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A Spatial Analysis of Passenger Vehicle Attributes, Environmental Impact and Policy

Gregory M. Gould

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**A SPATIAL ANALYSIS OF PASSENGER VEHICLE ATTRIBUTES,
ENVIRONMENTAL IMPACT AND POLICY**

By

Gregory M. Gould

B.S. University of Maine, 2003

A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

(in Resource Economics and Policy)

The Graduate School

The University of Maine

August, 2006

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Passenger vehicle use contributes significantly to energy consumption, criteria air pollution and greenhouse gas (GHG) emissions. Recent developments in Geographic Information Systems (GIS) and Vehicle Identification Number (VIN) decoding enable researchers to make use of vehicle registration records to consider the spatial distribution of the vehicle fleet when modeling emissions. In this thesis, these techniques are used to view spatial variation in passenger vehicle attributes and environmental characteristics. The distributions of vehicle type, make and model, size, age, criteria and GHG emission rates, and fuel economy are analyzed. Next, the spatial distribution of private costs and benefits resulting from a hypothetical 30 percent increase in Corporate Average Fuel Economy (CAFE) standards are modeled to demonstrate how spatial information may be used to expand and improve an economic analysis of transportation policy.

A complete set of vehicle registration records from the state of Maine, VIN decoding, the EPA Mobile6.2 emission factor model, and fuel economy technology cost curves are used in conjunction with a GIS to create a series of thematic maps. Spatial

variation in vehicle attributes and environmental characteristics is found to lead to significant spatial variation in the impacts resulting from an increase in CAFE standards. Communities that on average receive the greatest net private benefits are typically rural and have lower median household incomes. The spatial distribution of the net present value of the benefits between high and low income areas may be tempered given evidence in the literature that lower income households discount future savings at a higher rate than higher income households. Increasing fuel economy, which reduces the costs of driving, also increases vehicle miles traveled resulting in greater annual criteria emission rates. The largest increase in criteria emission rates are in vehicles from rural towns where the largest increases in fuel economy occur. The significance of the spatial patterns observed are statistically tested using Moran's I and most are found to be significant at the 1% significance level. The finding that the lowest income areas of the state receive the greatest net benefits suggests that increasing CAFE standards may be considered a progressive policy and a better choice than an equivalent gas tax which is generally considered to be regressive.

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ACKNOWLEDGEMENTS

This research has been supported in part by a grant from the U.S. Environmental Protection Agency's Science to Achieve Results (STAR) program. Although the research described in this thesis article has been funded in part by the U.S. Environmental Protection Agency's STAR program through grant 830836010, it has not been subjected to any EPA review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

I would like to thank my advisor, Dr. Jonathan Rubin, for the exceptional opportunities he has provided me with while completing my degree. His guidance and knowledge has been invaluable in my current research and future plans. I would also like to thank Dr. Kathleen P. Bell for introducing me to GIS and providing me with the initial inspiration to pursue this research. I am also grateful for my family, especially my parents, who have supported me throughout all my academic pursuits.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	ii
LIST OF TABLES.....	vi
LIST OF FIGURES.....	viii
Chapter	
1. INTRODUCTION.....	1
1.1. Approach.....	4
1.2. Summary of Results and Conclusions.....	6
1.3. Thesis Organization.....	7
2. LITERATURE REVIEW.....	8
2.1. The Passenger Vehicle Fleet.....	8
2.1.1. Consumer Valuation of Vehicle Attributes.....	8
2.1.2. Location and Vehicle Type.....	10
2.1.3. Demographics and Vehicle Type.....	12
2.1.4. Vehicles and the Environment.....	14
2.1.5. Vehicles and Safety.....	18
2.2. The Use of Spatial Vehicle Data.....	19
2.3. Spatial Analysis and the CAFE Debate.....	21
3. DATA AND METHODS.....	27
3.1. Vehicle Database.....	28
3.2. Emission Estimates.....	33
3.2.1. EPA MOBILE6 Model.....	33

3.2.2. Climate Data.....	34
3.2.3. Fuel Data.....	36
3.2.4. Fuel Economy.....	37
3.2.5 Maine Tailpipe Emission Standards.....	39
3.2.6. Running MOBILE6.....	40
3.2.7. Greenhouse Gas Calculations.....	46
3.2.8. Annual Emissions.....	47
3.3. Policy Analysis: Impacts of Increasing CAFE Standards.....	49
3.3.1. Estimating Private Costs.....	50
3.3.2. Estimating Private Benefits.....	57
3.3.3. Estimating Changes in Emissions	66
3.4. Displaying the Data Spatially.....	68
3.4.1. Creating Spatial Data.....	69
3.4.2. Thematic Display.....	70
3.5. Quantifying and Statistically Testing Spatial Heterogeneity.....	73
3.5.1. Calculating Moran's I.....	74
3.5.2. Testing the Significance of Moran's I.....	75
4. RESULTS: A SPATIAL VIEW.....	76
4.1. The Spatial Distribution of Passenger Vehicles.....	77
4.2. The Spatial Distribution of Passenger Vehicle Environmental Attributes.....	89
4.3. Spatial Policy Analysis: Increasing CAFE Standards.....	95
5. SUMMARY AND CONCLUSIONS.....	106
5.1. Spatial Variation in the Passenger Vehicle Fleet.....	107

5.2. Policy Implications.....	109
5.2.1. Equity.....	110
5.2.2. Policy Improvements.....	113
5.3. Generalization of the Results.....	115
5.4. Limitations and Future Research.....	115
REFERENCES.....	117
APPENDIX.....	124
BIOGRAPHY OF THE AUTHOR.....	152

LIST OF TABLES

Table 3.1. Registration Records from InforME.....	29
Table 3.2. Data Gained Through VIN Decoding.....	31
Table 3.3. Maine Passenger Vehicles.....	32
Table 3.4. MOBILE6 Vehicle Classifications.....	34
Table 3.5. MOBILE6 Input Parameters for Maine Climate.....	36
Table 3.6. MOBILE6 Input Parameters for Maine Fuel.....	37
Table 3.7. Federal and California Exhaust Emission Standards.....	40
Table 3.8. VOC MOBILE6.2 Emission Factors (grams/mile).....	42
Table 3.9. NO _x MOBILE6.2 Emission Factors (grams/mile).....	43
Table 3.10. CO MOBILE6.2 Emission Factors (grams/mile).....	44
Table 3.11. PM ₁₀ MOBILE6.2 Emission Factors (grams/mile).....	45
Table 3.12. Annual VMT Accumulation OLS Regression Results.....	48
Table 3.13. Maine Motor Vehicle Registrations.....	50
Table 3.14. NAS Quadratic Fuel Economy Cost Curves Parameters.....	52
Table 3.15. Fractional Decrease in Fuel Intensity with a 30% Increase in CAFE standards.....	54
Table 3.16. Technology Costs for a 30% Increase in CAFE Standards.....	55
Table 3.17. Parameter Values used in Equation 3.9.....	59
Table 3.18. NPV of a 30% increase in CAFE Standards: High Consumer Valuation of Fuel economy.....	64
Table 3.19. NPV of a 30% increase in CAFE Standards: Low Consumer Valuation of Fuel economy.....	65

Table 3.20. Model Year 2015 MOBILE6.2 Gram/Mile Emission Factors.....	67
Table 4.1. Spatial Cluster Analysis of Light-duty Vehicle Attributes.....	84
Table 4.2. Spatial Cluster Analysis of Light-duty.....	91
Table 4.3. Average Statewide Impacts of a 30% Increase in CAFE Standards.....	95
Table 4.4. Spatial Cluster Analysis of the Impacts, Costs and Benefits of Increasing CAFE Standards.....	100

LIST OF FIGURES

Figure 3.1. MOBILE6 Default and Adjusted Fuel Economy.....	39
Figure 3.2. Annual Vehicle Miles Traveled vs. Vehicle Age.....	48
Figure 4.1. Number of LDVs by Town.....	78
Figure 4.2. Year 2000 Population by Town.....	78
Figure 4.3. 1999 Household Median Income.....	79
Figure 4.4. Percent Small Car by Town; Departure from the Mean.....	85
Figure 4.5. Percent Large Car by Town; Departure from the Mean.....	85
Figure 4.6. Percent Pickup Truck by Town; Departure from the Mean.....	86
Figure 4.7. Percent SUV by Town; Departure from the Mean.....	86
Figure 4.8. Percent General Motors (GM) by Town; Departure from the Mean.....	87
Figure 4.9. Percent Daimler Chrysler Corp. (DCC) by Town; Departure from the Mean.....	87
Figure 4.10. Most Popular LDV Model by Town.....	88
Figure 4.11. Average Age of LDVs by Town; Departure from the Mean.....	88
Figure 4.12. Average LDV Fuel Economy (MPG) by Town; Departure from the Mean.....	92
Figure 4.13. Average Annual LDV PM10 Emissions by Town; Departure from the Mean.....	92
Figure 4.14. Average Annual LDV VOC Emissions by Town; Departure from the Mean.....	93
Figure 4.15. Average Annual LDV CO Emissions by Town; Departure from the Mean.....	93

Figure 4.16. Average Annual LDV NO _x Emissions by Town; Departure from the Mean.....	94
Figure 4.17. Average Annual LDV CO ₂ Emissions by Town; Departure from the Mean.....	94
Figure 4.18. Private Costs of a 30% Increase in CAFE Standards.....	101
Figure 4.19. NPV of a 30% Increase in CAFE Standards: Low Fuel Economy Valuation Case.....	101
Figure 4.20. Private Benefits of a 30% Increase in CAFE Standards: High Fuel Economy Valuation Case.....	102
Figure 4.21. NPV of a 30% Increase in CAFE Standards: Low Fuel Economy Valuation Case.....	102
Figure 4.22. Average Percent Increase in Fuel Economy from a 30% Increase in CAFE Standards.....	103
Figure 4.23. Average Increase in Annual CO ₂ Emissions from a 30% Increase in CAFE Standards.....	103
Figure 4.24. Average Increase in Annual VOC Emissions from a 30% Increase in CAFE Standards.....	104
Figure 4.25. Average Increase in Annual PM ₁₀ Emissions from a 30% Increase in CAFE Standards.....	104
Figure 4.26. Average Increase in Annual CO Emissions from a 30% Increase in CAFE Standards.....	105
Figure 4.27. Average Increase in Annual NO _x Emissions from a 30% Increase in CAFE Standards.....	105

Chapter 1

INTRODUCTION

Over 220 million passenger vehicles were driven more than 2.8 trillion miles in the United States during 2002 (Davis and Diegel, 2004). The number of passenger vehicles and the distance they are driven each year has also been increasing annually; the number of passenger vehicles increasing by 2 percent annually and vehicle miles traveled (VMT) increasing by 2.4 percent annually between 1992 and 2002 (Davis and Diegel, 2004). Such a high rate of motorization has serious impacts. Light duty vehicles account for 40 percent of U.S. petroleum consumption (NRC, 2002). The combustion of this fuel results in emissions of air pollutants and greenhouse gases (GHG). Automobiles are the primary source of carbon monoxide (CO) emissions and rank second as a source of nitrous oxide (NO_x) and volatile organic compound (VOC) emissions nationally (Davis and Diegel, 2004). Each of these emissions are considered criteria air pollutants by the U.S. EPA and together are the primary precursors of smog and ground level ozone.

