Southern California has been politically controversial. Some critics also argue that Rule 2202 is cumbersome and ineffective partly because congestion and air pollution have been increasing in recent years. In fact, the reach of Rule 2202 is limited as it applies to less than half of the workforce and only to work trips, which make up less than half of all peak period trips (4). Moreover, the impact of Rule 2202 on air quality does not seem to have been adequately analyzed. Worse still, we could not find any published academic study that assessed the effectiveness of Rule 2202. One goal of this study is to start filling this gap.

By contrast, some successful TDM programs appear to have been created in other states. One example is the Washington State Commute Trip Reduction (CTR) program. This employer-based regional TDM, which was started in 1991, is given credit for reducing the percentage of commuters who drive alone to work (6). This chapter will assess two travel demand management (TDM) programs to identify elements that may contribute to the success of a TDM: Rule 2202 (the on-road motor vehicle mitigation options in Southern California) and the Commute Trip Reduction Program (CTR) in Washington State.

This chapter is organized as follows. In the next section, I briefly review some of the relevant TDM literature. I then present an overview of both Rule 2202 and the CTR program, before summarizing data and testing hypotheses about both programs. Finally, I present conclusions and make some policy recommendations.

LITERATURE REVIEW

Most published studies on TDM in Southern California (e.g., see 4, 5, 7, or 8) focus on Regulation XV. In an early paper, Hwang and Giuliano (5) summarize the literature on employee ridesharing programs, including employee ridesharing behavior and attitudes, relationships between workplace characteristics and ridesharing, impacts of public programs on ridesharing, and effectiveness of employer-based ridesharing programs.

Both (5) and (8) find that employee mode choices depend on travel time, cost, convenience, household characteristics, and auto availability. Ridesharing studies also find that occupation affects mode choice. Professional employees generally place a higher premium on flexible and convenient forms of transportation, and thus they are more likely to drive alone. On the other hand, laborers are more likely to rideshare due to their lower rate of auto-ownership and their sensitivity to trip costs.

Wachs (7) investigated a panel of 1,110 worksites that had implemented Regulation XV for one full year. He reports that overall AVR increased from 1.22 to 1.25 and that 69% of worksites experienced increases in AVR. Remarkably, approximately 20% of worksites experienced AVR increases in excess of 10% and half had increases of up to 10%, so that driving to work alone decreased from 75.5% to 70.9%. For a smaller sample of 243 worksites for which Regulation XV had been implemented for two full years, the AVR continued to rise in the second year to 1.30 while the proportion of employees driving alone to work declined to 65.4%. The largest mode shift was toward carpooling and vanpooling (4, 7, 8). Wachs (7) also points out that the greatest AVR improvements came from worksites with a low initial AVR; interestingly none of the worksites characteristics were statistically associated with the extent of AVR improvements (4, 7, 8). He concludes that the observed AVR changes are related to the implementation of Regulation XV.

Giuliano, Hwang & Wachs (4) find that both location and industry are significantly related to AVR, while size is only significant jointly with industry. Indeed, wholesale and retail trade firms are typically smaller and they tend to have a higher than average AVR; by contrast, transportation and communication firms tend to be large and to have a lower than average AVR.

In addition, Rye (9) points out that location affects what TDM strategies are selected. If a worksite locates where public transportation is poor, bus related strategies are ineffective (10). In addition, working patterns and activities, which are related to firm traditions, can have a significant influence on both AVR and the effectiveness of strategies used. If employees arrive at the same time, carpooling is much easier than if they arrive in multiple shifts. Socio-economic status is also important as lower income employees are much more likely to carpool or to take public transportation; they are also willing to have longer commutes for the sake of better housing.

The most recent study of Rule 2202 dates back to 2000. In this study, Kneisel (11) uses a stratified random cluster sample to analyze the trips of window employees at deregulated worksites, i.e., worksites with 100 to 249 employees that were exempted from Rule 2202 after January 1997. Results show that these worksites continue to provide rideshare programs after their deregulation. Moreover, even though their AVRs declined, they remained above the AVRs of worksites that had never been regulated.

Another program that has received a lot of attention is the Washington State' Trip-Reduction Program (WATRP) (e.g., see 12 or 13). Hillsman, Reeves, and Blain (13) studied the effectiveness of that program on traffic congestion by tracking trip origins and destinations (O-D). They found that the WATRP reduces morning peak traffic by approximately 1%, which is locally significant.

Using multivariate regression, Cleland and Winters (14) analyzed statewide TDM plans and found that their impacts are not identical in all cities. They conclude that standardized or statewide plans should be de-emphasized in favor of tailoring commuter assistance programs to local realities. On the employer side, the effectiveness of a program depends on the incentives provided and on the environmental characteristics of the worksite. The more effective strategies appear to be those that significantly affect the relative cost or convenience of driving solo, such as pricing parking or providing cash subsidies for transit (14).

A couple of studies focused on developing general approaches for analyzing the impacts of TDM programs. They tried to develop a standardized method for consistently evaluating the travel and the emission impacts of TDM programs. Using data from Los Angeles, Tucson, and Washington State, Winter *et al.* generated a Worksite Trip

Reduction Manual (WTRM) to predict changes in vehicle trips, traffic volumes and parking needs at specific worksites. However attempts to develop a generalized model turned out to be very complex, as it would required a very large database, and the results were still questionable and inaccurate (15, 16).

TDM programs have also been separately evaluated by strategies, for instance, carpool/Vanpool programs (17, 18, or 19), parking strategies (20, 21, or 22), public transportation programs (23), compressed work week strategies: (24), and personalized commute assistance (25).

After reviewing the ridesharing literature, Hwang and Giuliano (5) conclude that conditions that encourage ridesharing are large employment sites, good transit access, restricted parking, and long commute times. For example, employees working at a CBD are more likely to rideshare because their work trips are generally longer, more costly, they take place during peak period traffic, and parking is expensive. Moreover, ridesharing is more effective when combined with ride-matching, and it works better when it is offered region-wide to provide multiple viable matches. Although personal attitudes (e.g., concerns for the environment or cost) are important in the decision to rideshare, attitudes alone do not affect ridesharing much in the long run unless they are supported by clear individual benefits (5, 26). Surprisingly, however, this does not appear to be the case in Canada as Buliung *et al.* (18) report that auto ownership and socio-demographics are the only statistically significant reasons for carpooling.

Parking policies often appear to be quite influential. Indeed, there is a strong correlation between parking subsidies and solo driving: several studies (20, 22) find that when parking subsidies are reduced or removed, a significant number of solo drivers shift to carpools and/or transit. A majority of U.S. employers offer free or subsidized employee parking (20, 21, 22), which fosters automobile use (20).

Planners often advocate lowering the cost of public transportation to entice drivers to leave their cars at home. In their comparison of road pricing and public transport subsidization in the United Kingdom, Ison and Rye (23) find that, in the short run, subsidizing public transport has relatively little impact on mode shift from cars. They suggest combining both policies to increase their effectiveness.

Bianco (27) assesses the effects of combined parking pricing and discounted transit passes strategies on travel and parking behaviors in Portland, Oregon. She finds that one year after parking meters were installed and transit pass program had been discounted, drive-alone commutes decreased by 7 %. However, implementing these strategies alone is insufficient to convince many commuters to give up driving-alone.

Personalized commute assistance has also received some attention in the transportation literature. For example, Cleland (25) conducts an analysis of covariance on travel behavior before and after the provision of customized travel advice while Weber, Nice, Lovrich (28) analyze the characteristics of urban commuters in Washington State and their decision to switch modes of transportation. Both studies find that the provision of travel advice may change travel behavior and reduce VMT.

Another way to decrease VMT is for employers to implement compressed work weeks (CWW). Zhou and Winters (24) investigate trends and determinants of CWW using the Washington State commute Trip Reduction (CTR) data. They find that participation in CWW increased steadily between 1993 and 2005. While most people still work four days per week for 40 hours (4/40), the percentage of employees working nine days for 80 hours every two weeks (9/80) doubled between 1993 and 2005. They also conclude that employees are more likely to participate in CWW programs when they are more familiar with them and when their employers are supportive. On the other hand, employees who commute by transit or shared ride are less likely to adopt a CWW.

Let us now review key features of both Southern California's Rule 2202 and Washington State's CTR program.

BACKGROUND

Overview of the Rule 2202

In December 1995, the AQMD Board adopted Rule 2202, which replaced Rules 1501 (Work Trip Reduction Plans) and 1501.1 (Alternatives to Work Trip Reduction Plan) (29). Rule 2202 was designed to reduce vehicle emissions from commuting trips. It gives employers in four Southern California counties (Los Angeles, Orange, Riverside, and San Bernardino; see Figure 3.1) a menu of emission reduction strategies to meet emission reduction targets (ERT) for their worksites (30).

Rule 2202 must be implemented for each worksite with 250 or more employees, on a full or part-time basis, calculated as a monthly average over the past six consecutive months. Once employers become subject to Rule 2202, they must notify the South Coast Air Quality Management District (SCAQMD) in writing within 30 days.

Under Rule 2202, employers can rely on compliance alternative such as air quality investment options (AQIP), or implement Emissions Reduction Strategies (ERS); we focus herein on the latter. Employers can implement various ERS to receive credit towards their ERTs, including, for example, clean on-road and off-road mobile sources (regulation XVI), short term emission reduction credits (STERCS) from stationary sources (regulation XIII), and area source credits (regulation XXV).

Employers who elect to participate in the Air Quality Investment Program (AQIP) must pay $60 per employee per year or $125 per employee every three years, plus a $112.30 filing fee per worksite. These moneys go to an AQMD administered fund used to finance proposals that reduce emissions (31).

As an alternative to meeting an ERT, employers may implement an Employee Commute Reduction Program (ECRP) that meets the rule exemption requirements. The ECRP focuses on reducing work-related vehicle trips and vehicle miles traveled to a worksite with the purpose of improving/maintaining average vehicle ridership (AVR). Within 90 days from the date of notification, employers who chose the ECRP option must submit an annual report that includes a measure of the regulated sites AVRs for the current year and an implementation plan that shows progress toward the ERT.

Let us now briefly discuss how employers estimate the AVR for their regulated worksites. The AVR is based on data collected via an AQMD approved survey method; the response rate must exceed 60 percent. This survey must cover five consecutive workdays (Monday through Friday) representative of a typical week, and identify the transportation modes that employees use to travel to their worksite during the 6 AM to 10 AM peak commute window. These data cannot be more than six months old at the time of program submittal. Employers with a minimum of 400 employees reporting at a worksite during the peak commute window may estimate their AVR by random sampling. The AVR is then calculated by dividing the number of weekly window employees by the number of their weekly trips.

Employees who are on vacation or sick are counted toward the 250 employee threshold but they are not included in the AVR calculations. Temporary or seasonal employees as well as volunteers, field personnel, and independent contractors are not considered for calculating the AVR. The last group of employees is considered for rule applicability but it is not required to be counted in the peak window hour. It is up to the employer to include them in the window count or not.

The calculated AVR is then adjusted with credits and debits. Different types of credit can be used. For example, credit for carpools is given by dividing the actual number of occupants in a vehicle by the maximum occupancy of that vehicle. Employees walking, bicycling, telecommuting, using public transit, or driving zero emission vehicles are counted as employees arriving at their worksite without a vehicle. Employers may also receive credits from employee trip reduction that happen outside of the peak window. Non-Regulated Credit for volunteers includes worksites with less than 250 employees; it can be used for aggregating AVR for multiple worksites. Reduced staffing credits are also given during school breaks or temporary facility closures.

Employees who report to their worksite during the window and do not complete their survey count the same as employees who drive alone.

If the adjusted AVR meets the AVR Target, then rule requirements are satisfied. Otherwise, an employer has two options: the Good Faith Effect program or the ECRP Offset (see Appendix B for more information). Employers may select an option based on total cost and convenience. Within 90 days from the date of notification, an initial ECRP must be submitted, if this compliance option is chosen.

Employers must select at least five, but not more than seven sub-strategies to increase AVR; they must also keep records and submit them to AQMD upon request. Examples of marketing strategies include advertizing in a quarterly newsletter, flyers, announcements, memos, or quarterly letters describing the program, in addition to semi-annual rideshare meetings or focus groups. If an employer decides to implement basic support strategies, he may pick sub-strategies such as flexible time schedule, personalized commute assistance, and preferential parking for rideshares. The complete list of strategies is included in Appendix B.

The AQMD staff reviews submitted ECRPs. ECRPs are approved for employers who demonstrate good faith efforts towards achieving their target AVR. If program submittals fail to show an overall AVR improvement above a previously submitted annual program and if AQMD believes the employer did not make good faith efforts, the employer may not be approved. An ECRP will also be disapproved if it demonstrates a disproportionate impact on minorities, women, low-income or disabled employees.

When an ECRP is disapproved, the AQMD notifies the corresponding employer in writing. The ECRP must then be revised and the employer has 30 calendar days to resubmit it to the AQMD. If a second disapproval notice is given, the employer is in violation of Rule 2202 until a revised program is submitted and approved by the AQMD. Figure 3.3 summarizes compliance requirements for Rule 2202.

Overview of the Washington State CTR program

In 1991, the Washington State Legislature passed the Commute Trip Reduction (CTR) Law and incorporated it into the Washington State Clean Air Act. The main goals of the

CTR program are to decrease traffic congestion, reduce air pollution, and cut petroleum consumption through employer-based programs that reduce the number of commute trips made by employees driving alone.

Compared to other TDM programs, the CTR has been successful. According to the Washington State Department of Transportation, Washington and Oregon were the only states where the percentage of employees driving alone to work decreased between 1993 and 2000. Moreover, the drive-alone rate for participating worksites in Washington State dropped from 70.9 percent in 1993 to 65.5 percent in 2007 (32).

The CTR law affects the ten most populated counties in Washington State (see Figure 3.2). Employers in those counties must participate in the CTR if they have 100 or more full-time employees at a single worksite who report to work between 6 and 9 AM.

The CTR Law directs participating worksites to conduct employee commute behavior surveys every two years to determine their progress toward CTR goals (33). However, employers report yearly on their programs, activities, and expenditures while jurisdictions report progress and account for the expenditure of state funds every quarter. The CTR program had a budget of $5.6 million for fiscal year 2005, the last year when detailed data are available. Of this amount, $3.9 million went to counties for program management (counties contributed another $1.8 million). Employers paid over $49 million to the CTR, 75 percent of which was used for commute subsidies.

DATA

Rule 2202

Rule 2202 data were provided by the South Coast Air Quality Management District (SCAQMD) office in Diamond Bar, CA. These data cover the 6 year period that extends from 2002 to 2007; they include information about the worksites regulated by Rule 2202 that chose to implement an Employee Commute Reduction Program (ECRP).

Worksite data includes business type, location, and employees. Business type is given by a four digits Standard Industrial Classification code (SIC) (34). The location of a worksite is summarized by whether or not it belongs to one of three Performance Zones defined by the SCAQMD, each of which has a different AVR target (see Figure 3.1). Employee information for each regulated worksite is more detailed. First, it gives the average number of employees who report to work during the peak commute window of 6AM to 10 AM, Monday through Friday; these are called "window employees." Second, it tells us how these employees commute to work (drive alone, ride a motorcycle or a bicycle, commute in a 2-15 person vehicle, take the bus or a train, drive an electric vehicle, telecommute, or working from home). And third, it gives the number of weekly vehicle trips for the transportation mode used by each window employee's home-to-work commute trip, as well as the average vehicle ridership (AVR).

The dataset also contains information about the incentive plans used by each regulated worksite, including the incentives used (type and value), when they were put in place, and eligibility requirements.

However our database has some limitations. First, individual employee information is not available, and we do not know the origin or the length of commute trips, which makes it difficult to accurately estimate the associated air pollution. Second, our dataset relies on the Standard Industrial Clarification System (SIC), which was replaced by the U.S. Census Bureau with the North American Industry Classification System (NAICS) in 2003. This creates discrepancies because SIC codes do not seamlessly convert to NAICS codes, so a firm's classification may change over the period considered (35). In addition, some records were incomplete or incorrect, so we combed carefully through our data to insure its validity.

After checking our data and dropping incomplete records, we combined worksite information with incentive plan data using facility ID as a key. We then reduced 4-digit SIC codes to two digits, which allowed us to simplify the 327 unique 4-digit SIC codes in the original dataset to 70 unique 2-digit codes, that were aggregated into 10 categories: agriculture, forestry and fishing, mining, construction, manufacturing, transportation and communication, wholesale trade, retail trade, finance, insurance and real estate, service, and public administration. Note that this classification is more detailed than the one used by Giuliano, Hwang, and Wachs (4), who relied simply on 3 different categories.

Next, following Giuliano, Hwang, and Wachs (4) and the U.S. Census Bureau (36), we combined the number of window employees into four groups: less than 250, 250 to 499, 500 to 999, and 1000 and above. It is interesting to note that 71% of businesses in Los Angeles County have between 100 and 249 employees (71%), while only 18% of firms have between 250 and 499 employees (36). Our dataset also includes a few worksites with fewer than 250 employees even though they are not subjected to Rule 2202. These worksites participated voluntarily in the program; they correspond primarily to employers with multi-worksite programs who wanted to aggregate AVRs from different worksites located within the same AVR Zone to boost their results.

In addition, employee modal splits were re-categorized using the SCAQMD's original specification (30). Employees traveling in a vehicle as part of a group of 2-6 people were captured under "Carpool" and those sharing a vehicle with 7-15 people were assigned to the "Vanpool" category. Moreover, because of their small number, employees walking or riding a bicycle to work were combined into "Walk/Bike".

The final data set has information about worksites (location, size, and industry), incentive plans (options, frequency, and dollar value), and mode splits. From Table 3.1, we observe that most worksites in our dataset are located in the Metro-Central area; 40% are in the service sector and about half of the worksites have between 250 and 500 employees. These numbers are fairly consistent over the 2002-2007 period. A look at AVR statistics reveals that worksite size does not seem to have a practical impact on AVR; we note that mining and construction worksites tend to have higher AVRs than other industrial sectors, but this may be a small sample peculiarity.

Table 3.1 also shows how AVRs changed over time for different locations, industries, and worksite sizes. Interestingly, we observe that over period considered, average AVR is fairly stable for Zone 2; it increased in Zone 1 (downtown; from 1.65 to 1.75) but decreased slightly in Zone 3 (from 1.29 to 1.27). Industries that increased their AVR include Mining, Construction, Wholesale Trade, "Finance, Insurance, and Real Estate", as well as Public Administration. AVR also increased for small (less than 250 employees) and medium large (500 to 999 employees) worksites.

Table 3.2 shows the share of each mode for 2003, 2005, and 2007. We see that over 67% of employees commute by driving alone to work; moreover, carpooling is by far the dominant form of ride-sharing. By contrast, the share of bus is just over 4%, while walking and biking combined attract only 2.5% of commuters. Unsurprisingly, telecommuting, working from home, or using electric vehicles is quite uncommon (less than 1%); they are combined in "Others". The modal split did not change much from 2003 to 2007. We note, however, that the number of people who drive alone increased (from 67.3% in 2003 to 68.0% in 2007) while the number of commuters in carpools or vanpools decreased (from 20.2% and 1.3% in 2003 to 18.4% and 1.0% in 2007, respectively). At the same time, the share of bus increased slightly.

Let us now look at incentives (Table 3.3 and Figure 3.4). According to Rule 2202, worksites that did not meet their target AVR must offer at least 5 incentives to boost their AVR. From Table 3.3, we see that Rideshare Matching Services, Guaranteed Return Trip, Personalized Commute Assistance and Direct Financial Awards are the most popular incentive used by worksites while time off with pay and parking charges are almost never offered. Disappointingly, Flex Time Schedules is also seldom offered. Year 2005 also saw a big jump in the number of incentives offered but a substantial share of these incentives disappeared in 2007. Figure 3.4 shows that on aggregate, the share of each incentive did not change drastically between 2002 and 2007. We simply observe that rideshare matching and direct financial awards became more popular while personal commute assistance, guaranteed return trips, and other became less common.

Analyzing TDM data is complicated by the fact that over time some new worksites are regulated while others drop out. According to SCAQMD, a worksite is exempt from Rule 2202 when: (a) the number of its employees decreases to fewer than 250 for the prior six months or to fewer than 33 window employees as a monthly average; (b) it declares bankruptcy; (c) it complies with the good faith effort determination elements; or (d) it participate in the Air Quality Investment Program (AQIP) by investing annually $60 per employee or triennially $125 per employee into an AQMD administered restricted fund; this fund is used to finance projects that reduce emissions to meet the emission reduction target (ERT) equivalent to the level of participation in the AQIP. After December 31, 2004, employers who do not meet their target AVR need to demonstrate that the following strategies are implemented (see Appendix B for details): marketing, basic support strategies, direct strategies, clean fleet vehicle purchase/lease, and the mobile source diesel PM/NOx emission minimization plan. Primary or secondary schools that bus at least two students for every peak window employee, primary or secondary school with financial hardship and police/sheriff/federal field agents are also exempt.

Washington State CTR

The Washington State CTR data was kindly provided by the Washington State Department of Transportation. In this chapter, I analyze three years (2003, 2005 and 2007) of survey data from 5 Counties: King, Kitsap, Pierce, Snohomish and Thurston.

Basic characteristics of worksites and employees regulated by the Washington State DOT for these 5 counties are summarized in Table 3.4. Out of 1,733 worksites, approximately 70% are located in King County (1,212 worksites); moreover, 10%, 9% and 8% of the worksites are located in Thurston, Snohomish, and Pierce counties, respectively; Kitsap has only approximately 3% of worksites. This is consistent over the three survey periods. On average most worksites in the CTR program are in the "small-medium" category (between 100 and 249 employees); it ranges from a low of 34.8% in Thurston County to a high of 55.8% in Snohomish County. The second largest worksite size is "medium" (between 250 and 499 employees), followed by "medium large" (between 500 and 999 employees); both Snohomish and King have more large worksites (>999 employees) than small ones (<100); the reverse is true for the other three counties. CTR surveys focus on the single occupant vehicle index (SOV), which is obtained by dividing the number of employee-solo-trips by the number of trips. For purposes of comparison with Rule 2202, however, I also calculate the AVR for each participating worksite using Rule 2202's definition. Note that CTR surveys also collect the home-to-work distance of employees' commutes, which is useful to estimate air pollutant emissions for example. By contrast, this information is optional on Rule 2202 compliance forms so it is mostly left out.