Light-duty vehicles also produce 19 percent of U.S. carbon dioxide (CO₂) emissions (EPA, 2005). CO₂ is considered a GHG and recent studies have raised concerns that GHG emissions may be raising global temperatures¹. The latest assessment report by the Intergovernmental Panel on Climate Change finds that the global average surface temperature has increased by 0.6°C since 1900 (ICPP, 2001). Climate models used in the assessment indicate that an increase of 1.4°C to 5.8°C in global average

¹ Nitrous Oxide (N₂O) is also a GHG present in vehicle exhaust but it is not the focus of this analysis. Levels of N₂O in vehicle exhaust are poorly understood and the focus of current research (Behrentz, 2003). Though N₂O levels are much less than CO₂, it may be a significant contribution to GHG emissions because it has a warming potential 296 times greater than that of CO₂ (EPA, 2002).

temperature and a 0.09 m to 0.88 m average sea level rise over 1990 levels by 2100 are possible. These changes are attributed in part to increasing GHG concentrations.

There are 220 million passenger vehicles in the U.S. but they are not all equal. Americans drive a wide variety of passenger vehicles that include cars, sport utility vehicles (SUVs), pickup trucks and minivans. Each of these vehicle types come in a variety of styles and sizes. In addition to the variety of physical attributes, the environmental attributes of passenger vehicles also vary. Some vehicles are much more fuel efficient or have lower criteria emissions than other vehicles.

Previous research, which is discussed in detail in the next chapter, has found that consumers value a number of vehicle attributes, and that socioeconomic factors and location play a role in determining the bundle of attributes, which determines the type of vehicle, people choose. Differences between the types of vehicles driven in rural and urban areas are found using survey data. There has also been research on the use of spatial data gathered from vehicle registration records and remote sensing for modeling passenger vehicle emissions. Emissions rates are found to be spatially distributed dependent upon the spatial distribution of vehicle attributes and activity. However, the previous research does not study the spatial distribution of passenger vehicles outside of broad categories such as urban or rural. Additionally, studies that have made use of detailed spatial data have used it to improve the spatial resolution of emission estimates, but no studies have used such data to study the spatial distribution of the impacts, costs and benefits of changes in transportation policies. In response, this thesis investigates the following three research questions:

1. Is the spatial distribution of passenger vehicles heterogeneous? Do different regions have unique fleets of passenger vehicles with respect to size, age, type, make, and model?
2. If the spatial distribution of the passenger vehicle fleet is heterogeneous, then is the spatial distribution of the environmental attributes of the passenger vehicle fleet also heterogeneous? Do the passenger vehicle fleets in different regions have unique sets of environmental attributes such as fuel economy, criteria air pollutant emission rates, and GHG emission rates?
3. If the spatial distribution of the passenger vehicle fleet is heterogeneous with respect to the physical and environmental attributes in (1) and (2), then will the impact, costs and benefits of a policy targeting an environmental attribute of passenger vehicles, such as increasing fuel economy standards, vary across regions? Will there be spatial variation in the private cost and benefits of the policy? Will externalities resulting from the policy such as changes in criteria air pollutant emission rates and GHG emission rates vary spatially? What are the effects on social welfare?

It is also interesting to examine the preferences for different types, makes and models of passenger vehicles across geographic regions. This information can be useful in understanding the demand for various types of vehicles, not only for vehicle manufactures and retailers, but also for those concerned with promoting the use of more efficient vehicles. If there is spatial heterogeneity in the physical and environmental attributes of passenger vehicles, policies may have heterogeneous impacts. Additionally, policies may be more effective if they incorporate this heterogeneity in their design.

1.1. Approach

The three research questions are evaluated by creating a spatial view of the passenger vehicle fleet in the state of Maine. Maine is chosen as the study area because detailed registration data were made available by the state government. The registration data which contains over 1.3 million records is the backbone of this thesis because it links each vehicle in the state to a physical street address which enables a spatial view using a Geographic Information System (GIS). The registration data also contain some basic information about each vehicle including the vehicle identification number (VIN), age, type, make and model. More detailed information about each vehicle is obtained through a service known as VIN decoding. This service provided by a private company provides information on the size, weight, engine design, fuel economy, EPA emission class, fuel type, and styling of each vehicle. This information is used with the EPA Mobile6.2 emission factor model to produce gram per mile criteria and GHG emission factors for each passenger vehicle.

To address the first research question, thematic maps are created that display the distribution of passenger vehicles by type, size, age, manufacturer and model by town. The second research question is addressed similarly by displaying the distribution of average annual criteria emissions (NO_x , CO, VOC, and PM_{10}^2), CO_2 emissions, and average fuel economy by town. The presence of statistically significant spatial clustering in these distributions is quantified and tested using Moran's I.

The thesis also conducts a policy analysis using the above vehicle data and spatial information to address the final research question: how are the impacts, costs, and benefits of policies targeting the environmental attributes of passenger vehicles spatially

² Particulate Matter less than $10\mu\text{m}$ in diameter

distributed? The policy analysis considers the impacts of an increase in Corporate Average Fuel Economy (CAFE) standards which are currently used to regulate light-duty vehicle fuel efficiency in the U.S. CAFE standards regulate the sales weighted average fuel economy of each manufacturer's car and truck fleet, setting a minimum standard for each. The costs and benefits of increasing CAFE standards by 30 percent are estimated and viewed spatially by town. The presence of statistically significant spatial clustering in these distributions is quantified and tested using Moran's I.

The private benefits are assumed to be the present discounted value of fuel savings and the private costs assumed to be the increase in retail cost due to the cost of fuel economizing technology. Subtracting the present discounted value of fuel savings from the increased retail costs provides the net present value (NPV) of fuel savings due to the change in CAFE standards for each vehicle. The average NPV is displayed spatially by town.

Reduced levels of CO₂ emissions and petroleum consumption are also benefits and increased levels of criteria emissions are also costs, but these are more or less public goods which make it difficult to quantify them in dollars. The benefits of reducing CO₂ emissions, potentially reducing global warming, are distributed across the entire globe and will not be fully realized until some time in the future. Similarly, the benefits of reduced oil consumption today will be spread across the country and realized some time in the future. The costs of increased criteria air emissions are difficult to quantify because the health and environmental costs depend on the ambient level of these pollutants at a given time and place. This thesis does not model local air quality which requires additional travel demand and atmospheric models. The application of these models to this

thesis would be an interesting research project. Additionally, the costs of criteria emissions are bared by those that are repeatedly exposed to high levels of emissions which does not necessarily include the driver of a particular vehicle. Therefore no attempt is made to quantify these costs in dollars, the reduction in CO₂ emissions and fuel consumption and increase in criteria emissions are estimated for each vehicle and the average for each town is displayed.

1.2. Summary of Results and Conclusions

The results of the spatial analysis of passenger vehicle attributes in Maine indicate that the fleet is not homogeneous. Spatial patterns are observed in the distribution of vehicle makes, models, types, sizes and age across the state. It is also found that the environmental attributes of passenger vehicles vary across the state. Further, the policy analysis provides an example of how detailed vehicle information, including spatial information, can be used to explore the equity of transportation polices. The analysis finds that the costs and benefits of raising CAFE standards are not equally distributed across the state. Rural areas and regions where households earn lower incomes receive the highest level net of private benefits. The spatial distribution of the net present value of the benefits between high and low income areas may be tempered given evidence in the literature that lower income households discount future savings at a higher rate than higher income households. The results which indicate that lower income areas receive the greatest net private benefits suggests that increasing CAFE standards may be considered a progressive policy and more favorable than choosing an equivalent tax which is generally considered to be regressive. The results also indicate that increasing CAFE standards will increase the level of criteria emissions across most regions of Maine

because of an increase in VMT due to the rebound effect. Based on these findings it is recommended that if CAFE standards are increased a complimentary policy should be created to reduce the rebound effect, such as distance based fees or taxes and congestion charging. This analysis can be applied to any region where the required registration data is made available and the results can be used to better understand the current vehicle fleet and the equity of transportation policies.

1.3. Thesis Organization

The remainder of this thesis consists of four chapters. The following chapter will present a review of the literature on the demand for vehicle attributes, the spatial characteristics of passenger vehicles, the use of spatial data in passenger vehicle transportation policy analysis and emission modeling, and an overview of the concerns expressed over increasing CAFE standards. Chapter 3 provides a detailed description of the data, models and methods used to create a spatial view of the passenger vehicle fleet and impacts of an increase in CAFE standards. Chapter 4 presents a spatial view of the automobile fleet and also presents the results and a discussion of the policy analysis. The final chapter provides a summary and conclusions drawn from this work and discusses additional applications and future research.

Chapter 2

LITERATURE REVIEW

This thesis builds on the ideas and methods of a large body of previous work. The literature review discusses the use of spatial vehicle data in transportation research and the implications its use may have in informing transportation policy. The discussion starts by examining the demand for vehicle attributes and why a spatial analysis of the passenger vehicle fleet is of interest. The following section reviews studies that have used spatial data in transportation models, research, and policy. The majority of studies focus exclusively on emission modeling and do not make the connection to the spatial distribution of the resulting economic costs and benefits. The final section discusses how a spatial analysis of the impacts and private costs and benefits of transportation policies, in this case increasing CAFE standards, can improve policy analysis.

2.1. The Passenger Vehicle Fleet

The U.S. passenger vehicle fleet is made up of many types, sizes and vintages of vehicles. Each of these vehicles is a composite good which has various characteristics that are important to consumers and also to transportation researchers and policy makers. The preference for different passenger vehicles has changed over time and varies spatially across geographic regions. The following sections discuss these topics.

2.1.1. Consumer Valuation of Passenger Vehicle Attributes

Passenger vehicles can be described as a composite good, each vehicle being composed of a bundle of attributes. There have been numerous studies which have sought to understand how consumers value each of the attributes that make up a passenger vehicle and how this effects their choice in purchasing a vehicle. The focus of many

studies has been on how consumers value safety and fuel economy as compared to other vehicle attributes. Hedonic and discrete choice models are commonly used to elicit the value or significance that consumers have for particular attributes or groups of attributes.

The multitude of studies in the economic, transportation and marketing literature use a variety of data sources, for various time periods, and contain a variety of variables often defined uniquely in each study. It is therefore difficult to summarize average willingness to pay values and other results across the studies. This being the case, common findings from the most comprehensive and more recent studies are discussed.

The most common findings are that performance and comfort are significant attributes in vehicle choice. Studies have found the consumers have a positive and significant willingness to pay for better handling (Agarwal and Ratchford, 1980; Boyd and Mellman, 1980; McCarthy and Tay, 1989), lower noise levels (Boyd and Mellman, 1980; McCarthy and Tay, 1989), greater smoothness of ride (Agarwal and Ratchford, 1980), increased interior space or leg room (Agarwal and Ratchford, 1980; McCarthy and Tay, 1989) and greater ease of entry and exit (McCarthy and Tay, 1989). However, one measure of performance, acceleration or power, has mixed findings. A positive willingness to pay for an increase in acceleration or power is estimated by some studies (Boyd and Mellman, 1980; Dreyfus and Viscusi, 1995; Lave and Train, 1979) while a negative willingness to pay is estimated by others (Asher, 1992; Agarwal and Ratchford, 1980; McCarthy and Tay, 1989). Differences may be due to different definitions of power and acceleration used and problems with collinearity. Studies also have found that consumers have significant and positive willingness to pay for increased cargo space (Dreyfus and Viscusi, 1995), reliability (Asher, 1992; Boyd and Mellman, 1980; Dreyfus

and Viscusi, 1995; McCarthy and Tay, 1989;), and a number of other vehicle attributes such as type of sound systems, sunroofs and cruise control (Asher, 1992).

It has also been found that consumers value vehicle safety (Asher, 1992; Dreyfus and Viscusi, 1995; McCarthy and Tay, 1989). Dreyfus and Viscusi estimate that consumers implicitly value a statistical life at between 2.6 million and 3.7 million dollars, which they state is within the range found in other studies of the value of a statistical life. Their results suggest that consumers take safety into consideration when choosing a vehicle and that they appear to reasonably value vehicle safety when making their decisions.

Studies also find that consumers value fuel economy. Most studies find that consumers have a positive and significant willingness to pay for an increase in fuel economy (Boyd and Mellman, 1980; Dreyfus and Viscusi, 1995; Lave and Train, 1979; McCarthy and Tay, 1989), although at least one study finds the relationship to be negative (Asher, 1992). Asher gives as a possible explanation for the negative willingness to pay for an increase in fuel economy; if vehicles already provide the fuel economy that consumers want then an increase in fuel economy may sacrifice other attributes that consumers want. Although, Boyd and Mellman find a positive willingness to pay for an improvement in fuel economy that also caution that improvements in fuel economy may sacrifice other attributes that consumers also value.

2.1.2. Location and Vehicle Type

A number of studies have provided evidence that people living in different places tend to drive different types of vehicles. A common finding is that SUVs and light-duty trucks are more common in suburban neighborhoods and rural areas. Niemeier et al.

(2001) using the 1995 National Household Transportation Survey find that men and women travel more frequently by light-duty truck³ in suburban and second city neighborhoods; 36.4 percent and 20.8 percent of trips for men and women respectively as compared to 22.5 percent and 14.1 percent of trips respectively in urban areas. Plaut (2004) using the American Housing Survey, which is part of the U.S. Census, finds that commuters who live in rural areas and those who live near green spaces are more likely to drive SUVs. Plaut also notes that SUVs are more popular on the west coast of the U.S. Kockelman and Zhao (2000) create a Poisson model of vehicle ownership using data from the 1995 National Personal Transportation Survey. They find that population density is a significant determinant in light-duty truck and SUV ownership. Increasing density has a negative effect on the likelihood of owning a light-duty truck or SUV. Bhat and Sen (2006) using the 2000 San Francisco Bay Area survey also find that household light-duty truck ownership is greater in low density neighborhoods. Interestingly, Choo and Mokhtarian (2004) using their own survey of the San Francisco bay area find that individuals with “pro-high density” attitudes are most likely to own small cars or luxury cars and SUVs.

The trend of relatively large vehicles, notably SUVs and pickup trucks, being popular in suburban and rural areas can be explained in part by how consumers value various vehicle attributes as discussed in Section 2.1.1. Consumers value comfort, safety and performance, which many new SUVs and pickup trucks offer an abundance of. New SUVs and pickup trucks offer powerful engines, lots of cargo and leg space, smooth, quiet rides, four wheel drive and a perceived level of greater safety. Agarwal and Ratchford (1980) find that the more people expect to drive, the higher their willingness to

³ Light-duty trucks include SUVs, pickup trucks, and minivans less than 8500lbs GVWR

pay for comfort and performance. Since suburban and rural consumers are likely more dependent on their vehicles than urban residents, it is not surprising that they drive vehicles that offer greater levels of these valued attributes.

2.1.3. Demographics and Vehicle Type

Preferences for different types of vehicles also depend on demographic factors. This is important when considering the spatial distribution of the vehicle fleet because demographics vary spatially. Demographics also add an additional layer of complexity to the spatial distribution of vehicles types. The previously discussed studies found that light-duty trucks are preferred in rural and suburban neighborhoods as compared to cars. Whether this generalization holds for a particular neighborhood depends on the demographic make up of the neighborhood in question. For example, light-duty trucks on average are much more expensive than cars (Kockelman and Zhao, 2000) so residents of low income rural and suburban neighborhoods may not have the financial resources to purchase such vehicles even if they desire them just as much as residents of wealthy neighborhoods.

There have been many studies on the effects of various demographic variables on vehicle choice. This is due to the importance of the results for marketing by vehicle manufactures and those who want to change the type of vehicles people drive through policy. Below is a discussion of the most significant demographic variables.

Income is an important variable in most studies. Higher incomes are associated with higher rates of SUV ownership (Bhat and Sen, 2006; Plaut, 2004; Choo and Mokhtarian, 2004; Niemeier et al., 2001; Kockelman and Zhao, 2000). This is not surprising since the average SUVs costs 58 percent more than the average car

(Kockelman and Zhao, 2000). Higher incomes also tend to reduce the likelihood of owning a pickup truck (Bhat and Sen, 2006; Kockelman and Zhao, 2000). Argarwal and Ratchford (1980) find that higher income increases the willingness to pay for comfort which may also explain why SUVs are associated with higher income while pickup trucks are not. While higher incomes are associated with a higher rate of SUV ownership, some studies have also found that increasing income also increases the probability of owning a small car (Choo and Mokhtarian, 2004; Dardis and Soberon-Ferrer, 1992). This result is hypothesized to be caused by the definition of a small car which includes sports cars. This result is contradictory to an earlier study by Lave and Train (1979) who found that increasing income increased the probability of owning a large car. This is most likely due to SUVs not being introduced to the market at the time of their analysis.

Household size is also an important demographic factor in vehicle type ownership. As would be expected, larger households own vehicles that are capable of holding more people. Plaut (2004) finds that larger households are more likely to own SUVs. Kockelman and Zhao (2000) and Bhat and Sen (2006) find that larger households are more likely to own SUVs or minivans and less likely to own pickup trucks. Lave and Train (1979) find that as the number of people in a household increase the probability of owning a sports car decreases.

Other variables are also found to be significant determinants of which types of vehicles people own. Higher education up to an undergraduate degree is found to increase the probability of owning an SUV (Plaut, 2004; Choo and Mokhtarian, 2004) and also increase the probability of owning a small car over a large car (Choo and Mokhtarian, 2004; Dardis and Soberon-Ferrer, 1992; Lave and Train, 1979). Less education is

associated with owning a pickup truck (Choo and Mokhtarian, 2004). Agarwal and Ratchford (1908) find that an increase in the level of education reduces the willingness to pay for all car attributes that they considered which included various comfort and performance attributes. Gender is also significant. Females are less likely than males to own large cars (Dardis and Soberon-Ferrer, 1992), SUVs (Plaut, 2004; Niemeier, 2001) and pickup trucks (Bhat and Sen, 2006). Choo and Mokhtarian (2004) also find that the number of persons older than 65 in a household increases the probability that a household owns a large car or luxury vehicle.

2.1.4. Vehicles and the Environment

It has been shown that people of different demographics or that live in different places own different types of vehicles. These results have important environmental implications. Passenger vehicles are responsible for a number of environmental problems which are discussed in Chapter 1, but not all vehicles contribute to these problems equally.

Federal Tier 2 exhaust emission standards and California Low Emitting Vehicle II (LEVII) exhaust emission standards require all light-duty vehicles to meet the same set of standards. These standards force manufacturers to place emission control devices on their vehicles which should result in criteria emissions of new vehicles being approximately the same. However, Beydoun and Guldman (2006) find that the rate at which emissions increase due to the gradual breakdown of emission control devices over time and with increasing accumulation of VMT varies significantly dependent on the make of the vehicle. They regress criteria emission rates from Massachusetts inspection and maintenance program data on a variety of vehicle attributes and registration information.