Not all the desired information is available. First, Washington CTR surveys do not ask for SIC codes, so the industry of a worksite may be difficult to identify. The closest substitute is to use a survey question asking employees to identify their job type. Second, the datasets provided by Washington State DOT do not contain incentive information. In addition, the CTR program does not have a list of incentive options that employers can choose (as for Rule 2202). In Washington State, employers may use any incentive they think is effective and appropriate.

Let us now examine the one-way commute distance (from home to their worksite) of employees in participating worksites. This is captured by "miles per trip (MPT)", which is shown on Figure 3.5 by year and by county. We note that the MPT statistic increased for Kitsap, Thurston, and Pierce between 2003 and 2007 (it went down slightly for Pierce between 2005 and 2007); by contrast, it reverted to the same level or decreased very slightly for King and Snohomish over the same period. One hypothesis that will be tested is whether the change in average MPT is related to the CTR program.

Let us now consider modal split (Figure 3.6). As expected, most employees commute to work by driving alone but this percentage decreased from 2005 to 2007 and from 2003 to 2007 as the share of other modes increased. Note that approximately 80% of employees drive alone to work in Pierce, Thurston, and Snohomish counties compared to only approximately 60% for the other two counties. Figure 3.7 also shows that bus and carpool are the second and third most popular commuting modes (although only in King County is the percentage of bus users higher than the percentage of carpool users). These modal split percentages are similar to those observed for Rule 2202 but with a higher bus usage. Interestingly, walking/biking comes in fourth place overall (3.7%) and this mode has been edging up between 2003 and 2007.

Figure 3.7 gives a breakdown of AVR by county and by year for Washington State's CTR program; these AVRs were calculated using SCAQMD Rule 2202's AVR definition and adjustments. With the exception of King County that has average annual AVRs comprised between 1.82 and 1.91 (which would exceed the most demanding target of Rule 2202), the other four counties have AVRs similar to those in Southern California (see Table 3.1). We also note that, except again for King County, AVRs decreased slightly between 2003 and 2007. Transportation planners have a tough task there because these counties are much more rural than King County and they don't offer the same level of service for public transportation.

METHODOLOGY

After examining some of the basic features of Rule 2202 and of the Washington State CTR program, I cleaned up the datasets for both programs (to eliminate redundant and extraneous records) and generated some basic statistics in order to examine a couple of questions.

Following Giuliano, Hwang, and Wachs (4), I will first examine whether worksite characteristics can explain AVR. I hypothesize that AVR is affected by: (a) worksite geographic location, represented by a worksite's target zone (see Figure 3.1); (b) size, represented by the number of window employees; (c) industrial sector, a surrogate for intra-organizational behaviors and characteristics; and (d) temporal conditions (accounted for by estimating our models for each year separately) that reflects changes in economic conditions and transportation factors such as the price of gasoline. Because of data availability, I will compare 3 years: 2003, 2005, and 2007.

The second question I examine is whether worksite characteristics have an impact on the share of different modes. For example, worksites with many window employees offer many more opportunities to carpool; moreover, people who work downtown Los Angeles, where congestion is high and parking expensive, would have more incentives to carpool or use public transportation; finally, a carpool program may have little success in retail stores where employees do not need to be at work at the same time but it may work well for a public administration worksite.

Like Giuliano, Hwang, and Wachs (4), I rely on Analysis of Variance (ANOVA) techniques to explore these questions. ANOVA compares the means of two or more groups using categorical independent variables to explain differences between these means. ANOVA offers a couple of advantages over other approaches. First, when the number of categories is large, ANOVA is statistically more powerful than a simple t-test. Second, interaction effects between variables can be easily detected with ANOVA, which helps to test more complex hypotheses. In addition, ANOVA can more easily than linear regression handle a large number of categorical variables. However, ANOVA will only indicate a difference between groups but not which groups are different (37). Although informative, comparisons between Rule 2202 and the CTR are complicated by differences in data collected. First, the CTR applies to firms with at least 100 window employees whereas Rule 2202 regulates worksites with at least 250 employees. Second, the location variable obviously differs between the two programs: it is based on regulatory zones for Rule 2202, and on counties for the CTR. Finally, Rule 2202 classifies worksites based on SIC codes whereas the CTR relies on job types. A comparison of the key characteristics of the features of Rule 2202 and the CTR program is presented in Table 3.5.

RESULTS

Rule 2202

Analysis of AVR

Let us first consider AVR by AVR target and by year, as shown in Table 3.6. First, we note that most worksites (approximately 85 percent) are in Zone 2 (target AVR=1.5);

only 5 to 6 percent of worksites are in Zone 3 (target AVR=1.3) and the balance (~9 percent) is in Zone 1 (target AVR=1.75). The second observation is that only worksites in Zone 1 made steady progress between 2003 and 2005, and on average reached their AVR target. By contrast, after an improvement between 2003 and 2005, worksites in Zone 3 saw a decrease in their AVR in 2007, although they are not far off the mark. However, the situation is roughly unchanged for the 85 percent of worksites in Zone 2, and on average they do not meet their target (1.32 versus 1.5). Third, we observe that there is a lot of variability within each AVR target group for each year, especially in Zone 2. Overall, the average AVR did not change noticeably between 2003 and 2005. Now that we know that there are differences in AVR, let us see what could explain them using ANOVA.

ANOVA results for Rule 2202 are summarized in Table 3.7. In 2003, three terms are statistically significant: "Zone", "Zone × Industry" and "Industry × Size". These three terms are also significant for 2005 and 2007, but in addition, other variables become statistically significant. In 2005, "Industry" as well as "Size" and all their interactions are statistically significant; in 2007, "Industry" is again statistically significant as well as the interactions where it is present, but not "Size". This suggests time variability in the differences in AVR; it may be partly explained by the implementation of many more strategies to decrease AVR in 2007 and especially in 2005, compared to 2003. The importance of "Zone" is not surprising since we observed a higher average AVR in Zone 1 compared to the two other zones. Zone 1 is downtown Los Angeles and it benefits from a better than average (for the region) range of public transportation options. The significance of "Industry × Size" reflects the availability of more car pooling or van pooling options in larger firms, although these opportunities for reducing AVR need schedule compatibility, which is sector industry dependent, to be realized.

Analysis of Mode Shares

Let us now examine the impact of worksite characteristics on the share of different transportation modes. From Table 3.3, we recall that 2007 and especially 2005 saw the implementation of quite a few additional strategies to reduce AVR compared to 2003.

Analysis of variance tests were conducted only for the top three modes (drive-alone, carpool, bus) as the other alternatives gather only a small percentage of commuters (see Table 3.3). Table 3.8 summarizes results of the ANOVA analysis of these modal shares. Let us first consider driving alone. For this mode, similarities with AVR results (Table 3.7) are the greatest, as the same factors are significant for both 2003 and 2005. For all three years analyzed, “Zone” and the interaction between “Industry” and “Size” are statistically significant as they impact the attractiveness of alternatives to driving alone. The interaction between “Zone” and “Industry” was also significant for 2003 and 2005.

Results for carpooling also suggest that important factors change with time, with the exception of industry, which is highly significant for all three years. The flexibility allowed by an employer is intuitively a key factor in making carpooling possible. I was also expecting “Size” to be important as larger work sites offer more opportunities to organize carpools, but “Size” is not statistically significant in 2007.

Of the three modes considered, bus exhibits the most statistical stability. Indeed, with a couple of exceptions, the same factors are significant for the three years analyzed.

As expected, both “Zone” and “Industry” are statistically significant, but also their interaction. Indeed, “Zone” is strongly related to the availability of bus service (especially in Zone 1, downtown Los Angeles), and “Industry” reflects the different scheduling demands of different sectors (administrative work, for example, is likely very compatible with commuting by bus). I was also expecting “Size” to matter as very large worksites may generate enough traffic to justify a stop on a bus route; although “Size” is not directly a significant factor, it matters indirectly (in 2003 through “Zone × Size” and after through “Zone × Industry × Size”.

Finally, the lack of statistical significance for some factors in 2007 may be related to the 8.5 percent drop in the number of regulated worksites between 2003 and 2007.

Washington State CTR

As explained above and in the notes below Table 3.7 and Table 3.9, different factors were available to explain both AVR and mode choice in Washington State’s CTR program. The main difference with Rule 2202 is that the CTR program does not collect SIC data or equivalent at each worksite; instead, it asks each survey respondent to describe his/her job by selecting one of the following categories: “administrative support”, “craft / production / labor”, “management”, “sales / marketing”, “customer service”, “professional / technical services” and “others”. As a starting point for our analysis, we calculated the percentage of responses to each category and assigned to a worksite the category corresponding to the largest number of respondents to generate the categorical variable “Work type”. Other alternatives should be explored in future work, especially in the light of the results of our ANOVA analyses.

Analysis of AVR

Table 3.9 presents results of our analyses of AVR using ANOVA for the CTR program. In contrast to results for Rule 2202, very few factors are significant. The exception is "County × Work type" in 2003 and "County" in 2007. Curiously, none of the factors considered is statistically significant in 2005, which may be due to an insufficient sample size combined with mean differences between categories that are too small. This is surprising as I was expecting at least "County" to be significant for all years since King County (where Seattle is located) has a denser public transportation network than the other counties considered.

Analysis of Mode Share

Table 3.10 presents the results of the analysis of variance of the percentage of employees who commute either by driving alone, carpooling or taking bus, which are again the most popular modes to go to work. My explanatory factors are similar to the ones used to analyze Rule 2202, but not identical for the reasons explained above.

For driving solo, only "County" was found to be statistically significant. The importance of this factor was expected as King County has a denser transportation infrastructure (and more public transportation alternatives) than the other four counties analyzed. This also suggests, however, that larger firms in other counties are able/willing to provide alternatives to their workers.

For carpooling, both "County" and the interactions "County × Work type" and "Work type × Size" are statistically significant (although for only two out of three years for the interactions). The importance of "Work type" is again related to the possibility that some employees have to start and finish work at a fixed time on a regular basis. Finally, my model for the share of workers commuting by bus has only one significant variable, which is "County", which again reflects a key difference in public transportation (and local density).

CONCLUSIONS

In this chapter, I considered and compared some key features of two TDM programs: Rule 2202 in Southern California, and the Commute Trip Reduction Program (CTR) in Washington State. An ANOVA analysis suggest that the AVR of Rule 2202 commuters is influenced by worksite location, size and location; for CTR commuters, however, only location, and to a lesser degree work type, are statistically significant. Looking at commuting modes, "Drive Alone" is still the mode of choice for 68% of Rule 2202 commuters, followed by "Carpool" with 18.4% and a paltry 4.7% for "Bus". This is not drastically different from the mode shares observed one year after the implementation of Regulation XV (see Table 3.7 in (4)), when 70.9% of commuters chose to drive alone, 18.4% carpooled, and 3.2% took the bus to work; note that Regulation XV also applied to worksites with 100 or more employees (the threshold for Rule 2202 is 250), so it likely faced a bigger hurdle. By contrast, the CTR program was more successful at moving commuters out of their cars, mostly thanks to King County: in 2007, 62.8% of CTR commuters chose to drive alone, 14.1% took the bus, and 11.6% carpooled. For Rule 2202, mode choices are again influenced by location, industry, and size (depending on the mode), whereas for the CTR program, location seems the main factor, which may suggest that public transportation was made convenient for people facing a wide range of scheduling constraints.

These results suggest that TDM has a place in the toolbox of policies to decrease congestion and fight global warming, in spite of its lack of popularity in Southern California. Rule 2202's bad reputation may be partly due to its complexity and its fairly burdensome reporting requirements, which may discourage some employers to be more involved. Note, however, that a balance needs to be found between enforcement, light reporting, and policy analysis. Enough data need to be gathered from worksites to allow a sound understanding of the impacts of a TDM program. Moreover, it would be useful if each major TDM program could gather a common set of variables to allow comparisons between different programs (it would be useful for the CTR program to gather more standard information about the nature of worksites, for example).

To make Rule 2202 more attractive to employers, most reporting could be moved to a more user friendly Internet platform. Employers could also be given more freedom to create new incentives for their employees to reduce their AVR (employers have more freedom with the CTR program). Monetary incentives and public praise could also be considered for employers who achieved excellent results at their worksites. More generally, TDM programs should be implemented with a broader view of transportation policy. To make TDM more effective, pricing parking better and creating tolls on freeways would help, although these policies are clearly not very popular in Southern California; in addition, the convenience of public transportation could be improved thanks to information technology so commuters could know precisely how long it will take them to reach their destination and when to go to a bus or metro station.

A lot more could be done to better understand both Rule 2202 and the CTR program. For example, a fixed effect panel model could be used to investigate the effectiveness of various incentives on AVR; a better characterization of work type should also be investigated for the CTR program; and spatial analysis could better inform the observed performance of TDM programs. This is left for future work.

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Table 3.1 Worksite characteristics and AVR (Rule 2202)

	2003	AVR	2005	AVR	2007	AVR
Location						
Downtown (Zone 1)	9.3%	1.65	8.7%	1.69	9.3%	1.75
Metro-Central (Zone 2)	85.4%	1.32	85.6%	1.30	84.0%	1.32
Metro-Suburbs (Zone 3)	5.3%	1.29	5.7%	1.32	6.7%	1.27
Industry						
Mining	0.1%	1.49	0.0%	- -	0.1%	1.69
Construction	0.1%	1.20	0.4%	1.67	0.6%	1.55
Manufacturing	20.0%	1.34	20.3%	1.33	18.1%	1.33
Transportation	3.9%	1.38	4.1%	1.31	4.6%	1.31
Wholesale Trade	0.9%	1.25	1.2%	1.33	1.2%	1.29
Retail Trade	11.6%	1.34	10.9%	1.31	12.4%	1.33
Finance, insurance, real estate	6.2%	1.30	6.5%	1.29	6.2%	1.35
Services	40.2%	1.35	41.5%	1.33	40.9%	1.36
Public Administration	16.8%	1.35	15.1%	1.38	15.9%	1.40
Size (number of window employees)						
<250	29.9%	1.36	30.1%	1.35	31.7%	1.37
250 to 499	38.8%	1.34	38.1%	1.35	36.0%	1.35
500 to 999	18.9%	1.35	19.6%	1.31	19.4%	1.37
>999	12.3%	1.32	12.2%	1.30	12.9%	1.31
AVR	1.35		1.33		1.35	
Number of worksites	739		735		675	
Number of window employees	401,800		444,668		383,922	

Notes: Percentages are based on the number of worksites in a given year. The AVR reported is the calculated AVR; it includes adjustments and credits described in the text.

Table 3.2 Modal split statistics (Rule 2202)

	2003	2005	2007	% change 05 vs. 03	% change 07 vs. 05
Drive Alone	67.3%	68.6%	68.0%	1.9%	-0.9%
Carpool	20.2%	18.8%	18.4%	-6.9%	-2.1%
Bus	4.4%	4.4%	4.7%	0.0%	6.8%
Walk/Bike	2.5%	2.5%	2.5%	0.0%	0.0%
Rail/Plane	2.2%	2.5%	2.7%	13.6%	8.0%
Motorcycle	0.8%	0.7%	1.2%	-12.5%	71.4%
Vanpool	1.3%	1.0%	1.0%	-23.1%	0.0%
Others	1.4%	1.5%	1.6%	7.1%	6.7%
Total Number of Commuters	968,309	688,207	646,511	-28.9%	-6.1%

Table 3.3 Incentive plans used (Rule 2202)

	Number of strategies (percentage)		
	2003	**2005**	**2007**
Basic/Support Strategies			
Preferential Parking for Rideshares	135 (3.9%)	421 (3.8%)	273 (4.1%)
Rideshare Matching Services	723 (20.7%)	2393 (21.9%)	1432 (21.7%)
Flex Time Schedules	43 (1.2%)	151 (1.4%)	59 (0.9%)
Personalized Commute Assistance	657 (18.8%)	2077 (19.0%)	1226 (18.6%)
Guaranteed Return Trip	694 (19.8%)	2307 (21.1%)	1406 (21.3%)
Transit Information Center	89 (2.5%)	200 (1.8%)	119 (1.8%)
Total	*2341 (66.9%)*	*7549 (69.0%)*	*4515 (68.5%)*
Direct Strategies			
Auto Service	58 (1.7%)	106 (1.0%)	62 (0.9%)
Bicycle Program	66 (1.9%)	246 (2.2%)	130 (2.0%)
Compressed Work Week	146 (4.2%)	568 (5.2%)	297 (4.5%)
Discounted or Free Meals	50 (1.4%)	128 (1.2%)	88 (1.3%)
Direct Financial Awards	539 (15.4%)	1697 (15.5%)	1156 (17.5%)
Prize Drawings	175 (5.0%)	434 (4.0%)	235 (3.6%)
Parking Charge/Subsidy	61 (1.7%)	0 (0.0%)	0 (0.0%)
Time Off with Pay	4 (0.1%)	1 (0.0%)	0 (0.0%)
Points Program	18 (0.5%)	44 (0.4%)	22 (0.3%)
Vanpool Program	43 (1.2%)	164 (1.5%)	85 (1.3%)
Total	*1160 (33.1%)*	*3388 (31.0%)*	*2075 (31.5%)*
Total all strategies	*3501(100.0%)*	*10937 (100.0%)*	*6590 (100.0%)*

Table 3.4 Characteristics of worksites regulated by the CTR program.

	Number of regulated worksites (% of total)			
	2003	**2005**	**2007**	**Total**
All				
<100	29 (5.1%)	35 (5.9%)	59 (10.4%)	123 (7.1%)
100-249	287 (50.5%)	285 (47.7%)	284 (50.0%)	856 (49.4%)
250-499	132 (23.2%)	133 (22.3%)	118 (20.8%)	383 (22.1%)
500-999	75 (13.2%)	89 (14.9%)	68 (12.0%)	232 (13.4%)
>999	45 (7.9%)	55 (9.2%)	39 (6.9%)	139 (8.0%)
Total	*568 (100%)*	*597 (100%)*	*568 (100%)*	*1,733 (100.0%)*
King				
<100	18 (4.6%)	25 (5.9%)	32 (8.0%)	75 (6.2%)
100-249	205 (52.7%)	208 (48.9%)	214 (53.8%)	627 (51.7%)
250-499	90 (23.1%)	94 (22.1%)	82 (20.6%)	266 (21.9%)
500-999	41 (10.5%)	54 (12.7%)	40 (10.1%)	135 (11.1%)
>999	35 (9.0%)	44 (10.4%)	30 (7.5%)	109 (9.0%)
Total	*389 (100%)*	*425 (100%)*	*398 (100%)*	*1,212 (100%)*
Kitsap				
<100	3 (11.1%)	3 (11.5%)	3 (12.0%)	9 (11.5%)
100-249	12 (44.45)	12 (46.2%)	11 (44.0%)	35 (44.9%)
250-499	6 (22.2%)	6 (23.1%)	6 (24.0%)	18 (23.1%)
500-999	4 (14.8%)	3 (11.5%)	3 (12.0%)	10 (12.8%)
>999	2 (7.4%)	2 (7.7%)	2 (8.0%)	6 (7.7%)
Total	*27 (100%)*	*26 (100%)*	*25 (100%)*	*78 (100%)*
Pierce				
<100	2 (4.2%)	2 (4.3%)	13 (26.0%)	17 (11.8%)
100-249	24 (50.0%)	20 (43.5%)	17 (34.0%)	61 (42.4%)
250-499	11 (22.9%)	10 (21.7%)	9 (18.0%)	30 (20.8%)
500-999	9 (18.8%)	11 (23.9%)	9 (18.0%)	29 (20.1%)
>999	2 (4.2%)	3 (6.5%)	2 (4.0%)	7 (4.9%)
Total	*48 (100%)*	*46 (100%)*	*50 (100%)*	*144 (100%)*
Snohomish				
<100	1 (2.2%)	1 (2.2%)	1 (2.1%)	3 (2.2%)
100-249	26 (56.5%)	24 (53.3%)	27 (57.4%)	77 (55.8%)
250-499	9 (19.6%)	9 (20.0%)	9 (19.1%)	27 (19.6%)
500-999	7 (15.2%)	8 (17.8%)	8 (17.0%)	23 (16.7%)
>999	3 (6.5%)	3 (6.7%)	2 (4.3%)	8 (5.8%)
Total	*46 (100%)*	*45 (100%)*	*47 (100%)*	*138 (100%)*
Thurston				
<100	5 (8.6%)	4 (7.3%)	10 (20.8%)	19 (11.8%)
100-249	20 (34.5%)	21 (38.2%)	15 (31.3%)	56 (34.8%)
250-499	16 (27.6%)	14 (25.5%)	12 (25.0%)	42 (26.1%)
500-999	14 (24.1%)	13 (23.6%)	8 (16.7%)	35 (21.7%)
>999	3 (5.2%)	3 (5.5%)	3 (6.3%)	9 (5.6%)
Total	*58 (100%)*	*55 (100%)*	*48 (100%)*	*161 (100%)*

Table 3.5 A comparison of key characteristics of Rule 2202 and the CTR program

Criteria	Rule 2202*	CTR program**
Number of employees	250 or more (full time)	100 or more (window Employee)
Work schedule	No requirement	6:00 a.m. – 9:00 a.m.
Number of participating worksites	1,500	1,110
Affected Area	Four counties: Los Angeles, Orange, Riverside, and San Bernardino	Ten counties: Clark, King, Kitsap, Pierce, Snohomish, Spokane, Thurston, Whatcom, and Yakima Counties
Objectives	Increase Average Vehicle Rideshare (AVR)	Decrease Single Occupancy Vehicle trips (SOV) and Vehicle Mile Travel (VMT)
Objective Targets	AVR Target: Zone 1: Downtown → 1.75 Zone 2: Metro-Central → 1.5 Zone 3: Metro-Suburb → 1.3	SOV: (from the 1992 base year value) 15% by Jan 1, 1995 25% by Jan 1, 1997 25% by Jan 1, 1999 35% by Jan 1, 2005 VMT: (from the 1992 base year value) 15% by Jan 1, 1995 20% by Jan 1, 1997 25% by Jan 1, 1999 35% by Jan 1, 2005
Budget	SCAQMD $942,857 (FY-2008)***	State: $5.6 millions Local government: $1.8 millions Employers: $49 millions (FY 2005-2007)
Frequency	Annual or Triennial	Annual
Data collection method/frequency	Annual survey	Survey every two years
Reports	Annually compliance form	Employer Annual Report & Program Description form
Brief description	SCAQMD provides lists of ECRP options for employers to choose from	Employers develop their own commuter reduction program
Main tools	• Personalized commute assistance • Guaranteed return trip • Rideshare Matching service • Direct financial awards	• Parking strategies • Benefits/Subsidies • Carpooling • Telecommuting • Compress Workweek

Sources: * http://www.aqmd.gov/rules/reg/reg22/r2202.pdf
**http://www.wsdot.wa.gov/TDM/CTR/overview.htm
***http://www.aqmd.gov/hb/attachments/2009/June/090637AB.doc

Table 3.6 Change in calculated AVR for each preferred target zone (Rule 2202)

AVR Zone (Target)		2003	2005	2007	% change 05 vs. 03	% change 07 vs. 05
Zone 1 (1.75)	Number of worksites	69	64	63		
	Actual AVR	1.65	1.69	1.75	+2.8%	+3.5%
	AVR range	[1.09,3.72]	[1.06,2.81]	[1.04,3.91]		
Zone 2 (1.5)	Number of worksites	631	629♣	567		
	Actual AVR	1.32	1.30	1.32	-1.5%	+1.5%
	AVR range	[1.02,3.81]	[1.00,2.93]	[1.03,3.34]		
Zone 3 (1.3)	Number of worksites	39	42	45		
	Actual AVR	1.29	1.32	1.27	+2.7%	-3.8%
	AVR range	[1.06,1.69]	[1.07,2.62]	[1.03,2.60]		
All	Number of worksites	739	735	675		
	Actual AVR	1.35	1.33	1.35	-1.5%	+1.5%
	AVR range	[1.02,3.81]	[1.00,2.93]	[1.03,3.91]		

Notes:
The AVR reported is the calculated AVR; it includes adjustments and credits described in the text.
♣: One worksite was excluded from the 2005 AVR target zone because its actual AVR was suspiciously high (27.43); it corresponds to the Church Of Scientology Western U S.