The results indicate that emissions from foreign vehicles increase more with increasing VMT than domestic vehicles. For example, they find the elasticity of HC⁴ emissions with respect to VMT to be 0.081 for Ford cars and 0.37 for Mitsubishi Cars. A 10 percent increase in VMT would increase Ford HC emissions by 0.8 percent and Mitsubishi HC emissions by 3.7 percent. The results also indicate that Toyota vehicles have the smallest increase in criteria emissions as age increases. These results could help explain the findings of an earlier study by Beaton et al. (1995). They found that 20 percent of the highest emitting new vehicles were worse polluters than the lowest emitting 40 percent of vehicles from any model year, including vintages that pre-date catalytic converters.

Light-duty vehicles of vintages prior to the implementation of Tier 2 and LEVII standards were held to various standards depending on vehicle type (truck or car) and size. For these vehicles, which make up the current light-duty vehicle fleet, the type of vehicle certainly has an effect on criteria emissions (Malcolm et al., 2003). Light-duty trucks, notably those in the heaviest categories, have historically been held to more lenient standards. The heaviest light-duty truck standards under Tier 1 is 56 percent higher for NMOG⁵, 47 percent higher for CO and 75 percent higher for NO_x emissions as compared to the standards for cars and the lightest light-duty trucks (BTS, 2004). State inspection and maintenance data analyzed by Beydoun (2004) indicates that residents of poor areas drive vehicles with higher criteria emission rates than residents of wealthy areas. Similarly it is found that vehicles owned by residents in rural areas emit more than vehicles owned by residents of urban areas.

⁴ Hydrocarbons (HC)

⁵ Non-methane organic gases (NMOG)

In addition to criteria emissions, vehicles are also responsible for a large percentage of GHG emissions, mostly in the form of CO₂. Emissions of CO₂ cannot be removed with emission controls but are a direct function of fuel economy (see Equations 3.1 and 3.2) and VMT. Light-duty vehicles have been held to federal fuel economy standards under the CAFE program since 1978 but the standards are different for cars and light-duty trucks. The current 2006 CAFE standards are 27.5 MPG for cars and 21.6 MPG for trucks (Davis and Diegel, 2004). The CAFE standard is a sales weighted harmonic average by manufacturer by year which allows manufactures to sell vehicles with a wide range of fuel economy. It was shown above that preferences for different types of vehicles vary across location and demographics so it should be expected that fuel economy also does. Studies by Kayser (2000) and Lin et al. (1985) confirm this. Kayser (2002) finds that fuel economy is lower in rural areas than urban areas while Lin et al (1985) find that fuel economy differences are a significant factor in explaining differences in state fuel consumption.

Differences in fuel economy can also cause differences in criteria emissions rates. Criteria emissions are a by product of the combustion of motor fuel. In the absence of emission controls less fuel efficient vehicles, which use more fuel, would produce more criteria emissions. However, the fuel economy of new vehicles has no immediate effect on criteria emission rates. This is a result of the the federal Clean Air Act and California Low Emission Vehicle (LEV) programs which require manufacturers to comply with gram per mile criteria air emission standards which are independent of fuel economy. The standards are met by adding technology to vehicles, such as catalytic converters, to reduce emissions. However, as vehicles age their emission controls become increasingly

ineffective and fuel economy becomes an increasingly important factor. Beydoun and Guldmann (2006) estimate that a 1 percent increase in fuel economy decreases CO emissions by 0.62 percent to 1.01 percent, HC emissions by 0.49 percent to 0.79 percent and NO_x emission by 0.45 percent to 0.84 percent depending on the make and type of vehicle. Emission controls may also be damaged or deliberately tampered with, which also makes fuel economy a significant factor. Beaton et al.(1995) found that 41 percent of vehicles identified by roadside sensors as “gross polluters” were deliberately (and illegally) tampered with and 25 percent had defective equipment.

Criteria emissions and CO₂ emissions are also effected by annual VMT. The more a vehicle is driven the greater the quantity of pollution emitted. Additionally, higher annual VMT breaks down emission control equipment at a faster rate which can have a significant effect on criteria emissions (Kear and Niemeier, 2003). Data from the 2001 National Household Transportation Survey indicate that different vehicle types have different levels of annual VMT. As shown later in Table 3.11, new pickup trucks have the highest annual VMT, 17,504 miles, while cars have the lowest annual VMT, 14,380 miles. Increasing VMT also leads to greater congestion which tends to increase emissions (Malcolm et al., 2003). Furthermore, Kockelman and Shabih (2000) find that light-duty trucks increase congestion, particularly at signalized intersections. It is hypothesized that large SUVs and pickup trucks reduce the visibility of other drives which results in more space between vehicles and slow acceleration once the traffic signal has changed. They also calculate that a large SUV is equivalent to 1.41 passenger cars on the road.

2.1.5. Vehicles and Safety

Traffic accidents are the leading cause of death for people between the ages of 3 and 33 in the U.S. Overall traffic accidents rank 3rd in the number of years of life lost behind heart disease and cancer (Subramanian, 2005). Therefore it is not surprising that many studies, including those discussed in Section 2.1.1, find that consumers value vehicle safety. Agarwal and Ratchford (1980) find that the more consumers expect to drive the more they value vehicle attributes. Extending this finding to vehicle safety, it is likely that consumers who drive more also place a higher value on safety. If this is true, then consumers who drive the most or rely the most on vehicles are likely to choose vehicles that offer greater levels of safety. These drivers are likely to live in suburban and rural areas as discussed in Section 2.1.2.

It is commonly perceived that SUVs and pickup trucks provide more safety for their occupants than cars. This is not necessarily true. Kockelman (2000) describes data from NHTSA that show SUV occupants are almost twice as likely to die in a roll over as are occupants of any other vehicle type. Cars were the safest in this respect. The Insurance Institute for Highway Safety (IIHS, 2004) reports the driver death rate per million registered vehicles for vehicles less than 3 years old by vehicle type and size. The data indicates that pickup trucks have the highest driver death rate, followed by cars and then SUVs. The driver death rates depend upon vehicle size. The data indicates that large cars are the safest vehicles on the road at 50 driver deaths per million registered vehicles. This compares to 118 driver deaths per million registered vehicles for small pickup trucks. Light-duty trucks may also pose a greater risk to occupants of smaller vehicles (Kockelman, 2000; NRC, 2002). Therefore, assuming that consumers who drive more

place a higher value on vehicle safety, it would be expected to find greater amounts of SUVs and large cars in suburban and rural areas.

2.2. The Use of Spatial Vehicle Data

Given the variety of vehicle types and attributes in the passenger vehicle fleet many transportation studies have begun to use disaggregate vehicle data. Surprisingly few studies have studied the impact of the spatial distribution of the vehicle fleet on their findings. No studies could be found that explicitly analyze the spatial distribution of the vehicle fleet.

Lin et al. (1985) found that gasoline consumption per household and average fuel economy varied significantly across states due to differences in the composition of the vehicle fleet.

More recently Kear and Niemeier (2003), and Brandmeyer and Karimi (2000) have noted that there is spatial variation in the distribution of VMT due to differences in the spatial distribution of the vehicle fleet. Kear and Niemeier (2003) acquire vehicle age data from the California DMV and mileage accumulation data from the Bureau of Automotive Repair. They use this data to estimate local distributions of VMT and vehicle age and find that there are significant impacts on the estimation of criteria emissions using MOBILE6 and California's EMFAC emission factor model. They show that different assumptions about VMT and age distributions can vary emission estimates of total organic gases (TOG) by as much as 66 percent. Brandmeyer and Karimi (2000) investigate an alternative method to estimate the spatial variation of VMT by road type using the spatial variation in the density of the road network as a proxy for VMT. The current method is to use population density as a proxy for VMT. Using a GIS they

compare the two methods and find the road density to be a better proxy for estimating the spatial distribution of VMT for use in mobile emission factor models. Hallmark and O'Neill (1996) also use a GIS to study VMT distributions in order to estimate criteria emission rates. Their analysis however is an extremely small scale, looking at emissions from particular intersections and restaurant drives thru's. Although they measure the local VMT, they do not account for spatial differences in the composition of vehicle fleet.

Expanding on the above studies Malcolm et al. (2003) collect data on the spatial variability in vehicle activity and fleet distributions. They use this data with emission factor models to show significant differences in the mobile emissions of the vehicle fleet between three counties in California due to differences in age and activity. Spatial vehicle data is collected by monitoring roads with video cameras that capture license plate numbers and by taking digital pictures of license plates in parking lots. The license plate numbers captured by the video cameras are matched to vehicle registration records and VINs. The VINs are subsequently decoded to obtain detailed vehicle information. The video data is also used to estimate traffic volume and speed. The digital camera information is similarly matched to the registration database and the VINs are decoded. This data is used to obtain information on the destination of each vehicle. California's EFMAC emission factor model is used to estimate criteria emission factors for the three counties (Riverside, Orange, and Los Angeles) using county average fleet data and the on-road data collected above. The results indicate large differences between using county average fleet data and the on-road data. Emission estimates for Riverside County of CO, HC, and NO_x were 41 percent, 45 percent and 31 percent lower respectively using the on-road data. Large differences also exist between the three counties. Emissions are CO, HC

and NO_x were over 30 percent lower in Orange County compared to Los Angeles County.

Using a similar approach to collecting data as Malcolm et al. (2003), Bachman et al.(2000) combine this data with geocoded⁶ registration records using a GIS. This work expands on the ideas of Tomeh (1996) in which he allocated vehicle attributes from VIN decoded registration records to road segments. This was performed by geocoding the registration records and aggregating them to census blocks. Numerical methods were then used to allocate vehicle attributes from various census blocks to road segments. Bachman et al (2003) expand on this by geocoding VIN-decoded registration records in Atlanta to street addresses. The attributes of vehicles on a road is then estimated to be a function of the vehicle population in a radius around the road segment. This is accomplished using a GIS. This data is also supplemented with actual on-road fleet data collected by video camera using a method similar to Malcolm et al. (2003). The video camera data also collects volume and speed data. This data is used to estimate mobile emissions using the author's MEASURE model. The MEASURE model, unlike EFMAC and MOBILE6 produces ambient air emission levels by combining a vehicle activity model, emission factor model and atmospheric model along with the vehicle fleet information in a GIS framework. The result is a map with a grid displaying estimates of ambient air emissions across Atlanta.

2.3. Spatial Analysis and the CAFE Debate

The previous section discussed studies that have used spatial vehicle data in transportation research involving passenger vehicles. All of these studies were concerned

⁶ Geocoding is a GIS function that matches data with street address information to a point along a road on a map.

with modeling fuel economy, VMT, and criteria emissions. No studies have been published that use spatial vehicle data to model and analyze the economic impacts of transportation policies. Of particular concern are policies that target a particular attribute of a vehicle, either physical or environmental, since the previous studies have shown these to have a heterogeneous spatial distribution. Policies that place standards or taxes on vehicles, their owners, or manufacturers, will have costs and benefits. Given the distribution of the passenger vehicle fleet, these costs and benefits are unlikely to be evenly distributed; spatially or demographically.

In response to the 1973-74 Arab Oil Embargo congress passed the Energy Policy Conservation Act in 1975 which established CAFE standards for light-duty vehicles. Ever since its adoption, the CAFE program has been the subject of controversy among policy makers and researchers. Recent attempts to increase the CAFE standard have raised the following concerns.

There have been questions about the effect of CAFE on the down weighting of vehicles and safety (Harrington and McConnell, 2003; NRC, 2002). These questions stem from evidence that manufacturers down weighted their vehicles in the 1980's to increase fuel economy and comply with CAFE standards. Data from the IIHS (2004) suggests that smaller cars are more dangerous than larger cars. However, a recent study by Noland (2005) using an international data set finds that increasing fuel economy has not been correlated with vehicle safety

The economic efficiency of CAFE standards, especially as it compares to an equivalent gas tax has also been called into question (Austin and Dinan, 2005; Espey and Nair, 2005; Parry et al., 2004; Kleit, 2004). The debate concerns how consumers trade off

current dollars for future savings in fuel consumption, the time discount rate. It has been argued by Greene et al. (2005) and Plotkin and Greene (1997) that there is a fuel economy market failure. Consumers are unsure of future gasoline prices, do not consider savings over the life of the vehicles, use high discount rates, and do not know what the premium on fuel economy is or do not consider it because it is such a small fraction of the vehicle price.

A review of the economic literature on time discounting and time preferences by Frederick et al. (2002) found that estimates of annual discount rates ranged from less than zero to well over 100 percent, indicating a large uncertainty in how consumers discount future savings. A review of the economic literature on consumer discount rates related to energy decisions by Train (1985) found a similar range of estimated discount rates for investments in energy efficiency. Houston (1983) conducted a survey that presented a random sample of households with an energy saving investment problem. The survey presented the respondents with a hypothetical device that would reduce energy costs for a given installation and purchase cost of the device. The respondents were asked to choose how many dollars in annual energy savings would be required for them to make the investment. The respondents could also choose an option stating that they “did not know or were unsure” how much they would require. The results indicated that many respondents choose the “did not know or unsure” option, indicating the uncertainty that consumers may have about time discounting when attempting to make an energy saving investment decision. Asher (1992) finds that consumers have a negative willingness to pay for improvements in fuel economy. These results and the large range of estimated discount rates in the literature appear to support the argument of Greene et al. that there

may be a market failure. The NRC (2002) also finds that consumers may only value the first 3 years of fuel savings, not the savings over the lifetime of the vehicle. If this is true, consumers under value fuel economy by up to 60 percent (Greene et al, 2005).

Under assumptions of such a market failure, taxes would be inefficient at increasing fuel economy and standards would be the preferred policy tool. However, Dreyfus and Viscusi (1995), Kleit (2004) and Espey and Nair (2005) disagree. They argue that there is no evidence to support the claim of a market failure in fuel economy and it is likely that consumers accurately value fuel economy. Dreyfus and Viscusi use a hedonic model of household vehicle holdings and estimate that consumers use reasonable discount rates in the range of 11 to 17 percent when making fuel economy decisions. Others have also found the consumers have a positive willingness to pay for an increase in fuel economy (McCarthy and Tay, 1989; Boyd and Mellman, 1980). Parry et al. (2004) do not take a position but they acknowledge the importance of this argument in determining the costs and benefits of CAFE.

A third area of concern has to do with the price elasticity of VMT which has been termed the “rebound effect”. CAFE standards have increased the fuel economy of vehicles and therefore reduced the cost per mile of driving. The price elasticity of VMT has been estimated to be about -0.2 (Greene et al., 1999). Given this elasticity, an increase in CAFE standards would increase VMT. This would dampen the effect of the policy to some degree though not enough to completely offset the reduction in fuel consumption due to increased fuel economy. The concern is that the externalities associated with the increase in VMT may be greater than the benefits of reduced fuel consumption (Kleit, 2004; Parry et al., 2003; Harrington and McConnell, 2003). These

externalities include increased congestion, traffic accidents and criteria air emissions. In a recent testimony before the U.S. House Science Committee, Paul Portney, the Chairman of the CAFE Committee Board on Energy and Environmental Systems and the NRC Transportation Research Board stated that the NRC's report on the effectiveness of CAFE (NRC, 2002) should have paid closer attention to the rebound effect (Portney, 2005)

These three concerns are questions about the relative costs and benefits of increasing CAFE standards. These debates are likely to continue as they have for some time. CAFE standards for cars have not changed in the past 20 years, they have increased slightly for light-duty trucks recently (Davis and Diegel, 2004). Harrington and McConnell (2003) state that issues of horizontal equity, the unequal treatment of similar groups, may be an explanation for why economic policies regarding personal transportation have been stagnant. Horizontal equity may be a concern because as discussed above, people own a variety of vehicles with various attributes. Cost benefit analysis is important but should not be the sole consideration of policy makers. Arrow et al. (1996) state that a good analysis will also identify important distributional effects. Even if a policy is found to have positive net benefits it may be found unfavorable if it benefits one group over another. With environmental policies this can often be the rich over the poor. This is caused by differences in their respective valuation of environmental damages and because distribution effects tend to have a greater impact on the poor than the rich (Baumol and Oats, 1988). Levinson (2002) adds that the use of both quantitative and qualitative approaches to equity would help give importance to factors not included in benefit cost analysis.

The debate over the impacts of CAFE however has been relatively quite on issues of equity. A report by the Congressional Budget Office states that its criteria for evaluating policies to reduce gasoline consumption include the distributional effects between rich and poor and across regions. The report states that the gas tax has been found to impact rural residents more than urban residents and may be considered regressive. However no such study exists for CAFE (CBO, 2002). One of the main objectives of this thesis is to provide such a study. The other objectives are to provide an explicit analysis of the spatial variation of the passenger vehicle fleet with respect to physical and environmental attributes. The discussion in this chapter has made it clear that these objectives have significant policy importance.

Chapter 3

DATA AND METHODOLOGY

This chapter presents the data and methodology used to examine the spatial distribution of passenger vehicles, their attributes, and the impacts of increasing fuel economy standards. The final product is a comprehensive database containing details on the attributes, emissions and location of each passenger vehicle in the state. The database may be easily queried for particular attributes and aggregated from the town level to the state level. A GIS can be used with this database to view the results spatially and test the significance of spatial clustering and patterns. By geocoding the database, finer levels of aggregation may be used such as census blocks or a grid with a user defined cell size. There are some limiting factors with such processes and they are discussed at the end of this chapter.

This thesis uses spatially explicit data from the population of all Maine vehicle registration records. VIN decoding provides additional information about the attributes of each vehicle. This data is combined with national engineering estimates of the costs of fuel economy technology from the NRC (2002) and following the methodology of Rubin et al. (2006). Criteria air pollutant emission rates are estimated for each vehicle using the EPA's MOBILE6.2 emission factor model. The MOBILE6.2 model is calibrated to represent Maine's vehicle fleet, climate, fuel properties and vehicle regulations.

The following steps are taken to create a spatial view of the Maine passenger vehicle fleet and evaluate the research questions put forth in the previous section:

- 1) Build a database containing each vehicle's attributes and location.

- 2) Estimate criteria air pollutant and GHG emissions for each passenger vehicle using the EPA Mobile6.2 emission factor model.
- 3) Estimate the costs of increasing CAFE standards by using technology cost curves.
- 4) Estimate the net present value of increasing CAFE standards (fuel savings – technology costs).
- 5) Estimate the impact of increased CAFE standards on criteria air pollutant and GHG emissions.
- 6) Display the previous steps spatially using a GIS.
- 7) Use a GIS to test for the presence of statistically significant spatial clustering using Moran's I.

3.1. Vehicle Database

Registration records were obtained through InforMe, Maine's online information resource service (<http://www.maine.gov/informe/>). The registration data were provided in fixed width text format and contained 1,331,421 records which included every highway vehicle registered in Maine on March 31, 2005. Additionally, the data included trailers, ATVs, construction equipment and other non-highway vehicles. Table 3.1 describes the information included in the registration records.

Table 3.1 Registration Records from InforME

Field	Comments
Name	First, Last and MI
Date of Birth	month, day, year
VIN	Vehicle Identification Number
Expire Date	registration expiration date
Geocode	State of Maine numeric code for town name
Address1	street address
Address2	not used
Town	
State	
Zip	zip code
Reg_make	4 character make abbreviation
Reg_model	6 character model abbreviation
Reg_vehyear	vehicle model year
Reg_style	2 character body style code (SUV, Pickup Truck, etc.)
Odometer	self reported odometer reading (many records lack this data)
Listprice	vehicle suggested retail price (most records lack this data)

The registration records contained a wealth of information but inconsistency in the spelling of abbreviations used for makes, models, body style and town names along with numerous spelling errors made working with the raw data set difficult. Additionally, some records had incomplete information. To standardize the data and fill in missing information two steps are taken. The first, extensive data cleaning and the second, VIN decoding. Before these tasks are completed the data is imported into a Microsoft® Access database which is ideal for working with such a large data set and can be read and manipulated by ESRI® ArcMap™ 9.0 which is the GIS software used in this research.

The data is cleaned using alias tables and manual editing. Data cleaning efforts focus on town names because the data is eventually aggregated to the town level. The major problem encountered with town names are differences in the conventions used to designate prefixes such as South, North, East, West, Center and suffixes such as Township and Plantation⁷. There is also confusion over the actual name of certain towns.