Table 3.7 Yearly ANOVA results for AVR (Rule 2202)

Year	Mean Square	F
Year 2003		
Model	0.23	4.03***
Zone	1.04	17.91***
Industry	0.06	1.04
Size	0.12	2.01
Zone × Industry	0.18	3.05***
Zone × Size	0.10	1.77
Industry × Size	0.10	1.75**
Zone × Industry × Size	0.09	1.49
N = 739		
Year 2005		
Model	0.28	6.23***
Zone	0.79	17.28***
Industry	0.10	2.16**
Size	0.16	3.57**
Zone × Industry	0.14	3.06***
Zone × Size	0.09	2.02*
Industry × Size	0.14	3.15***
Zone × Industry × Size	0.11	2.37***
N = 735		
Year 2007		
Model	0.31	5.07***
Zone	1.09	18.05***
Industry	0.16	2.69***
Size	0.05	0.84
Zone × Industry	0.13	2.17**
Zone × Size	0.01	0.21
Industry × Size	0.14	2.38***
Zone × Industry × Size	0.12	1.96**
N = 675		

Notes. Zone refers to the three AVR target zones (see Figure 3.1). Industry classifies worksites in 9 groups: "Construction" (21), "Finance, Insurance, and Real Estate" (275), "Manufacturing" (856), "Mining" (6), "Public Administration" (692), "Retail Trade" (485), "Services" (1779), "Transportation, Communications, Electric, Gas and Sanitary Services" (188), and "Wholesale Trade" (53). Size refers to the number of worksite employees; it has four categories: 1: <250; 2: 250 to 499; 3: 500 to 999; and 4: >999.

*significant at $p \leq .10$; **significant at $p \leq .05$; ***significant at $p \leq .01$

Table 3.8 ANOVA results for three modal shares (Rule 2202).

	2003 Mean Square	F	2005 Mean Square	F	2007 Mean Square	F
Model 1: Explanatory variable = % of workers who drive alone						
Model	0.074	3.51***	0.082	4.49***	0.064	3.08***
Zone	0.194	9.23***	0.211	11.59**	0.201	9.67***
Industry	0.022	1.05	0.030	1.67	0.035	1.68
Size	0.042	2.00	0.125	6.85***	0.015	0.72
Zone × Industry	0.041	1.94**	0.034	1.85**	0.028	1.34
Zone × Size	0.036	1.72	0.039	2.12**	0.008	0.4
Industry × Size	0.047	2.24***	0.056	3.08***	0.034	1.62**
Zone × Industry × Size	0.009	0.41	0.036	2.00**	0.024	1.17
Model 2: Explanatory variable = % of workers who carpool						
Model	0.046	3.86***	0.038	3.12***	0.031	2.38***
Zone	0.029	2.43*	0.041	3.4**	0.021	1.63
Industry	0.063	5.32***	0.033	2.74***	0.045	3.44***
Size	0.028	2.33*	0.057	4.7***	0.006	0.45
Zone × Industry	0.010	0.87	0.005	0.45	0.010	0.79
Zone × Size	0.011	0.94	0.010	0.79	0.002	0.19
Industry × Size	0.023	1.91**	0.019	1.58*	0.012	0.91
Zone × Industry × Size	0.004	0.35	0.014	1.19	0.010	0.78
Model 3: Explanatory variable = % of workers who take the bus						
Model	0.023	7.61***	0.029	6.27***	0.025	4.75***
Zone	0.067	21.78**	0.099	21.02**	0.088	16.91**
Industry	0.009	2.98***	0.019	4.01***	0.023	4.39***
Size	0.003	0.97	0.005	0.98	0.004	0.86
Zone × Industry	0.016	5.15**	0.010	2.16**	0.011	2.06**
Zone × Size	0.006	1.93*	0.011	2.42	0.008	1.6
Industry × Size	0.007	2.16***	0.015	3.24***	0.012	2.38***
Zone × Industry × Size	0.003	0.99	0.012	2.65***	0.011	2.09***
Number of worksites	738		731		675	

Notes. For a definition of the explanatory variables, see the notes below Table 7.
*significant at $p \leq 0.10$; **significant at $p \leq 0.05$; ***significant at $p \leq 0.01$.

Table 3.9 Yearly ANOVA for AVR (5 counties in the CTR program).

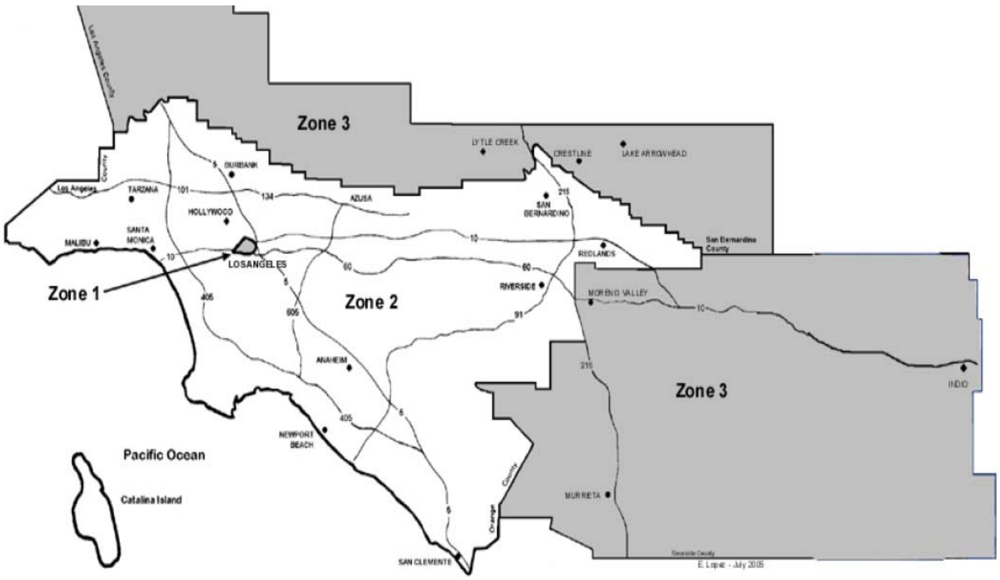
Year	Mean Square	F
Year 2003		
Model	2.14	1.85***
County	0.95	0.82
Work type	1.88	1.63
Size	0.83	0.72
County × Work type	2.70	2.34***
County × Size	0.29	0.25
Work type × Size	0.60	0.52
County × Work type × Size	0.20	0.18
N = 841		
Year 2005		
Model	2.40	0.84
County	0.99	0.35
Work type	0.58	0.20
Size	1.28	0.45
County × Work type	0.61	0.21
County × Size	0.13	0.05
Work type × Size	1.26	0.44
County × Work type × Size	0.10	0.04
N = 844		
Year 2007		
Model	2.50	1.71***
County	3.39	2.32*
Work type	0.46	0.31
Size	0.64	0.43
County × Work type	0.46	0.31
County × Size	0.18	0.12
Work type × Size	0.79	0.54
County × Work type × Size	0.15	0.11
N = 847		

Notes: County refers to one of the five counties we analyze (see Figure 3.2). Work type refers to seven categories used in CTR surveys: “administrative support”, “craft / production / labor”, “management”, “sales/marketing”, “customer service”, “professional / technical services” and “others”. Size refers to the number of window employees; it has five categories: 1: <100; 2: 100 to 249; 3: 250 to 499; 4: 500 to 999; and 5: >999.
*significant at 10%; **significant at 5%; ***significant at 1%.

Table 3.10 ANOVA results for three modal shares (CTR program)

	2003 Mean Square	F	2005 Mean Square	F	2007 Mean Square	F
Model 1: Explanatory variable = % of workers who drive alone						
Model	0.11	2.59***	0.13	3.24***	0.15	3.98***
County	0.19	4.51***	0.16	3.97***	0.34	8.98***
Work type	0.05	1.26	0.03	0.68	0.04	1.02
Size	0.06	1.38	0.06	1.45	0.05	1.44
County × Work type	0.02	0.51	0.04	0.92	0.03	0.68
County × Size	0.02	0.45	0.02	0.45	0.02	0.56
Work type × Size	0.04	0.84	0.04	0.93	0.05	1.41
County × Work type × Size	0.02	0.36	0.02	0.51	0.02	0.50
Model2: Explanatory variable: % of workers who carpool						
Model	0.01	1.9***	0.01	2.26***	0.01	2.55***
County	0.03	5.82***	0.02	5.24***	0.01	2.64**
Work type	0.00	0.2	0.00	1.43	0.01	1.74
Size	0.00	0.93	0.00	0.1	0.00	0.39
County × Work type	0.01	1.66**	0.01	1.74**	0.00	1.44
County × Size	0.00	1.03	0.00	1.17	0.00	0.97
Work type × Size	0.01	1.5*	0.00	0.89	0.01	1.72**
County × Work type × Size	0.00	0.92	0.00	1.33	0.00	0.87
Model 3: Explanatory variable: % of workers who take the bus						
Model	0.07	2.34***	0.08	2.73***	0.08	3.02***
County	0.09	2.86**	0.07	2.51**	0.17	6.33***
Work type	0.03	1.06	0.02	0.68	0.02	0.83
Size	0.03	1.06	0.04	1.38	0.04	1.32
County × Work type	0.01	0.21	0.01	0.51	0.01	0.44
County × Size	0.01	0.3	0.01	0.25	0.01	0.34
Work type × Size	0.02	0.62	0.03	1.12	0.03	1.26
County × Work type ×Size	0.00	0.11	0.00	0.17	0.00	0.14
Number of worksites	841		844		847	

Notes. For a definition of the explanatory variables, see the notes below Table 3.9.
*significant at $p \leq 0.10$; **significant at $p \leq 0.05$; ***significant at $p \leq 0.01$.



Zone	Description	AVR Target
1	Downtown (Los Angeles' central business district)	1.75
2	Metro-Central (The remainder of Los Angeles county)	1.5
3	Metro-Suburbs (The remainder of the region)	1.3

Figure 3.1 Performance zones for Rule 2202

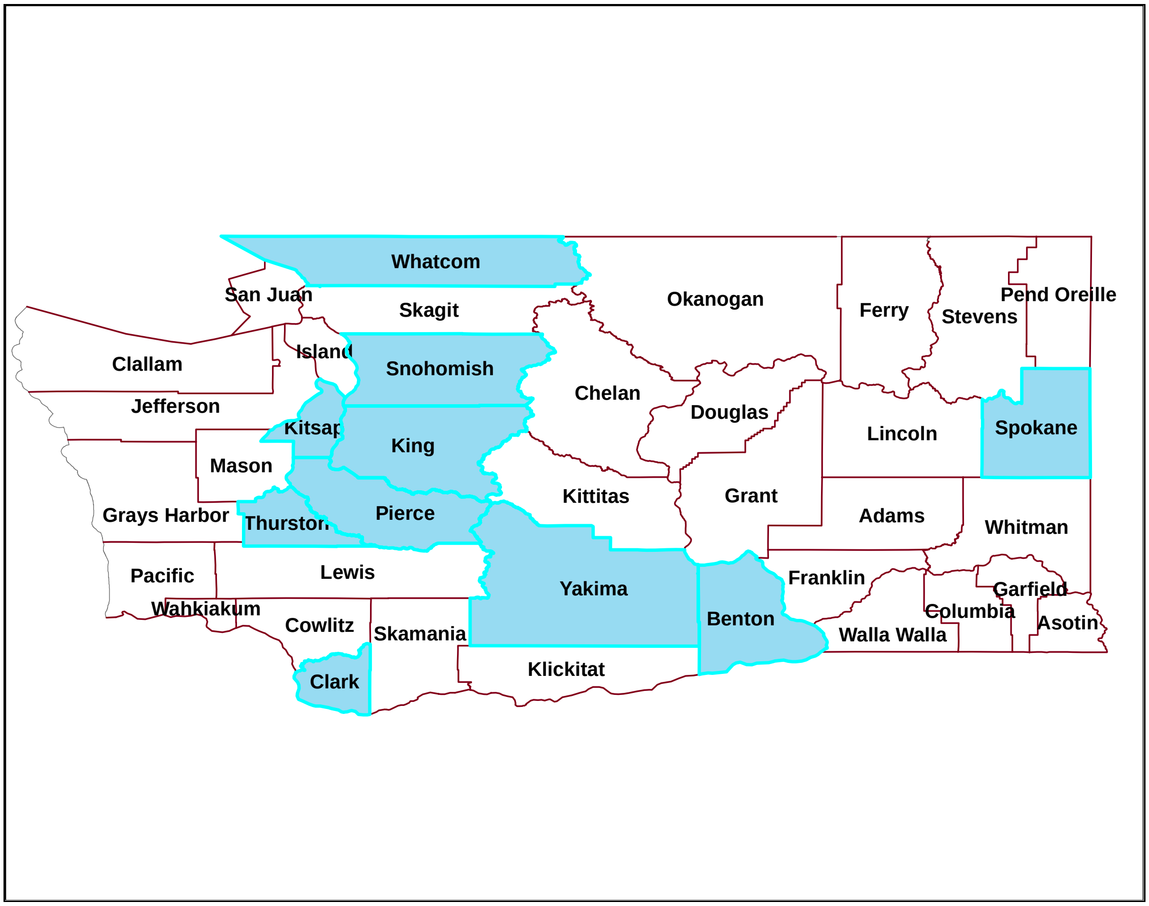


Figure 3.2 Counties participating in Washington State's CTR program (2007)

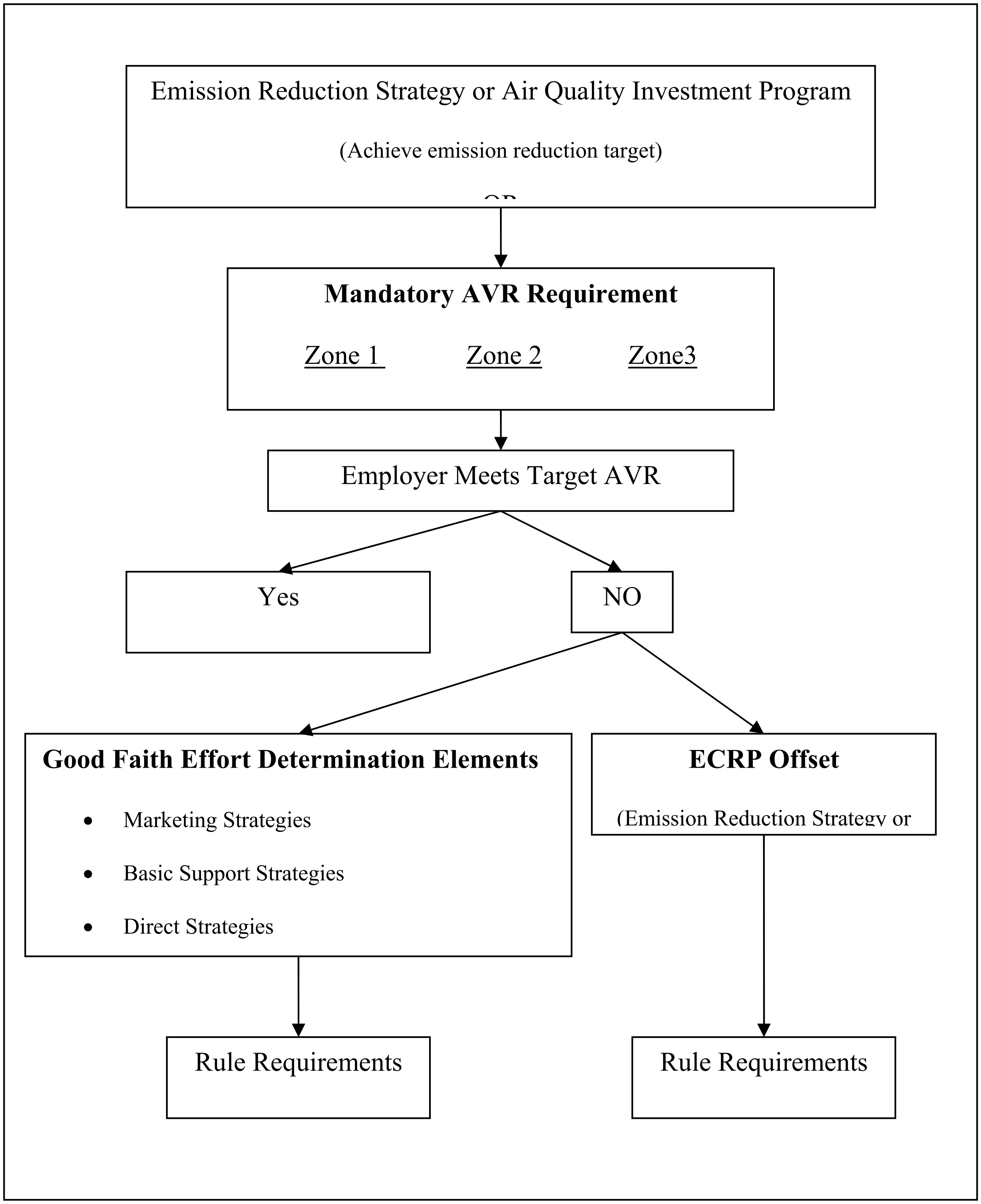


Figure 3.3 Rule 2202 requirement – compliance flow chart

Source: (http://www.aqmd.gov/rules/doc/r2202/r2202_ecrp_guideline.pdf)

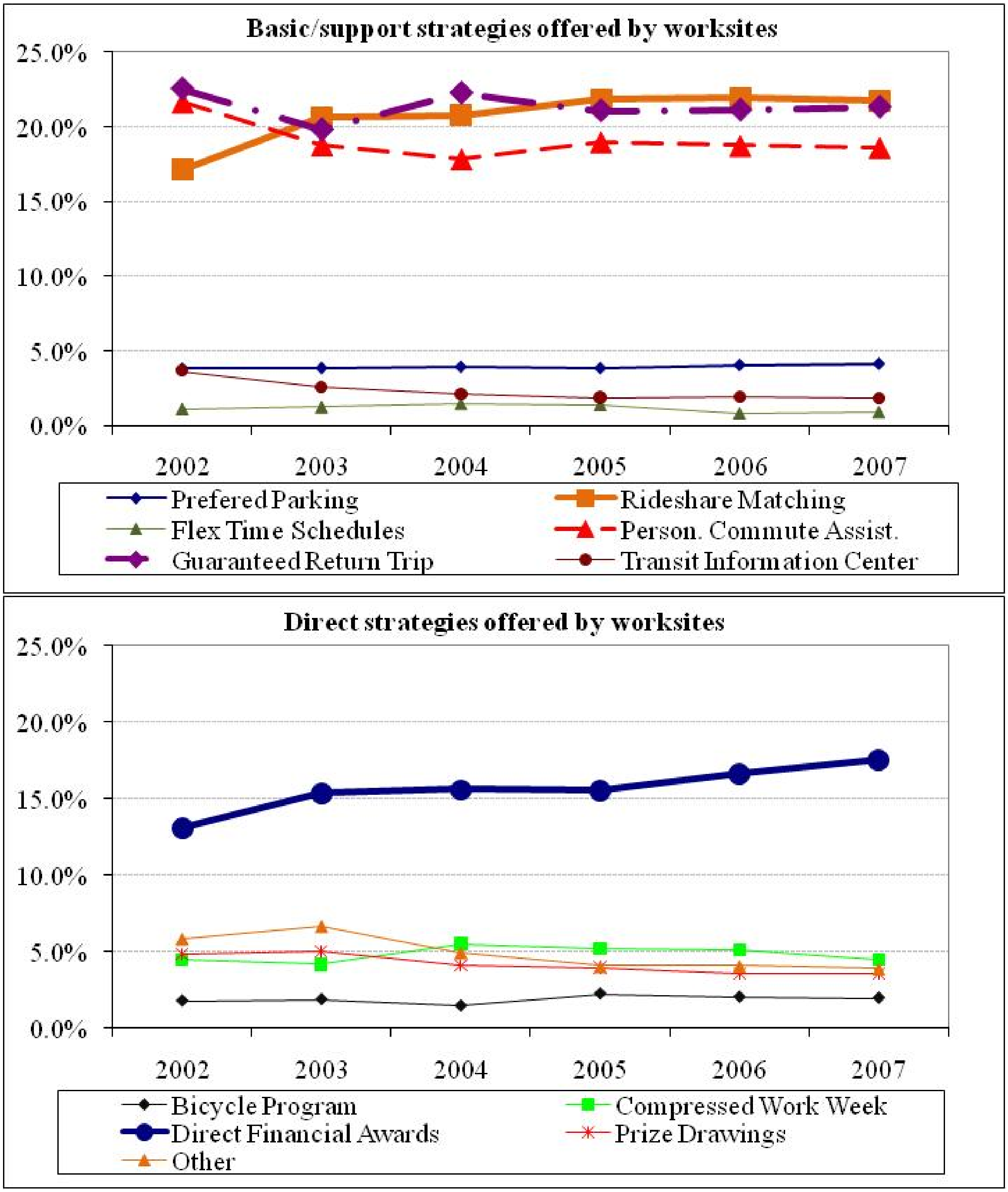


Figure 3.4 Incentives offered by worksites (Rule 2202)

Notes. In the lower panel above, “Other” includes auto service, discounted or free meals, parking subsidies, time off with pay, point programs, and vanpool programs.