⁷ Plantations are unorganized territories similar to Townships

Some towns in Maine contain smaller subdivisions, such as villages which have their own post office and zip code, but are completely within the borders of a larger town. There is also a high frequency of misspelling, especially for towns with long names. Since some towns had few spelling errors while others had many, all miss-spelled town names are edited to avoid introducing a bias. Town names are sorted and edited, manually and by using relational alias tables. A relational alias table is created by making a list of all town names, correct and misspelled, and then the misspelled names are corrected in an adjacent column. This table which now contains the misspelled and corrected names can be related to the registration table in Microsoft® Access and then an update query will replace the misspelled names. This procedure makes standardizing over a million town names possible because each error only needs to be corrected once. The town names are chosen to match the names used by the Maine Office of GIS which can be found in the file geocodes.zip at the office's website (ME-GIS, "Geocodes").

In order to standardize the records, fill in missing data, and obtain additional vehicle attribute information, VIN decoding is used. VIN decoding relates the VINs in the registration records to a database of vehicle attributes and other information provided by the manufacturers and maintained by a few private companies. ESP Data Solutions Inc. of Lawrence Massachusetts was selected to decode the VINs. In addition to information supplied by manufacturers, ESP Data Solutions provided EPA estimated city, highway and combined fuel economy and EPA Mobile6.2 vehicle classes. ESP Data Solutions was provided with a comma separated variable text file (.csv) of VINs to decode on their computer system and returned a file in the same format. SAS® 9.1 for windows is used to merge the decoded data file with the registration data based on the VINs and then

imported back into Microsoft® Access. Table 3.2 describes the data gained through VIN decoding.

Table 3.2 Data Gained Through VIN Decoding

Field	Comments
VIN	Vehicle Identification Number
Model Year	model year or error description for un-decodable VIN
Make	
Model	
Body Type	number of doors and body type
Trim Level	base, luxury, sports, etc.
Engine Type	number of cylinders, displacement, configuration
GVWR Class	Gross Vehicle Weight Rating Class
Series	indicates differences within the same make and model
Vehicle Type	car, pickup truck, van, etc.
Vehicle Class	further sub classification of Type (small car, midsize car, etc.)
Mobile6 Class	EPA Mobile6 model vehicle classification
Drive Line Type	2/4 wheel drive and front/rear wheel drive
Manufacturer	
Trailer Type	not used
Fuel Type	gasoline, diesel, electric, natural Gas
Axle Configuration	not used
Motorcycles Type	on road/off road
Highway MPG	EPA estimated fuel economy for vehicles < 8,500 lbs GVWR
City MPG	EPA estimated fuel economy for vehicles < 8,500 lbs GVWR
Combined MPG	EPA estimated fuel economy for vehicles < 8,500 lbs GVWR

There are a couple limitations to VIN decoding. Only vehicles model year 1981 and newer can be decoded. Prior to 1981 the National Highway Traffic Safety Administration (NHTSA) did not require standardized 17 character VINs. 4.9 percent of registration records are prior to 1981 and thus not decoded. Additionally, EPA estimated fuel economy is only available for passenger vehicles less than 8,500 lbs GVWR model year 1996 and newer. EPA does not evaluate fuel economy for vehicles weighing greater than 8,500 lbs GVWR because these vehicles are exempt from CAFE regulation. Additionally, ESP Data Solutions does not have information on fuel economy prior to model year 1996.

The final step in preparing the registration records for the research project is to flag the records pertinent to the thesis, passenger vehicles. For the purpose of this thesis passenger vehicles are considered any light-duty⁸ vehicle (LDV). Many medium-duty pickup trucks and SUVs are also used primarily as passenger vehicles (Davis and Truett, 2002) but are not considered here. These vehicles are not regulated by the current⁹ CAFE program and models earlier than the 2004 model year were regulated under less stringent emission standards than light-duty vehicles (BTS, 2004). Table 3.3 describes the distribution of the Maine passenger vehicle fleet.

Table 3.3 Maine Passenger Vehicles

Light Duty Vehicles (< 8,500 lbs GVWR)	Count	Percentage of Total Passenger Vehicles
Small Car	171,552	17.1%
Mid-size Car	257,067	25.6%
Large Car	63,016	6.3%
Small SUV	52,478	5.2%
Mid-size SUV	92,860	9.2%
Large SUV	21,999	2.2%
Small Pickup Truck	77,606	7.7%
Large Pickup Truck	139,661	13.9%
Mini Van	66,557	6.6%
Large Van	13,814	1.4%
		0.0%
Medium Duty Passenger Vehicles (> 8,500 lbs GVWR)		
Pickup Truck	47,584	4.7%
SUV	1,252	0.1%
		0.0%
Total Light-Duty Vehicles	956,610	95.1%
Total Medium-Duty Passenger Vehicles	48,836	4.9%
Total Passenger Vehicles	1,005,446	100.0%

⁸ Light-duty vehicles include all cars and pickup trucks, SUVs, and vans less than 8,500lbs GVWR

⁹ The CAFE program was updated in March 2006 and will include medium-duty pickup-trucks and SUVs for the first time starting with model year 2011. The new rule will categorize medium and light duty trucks by “foot print” size (wheel base multiplied by track width) rather than weight. Each foot print size class will be subject to a fuel economy standard (NHTSA, 2006).

3.2. Emission Estimates

Criteria air emissions, CO, VOCs, NO_x, PM₁₀, are estimated using the EPA MOBILE6.2 model. GHG emissions, CO₂, are estimated using a simple relationship between fuel economy and CO₂ provided by the EPA. The model output and the CO₂ estimates provide gram per mile emission factors, which are then multiplied by the annual VMT of each individual light-duty vehicle, providing estimates of annual emissions for each vehicle. The emissions of each light-duty vehicle are then aggregated by town and averaged to estimate the average annual emissions of individual vehicles by town. The following sections describe how the model is specified and run for Maine light-duty vehicles and how annual emission estimates are calculated.

3.2.1. EPA MOBILE6 Model

The EPA MOBILE6.2 model is the latest in a series of peer reviewed mobile emission factor models developed by the EPA to be used for estimating criteria air emissions from on-road vehicles in the U.S. The model is used by the federal government and states to determine compliance with federal regulations and the effects of new policies or transportation infrastructure on air emissions. The model provides gram per mile emission factors for 28 groups of vehicles classified by weight, type and fuel as shown in Table 3.4. Eight groups pertain to light-duty vehicles and are shown in bold. The model and complete documentation is freely available on the Internet (EPA, “Mobile6”).

The model as downloaded contains national average data as a default, but allows the user great flexibility in providing input and data specific to local conditions. The model may be tailored to local conditions by specifying local climate, vehicle fleet, fuel, vehicle use, inspection program data, and regulatory information. For this thesis, a

combination of default and Maine specific data are used. Default data are used for vehicle use characteristics, such as trip distance, speed, and engine starts per day. The following subsections describe data and inputs that are changed from the defaults

Table 3.4 MOBILE6 Vehicle Classifications

Abbreviation ¹	Description
LDGV	Light-Duty Gasoline Vehicles
LDGT1	Light-Duty Gasoline Trucks 1 (0 - 6,000 lbs. GVWR, 0 - 3,750 lbs. LVW)
LDGT2	Light-Duty Gasoline Trucks 2 (0 - 6,000 lbs. GVWR, 3,751 - 5,750 lbs. LVW)
LDGT3	Light-Duty Gasoline Trucks 3 (6,001 - 8,500lbs. GVWR, 0- 5,750 lbs. ALVW)
LDGT4	Light-Duty Gasoline Trucks 4 (6,001 - 8,500 lbs. GVWR, > 5751 lbs. ALVW)
HDGV2b	Class 2b Heavy-Duty Gasoline Vehicles (8,501 - 10,000 lbs. GVWR)
HDGV3	Class3 Heavy-Duty Gasoline Vehicles (10,001-14,000lbs.GVWR)
HDGV4	Class 4 Heavy-Duty Gasoline Vehicles (14,001 - 16,000 lbs. GVWR)
HDGV5	Class 5 Heavy-Duty Gasoline Vehicles (16,001 - 19,500 lbs. GVWR)
HDGV6	Class 6 Heavy-Duty Gasoline Vehicles (19,501 - 26,000 lbs. GVWR)
HDGV7	Class 7 Heavy-Duty Gasoline Vehicles (26,001 - 33,000 lbs. GVWR)
HDGV8a	Class 8a Heavy-Duty Gasoline Vehicles (33,001 - 60,000 lbs. GVWR)
HDGV8b	Class 8b Heavy-Duty Gasoline Vehicles (>60,000 lbs. GVWR)
LDDV	Light-Duty Diesel Vehicles
LDDT12	Light-Duty Diesel Trucks 1 and 2 (0 - 6,000 lbs. GVWR)
LDDT34	Light-Duty Diesel Trucks 3 and 4 (6,001 - 8,500 lbs. GVWR)
HDDV2b	Class 2b Heavy-Duty Diesel Vehicles (8,501 - 10,000 lbs. GVWR)
HDDV3	Class 3 Heavy-Duty Diesel Vehicles (10,001 - 14,000 lbs. GVWR)
HDDV4	Class 4 Heavy-Duty Diesel Vehicles (14,001 - 16,000 lbs. GVWR)
HDDV5	Class 5 Heavy-Duty Diesel Vehicles (16,001 - 19,500 lbs. GVWR)
HDDV6	Class 6 Heavy-Duty Diesel Vehicles (19,501 - 26,000 lbs. GVWR)
HDDV7	Class 7 Heavy-Duty Diesel Vehicles (26,001 - 33,000 lbs. GVWR)
HDDV8a	Class 8a Heavy-Duty Diesel Vehicles (33,001 - 60,000 lbs. GVWR)
HDDV8b	Class 8b Heavy-Duty Diesel Vehicles (>60,000 lbs. GVWR)
MC	Motorcycles
HDGB	Gasoline Buses (School, Transit and Urban)
HDDBT	Diesel Transit and Urban Buses
HDDBS	Diesel School Buses

¹Classifications in **bold** are those that refer to light-duty vehicles.

3.2.2. Climate Data

MOBILE6.2 allows the user to input basic climate data, including temperature, absolute humidity, elevation (either high or low), and solar load. Temperature is important factor in determining VOC, CO, and NO_x emission rates. An EPA sensitivity analysis of MOBILE6 (EPA, 2002) concludes that temperature effects can change

emission rates by over 20 percent. The sensitivity analysis finds that on average emission estimates of VOC, CO and NO_x are lowest between 60 and 70 degrees Fahrenheit and increase with lower and higher temperatures. The sensitivity analysis also finds that humidity effects NO_x emission rates by 5 percent to 20 percent, with increasing levels of humidity reducing emissions, but has little effect on the other criteria pollutants. The effect of temperature is also dependent upon vehicle age and model year. Older vehicles are typically effected more by temperature and humidity (EPA, 2002).

This analysis holds constant the effect of the spatial distribution of temperature and humidity across the state of Maine. This is in part a simplifying assumption while also being necessary to view the effect of the spatial heterogeneity of the vehicle fleet on emission rates. Temperatures can vary greatly across the state and even within a town. Locations along the immediate coast and higher elevations can be much cooler than inland and lower elevation regions located close by. Vehicles are driven over a wide area so that the temperature and humidity where the vehicle is parked is not necessarily the same temperature and humidity that the vehicle is normally operated in. An analysis of these climate induced spatial effects is beyond the scope of this thesis which is focused on vehicle fleet effects. Additionally, if the spatial distribution of climate effects are modeled it would mask the effects due to the spatial heterogeneity of the vehicle fleet leading to ambiguous results. Therefore, a single value for temperature and humidity is used for the entire state.

Temperature and humidity data for Maine are obtained from the National Oceanic and Atmospheric Administration (NOAA) for Portland and Caribou (NOAA, “Climate Data”). These are NOAA’s two Maine climate data collection sites, representing southern

coastal Maine and northern interior Maine respectively. The average temperature and humidity from the two sites are assumed to roughly approximate the climate across the state. The difference in temperature between Portland and Caribou is 2°F during the summer and 10°F during the winter. There is little difference in humidity levels. MOBILE6.2 is run for both winter and summer conditions, therefore requiring both summer and winter climate data which are taken as July and January respectively. Relative humidity provided by NOAA must be transformed to absolute humidity for inputting in to the model. The EPA provides an excel worksheet tool to carry out this transformation (EPA, “Humidity Tool”).

The altitude variable is set to 1, indicating low altitude and the solar load is left at the default values. The solar load is only applicable when using Mobile6.2 to estimate the effects of car air conditioner use, which is not considered in this research project. Table 3.5 describes the climate data specified for Maine in the model.

Table 3.5 MOBILE6 Input Parameters for Maine Climate

Parameter	Unit	Winter (January)	Summer (July)
Average Daily Temp. Range (MIN/MAX) ¹	°F	6.1 / 25.1	56.7 / 77.6
Humidity ¹	grains/lb	9.167 ⁽²⁾	69.351
Altitude (1 = low)	n/a	1	1

¹ Average of Portland and Caribou Values

² This value is below the MOBILE6 minimum value. The model replaces it with a value of 20.

3.2.3. Fuel Data

The properties of automobile fuels vary from state to state, between winter and summer, and over time as new regulations are adopted. To account for this, the model allows the user to input local fuel property data. This includes Reid Vapor Pressure (RVP), sulfur content, alcohol and ether market share, and alcohol and ether content. The Maine Department of Environmental Protection provides this information on its fuels

website (DEP, “Fuel Spreadsheets”). Diesel fuel sulfur content, which is regulated by the EPA, is obtained from the EPA (EPA, 2000). The EPA will require a 97 percent reduction in the sulfur content of diesel fuel to be phased in between June of 2006 through 2009 and the state of Maine will ban methyl tert-butyl ether (MTBE) from gasoline starting January 2007.

Table 3.6 describes the properties of motor fuel used in Maine that are specified in the model.

Table 3.6 MOBILE6 Input Parameters for Maine Fuel

Year Parameter	Units	2005		2015	
		January	July	January	July
Reid Vapor Pressure	psi	12.7	8.26	12.7	8.26
Fuel Program	n/a	1	1	1	1
Diesel Sulfur Content	ppm	500	500	15	15
Ether blend market share	fraction	1	1	0	0
Alcohol blend market share	fraction	0	0	0	0
Ether oxygen content	w% frac ¹	0.0045	0.0033	0	0
Alcohol oxygen content	w% frac ¹	0	0	0	0

¹ Weight Percent Fraction

3.2.4. Fuel Economy

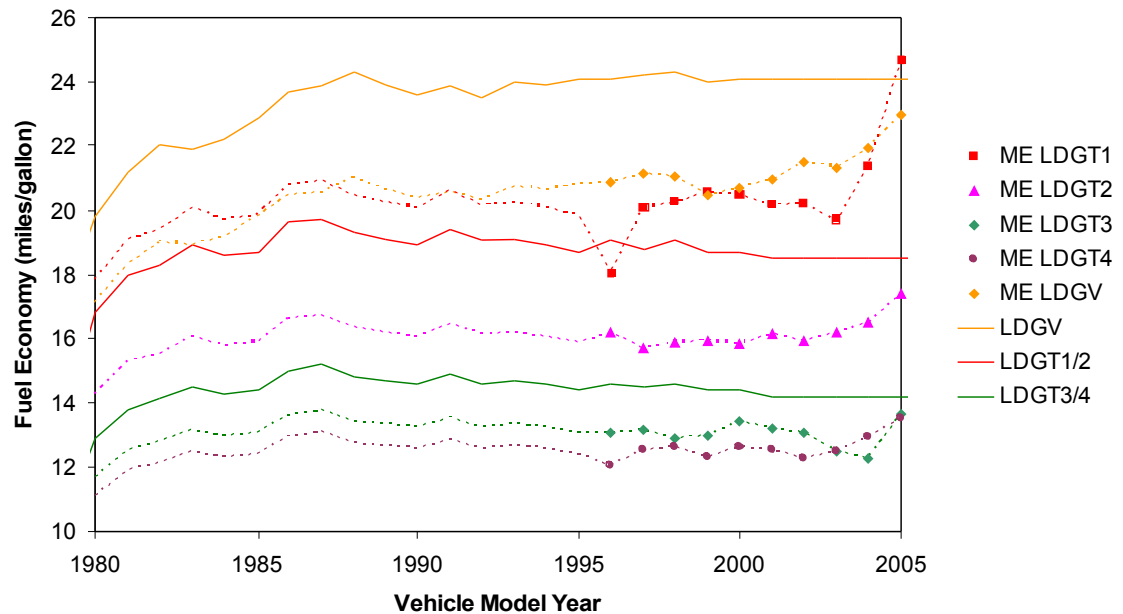
Fuel economy plays the dominant role in determining CO₂ emissions and to a much lesser extent, criteria emissions. The impact of fuel economy on criteria emissions is limited because federal and state emission standards require manufactures to add technology to their vehicles to reduce criteria emissions. Larger, less fuel efficient, vehicles have larger emission controls to handle the increased flow of criteria emissions. Over time emission controls become less effective, or are tampered with, making fuel economy an increasingly significant factor in criteria emissions. A recent study of state inspection and maintenance programs by Beydoun and Guldman (Beydoun, 2006) supports this. They estimate that a 1 percent increase in fuel economy decreases CO

emissions by 0.62 percent to 1.01 percent, HC emissions by 0.49 percent to 0.79 percent and NO_x emission by 0.45 percent to 0.84 percent. The elasticity of emission levels with respect to fuel economy varies across manufactures and makes. Though MOBILE6 does model the effects of aging, tampering, inspection programs and regulations in place during the time a vehicle was manufactured, it does not account for fuel economy in these calculations. Thus changes or differences in fuel economy do not significantly affect criteria emission estimates produced by MOBILE6.

MOBILE6 allows local fuel economy data to be imputed and this has a small impact on VOC and PM10 emissions. The fuel economy is also necessary to calculate CO₂ emissions outside of the model. The model contains a file (MPG.csv) which contains national average fuel economy by MOBILE6 class, fuel type, and year from 1952 to 2025. The fuel economy data gained through VIN decoding for Maine vehicles model year 1996 through 2006 indicate that passenger vehicles in Maine are not accurately reflected by the national data default in MOBILE6. Maine cars of these model years are 14 percent less fuel efficient than the national average. Similarly, light trucks range from 15 percent less fuel efficient in the LDGT2 class to 6 percent more fuel efficient for the LDGT1 class (see Figure 3.1 below). To account for this, the EPA estimated combined fuel economy data from VIN decoding is first adjusted downward by 15 percent. This is a standard discount factor recommended by EPA to reflect expected on road performance. The fuel economy data is then averaged by MOBILE6 class and year for model years 1996 through 2005. For vehicles model year 1995 and older, for which VIN decoding did not provide fuel economy data, the EPA national estimates are adjusted to reflect the average difference observed between national average fuel economy and Maine average

fuel economy over the years 1996 to 2005. Figure 3.1 shows the national average fuel economy data that is default in Mobile6 and Maine average fuel economy (points) and adjusted national estimates (dashed lines).

Figure 3.1 MOBILE6 Default and Adjusted Fuel Economy



Vehicle Types: Maine Light-duty gas trucks 0 - 6,000 lbs. gross vehicle weight rating, 0 - 3,750 lbs. loaded vehicle weight (ME LDGT1), Maine Light-duty gas trucks 0 - 6,000 lbs. gross vehicle weight rating, 3,751 - 5,750 lbs. loaded vehicle weight (ME LDGT2), Maine Light-duty gas trucks 6,001 - 8,500 lbs. gross vehicle weight rating, 0 - 5,750 lbs. loaded vehicle weight (ME LDGT3), Maine Light-duty gas trucks 6,001 - 8,500 lbs. gross vehicle weight rating, greater than 5,750 lbs. loaded vehicle weight (ME LDGT4), Maine Light-duty gas vehicles (ME LDGV), Light-duty gas vehicles (LDGV), Light-duty truck less than 6,001 lbs gross vehicle weight rating (LDT1/2), Light-duty truck 6,001 - 8,500 lbs gross vehicle weight rating (LDT3/4).