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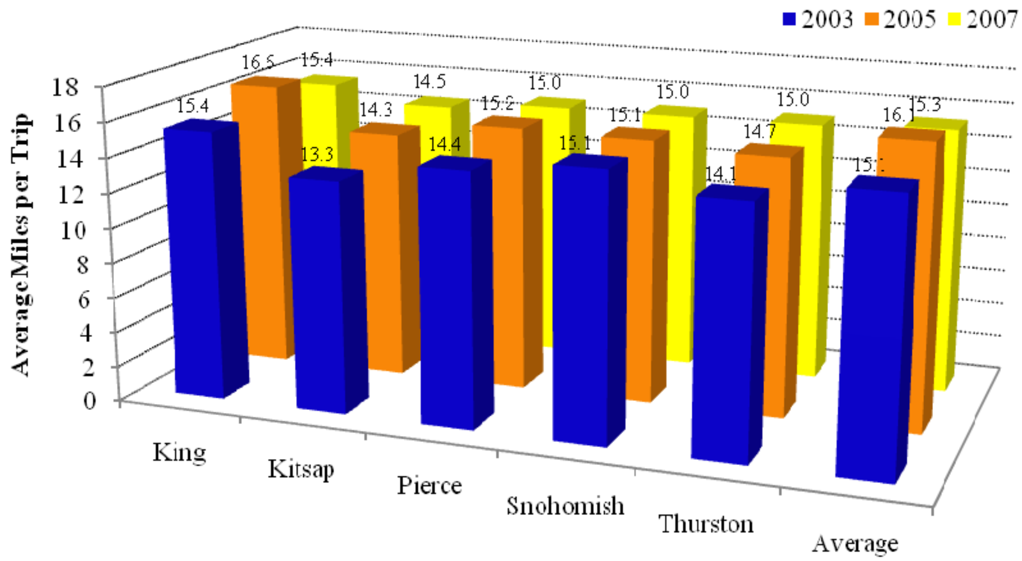

Figure 3.5 Average miles per trip for one-way trips from home to work for the CTR program

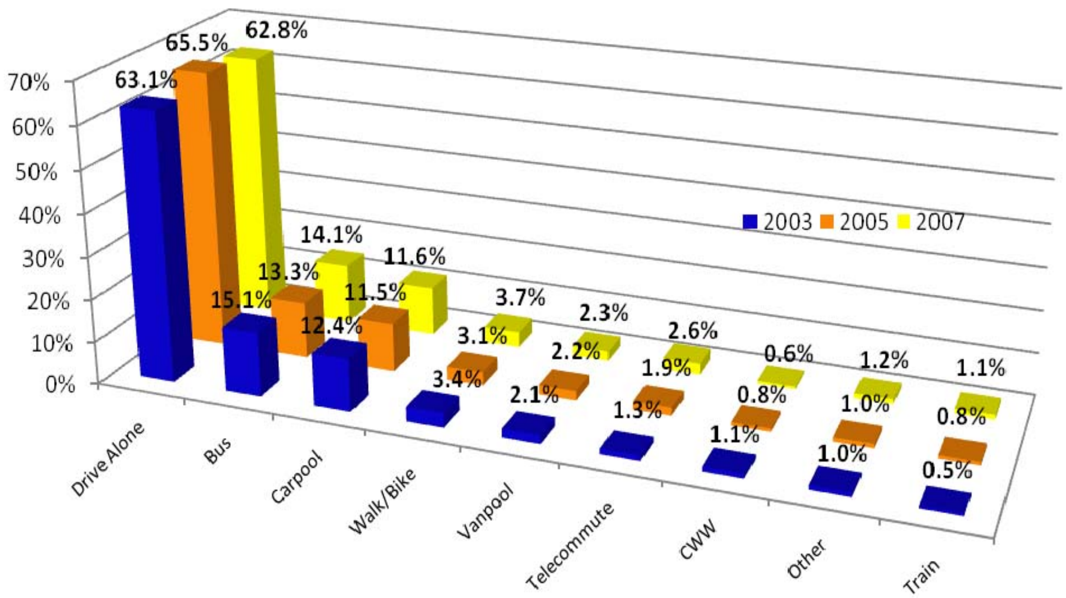

Figure 3.6 Average model split for the 5 counties in the CTR program

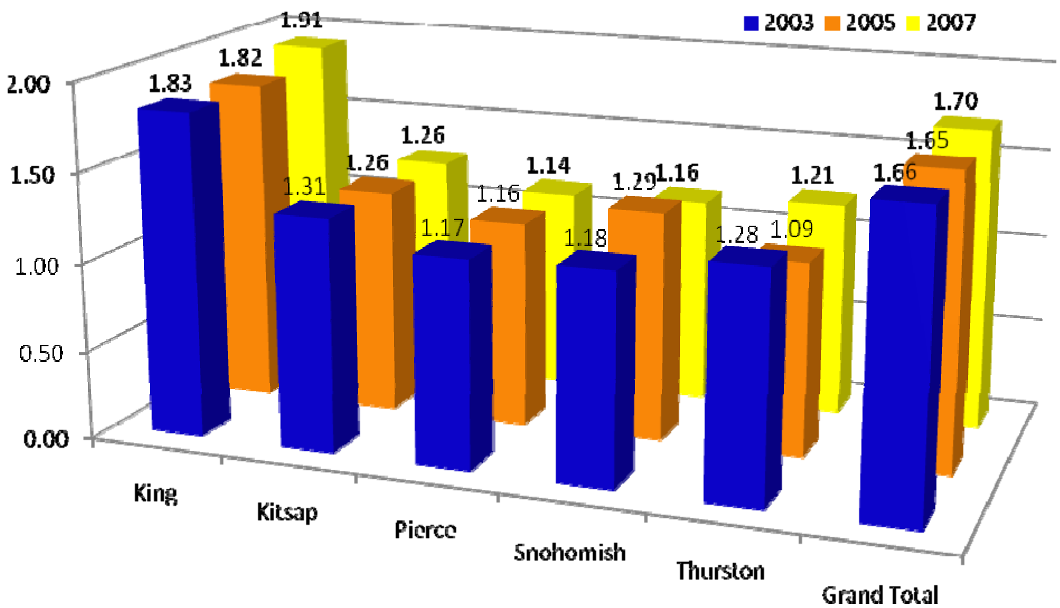

Figure 3.7 AVR comparison for the 5 counties in the CTR program

APPENDIX A: INCENTIVE PLANS FOR RULE 2202

	2002	2003	2004	2005	2006	2007	Total
Auto Service							
Car Wash	40	26	13	2	3	2	86
Fuel	27	19	9	7	1		63
Oil	17	14	7	1	1		40
Other	6	2					8
Repair Certificate	6	6					12
Tune-Up	9	8	1	1			19
Total	*105*	*75*	*30*	*11*	*5*	*2*	*228*
Bicycle Program							
Bicycle Matching	67	17	10	8	3		105
Bicycle Repair Kit	81	43	22	6	6		158
Discount at Local Bike Shops	30	15	10	3	5		63
Helmets Or Locks etc	21	5	2				28
Shoes Or Clothing	58	29	13	8	2		110
Total	*257*	*109*	*57*	*25*	*16*		*464*
Compressed Work Week							
3/36 Compressed Work Week	108	51	39	36	11		245
4/40 Compressed Work Week	152	75	68	69	21	1	386
9/80 Compressed Work Week	111	56	58	53	19	1	298
Total	*371*	*182*	*165*	*158*	*51*	*2*	*929*
Discounted or Free Meals							
Total	*81*	*55*	*31*	*24*	*8*	*9*	*208*
Direct Financial Awards							
2 Person Vehicle	98	50	48	53	24		273
3 Person Vehicle	95	54	46	52	23		270
4 Person Vehicle	97	54	47	48	22		268
5 Person Vehicle	92	48	45	46	20		251
6 Person Vehicle	94	50	44	45	18		251
Bicycling	104	54	47	55	24		284
Bus	146	63	57	64	27		357
Rail/Plane	134	54	49	55	21		313
Telecommuting	29	20	9	9	2		69
Vanpool-7-15	118	46	39	30	15		248
Walking	98	54	43	58	22		275
Total	*1105*	*547*	*474*	*515*	*218*		*2859*

	2002	2003	2004	2005	2006	2007	Total
Flex Time Schedules							
Grace Period	59	19	7	3	1		89
Shift Flexibility	112	64	23	9	3		211
Total	*171*	*83*	*30*	*12*	*4*		*300*
Personalized Commute Assistance							
Assist in Identifying Bicycle and Pedestrian Routes	220	121	137	73	48	1	600
Assist in Identifying Park & Ride Lots	217	131	150	108	55	3	664
Assist in Providing Personalized Transit Routes and Schedule Info.	223	146	166	120	67	3	725
E-mail, Memorandum	85	4					89
Establish an Employee Transportation Advisory Group	20						20
Individual Contact	114	3					117
Organize Carpool / Vanpool Formation Meeting(s)	169	102	107	67	28	2	475
Organize Focus Group(s) or Task Force(s)	86	26	18	7	10		147
Organize Meet Your Match / Zip Code Meeting(s)	38	2					40
Personalized Assistance to Maintain Employee Participation in Commuting Program	228	133	125	79	45		610
Phone Contact	87	2	1				90
Total	*1487*	*670*	*704*	*454*	*253*	*9*	*3577*
Points Program							
Total	*44*	*21*	*11*	*7*	*2*		*85*
Preferential Parking for Ridesharers							
Total	*209*	*106*	*140*	*116*	*71*	*5*	*647*
Prize Drawings							
Cash	87	36	26	18	10		177
Food/Meal	57	9	2	3	1		72
Gift Certificates	188	142	81	38	22	1	472
Services	109	34	18	3			164
Trips	21	4	3				28
Total	*462*	*225*	*130*	*62*	*33*	*1*	*913*

	2002	2003	2004	2005	2006	2007	Total
Parking Charge/Subsidy							
2 Person Vehicle	28	5	1				34
3 Person Vehicle	27	5	1				33
4 Person Vehicle	26	5	1				32
5 Person Vehicle	26	2	1				29
6 Person Vehicle	25	2	1				28
Bicycling	12	1	1				14
Rail/Plane		1					1
Transit	15	4	1				20
Vanpool-7-15	19	4	1				24
Walking	10	2	1				13
Total	*188*	*31*	*9*				*228*
Guaranteed Return Trip							
Company Vehicle	143	65	67	56	31	1	363
Inclement Weather	81	5					86
Personal Emergency Situation	239	139	173	167	84	5	807
Planned Overtime	103	60	38	29	8		238
Program Participants	159	6					165
Rental Car	150	63	42	27	16		298
Supervisor or Fellow Employee	191	106	139	89	44	2	571
Taxi	192	121	144	129	53	1	640
TMA / TMO Provided	34	8	10	4	3	1	60
Unplanned Overtime	222	115	136	117	55	3	648
Total	*1514*	*688*	*749*	*618*	*294*	*13*	*3876*
Rideshare Matching Services							
Employer Based System	164	89	85	60	33	1	432
How and when do you match people as part of a company-wide survey?	203	114	105	65	30		517
How and when do you match people during New Hire Orientation?	219	118	106	79	36		558
How and when do you match people:- On Demand?	222	144	171	138	68	2	745
Meet Your Match Meeting	28	2					30
Regional Commute Management Agency	191	101	114	74	26	1	507
TMA / TMO System	41	19	18	13	5		96
Zip Code List	191	114	97	69	34		505
Zip Code Maps	159	123	100	61	28	1	472
Total	*1418*	*824*	*796*	*559*	*260*	*5*	*3862*

	2002	2003	2004	2005	2006	2007	Total
Time Off with Pay							
Bicycling	9	2					11
Carpooling	12	3					15
Transit	9	3					12
Vanpooling	6	2					8
Walking	5	2					7
Total	*41*	*12*					*53*
Transit Information Center							
N	122	18	2				142
Y	93	76	58	56	20		303
Total	*215*	*94*	*60*	*56*	*20*		*445*
Vanpool program							
Total	*109*	*48*	*46*	*35*	*12*	*1*	*251*
Incentive Plan							
Auto Service	105	75	30	11	5	2	228
Bicycle Program	257	109	57	25	16		464
Compressed Work Week	371	182	165	158	51	2	929
Discounted or Free Meals	81	55	31	24	8	9	208
Direct Financial Awards	1105	547	474	515	218		2859
Flex Time Schedules	171	83	30	12	4		300
Personalized Commute Assistance	1487	670	704	454	253	9	3577
Points Program	44	21	11	7	2		85
Preferential Parking for Ridesharers	209	106	140	116	71	5	647
Prize Drawings	462	225	130	62	33	1	913
Parking Charge/Subsidy	188	31	9				228
Guaranteed Return Trip	1514	688	749	618	294	13	3876
Rideshare Matching Services	1418	824	796	559	260	5	3862
Time Off with Pay	41	12					53
Transit Information Center	215	94	60	56	20		445
vanpool program	109	48	46	35	12	1	251
Total	*7777*	*3770*	*3432*	*2652*	*1247*	*47*	*18925*

APPENDIX B: LIST OF STRATEGIES FOR RULE 2202

The ECRP offset

The Emission Reduction Target (ERT) is calculated, using Employee Emission Reduction Factors provided by AQMD (SCAQMD, 2008), with respect to the worksite's Performance Zone. Then the amount of dollar to offset the ERT, equivalent AQIP fee, is calculated.

Good Faith Effort Determination Elements

Employers must include at least five sub-strategies, but not more than seven, from the following strategies.

1. Marketing Strategies:
   - Attendance at a marketing class, at least annually,
   - Direct communication by CEO, at least annually,
   - Employer newsletter distributed at least quarterly, or a rideshare website where there is an update or notice sent to employees quarterly,
   - Employer rideshare events, at least annually,
   - Flyer, announcements, memo, or letters distributed on a quarterly basis to employees
   - New hire orientation
   - Rideshare bulletin boards

- Rideshare meetings or focus group(s), at least semi-annually, or
- Other marketing strategies that have been approved by the AQMD

2. Basic Support Strategies:

   - Commuter Choice Programs,
   - Flex time schedules,
   - Guaranteed return trip,
   - Personalized commute assistance,
   - Preferential parking for ridesharers,
   - Ride matching services, at least annually,
   - Transit information center, updated quarterly or
   - Other marketing strategies that have been approved by the AQMD

3. Direct Strategies:

   - Auto services,
   - Bicycle program,
   - Carpool program,
   - Compressed work week schedules,
   - Direct financial awards,
   - Discounted or free meals,
   - Employee clean vehicle purchase program,
   - Gift certificates,
   - Off-peak credit program,

- Parking charge or subsidy program,
- Points program,
- Prize drawings, at least quarterly,
- Startup incentive,
- Telecommuting,
- Time off with pay,
- Transit subsidy,
- Vanpool program, or
- Other marketing strategies that have been approved by the AQMD

4. Employer Clean Fleet Vehicles Purchase/Lease Program

When purchasing or leasing passenger cars and light-duty or medium-duty trucks for company vehicle operations in the AQMD, employers shall agree to acquire vehicles that meet CARB guidelines:

- Super low-emission vehicles (SULEV) medium-duty trucks or better,
- ULEV passenger car or better,
- ULEV light-duty trucks or better

5. Mobile Source Diesel PM/NOx Emission Minimization Plan

Employers shall submit a diesel PM/NOx emission minimization plan form provided by the AQMD, if the annual plan submittal includes 1,000 or more window employees and the employer owns or operates mobile diesel equipment that operates exclusively and is located more than 12 consecutive months at that worksite. The following elements must be included, at a minimum, in the annual plan:

- An inventory of mobile diesel equipment,
- Fuel usage, and
- Use of control technologies, if any.
- Sum of the annualized capital costs, operating and maintenance costs do not exceed the cost per number of window employees, reported at (http://www.aqmd.gov/trans/doc/r2202_ecrp_guide.pdf)

AQMD staff will conduct technical feasibility and cost analysis in consultation with employers. Feasible minimization strategies shall be identified as conditions in the approved plan. To conducting the cost analysis, the capital cost will be annualized over the equipment life or apply a 10 year default file with a 4% real interest rate. Capital costs are one-time costs; examples include the price of control equipment, engineering design, and installation, if applicable. Operating and maintenance costs are annual recurring costs and include expenditure on utilities, labor, and material costs associate with control equipment operation.

CHAPTER 4 AN ANALYSIS OF THE HEALTH IMPACTS OF PM AND NO_X EMISSIONS FROM TRAIN OPERATIONS IN THE ALAMEDA CORRIDOR, CA

INTRODUCTION

The economic importance of the contiguous Ports of Los Angeles and Port of Long Beach in Southern California, also known as the San Pedro Bay Ports (SPBP), is difficult to overstate: a 2007 economic impact study finds that these two Ports handle more than 40% of the nation's total containerized cargo import traffic and 24% of the nation's total exports (1). The SPBP also play a critical role in California's economy: a February 2007 trade impact study found that over 886,000 jobs in California are related to international trade activities conducted through the SPBP, which also generated more than $6.7 billion in state and local tax revenue benefits (2). Before slowing down in 2008, container traffic at the ports soared 65% from 2000 to 2007, and it is expected to continue expanding once the economy recovers.

However, this growth and its associated economic benefits are threatened by increasing congestion and pollution generated by the SPBP complex. According to the draft Emission Reduction Plan for Ports and International Goods Movement in California published by the California Air Resources Board (2), roughly one-third of all goods movement emissions statewide are generated in the Los Angeles region. Moreover, on a typical day, more than 400 tons of NOx are emitted from port and goods movement activities in California, which represents 10% of the statewide NOx inventory. Diesel particulate matter (DPM) emissions are also a problem: according to the South Coast Air Quality Management District (SCAQMD)'s MATES II study, diesel PM emissions are responsible for 70% of excess lifetime cancer risk from toxic air pollutants in the region. In addition, SCAQMD's MATES III study reveals that diesel exhaust is the major contributor to air toxics risk (it contributes approximately 84% of total toxic emissions) (3). Although USEPA has determined that DPM is likely to be carcinogenic to humans who inhale it, the available data are not sufficient to develop a confident estimate of cancer potency (4).

Air pollution from the SPBP originates from sources on the ocean-side (ships), within the ports (heavy equipment used for moving containers), and on the land-side (due to heavy reliance on diesel locomotives and large diesel trucks to transport containers to and from the ports). In particular, the major freight corridor that provides access to the port (the Alameda Corridor) comprises a major rail-line, which presently carries 50 trains per day on average, flanked by the I-110 and I-710 freeways, which both carry thousands of trucks per day. These links connect the SPBP complex to roads and railyards, as well as to intermodal and other freight terminals within the corridor itself, near downtown Los Angeles some 22 miles away (as shown in Figure 4.1), and in the inland empire region.

Although the economic benefits of the SPBP are enjoyed by the whole country, the burden of the resulting air pollution is primarily carried by the low income communities who live and work around the I-110 and I-710 freeways, and along the Alameda corridor. As documented in the medical literature (5, 6), these communities are at increased risk of respiratory problems, cancer and even death. Indeed, previous studies suggest that pollutant concentrations near sources are elevated (7) and one recent study finds that PM concentrations increase between 10% and 50% after the passage of a locomotive (8). Given the width of the Alameda Corridor and the volume of freight movement, health impacts of freight operations in the corridor could be substantial.

Estimates of air pollution from trains are often quite crude, however, as they typically rely on fuel use to quantify the amount of pollutants released (9). One key reason is the reluctance of railroad companies to release information about their fleets of locomotives and their railyard operations. Air pollution studies also tend to focus on truck traffic although train operations are one of the largest sources of air pollution in the South Coast Air Basin according to the Air Quality Management District (AQMD): NOx pollution from railroad operations in the South Coast Air Basin exceeds the emissions from the largest 100 oil refineries, power plants, chemical plants and other industrial facilities combined (10). In addition, Rail traffic in the South Coast Air Basin is projected to almost double in the next twenty years (11).

The purpose of this chapter is to present an analysis of 2005 PM and NO_x train emissions in the Alameda Corridor, California, with a focus on estimating the resulting health risks for the neighboring population for different endpoints, such as mortality, hospital admission from asthma, and chronic bronchitis, chronic lung disease and asthma exacerbation; this is our Baseline scenario. In addition, the benefits of switching all locomotives, for both line haul and switching operation, to Tier 2 (Scenario 2) and Tier 3 (Scenario 2) is estimated. A map of the study area is presented in Figure 4.1.

Findings indicate that mortality from PM exposure accounts for the largest health impacts, with health costs in excess of $40 million annually. A shift to Tier 2 locomotives would save approximately half of the annual health costs but the benefits of shifting from Tier 2 to Tier 3 locomotives would be much smaller.

This chapter is organized as follows. In the next section, I briefly review locomotive technology and operation before discussing some key regulations related to rail emissions. The data and methodology for emissions estimation are summarized in Section 3. This is followed by a presentation of the methodology for estimating the dispersion of air pollutants and their health impacts. After discussing the results, I conclude and present some suggestions for future research.

BACKGROUND

The SPBP complex is served by three railway companies: Burlington Northern and Santa Fe (BNSF); Union Pacific (UP); and Pacific Harbor Line (PHL). The first two are Class 1 railroads (they had operating revenues in excess of $250 million) that provide line haul services to the Port; line haul refers to the movement of cargo over long distances; it occurs within the Port as cargo is either picked up for transport across the country or is dropped off for shipment overseas. By contrast, PHL is a much smaller Class 3 railroad that focuses on switching operations in and around the Ports (Class 3 railroads have less than $40 million in annual operating revenues and less than 350 miles of tracks). Switching refers to the assembly and disassembly of trains, sorting of the cars into "fragments" for delivery to terminals, and the short distance hauling of rail cargo. PHL was created in 1998 to take over the Harbor Belt Line (HBL), as the Alameda Corridor was nearing completion.

Almost all locomotives in the U.S. come from two manufacturers: General Electric Transportation Systems and Electro-Motive Diesel (EMD). Their lifetime can reach 40 to 50 years but they are remanufactured periodically to maintain the performance of their engines.

Most locomotives used in the U.S. are diesel-electric. They use a diesel engine to power electric motors that drive the wheels, so the speed of the diesel engine is not related to the speed of the locomotive. Instead, diesel engines in locomotives operate at a series of steady-state points, known as notch settings. Typically, there are eight notches for power settings, one or two idle settings, and one or two settings for dynamic braking. Emission measurements from locomotives are made at each notch setting in terms of an emissions rate, e.g., grams per hour, and average emissions for a locomotive are computed from an assumed duty cycle (representing normal operation in the field). The average emission rate from a locomotive can then be computed based on the relative time spent in each notch setting, either in terms of an emission rate per unit power output, or as an emission rate per unit of fuel consumed.

Line Haul

Locomotives used for line haul operations are typically large, powerful engines of 3,000 to 4,500 hp. Line haul locomotives are operated in the Port by BNSF and UP. Since they transport freight to and from destinations across the country, line haul locomotives that call on the Ports are representative of BNSF and UP's nation-wide fleets.

According to the information provided by BNSF for the baseline emissions inventory study of the Ports, a representative locomotive is the 6-axle GE C44-9W (also known as Dash 9), which has an average of 4,256 horsepower.

Information about the UP fleet was obtained from its website. In 2005, it had approximately 6,500 line haul locomotives, which had an average power rating of 3,655 hp. Most of these locomotives were six-axle units, such as the 4,000-horsepower Electromotive Division (EMD) SD70s (the others were 4-axle units.)

Depending on the size and weight of a specific train and the horsepower capacities of available locomotives, line haul locomotives are typically operated in groups, which often vary between two and five units, with groups of four being fairly common. Multiple locomotives in a train are jointly operated by the train engineer from one of the locomotives.

Switching Locomotives

Locomotives used for switching tend to have smaller engines, typically between 1,200 and 3,000 hp. Older line haul locomotives have often been converted to switch duty as newer line haul locomotives with more horsepower have become available.

Most switching activities within the Port are conducted by PHL, although BNSF and UP are involved in switching at their yards outside of the Ports. In 2005, PHL's fleet consisted of 20 switch engines ranging from 1,200 to 2,000 hp, with an average of 1,823 hp, all of which were powered by 12- or 16-cylinder EMD engines. Early in 2006, PHL, the SPBP concluded an agreement with PHL whereby they will help fund the replacement of all of PHL's locomotives with new low-emission Tier 2 locomotives (defined in the next section). According to PHL, the switch engines used by BNSF and UP are typically powered by EMD engines, with an average power rating of 2,167 hp.

Emissions regulations

Regulation of off-road vehicles (which includes locomotives) is relatively recent. The first locomotive emissions regulations were promulgated by the U.S. EPA in 1998 and came into effect in 2000. These regulations were criticized for failing to provide a reliable methodology for estimating the local emissions impacts from rail traffic (12).

In addition to engine emissions standards, these regulations require that locomotives first built after 1973 meet emissions standards when they are remanufactured. This standard for the remanufacture of existing locomotives is referred to as Tier 0. In addition, these regulations created two standards for newly manufactured locomotives: Tier 1 applies to locomotives manufactured between 2002 and 2004, and Tier 2, applies to locomotives manufactured in 2005 or later.

Increasing awareness of the pollution impacts of locomotives has driven more regulatory activity recently. First, in May 2004, the U.S. EPA introduced new requirements for off-road diesel fuel that will decrease by 99 % the allowable levels of sulfur in fuel used in locomotives. Then, in June 2005, the Air Resources Board (ARB) entered into a pollution reduction agreement with UP and BNSF to achieve a 20% reduction in locomotive diesel particulate matter emissions near railyards (14).

More recently, in March 2008, the U.S. EPA finalized a three part program that will drastically cut emissions from diesel locomotives of all types: it will reduce their PM emissions by as much as 90% and NO_x emissions by as much as 80% when fully implemented (14). This program creates new emission standards for existing locomotives that are remanufactured. In addition, it provisions for clean switch locomotives, and introduces requirements for idle reduction for all locomotives. Finally, it creates Tier 3 emission standards for new locomotives, and beginning in 2015, Tier 4 standards for newly-built engines based on the application of high-efficiency catalytic after-treatment technology (15,17).

DATA AND METHODOLOGY

Emission estimation

Let us distinguish between line haul and switching activities. For modeling emissions from line haul activities, the Alameda Corridor is divided into three segments (north, mid-corridor, and south segment), which are characterized by different speed limits (25, 40, and 25 mph respectively); their length is 2, 10, and 8 miles respectively.

Based on conversations with representatives from PHL and from the Ports, I assume that line haul is primarily done by Tier 1 locomotives, which are in notch five on the mid-corridor segment, and in notch three on the other two segments. I then obtained the corresponding representative emission factors from (12), which is used in the State Implementation Plan to prepare locomotive emission inventories. After that, I calculated PM and NO_x emissions based on four locomotives per train. To find total annual emissions of these pollutants, I assumed an activity of two trains per hour around the clock. This is a slight overestimate for 2005 since the Alameda Corridor Authority recorded an average of 47 trains per day that year (16). A summary of line haul emissions is presented in Table 4.1.

As shown on Figure 4.1, seven railyards are associated with freight transportation from the SPBP, but two of them (the Commerce railyards, which consist of UP Commerce, BNSF Hobart, BNSF Mechanical Sheila and BNSF Commerce Eastern, and the combined ICTF/Dolores railyard) are much larger than the others. The starting point for estimating emissions is a series of recent health risk assessments of major California railyards conducted for the CARB (19). These studies only covered PM and NO_x emissions from the two main railyards in the study area.

To estimate emissions from the five smaller railyards (Watson, Transfer, Mead, Pier A, and Pier B), I assumed that their emissions are proportional to their area, which was measured using Google earth. I then based their emissions of PM and NO_x on those of the Commerce railyard. A summary of railyard emissions is presented in Table 4.2. Note, however, that my dispersion analysis is restricted to "train only" emissions.

Air Dispersion Modeling

Tools

To model the dispersion of various air pollutants, I relied on the CALPUFF modeling system, which is a multi-layer, multi-species non-steady-state puff dispersion modeling system initially designed by Sigma Research Corporation for the California Air Resources Board (CARB). This set of models has been improved over time to meet the needs of various federal agencies. In 1998, the U.S. EPA recommended this modeling system for estimating air quality impacts for the National Ambient Air Quality Standards (NAAQS) and prevention of significant deterioration (PSD) increments. CALPUFF simulates the effects of time- and space-varying meteorological conditions on pollution transport, transformation, and removal; it can be applied for long-range transport and for complex terrain.

For this study, CALPUFF View 5.8 was used because it adds a friendly user interface to CALPUFF. This software has three main components: CALMET, CALPUFF, and CALPOST.

CALMET is a meteorological model that creates hourly temperature and wind fields on a three-dimensional grid corresponding to the modeling domain. It combines the MM5/MM4 model with observational data. CALPUFF is a transport and dispersion model that advects "puffs" of pollutant from specific sources while simulating dispersion and transformations. Finally, CALPOST processes output files from CALPUFF to generate final results.

In addition, CALPUFF View provides a variety of pre-processing programs that interface with 2005 MM5 datasets, which integrate extensive geophysical data (terrain, land use, meteorology). The MM5 (National Center for Atmospheric research/Penn State Mesoscale Model) is a regional weather model used for creating weather forecasts and climate projections (20).

Puff Sampling Function Formulation

The basic equations for finding the contribution of a puff to a receptor are (21)

$$C = \frac{Q}{2\pi\sigma_x\sigma_y} g \exp\left[-d_a^2 / \left(2\sigma_x^2\right) \right] \exp\left[-d_c^2 / \left(2\sigma_y^2\right) \right], \tag{1}$$

$$g = \frac{2}{(2\pi)^{1/2}\sigma_z} \sum_{n=-\infty}^{\infty} \exp\left[-(H_e + 2nh)^2 / (2\sigma_z^2) \right], \tag{2}$$

where:

- C is the ground-level concentration (g/m^3),
- Q is the pollutant mass (grams) in the puff,

- σ_x is the standard deviation (meters) of the Gaussian distribution in the along-wind direction,
- σ_y is the standard deviation (meters) of the Gaussian distribution in the cross-wind direction,
- σ_z is the standard deviation (meters) of the Gaussian distribution in the vertical-wind direction,
- d_a is the distance (meters) from the puff center to the receptor in the along-wind direction,
- d_c is the distance (meters) from the puff center to the receptor in the cross-wind direction,
- g is the vertical term (meters) of the Gaussian equation
- H is the effective height (meters) above the ground of the puff center, and
- h is the mixed-layer height (meters).

The summation in the vertical term, g, accounts for multiple reflections off the mixing lid and the ground. It reduces to the uniformly mixed limit of 1/h for $\sigma_z > 1.6h$. In general, puffs within the convective boundary layer meet this criterion within a few hours after release.

For a horizontally symmetric puff, with $\sigma_x = \sigma_y$, Equation (1) reduces to:

$$C(s) = \frac{Q(s)}{2\pi\sigma_y^2(s)} g(s) \exp\left[-R^2(s) / (2\sigma_y^2(s))\right], \qquad (3)$$

where:

- R is the distance (m) from the center of the puff to the receptor; and
- s is the distance (m) traveled by the puff.

Integrating Equation (3) over the distance of puff travel, *ds*, during the sampling step, *dt*, yields the time average concentration $\overline{C}$:

$$\overline{C} = \frac{1}{ds}\int_{s_0}^{s_0+ds} \frac{Q(s)}{2\pi\sigma_y^2(s)} g(s)\exp\left[-R^2(s)/(2\sigma_y^2(s))\right]ds, \qquad (4)$$

where S_0 is the value of s at the beginning of the sampling step.

Pollutants considered

Two criteria pollutants associated with train operations are considered: DPM (diesel particulate matter) and NO_2 (Nitrogen oxides).

According to ARB studies, DPM emissions are the dominant toxic air contaminants in and around railyards. In California, diesel PM is responsible for approximately 80% of the estimated potential ambient air toxic cancer risks; moreover, residents of the South Coast Air Basin are exposed to higher risks than average in California (18). Exposure to diesel PM is hazardous, particularly to children (their lungs are still developing) and to the elderly with serious health problems. A key concern is that diesel PM particles from locomotives are very small: approximately 92% by mass of these particles have a diameter of less than 2.5 microns (22). As a result, diesel PM can penetrate deep into the lung and enter the bloodstream with a variety of toxics. A number of population-based studies around the world have demonstrated a strong link between elevated PM levels and premature deaths (23, 24, 25), increased hospitalizations for respiratory and cardiovascular causes, asthma and other lower respiratory symptoms, as well as acute bronchitis (26).

According to the U.S. EPA (27), NO_x causes a wide variety of health and environmental impacts as it reacts with different compounds to create harmful derivatives in the family of nitrogen oxides. First, NO_x can react with volatile organic compounds (VOCs) in the presence of sunlight to create ground level ozone. This compound can damage lung tissue and reduce lung function in children, people with lung diseases (such as asthma), and people who work or exercise outside. Ozone can be transported by wind and affect the health of people far from original sources. In addition, ozone can damage vegetation and reduce crop yields. Second, NO_x can react with sulfur dioxide and other airborne substances to form acids which may be deposited as rain, fog, snow or dry particles. This phenomenon can cause pollution hundreds of miles away. It can damage cars, buildings, and causes lakes and streams to become acidic and unsuitable for many fish. Third, NO_x can react with ammonia, moisture, and other compounds to form nitric acid, which can damage the respiratory system and even cause premature death. Finally, nitrate particles and nitrogen dioxide can reduce visibility in urban areas.

In the following, I do not distinguish between NO_x and NO_2 because they are roughly the same for NO_x concentrations below 80 $\mu g/m^3$ (28) and PM_{10} is converted to $PM_{2.5}$ using the conversion factor 0.92 (so 92% of PM_{10} is $PM_{2.5}$).

Health Impacts Analysis

Tools

BenMAP is a tool designed to estimate the economic impacts and the human health effects (such as reductions in premature mortality or chronic respiratory illnesses) associated with changes in ambient air pollution. It was originally created by the U.S. Environmental Protection Agency (U.S. EPA) to analyze large-scale air quality regulations such as the National Ambient Air Quality Standards for Particulate Matter (2006) and the Locomotive Marine Engine Rule (2008).

To estimate human health effects, BenMAP needs an estimate of change in ambient air pollution generated by an air quality model. It then estimates specific health effects (or health endpoints) resulting from changes in pollution concentration using a health impact function, also called a concentration-response (C-R) function in epidemiology, and applies these specific health effects to the exposed population. Conceptually, this process can be summarized by the relationship (29):

Health Effect = Δ(Air Quality) × Health Effect × Exposed Population × Health Baseline Incidence, (5)

where:

- Δ(Air Quality) is the difference between the baseline air pollution level and a change caused by a policy;
- The health effect estimates the percentage change in an adverse health effect due to a one unit change in ambient air pollution, based on epidemiological studies;
- The exposed population is the number of people affected by the air pollution reduction; and
- The health baseline incidence is an estimate of the average number of people that die in a given population over a given period of time.

To calculate the economic value of human health effects, BenMAP multiplies the change in the health effect by an estimate of the economic value per case. The latter can be estimated by different methods. For example, the value of an avoided premature death is generally calculated using the Value of a Statistical Life (VSL), which is the dollar amount people are willing to pay to reduce the risk of premature death by one unit. For other health effects, medical costs of an illness are used. Users can rely on the BenMAP database or they can input their own data.

Air Pollutant Monitoring and Data Modeling

The air pollutant monitoring data for 2005 is based on a database of ambient air pollution data collected from nine EPA standard monitors located in Los Angeles County. The concentrations of $PM_{2.5}$ and NO_x are reported as a 24-hour average calculated as the mean of observations recorded from midnight to 11:59 pm.

To go from point-based monitoring data to estimates of pollutant concentrations in the study area, BenMAP relies on interpolation. Three interpolation methods are available in BenMAP:

1) The Closest Monitor method simply uses the monitor closest to a grid cell's center as its representative value;

2) The Voronoi Neighbor Averaging (VNA) method takes an inverse-distance weighted average of a set of monitors surrounding a grid cell; and

3) The Fixed Radius method averages all of the monitors within a fixed radius.

I explored two different methods: Closest Monitor and VNA. The former is the default in BenMAP and the latter is preferred by EPA for regulatory analyses. The closest monitor method results in step concentrations while the VNA method estimates pollution gradients and provides a relatively smooth surface in densely monitored areas (30).

Baseline Incidence and Concentration-Response Functions

BenMAP provides an extensive list of concentration-response functions (C-R function) for various health end points, such as mortality or asthma. A C-R function (also called a Health Impact Function in epidemiology) measures the change in a health end point resulting from a change in the concentration of a given pollutant. It can be written:

$$f(\Delta Q, I, P) = (1 - \exp(-\beta * \Delta Q)) * I * P, \quad (6)$$

where:

- ΔQ is the estimated change in pollutants concentration;
- I is the incidence, i.e., the baseline mortality incidence rate from the EPA database;
- β is the parameter of the exponential distribution defined by

$$\beta = \frac{\ln(RR)}{\Delta Q} \quad (7)$$

In Equation (7), *RR* is the relative risk (or risk ratio) of the health end point considered. *RR* for an event can be defined as the ratio of the probability of an event occurring in the exposed group versus a non-exposed group. *P* is the potentially affected population. To estimate *P*, I used the 2005 Census block-level data and the PopGrids software to construct specific population grids matching the appropriate age-specific population from the overall population database for Los Angeles County

In this study, the following endpoints were selected for $PM_{2.5}$: mortality and chronic bronchitis; for NO_x, I chose asthma-related hospital admission, chronic lung disease-related hospital admission and asthma exacerbation. Unfortunately, some C-R functions are based on studies for other cities and others were estimated over time periods that do not include year 2005. For example, no asthma exacerbation function was provided either for Los Angeles County or for the year 2005. An alternative is to use available asthma exacerbation functions from 7 U.S. cities for 2008 (31). The next section discusses C-R functions used in this study.

Mortality for PM

The health impact function for premature mortality from $PM_{2.5}$ is based on a study by (32) of the spatial Analysis of Air Pollution and Mortality in Los Angeles that examined 22,905 subjects from the American Cancer Society (ACS) panel. They found a relative risk (*RR*) of 1.17 for a 10 $\mu g/m^3$ change in average annual $PM_{2.5}$ exposure.

An alternative is a pooled C-R function suggested in the 2007 Air Quality Management Plan for the South Coast Air Quality Management District. The pooled C-R function gives equal weight to three $PM_{2.5}$-related mortality studies, (25), (32) and (33). For this pooled C-R function, the *RR* is 1.11 for people aged 30 years and older for a 10 $\mu g/m^3$ change in average annual $PM_{2.5}$ exposure.

A 2006 study by Woodruff et al. examined mortality associated with $PM_{2.5}$ for infants aged between one and 12 months, who lived within five miles of a $PM_{2.5}$ monitor between 1999 and 2000 (35). They report a *RR* of 1.07 for a 10 $\mu g/m^3$ change in average annual $PM_{2.5}$ exposure.

Hospital Admission from Chronic Bronchitis for PM

Another health outcome considered is chronic bronchitis, a progressive chronic lung disease characterized by mucus in the lungs, which causes persistent wet coughing, and disrupts oxygen exchange between air and blood in the lungs for severely affected individuals (35). The *RR* for chronic bronchitis is derived from (36), which is the only available chronic bronchitis study that examines directly the impact of $PM_{2.5}$. The corresponding *RR* is 1.14 for a 10 μg/m^3 change in annual average $PM_{2.5}$ concentration.

Hospital Admission from different endpoints for NO_x

Hospitalization information from different endpoints, such as asthma or chronic lung disease, was obtained from the National Center for Health Statistics' (NCHS) National Hospital Discharge Survey (NHDS) (BenMAP Appendices, p. 243). The survey collects data on short-stay (less than 30 days) hospitals, patient characteristics, diagnostics, and medical procedures.

The C-R functions for asthma-related and chronic lung disease-related hospital admission are already included in the BenMAP health impact database. There are different β coefficients for different age-groups for the same endpoint. For example, the C-R function for asthma-related hospital admissions, which is derived from (37), has different β coefficients for two different age-groups: for people between 0 and 29 β=0.0024 and for people 30 and older β=0.0014. Moreover, the C-R function for chronic lung disease-related hospital admission for people 65 and older is derived from (38).

Asthma Exacerbation for NO_x

The asthma exacerbation health impact functions are based on acute respiratory health effects of air pollution on children with asthma in U.S. inner cities (31). The study analyzed data from 861 children aged 5 to 12 years old with asthma in Boston, the Bronx, Chicago, Dallas, New York, Seattle and Tucson. I selected the following endpoints for asthma exacerbation: missed school day, night-time asthma, slow play and more than one symptom. These functions come with BenMAP.

Health Valuation Functions

Health valuation functions available in BenMAP give a value to each case for a specific health effect.

Mortality

The appropriate method for valuing reductions in premature mortality risk is still being discussed by economists and public policy analysts. They quibble over the appropriate discount rate and whether factors, such as age or the quality of life should be included in the estimation process. BenMAP offers a variety of options for premature mortality. The Value of a Statistical Life (VSL) has a mean value of $6.3 million; it was obtained by fitting the distribution of 26 VSL estimates that appear in the economics literature and that the EPA frequently uses in Regulatory Impact Analyses (RIAs). Because the VSL-based unit value does not depend on age at death or the quality of life, it can be applied to all premature deaths.

In addition, BenMAP includes three alternatives based on recent work by (39) and (40). These studies have a mean value of $5.5 million (2000$), but with different distributions: normal, uniform, triangular, and beta. However in this study, we use the VSL based on a range from $1 million to $10 million with a normal distribution because of the population distribution assumption. The Consumer Price Index (CPI) for medical care was used to convert 2000 dollars to 2005 dollars (2000 CPI = 260.8 and 2005 CPI = 323.2; see (41)).

Chronic Bronchitis

PM-related chronic bronchitis is expected to last from the initial onset of the illness throughout the rest of an individual's life. In BenMAP, the "Chronic Bronchitis" endpoint group contains six COI (Cost of Illness) and one WTP (willingness to pay) functions. The (COI) functions are derived from estimates of annual medical costs and lost earnings (42); they do not include the cost of pain and suffering in the valuation estimation. The WTP to avoid chronic bronchitis incorporates the present discounted value of a potentially long stream of costs (e.g., medical expenditures and lost earnings) as well as the WTP to avoid the pain and suffering associated with the illness.

SCENARIOS

I compare health impacts for three scenarios. The baseline scenario assumes that all locomotives that operate in the Alameda Corridor belong to Tier 1. Scenario 2 consists in shifting from Tier 1 to Tier 2 locomotives and scenario 3 replaces all Tier 2 with Tier 3 locomotives, for both switching and line haul.

For the maximum of the seasonal average pollution, Table 4.1 also provides the percentage change from the baseline to Scenario 2 and from the baseline to Scenario 3. We note that Scenario 2 cuts PM emissions by over 50%, but NO_x emissions by only approximately 26%; by contrast, Scenario 3 achieves a relatively larger reduction of NOx emissions compared to PM emissions. These percentage changes in emissions are derived from 2008 EPA emission standard for locomotives.

RESULTS

Dispersion Analysis

Estimates of the dispersion analysis for both PM and NO_x are summarized in Table 4.3 and in Figure 4.2 to Figure 4.8.

From Table 4.3, we see that summer has the highest worst day maximum for both NO_x and $PM_{2.5}$, (74.97 and1.96 ug/m^3 respectively), followed closely by winter; fall has the lowest worst day maximum. By contrast, fall has the highest seasonal average maximum (7.99 and 0.88 ug/m^3 respectively), again followed by winter. Seasonal differences are entirely due to meteorological conditions as train activity is assumed constant throughout the year. As expected, these differences persist for the different scenarios analyzed.

I also find that pollutant concentrations from line haul activities are smaller than those from switching. This is illustrated by Figure 4.2, where the worst day maximum 24 hour concentration of NO_x from line haul operations for the first week of summer 2005 is 4.89 µg/m^3, or about half the maximum concentration from switching activities (8.69 µg/m^3). These result hold for PM and for each of the seasons investigated. Let us now consider specific results for both PM and NO_x.

Particulate Matter (PM)

In addition to Table 4.3, results for PM emissions (from both line haul and railyard operations) are presented in Figure 4.3 and Figure 4.4, and in Table 4.4. They show that the extent of PM pollution is larger in the winter, but not uniformly so because of the combined effect of the built environment and wind speeds. To put these results in context, note that the current California Ambient Air Quality Standards for the 24-hour average concentration for $PM_{2.5}$ is 35 $\mu g/m^3$ (43), which is the relevant threshold here given that 92% of PM particulates emitted by locomotives are smaller than 2.5 µm. The PM concentrations we found are well below the Air Quality Standard, but it does not mean that they are safe. Indeed, according to the WHO (44), adverse health effects associated with $PM_{2.5}$ have been demonstrated for background concentrations ranging between 3 and 5 $\mu g/m^3$. In addition, PM concentrations from train operations are combined with PM emissions from other sources such as drayage trucks that transport containers to and from the ports and industrial polluters, but their contribution can only be described as incremental.

Table 4.4 summarizes socio-economic characteristics of the populations exposed to the worst day maximum 24-hour average level of PM_{10} (see Table 4.3.) from train operations of each season (for level of PM ≥ 0.01 $\mu g/m^3$). These populations include large groups of minorities, including approximately 40% of Hispanics and between 7.5 and 9.8 percent of African Americans, whose weighted household income is below the California average. Furthermore, close to 40 percent of these residents are 21 years old or less, and close to 8 percent are 65 or older; we mention these two groups as they are often more susceptible to pollution than the rest of the population.

Nitrous Oxides (NO_x)

Seasonal results for both line haul and railyard operations are presented in Figure 4.5 and Figure 4.6, as well as in Table 4.3 and Table 4.5. From Figure 4.5 and Figure 4.6, we see clear seasonal differences. In the fall, the whole Alameda corridor is exposed to NO_x, although these concentrations are below EPA standards. By contrast, in the summer, a smaller area is exposed to NO_x but concentrations are higher. However, even during the summer, a sizable population is exposed to relatively high 24-hour average concentrations of NO_x, which should be cause for concern.

Although the EPA does not provide guidelines for the 24-hour average concentration of NO_x, WHO recommends that the maximum annual mean concentration of NO_2 be below 40 $\mu g/m^3$; in addition, the recommended maximum one-hour mean concentration for NO_2 is 339 $\mu g/m^3$. Yet between 5,000 people (in the spring), 18,000 people (in the summer) and 28,000 people (in the winter) are exposed to 24-hour average concentrations of NO_x above 40 $\mu g/m^3$ (Table 4.5). The percentage of population at risk (children under 5 and adults over 65) is slightly lower than for PM, but as above, the bulk of the populations exposed are Hispanics and to a lesser degree, African Americans, with a median household income between $28,084 and $30,913 based on 2000 Census data.

Health Impact Results

Table 4.6 reports the worst day maximum and the maximum of the seasonal average pollution concentrations for both PM and NO_x for the baseline and the two scenarios considered. It also shows comparison between two interpolation methods, closest monitor and VNA, for seasonal averages. I use the seasonal average concentration for estimating health impacts because we are interested in chronic health impacts resulting from typical daily conditions (see Figure 4.7 and Figure 4.8 for dispersion of seasonal average maximum for fall season for PM_{10} and NOx, respectively). The maximum seasonal average difference between closest monitor and VNA ranges from 24% to 41% for NO_x (26% to 43% for PM), which is substantial. However, differences between scenarios are smaller.

Let us first start with results for NO_x. For this pollutant, I considered six different health outcomes, based on the health impact functions available in BenMAP and in the literature. Two of these health impact functions were estimated at the Los Angeles County level: hospital admissions from asthma and chronic lung diseases. At the level of pollutants considered, however, they yielded only low damages compared to the other health impacts (under 5 cases and $60,000 in costs for all scenarios considered) so details of their estimation is omitted.

Results for the other four health outcomes were estimated based on data developed in studies that covered Boston, Chicago, Dallas, New York, Seattle, and Tucson. They focus on asthma exacerbation in children aged 5 to 12 years old; four conditions are considered: missed school days, nighttime asthma, slow play, and one or more symptoms. As shown in Table 4.6, the social costs under the baseline scenario reach 7.5 million dollars per year. Although the number of people affected is large, going from Tier 1 to Tier 2 locomotives (Scenario 2) would save approximately 2 million dollars per year, while switching from Tier 2 to Tier 3 (Scenario 3) locomotives would save only an additional $0.3 million (=$5.6-$5.3) annually, so this last move may not be cost effective.

Results for PM are summarized in Table 4.7 and illustrated on Figure 4.9 and Figure 4.10. The health outcomes considered include mortality from all causes related to PM exposure and chronic bronchitis. Not all age groups are represented because of the unavailability of health impact functions. I also analyzed mortality for infants (children younger than 1 year) but the number of cases and the corresponding dollar amounts were low so they are not reported here. As for NO_x, we observe strong seasonal variations, which are entirely due to climatic conditions. Fall is the worst season, followed by summer and winter (which are fairly similar); by contrast, spring has the lowest health impacts not only for mortality but also for chronic bronchitis linked to PM exposure.

As expected from the emission estimates, Figure 4.9 and Figure 4.10 show that the mortality cases resulting from PM exposure are located around the two major railyards (Commerce and ICTF/Dolores), but also in one area of the Alameda corridor where land use and prevailing wind patterns tend to concentrate pollution.

A look at Table 4.7 shows that the main health income is mortality from PM: it results in approximately 6 cases per year with a corresponding cost in excess of $40 million; elderly people (65 years old and over) are primarily affected with 3.20 to 3.37 cases per year. Shifting from Tier 1 to Tier 2 (Scenario 2) locomotives would cut health costs in half, whereas upgrading from Tier 2 to Tier 3 (Scenario 3) would save a much smaller additional amount (~$2 million).

Unfortunately, it is difficult to compare our results with those of the ARB railyard studies (17, 18, and 19) because they report their results using cancer risk isopleths for risk levels ranging between 10 and 500 in a million, and these maps do not show population density. In addition, their cancer risk estimates are based on all activities in the railyards, not just train activities.

CONCLUDING REMARKS

This chapter makes methodological and practical contributions. This is the first attempt at estimating the emission, the dispersion, and the health impacts of PM and NO_x train emissions in a major transportation corridor. According to the U.S. EPA scientists who are developing BenMAP, this is also the first application of BenMAP at the county level. However, this study has some limitations because only a limited set of C-R functions were available and they did not cover all age groups. I find seasonal effects and complex spatial dispersion patterns in the dispersion of both PM and NO_x, which result from changing wind directions; the choice of interpolation functions (closest monitor or Voronoi has only a minor impact on the results). Based on available functions, health impacts from PM are significantly larger than those of NOx. Although estimated PM concentrations from train operations in 2005 are well below international health standards, they result in annual damages that exceed $40 million from excess mortality cases alone. This is five times larger than estimated NOx health impacts, but note that these include only four health outcomes for a small subset of the population (children aged 5 to 12). My analyses also show that switching from Tier 1 to Tier 2 locomotives would cut health impacts in half. Switching from Tier 2 to Tier 3 (Scenario 3) locomotives would only produce approximately one tenth additional health benefits. Future research could be extended to other health outcomes and more subsets of the population provided the necessary health impact functions are available.

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Table 4.1 Estimated line haul emissions in the study area

				PM_{10}		NO_x	
Segment	**Segment Length (mi)**	**Speed Limit (mph)**	**Assumed Notch**	**Emission Factor (g/hr)**	**Emissions (metric ton/year)**	**Emission Factor (g/hr)**	**Emissions (metric ton/year)**
1	8	25	3	427.0	9.6	7267.0	163.0
2	10	40	5	348.0	6.1	25584.0	448.2
3	2	25	3	427.0	2.4	7267.0	40.7
Total	20	NA	NA	NA	18.1	NA	651.9

Notes: Each train is assumed to consist of four Tier1 locomotives; each train is assumed to travel at the speed limit for each section. Moreover, we assume two trains per hour around the clock, every day of the year. Our calculations ignore the grade in the Alameda corridor.

Table 4.2 Estimated railyard emissions in the study area

Railyard	Area (acres)	PM_{10} Trains only (metric ton/year)	PM_{10} All activities (metric ton/year)	NO_x Trains only (metric ton/year)	NO_x All activities (metric ton/year)
Combined Commerce (UP Commerce, BNSF Hobart, BNSF Eastern, and BNSF Sheila)	530	13.0	41.2	113.9	797.3
ICTF/Dolores (UP)	233	1.2	8.1	50.1	351.0
Wilmington-Watson (BNSF)	17	0.4	1.3	3.6	25.2
Transfer (PHL)	6	0.1	0.3	1.2	8.4
UP Mead (PHL)	10	0.3	1.0	2.2	15.4
Pier A (PHL)	23	0.6	1.9	5.0	35.0
Pier B (PHL)	14	0.3	1.0	3.1	21.7

Notes:
PM emissions for the combined Commerce railyards and for ICTF/Dolores are respectively from (17) and (18). PM emissions for other yards were assumed to have the same rate of emissions per unit area and per unit time as Commerce Eastern. Railyard areas were measured with Google Earth.
NO_x emissions for ICTF/Dolores are from (18). Other yards were assumed to have the same rate of NO_x emissions per unit area and per unit of time as ICTF/Dolores.
"All activities" includes all locomotive emissions, as well as emissions from drayage trucks, cargo handling equipment, as well as heavy equipment and transport refrigeration units (19).

Table 4.3 Seasonal pollutant concentrations (from CalPUFF)

		Worst day maximum		Seasonal average maximum		% change from baseline (seasonal average max)	
		NO_x (µg/m^3)	$PM_{2.5}$ (µg/m^3)	NO_x (µg/m^3)	$PM_{2.5}$ (µg/m^3)	NO_x	$PM_{2.5}$
Winter	Baseline	73.23	1.68	6.48	0.70		
	Scenario2	54.44	0.84	4.78	0.35	-26.3%	-50.3%
	Scenario3	54.43	0.65	3.13	0.27	-51.8%	-61.1%
Spring	Baseline	42.99	1.60	4.35	0.46		
	Scenario2	31.94	0.80	3.21	0.23	-26.3%	-50.3%
	Scenario3	31.94	0.62	2.60	0.18	-40.3%	-61.1%
Summer	Baseline	74.97	1.96	4.63	0.49		
	Scenario2	55.70	0.98	3.41	0.24	-26.4%	-50.3%
	Scenario3	55.69	0.76	2.74	0.19	-40.9%	-61.2%
Fall	Baseline	27.67	1.86	7.99	0.88		
	Scenario2	20.56	0.93	5.88	0.44	-26.3%	-50.3%
	Scenario3	20.43	0.72	3.85	0.34	-51.8%	-61.1%

Table 4.4 Characteristics of the population impacted by PM emissions

Category	Winter	Spring	Summer	Fall
Total Population (in thousands)	1,338	471	552	1,247
Percentage of female residents	50.6%	50.6%	50.4%	50.4%
Age				
Under 5	9.8%	9.2%	9.5%	9.6%
5 to 21	31.5%	30.2%	30.8%	30.8%
65 and up	7.6%	8.1%	7.6%	7.6%
Ethnicity				
African American	9.8%	9.1%	7.5%	8.4%
Hispanic	39.6%	38.1%	40.1%	39.3%
Weighted Household Income	$34,692	$38,023	$36,100	$37,298

Notes. These results are for the worst day of each season. Numbers above are based on the 2000 Census. They are upper bounds because they include all of a census block even if only one part of it is polluted at the concentration indicated above.

Table 4.5 Characteristics of the population impacted by NO_x emissions

Category	Winter		Spring		Summer		Fall	
	≥3 μg/m^3	≥40 μg/m^3	≥3 μg/m^3	≥40 μg/m^3	≥3 μg/m^3	≥40 μg/m^3	≥3 μg/m^3	≥40 μg/m^3
Total Population (in thousands)	1,312	28	404	5	403	17	920	NA
Gender								
Female	50.8%	50.6%	50.6%	49.8%	50.6%	50.6%	50.4%	NA
Age								
Under 5	10.2%	11.1%	9.8%	11.6%	9.8%	11.5%	9.9%	NA
5 to 21	32.8%	36.8%	32.4%	35.2%	31.9%	36.4%	32.0%	NA
65 and up	6.6%	4.2%	7.0%	4.2%	7.1%	3.9%	6.9%	NA
Ethnicity								
African American	13.6%	6.9%	10.3%	6.4%	7.5%	7.3%	10.4%	NA
Hispanic	40.0%	45.9%	40.7%	46.5%	42.4%	45.8%	40.1%	NA
Weighted Household Income	$32,803	$28,208	$35,521	$30,913	$34,922	$28,084	$35,067	NA

Notes. These results are for the worst day of each season. Numbers above are based on the 2000 Census. They are imperfect estimates because they include all of a census block even if only one part of it is polluted at the concentration indicated above.

Table 4.6 Some seasonal health impacts from NO_x exposure

Period	Scenario	Missed School Days CM	Missed School Days VNA	Nighttime Asthma CM	Nighttime Asthma VNA	One or more Symptoms CM	One or more Symptoms VNA	Slow Play CM	Slow Play VNA	Total Value ($2005) CM	Total Value ($2005) VNA
Winter	Baseline	$0.24 (1,229)	$0.24 (1,249)	$0.45 (2,339)	$0.46 (2,370)	$0.65 (3,375)	$0.66 (3,421)	$0.66 (3,389)	$0.67 (3,434)	**$2.00 (10,332)**	**$2.03 (10,471)**
	Scenario2	$0.18 (913)	$0.18 (925)	$0.34 (1,735)	$0.34 (1,758)	$0.48 (2,504)	$0.49 (2,536)	$0.49 (2,515)	$0.49 (2,548)	**$1.48 (7,666)**	**$1.50 (7,767)**
	Scenario3	$0.17 (861)	$0.17 (872)	$0.32 (1,637)	$0.32 (1,657)	$0.46 (2,362)	$0.46 (2,391)	$0.46 (2,372)	$0.47 (2,402)	**$1.40 (7,233)**	**$1.42 (7,322)**
Spring	Baseline	$0.17 (861)	$0.17 (870)	$0.32 (1,637)	$0.32 (1,653)	$0.46 (2,361)	$0.46 (2,385)	$0.46 (2,372)	$0.46 (2,396)	**$1.40 (7,231)**	**$1.41 (7,304)**
	Scenario2	$0.12 (639)	$0.12 (645)	$0.24 (1,214)	$0.24 (1,226)	$0.34 (1,751)	$0.34 (1,769)	$0.34 (1,759)	$0.34 (1,777)	**$1.04 (5,362)**	**$1.05 (5,418)**
	Scenario3	$0.12 (604)	$0.12 (609)	$0.22 (1,148)	$0.22 (1,158)	$0.32 (1,655)	$0.32 (1,669)	$0.32 (1,663)	$0.32 (1,677)	**$0.98 (5,070)**	**$0.99 (5,113)**
Summer	Baseline	$0.19 (976)	$0.19 (986)	$0.36 (1,856)	$0.36 (1,875)	$0.52 (2,678)	$0.52 (2,705)	$0.52 (2,689)	$0.53 (2,717)	**$1.59 (8,199)**	**$1.60 (8,284)**
	Scenario2	$0.14 (725)	$0.14 (732)	$0.27 (1,377)	$0.27 (1,391)	$0.38 (1,987)	$0.39 (2,006)	$0.39 (1,996)	$0.39 (2,015)	**$1.18 (6,085)**	**$1.19 (6,144)**
	Scenario3	$0.13 (685)	$0.13 (691)	$0.25 (1,301)	$0.25 (1,312)	$0.36 (1,876)	$0.37 (1,893)	$0.37 (1,885)	$0.37 (1,902)	**$1.11 (5,747)**	**$1.12 (5,798)**
Fall	Baseline	$0.30 (1,568)	$0.31 (1,586)	$0.58 (2,986)	$0.58 (3,020)	$0.83 (4,310)	$0.84 (4,360)	$0.84 (4,326)	$0.85 (4,376)	**$2.55 (13,189)**	**$2.58 (13,342)**
	Scenario2	$0.23 (1,165)	$0.23 (1,178)	$0.43 (2,216)	$0.43 (2,241)	$0.62 (3,198)	$0.63 (3,234)	$0.62 (3,211)	$0.63 (3,247)	**$1.90 (9,790)**	**$1.92 (9,900)**
	Scenario3	$0.21 (1,098)	$0.21 (1,109)	$0.40 (2,088)	$0.41 (2,109)	$0.58 (3,013)	$0.59 (3,043)	$0.59 (3,026)	$0.59 (3,056)	**$1.79 (9,225)**	**$1.80 (9,317)**
Year 2005	Baseline	$0.90 (4,634)	$0.91 (4,687)	$1.71 (8,817)	$1.73 (8,919)	$2.46 (12,725)	$2.49 (12,725)	$2.47 (12,871)	$2.50 (12,923)	**$7.54 (38,952)**	**$7.63 (39,400)**
	Scenario2	$0.67 (3,441)	$0.67 (3,480)	$1.27 (6,543)	$1.28 (6,617)	$1.83 (9,439)	$1.85 (9,545)	$1.84 (9,481)	$1.86 (9,588)	**$5.60 (28,903)**	**$5.66 (29,229)**
	Scenario3	$0.63 (3,248)	$0.64 (3,280)	$1.20 (6,174)	$1.21 (6,236)	$1.72 (8,907)	$1.74 (8,996)	$1.73 (8,947)	$1.75 (9,037)	**$5.28 (27,275)**	**$5.33 (27,550)**

Notes. These health impacts are for children aged 5 to 12; they are based on multi-city studies. All dollar amounts are in million of 2005 dollars. A number in parentheses underneath a dollar amount is the corresponding number of cases. Although they are incomplete, the health results for NO_x emitted by train operation suggest that its impacts are substantial but limited. Total values may appear slightly off because the table shows only two significant digits.

Table 4.7 Some seasonal health impacts from $PM_{2.5}$ exposure

Period	Scenario	$PM_{2.5}$ Mortality (Age: 30-65) CM	$PM_{2.5}$ Mortality (Age: 30-65) VNA	$PM_{2.5}$ Mortality (Age: 65 and over) CM	$PM_{2.5}$ Mortality (Age: 65 and over) VNA	Chronic Bronchitis CM	Chronic Bronchitis VNA	Total Value (2005$) CM	Total Value (2005$) VNA
Winter	Baseline	$4.47 (0.66)	$4.67 (0.69)	$5.15 (0.76)	$5.40 (0.79)	$0.22 (0.68)	$0.23 (0.71)	**$9.84**	**$10.31**
	Scenario2	$2.19 (0.32)	$2.45 (0.36)	$2.51 (0.37)	$2.86 (0.42)	$0.11 (0.34)	$0.12 (0.37)	**$4.81**	**$5.43**
	Scenario3	$1.98 (0.29)	$2.22 (0.33)	$2.25 (0.33)	$2.61 (0.38)	$0.10 (0.30)	$0.11 (0.34)	**$4.34**	**$4.95**
Spring	Baseline	$3.45 (0.51)	$3.61 (0.53)	$4.07 (0.60)	$4.32 (0.63)	$0.17 (0.53)	$0.18 (0.55)	**$7.69**	**$8.11**
	Scenario2	$1.67 (0.24)	$1.93 (0.28)	$1.93 (0.28)	$2.32 (0.34)	$0.08 (0.26)	$0.10 (0.29)	**$3.68**	**$4.35**
	Scenario3	$1.50 (0.22)	$1.77 (0.26)	$1.73 (0.25)	$2.14 (0.31)	$0.08 (0.23)	$0.09 (0.27)	**$3.31**	**$4.00**
Summer	Baseline	$4.21 (0.62)	$4.53 (0.67)	$5.16 (0.76)	$5.40 (0.81)	$0.21 (0.64)	$0.23 (0.69)	**$9.59**	**$10.16**
	Scenario2	$2.10 (0.31)	$2.34 (0.34)	$2.51 (0.37)	$2.86 (0.42)	$0.11 (0.32)	$0.12 (0.36)	**$4.72**	**$5.32**
	Scenario3	$1.88 (0.28)	$2.13 (0.31)	$2.25 (0.33)	$2.61 (0.38)	$0.09 (0.29)	$0.11 (0.32)	**$4.22**	**$4.85**
Fall	Baseline	$6.40 (0.94)	$6.69 (0.98)	$7.43 (1.09)	$7.75 (1.14)	$0.32 (0.97)	$0.33 (1.02)	**$14.14**	**$14.77**
	Scenario2	$3.17 (0.47)	$3.32 (0.49)	$3.65 (0.54)	$3.89 (0.57)	$0.16 (0.48)	$0.17 (0.51)	**$6.98**	**$7.38**
	Scenario3	$2.82 (0.41)	$3.02 (0.44)	$3.22 (0.47)	$3.55 (0.52)	$0.14 (0.43)	$0.15 (0.46)	**$6.18**	**$6.71**
Year 2005	Baseline	$18.52 (2.72)	$19.51 (2.87)	$21.80 (3.20)	$22.98 (3.37)	$0.93 (2.83)	$0.98 (2.97)	**$41.25**	**$43.47**
	Scenario2	$9.12 (1.34)	$10.04 (1.48)	$10.60 (1.56)	$11.94 (1.75)	$0.46 (1.39)	$0.50 (1.53)	**$20.18**	**$22.48**
	Scenario3	$8.18 (1.20)	$9.15 (1.34)	$9.46 (1.39)	$10.91 (1.60)	$0.41 (1.25)	$0.46 (1.39)	**$18.05**	**$20.52**

Notes. These health impacts are based on multi-city studies. All dollar amounts are in million of 2005 dollars. A number in parentheses underneath a dollar amount is the corresponding number of cases. Total values may appear slightly off because the table shows only two significant digits.

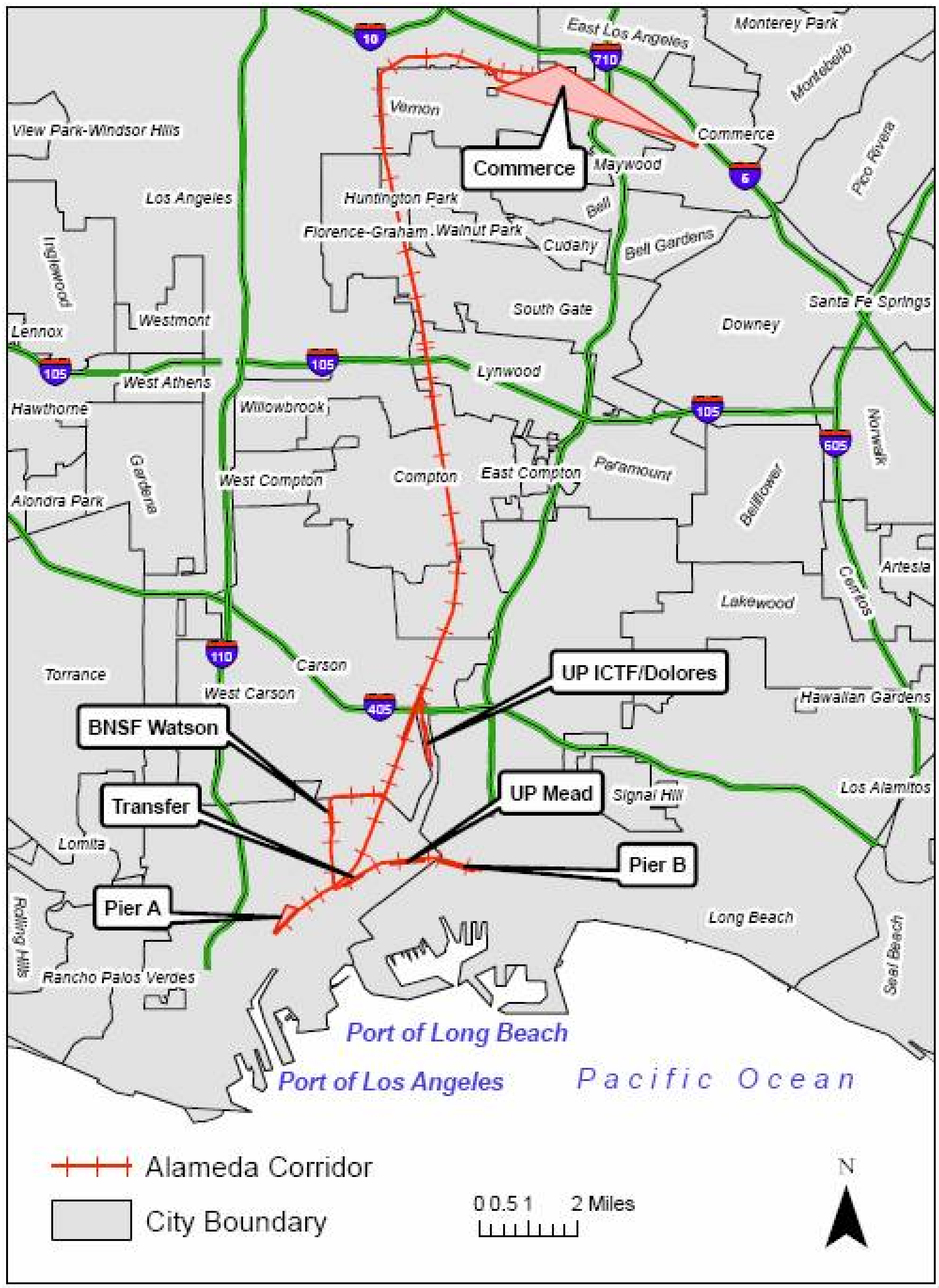

Figure 4.1 Study Area

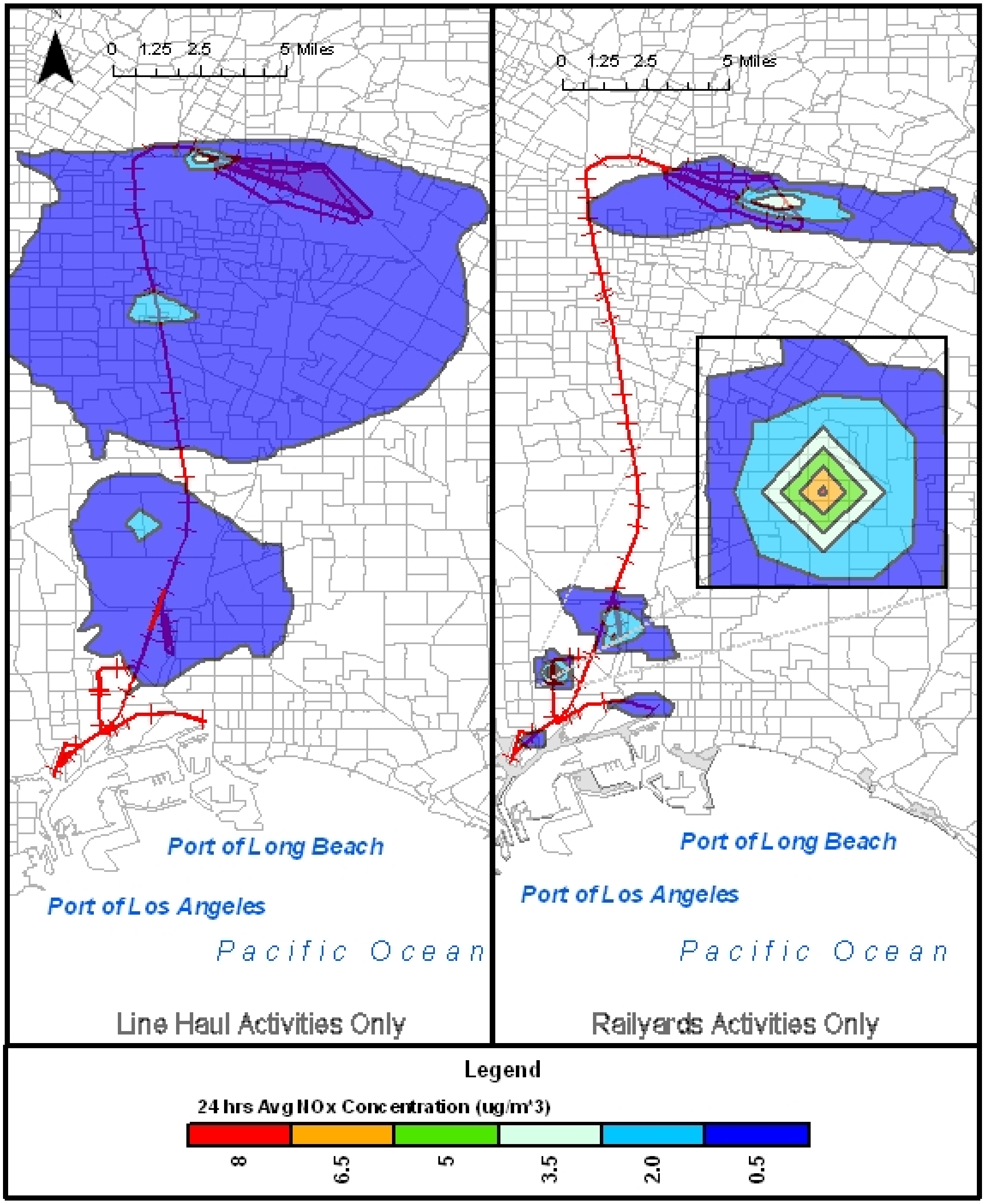

Figure 4.2 Comparison of 24-hour NO_x average concentrations.

Note: These concentrations were obtained for the first week of summer. They are representative of average concentrations resulting from both line haul and railyards operations.

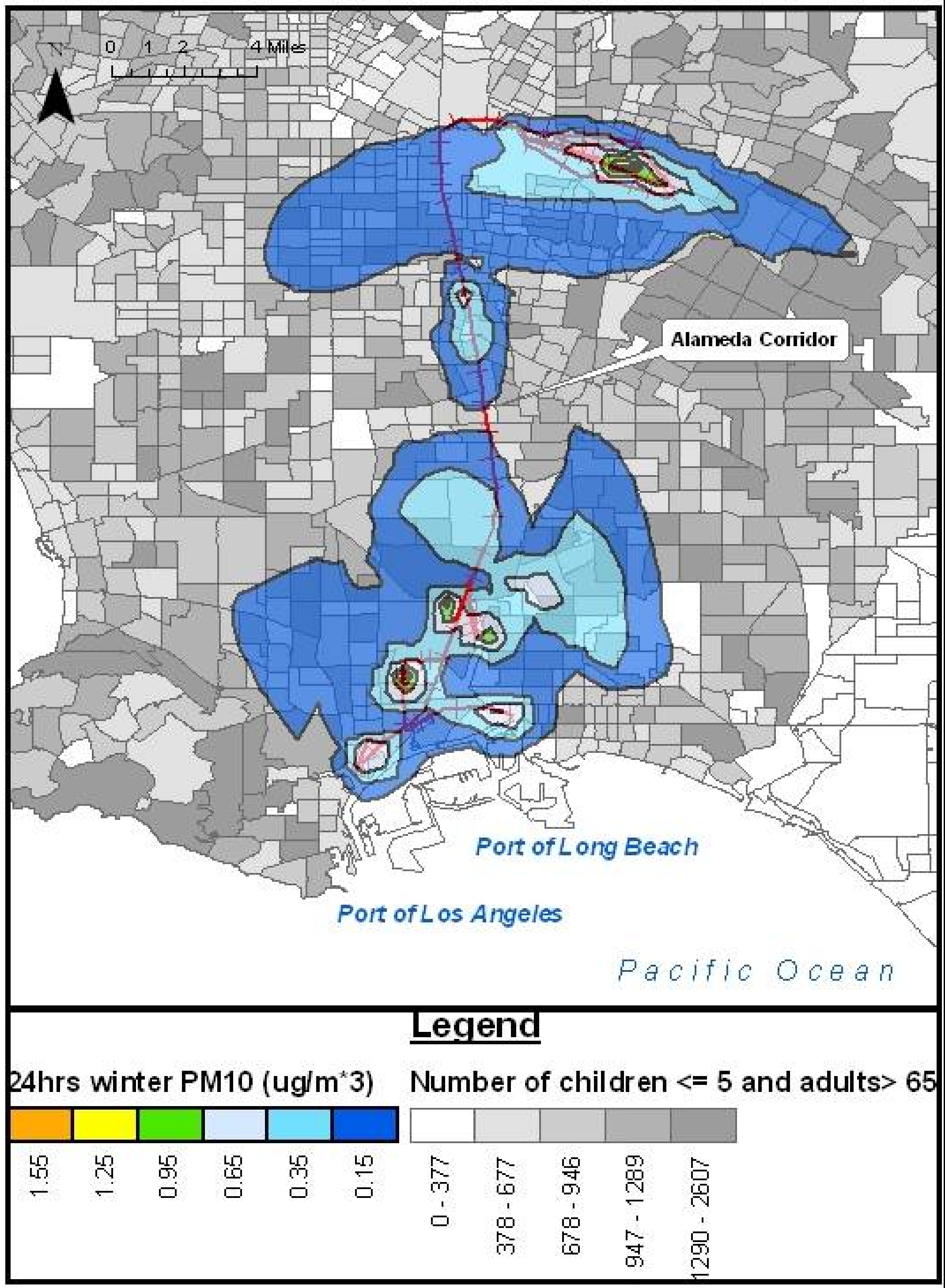

Figure 4.3 Worst winter day PM exposure for children ≤5 and adults >65.

Note: the maximum 24-hour average winter concentration of PM is 1.82 μg/m^3.

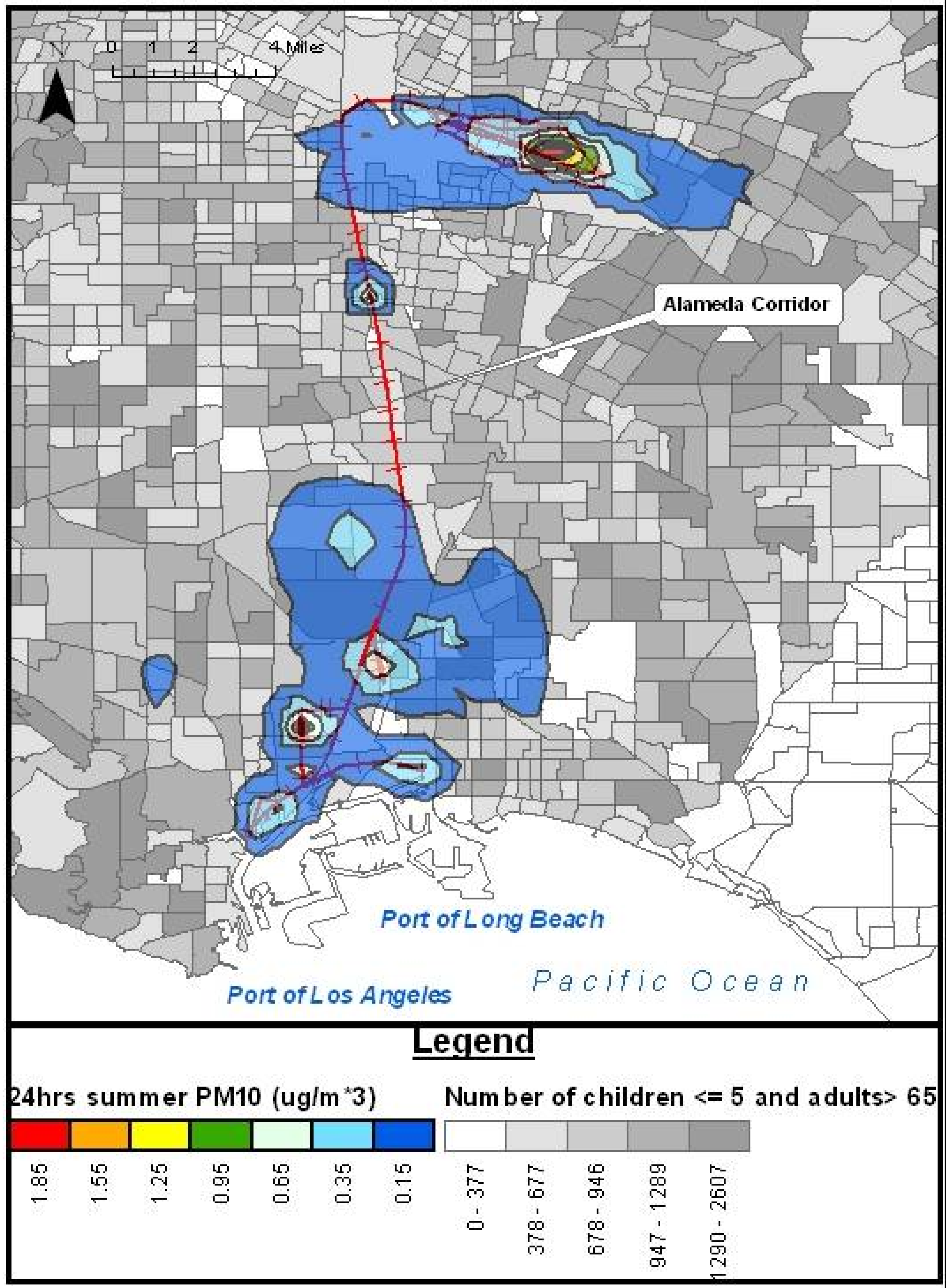

Figure 4.4 Worst summer day PM exposure for children ≤5 and adults >65.

Note: the maximum 24-hour average summer concentration of PM is 2.13 $\mu g/m^3$.

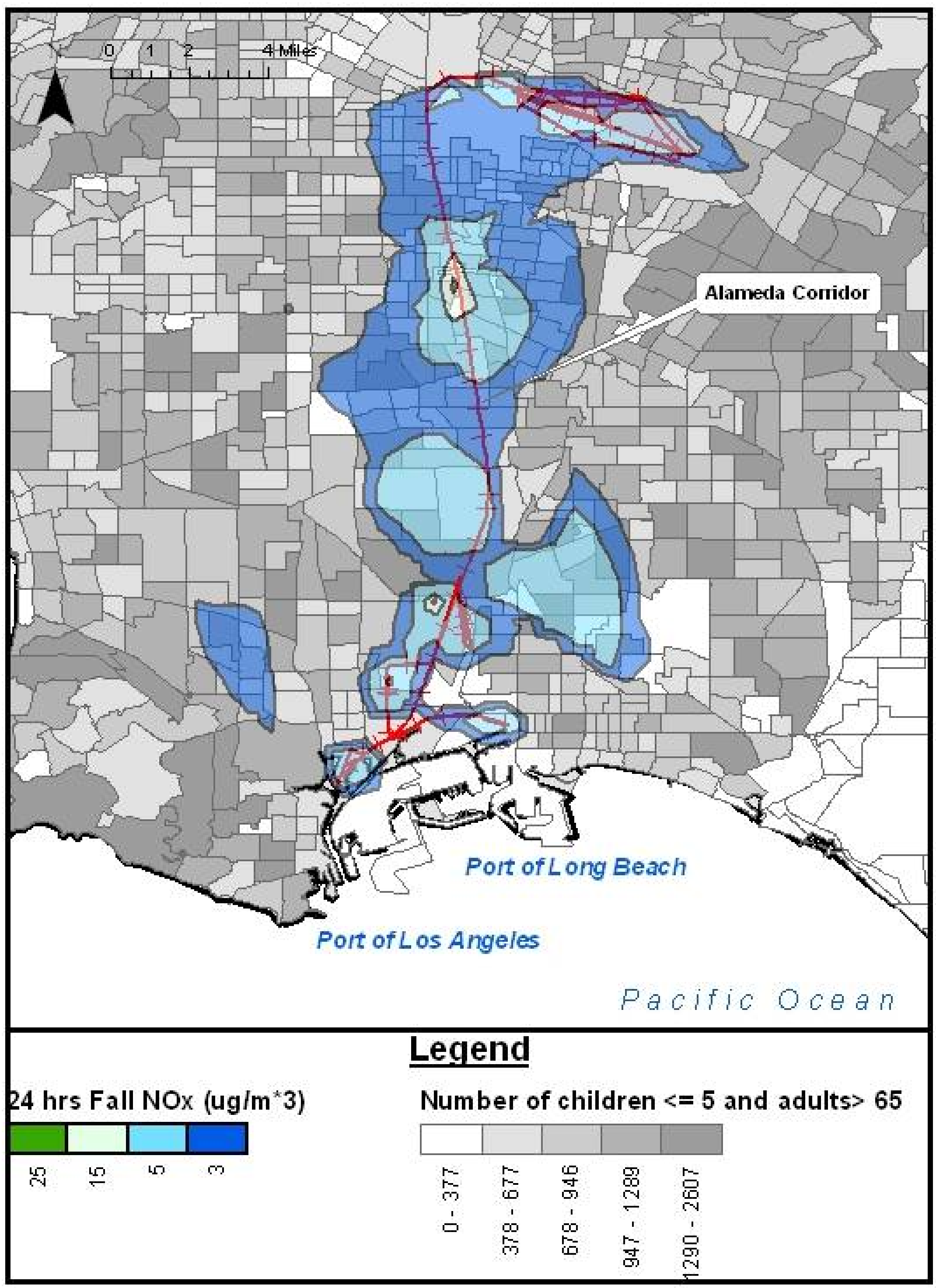

Figure 4.5 Worst fall day NO_x exposure for children ≤5 and adults >65.

Note: the maximum 24-hour average winter concentration of NO_x is 27.7 μg/m^3.

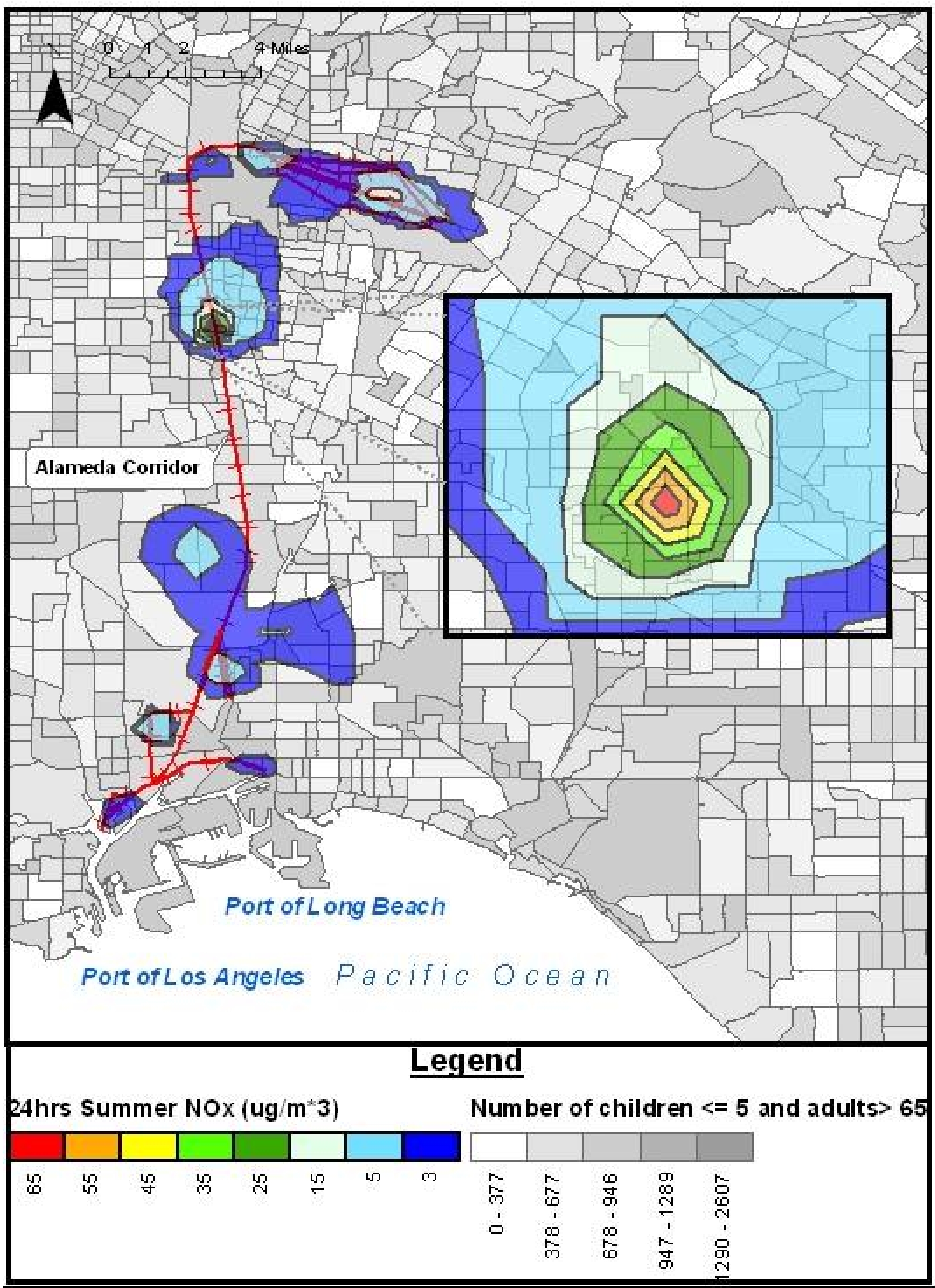

Figure 4.6 Worst summer day NO_x exposure for children ≤5 and adults >65.

Note: the maximum 24-hour average winter concentration of NO_x is 75 $\mu g/m^3$.

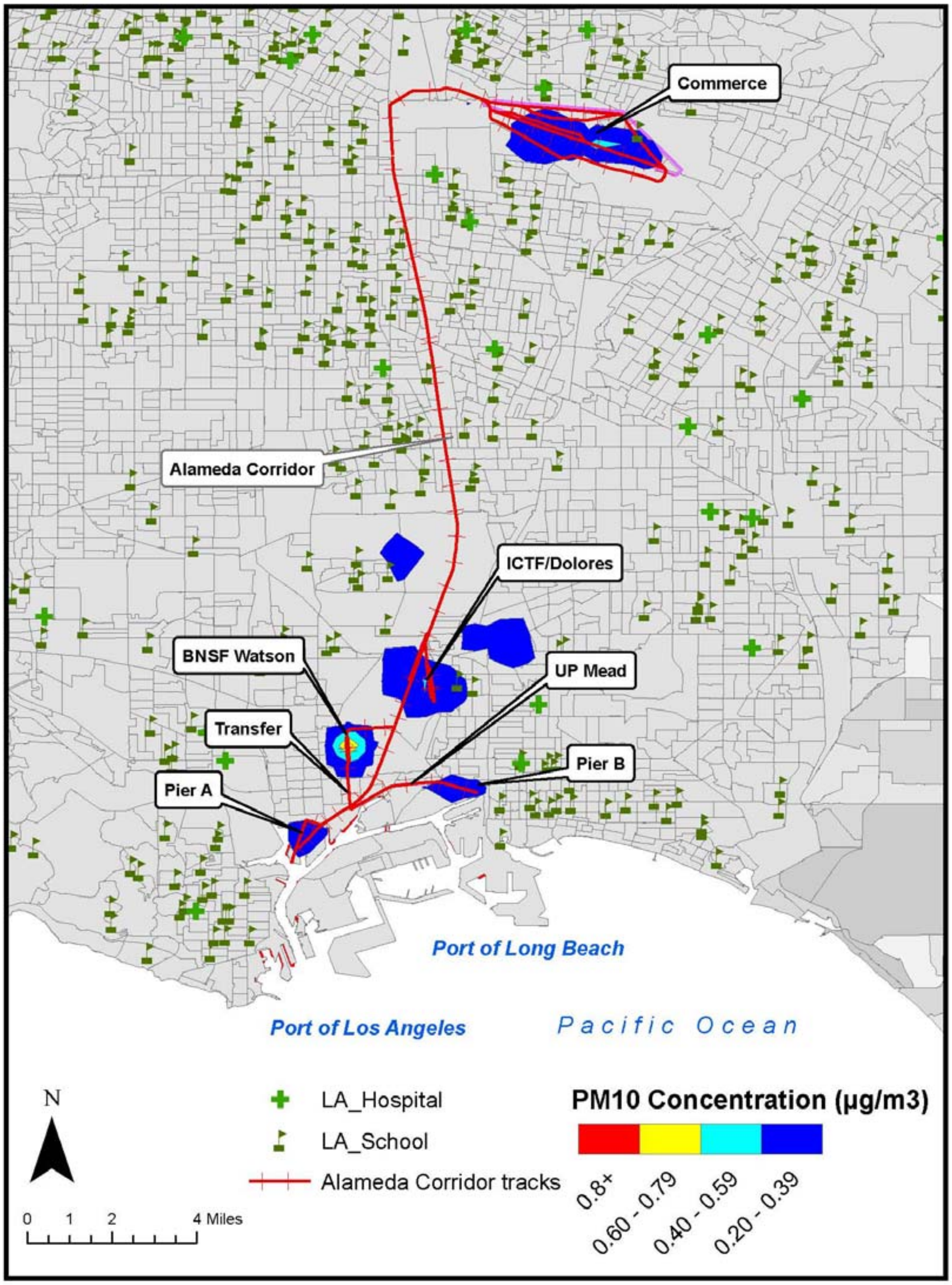

Figure 4.7 PM_{10} seasonal average concentrations (Fall 2005).

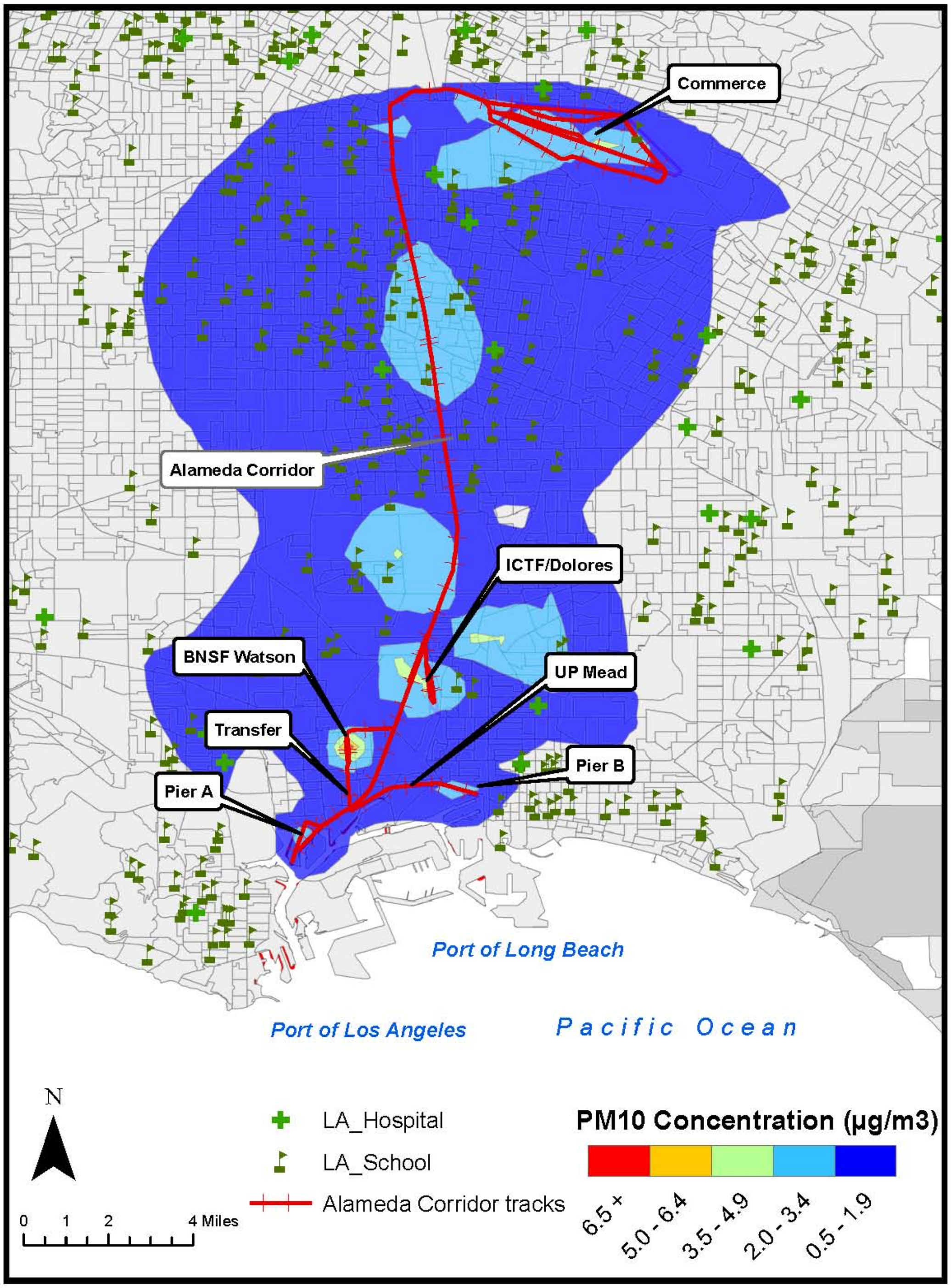

Figure 4.8 NO_x seasonal average concentrations (Fall 2005).

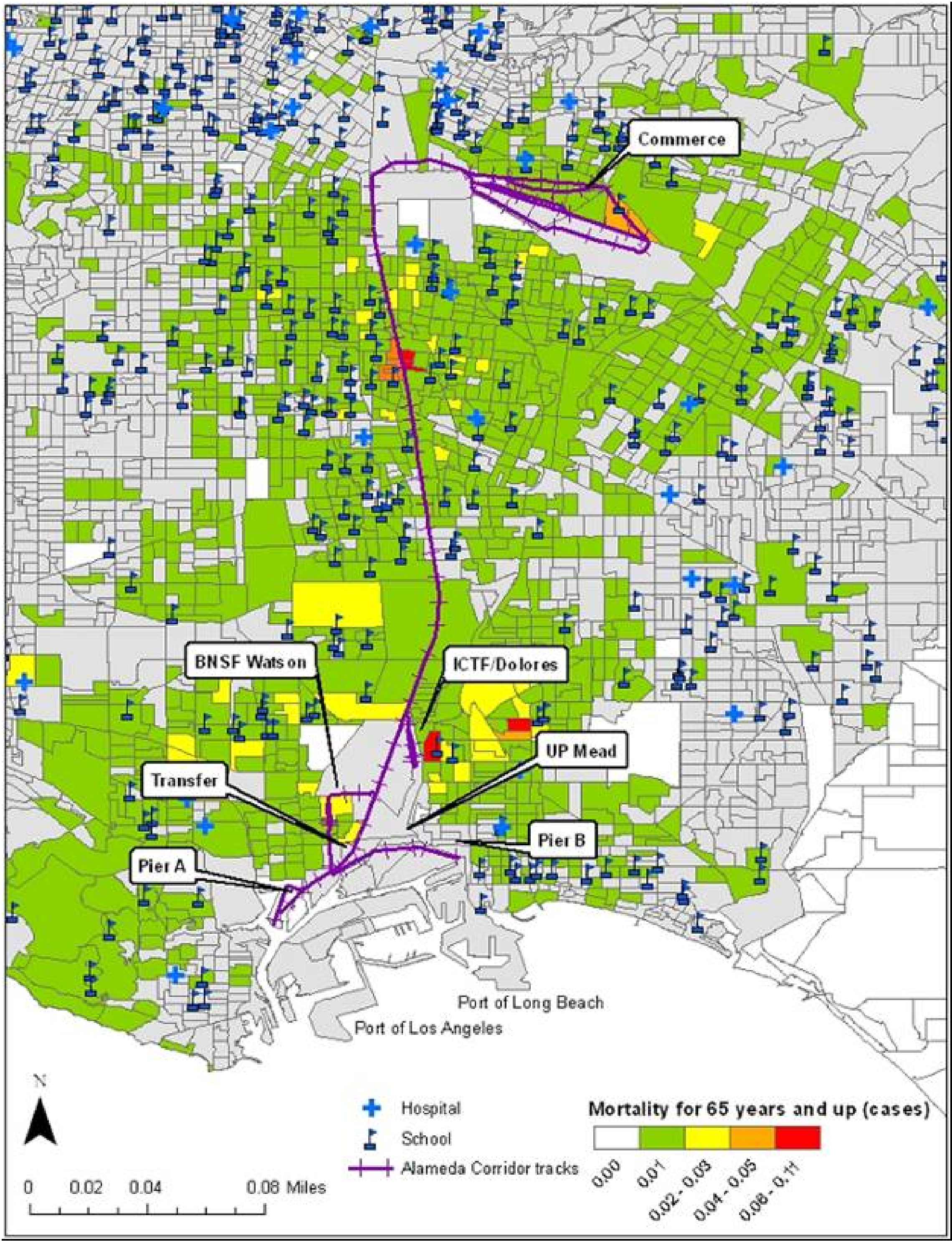

Figure 4.9 Number of statistical lives lost annually from trains $PM_{2.5}$ exposure.

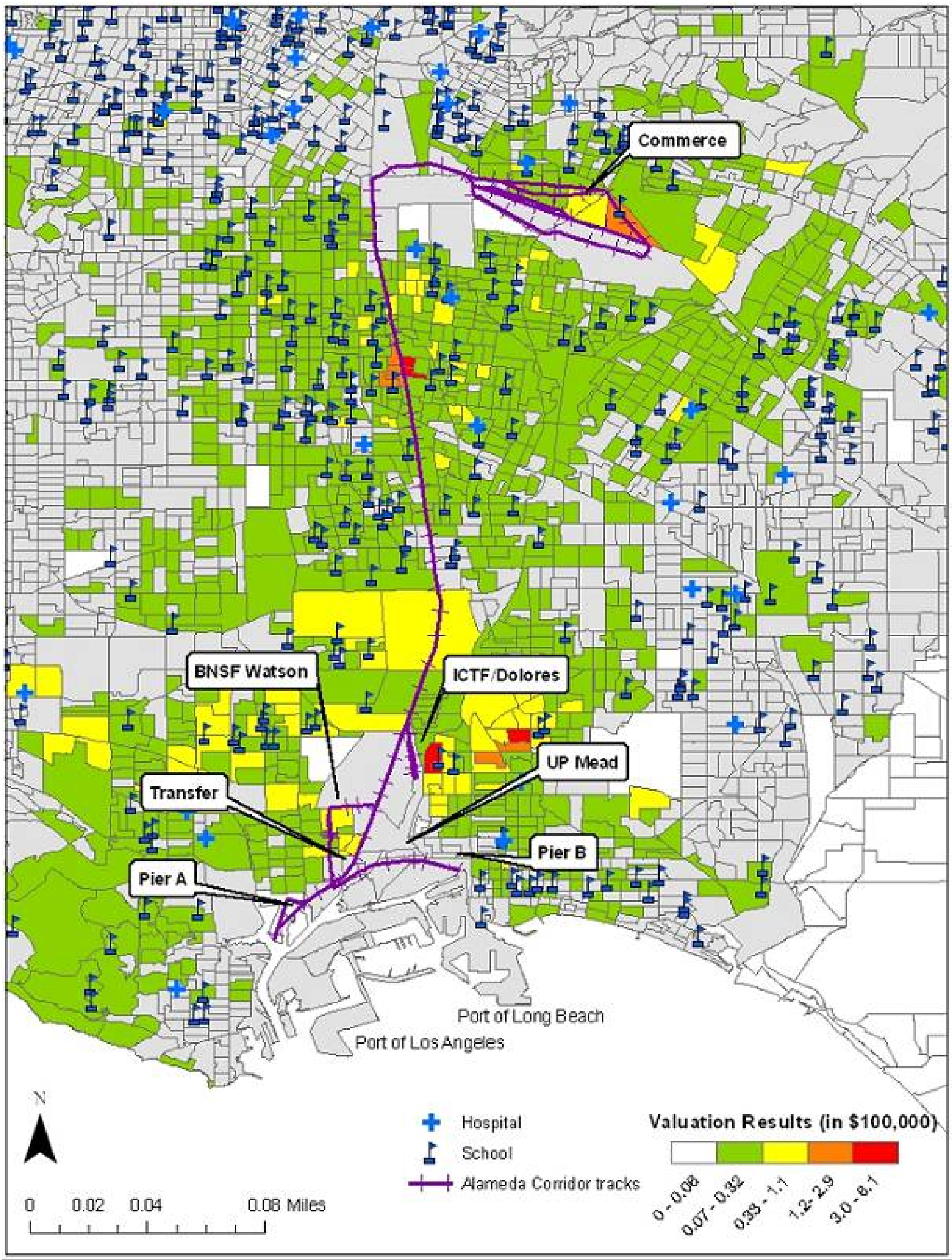

Figure 4.10 Value of statistical lives lost annually from train $PM_{2.5}$ exposure.

CHAPTER 5 CONCLUSIONS

Increasing concerns about the environmental impacts of motor vehicles, especially with regard to air pollution and climate change, are finally motivating U.S. policy makers to consider some tough choices to clean up transportation systems. The purpose of this dissertation is to explore three facets of the complex linkage between transportation and the environment that deal with transportation technology, infrastructure, and policy. I focus on California because of this state's special role in the fight against global warming and air pollution. Results from these three studies should be of interest to policymakers as they move to enact regulations and establish programs and policies to address one of the key challenges of the 21st century.

My first essay analyzes Californian's stated demand for hybrid cars using a statewide phone survey conducted in July of 2004 by the Public Policy Institute of California. Results indicate that, although concerns for the environment are not negligible, one of the main motivations behind their interest for hybrid vehicles is the possibility of using high occupancy vehicle (HOV) lanes while driving alone. This suggests that tangible measures are needed to promote the use of alternative fuel vehicles in order to close the price gap between them and conventional vehicles.

My second essay deals with two transportation demand management (TDM) programs: Rule 2202 for Los Angeles County and Commute Trip Reduction Program (CTR) in Washington State. TDM programs are a potentially important tool for reducing air pollution and decreasing congestion, yet their unpopularity in Southern California seemed to condemn their expansion. I find that the Washington State CTR program was more successful than Rule 2202 for increasing average vehicle ridership (AVR), although this is partly due to King County, by far the largest county covered by the CTR program. These results suggest that TDM programs can work effectively to increase AVR, provided commuters have alternatives to driving solo to work and they are given strong enough incentives.

My third essay deals with the environmental impacts of freight transportation, and more specifically with the health impacts of NO_x and PM generated by trains moving freight from/to the Ports of Los Angeles and Long Beach through the Alameda Corridor. Unfortunately, freight transportation (especially via trains) is often overlooked in public debates on transportation and the environment. I find that mortality from PM exposure (from trains only) accounts for the largest health impacts, with health costs in excess of $40 million annually. A shift to Tier 2 locomotives would save approximately half of these annual health costs but the benefits of shifting from Tier 2 to Tier 3 locomotives would be much smaller. These results consider only pollution from trains; they include neither drayage truck trips to and from the local rail yards, nor the equipment operating at these yards. They are a lower bound as health impact functions were not available for all the major health outcomes resulting from chronic exposure to these pollutants.

Possibilities for future research are numerous, and I will only mention some of the most promising ones.

First, more comprehensive studies are needed to understand what factors could best foster the adoption of alternative fuel vehicles; a number of options should be explored, in addition to access to HOV lanes, including tax incentives and parking privileges. Moreover, people's decision to buy cleaner vehicles should be studied in other states and other countries. In addition, more work is needed to include belief and lifestyle variables in vehicle type choice models.

More work is also needed to analyze the cost effectiveness of Rule 2202 and of the CTR program. For example a fixed effect panel model could be used to investigate the effectiveness of various incentives on AVR; a better characterization of work type should also be investigated for the CTR program; and spatial analysis could better inform the observed performance of TDM programs. It would also be of interest to better characterize the TDM program impacts on the emission of various pollutants.

Finally, future research on the environmental performance of freight transportation should compare different modes, and analyze other health outcomes provided the necessary health impact functions are available. It would also be informative to better understand their contribution to greenhouse gas emissions.

The emergence of new technologies and the current restructuration of the automobile industry, as well as the recent arrival of a new administration in the U.S. opened a window of opportunity to clean-up our transportation systems. Postponing action would likely shift an increasing burden on the next generation.