3.2.5. Maine Tailpipe Emission Regulations

MOBILE6 is designed to model the emissions of vehicles that comply with federal tailpipe emissions standards. Maine, along with several other states, has adopted California Low Emission Vehicle (LEV) standards. In Maine the new regulations took effect in 2001. LEV standards are in general tougher than federal standards (see Table 3.7 below). MOBILE6 has several commands and files that can be invoked to model alternative standards. These include the commands T2 EVAP PHASE-IN and T2 EXH

PHASE-IN which allow the user to define phase in schedules for the alternative standards. The T2 CERT command allows the user to define model year 2004 and newer 50,000 mile emission standards. Similarly, the 94+ LDG IMP command defines 1994 – 2003 emission standards. The files used with these commands, which define the phase in schedules and standards can be found in the appendix.

Table 3.7 Federal and California Exhaust Emission Standards

Model Years	New Vehicle Exhaust Standards ¹ 50,000 mile Certification Standards	Pollutant ²	LDV gm/mi	LDT12 gm/mi	LDT34 gm/mi
2001 - 2006	Federal Tier 1	NMHC	0.25	0.25	0.32
		CO	3.4	3.4	4.4
		NO _x	0.4	0.4	0.7
2001 - 2006	California LEVI Standards	NMOG	0.075	0.075	0.1
		CO	3.4	3.4	4.4
		NO _x	0.2	0.2	0.4
2007 +	Federal Tier 2	NMOG	0.1	0.1	0.1
		CO	3.4	3.4	3.4
		(Phased in 2004 - 2006)	NO _x	0.07	0.07
2007+	California LEVII Standards	NMOG	0.075	0.075	0.075
		CO	3.4	3.4	3.4
		(Phased in 2004 - 2006)	NO _x	0.05	0.05

Sources: California Air Resources Board (ARB, 2005) and U.S. DOT Bureau of Transportation Statistics (BTS, 2005)

¹Light-duty vehicle (LDV), Light-duty truck less than 6,001 lbs gross vehicle weight rating (LDT12), Light-duty truck 6,001 – 8,500 lbs gross vehicle weight rating (LDT34)

²Non-Methane Hydrocarbons (NMHC), Carbon dioxide (CO₂), Nitrogen Oxides (NO_x), Non-Methane Organic Gases (NMOG)

3.2.6. Running MOBILE6

A typical MOBILE6 model run calculates emission factors for each of the 28 vehicle groups. MOBILE6 combines the emission factors it calculates for vehicles of each age into one fleet emission factor for each of the vehicle groups. Since criteria emissions from vehicles vary widely with age due to deterioration of emission controls and tampering as noted above and also due to changing regulations, it is desirable to produce emission factors for vehicles of each age (see Tables 3.8-11 below). To

accomplish this, the MOBILE6 model is run for each age group individually by making use of the registration distribution file (Regdata.d). The registration distribution file allows the user to specify the fraction of vehicles in each of 25 age groups for each of the Mobile6 vehicle groups. The age groups range from less than one year old up to 24 years old with vehicles older than 24 years placed into the 24 year old group. By specifying that 100 percent of the fleet falls into one age group, emission factors specific to that age group are produced. This procedure is performed for each age group in order to produce vehicle type and age specific emission factors. To reduce the repetitiveness of this task, a DOS batch file is used to run the multiple cases and the resulting data is imported and organized in excel before being imported into Access. The process of importing MOBILE6.2 output into Excel and organizing the data is automated using macros created using visual basic. The appendix contains a sample of the MOBILE6.2 input commands, batch file, and raw output. The appendix also contains the visual basic program used to automate the data collection process. Tables 3.8 -3.11 contain the calculated emission factors for VOC, NO_x, CO, and PM10.

Table 3.8 VOC MOBILE6.2 Emission Factors (grams/mile)

MY	LDGV	LDGT1	LDGT2	LDGT3	LDGT4	LDDV	LDDT12	LDDT34
2006	0.110	0.104	0.110	0.111	0.112	0.051	0.039	0.039
2005	0.134	0.124	0.128	0.172	0.173	0.051	0.042	0.042
2004	0.155	0.150	0.160	0.311	0.302	0.058	0.055	0.054
2003	0.193	0.236	0.258	0.599	0.649	0.065	0.090	0.192
2002	0.257	0.346	0.379	0.686	0.762	0.073	0.104	0.221
2001	0.320	0.483	0.534	0.795	0.876	0.081	0.117	0.248
2000	0.649	0.926	1.090	1.140	1.282	0.293	0.398	0.550
1999	0.762	1.029	1.199	1.270	1.434	0.318	0.436	0.603
1998	0.923	1.157	1.348	1.424	1.595	0.342	0.475	0.654
1997	1.171	1.369	1.586	1.656	1.849	0.366	0.513	0.705
1996	1.398	1.636	1.853	2.010	2.131	0.390	0.552	0.848
1995	1.835	2.100	2.312	2.483	2.496	0.448	0.679	1.003
1994	2.236	2.552	2.685	2.766	2.779	0.546	0.914	1.067
1993	2.668	3.287	3.328	3.385	3.398	0.653	1.176	1.132
1992	2.993	3.734	3.775	3.808	3.821	0.687	1.255	1.198
1991	3.350	4.477	4.516	4.542	4.556	0.721	1.339	1.266
1990	3.737	4.906	4.947	4.884	4.897	0.756	1.428	1.336
1989	4.356	5.542	5.582	5.415	5.428	0.792	1.524	1.408
1988	4.664	6.457	6.496	6.198	6.210	0.827	1.628	1.484
1987	6.303	9.472	9.511	8.754	8.766	0.865	1.746	1.567
1986	6.806	11.200	11.239	10.030	10.043	0.902	1.870	1.652
1985	8.723	12.695	12.736	11.079	11.093	0.941	2.006	1.741
1984	10.240	14.385	14.426	12.133	12.147	0.980	2.155	1.836
1983	11.433	21.187	21.227	17.673	17.686	1.021	2.318	1.936
1982	12.062	23.536	23.578	18.964	18.977	1.062	2.498	2.044
1981	12.906	26.174	26.217	20.240	20.254	1.105	2.696	2.158

Vehicle Types: Light-duty gas vehicles (LDV), Light-duty gas trucks 0 - 6,000 lbs. gross vehicle weight rating, 0 - 3,750 lbs. loaded vehicle weight (LDGT1), Light-duty gas trucks 0 - 6,000 lbs. gross vehicle weight rating, 3,751 - 5,750 lbs. loaded vehicle weight (LDGT2), Light-duty gas trucks 6,001 - 8,500 lbs. gross vehicle weight rating, 0 - 5,750 lbs. loaded vehicle weight (LDGT3), Light-duty gas trucks 6,001 - 8,500 lbs. gross vehicle weight rating, greater than 5,750 lbs. loaded vehicle weight (LDGT4), Light-duty diesel vehicles (LDDV), Light-duty diesel trucks 0 - 6,000 lbs. gross vehicle weight rating (LDDT12), Light-duty diesel trucks 6,001 - 8,500 lbs. gross vehicle weight rating (LDDT34)

Table 3.9 NO_x MOBILE6.2 Emission Factors (grams/mile)

MY	LDGV	LDGT1	LDGT2	LDGT3	LDGT4	LDDV	LDDT12	LDDT34
2006	0.083	0.083	0.076	0.125	0.133	0.084	0.059	0.092
2005	0.185	0.185	0.129	0.237	0.246	0.120	0.084	0.151
2004	0.292	0.314	0.217	0.427	0.432	0.163	0.116	0.223
2003	0.409	0.523	0.717	0.789	1.117	0.210	0.380	1.137
2002	0.570	0.725	0.956	1.018	1.409	0.219	0.401	1.200
2001	0.727	0.918	1.178	1.279	1.751	0.227	0.420	1.259
2000	0.963	1.186	1.840	1.921	2.805	1.178	0.850	1.341
1999	1.084	1.334	2.059	2.145	3.106	1.217	0.881	1.393
1998	1.200	1.475	2.264	2.354	3.383	1.255	0.910	1.442
1997	1.311	1.615	2.457	2.549	3.636	1.291	0.936	1.487
1996	1.419	1.750	2.640	2.504	3.072	1.325	0.961	1.615
1995	1.639	1.973	2.718	2.394	2.394	1.358	1.132	1.744
1994	1.989	2.283	2.671	2.513	2.513	1.390	1.459	1.786
1993	2.383	2.816	2.816	2.841	2.841	1.421	1.798	1.826
1992	2.489	2.980	2.980	2.992	2.992	1.450	1.832	1.863
1991	2.661	3.363	3.363	3.336	3.336	1.479	1.865	1.899
1990	2.768	3.402	3.402	3.361	3.361	1.506	1.896	1.933
1989	2.976	3.547	3.547	3.477	3.477	1.533	1.973	2.010
1988	3.154	3.898	3.898	3.759	3.759	1.559	2.004	2.042
1987	3.679	3.638	3.638	3.615	3.615	1.584	2.507	2.533
1986	3.734	3.662	3.662	3.594	3.594	1.608	2.543	2.565
1985	4.170	3.481	3.481	3.354	3.354	1.632	2.581	2.597
1984	4.428	3.547	3.547	3.371	3.371	2.150	2.620	2.629
1983	4.573	4.016	4.016	3.790	3.790	2.174	2.660	2.660
1982	4.443	4.079	4.079	3.807	3.807	2.198	2.704	2.692
1981	4.559	4.225	4.225	3.874	3.874	2.221	2.751	2.725

Vehicle Types: Light-duty gas vehicles (LDV), Light-duty gas trucks 0 - 6,000 lbs. gross vehicle weight rating, 0 - 3,750 lbs. loaded vehicle weight (LDGT1), Light-duty gas trucks 0 - 6,000 lbs. gross vehicle weight rating, 3,751 - 5,750 lbs. loaded vehicle weight (LDGT2), Light-duty gas trucks 6,001 - 8,500 lbs. gross vehicle weight rating, 0 - 5,750 lbs. loaded vehicle weight (LDGT3), Light-duty gas trucks 6,001 - 8,500 lbs. gross vehicle weight rating, greater than 5,750 lbs. loaded vehicle weight (LDGT4), Light-duty diesel vehicles (LDDV), Light-duty diesel trucks 0 - 6,000 lbs. gross vehicle weight rating (LDDT12), Light-duty diesel trucks 6,001 - 8,500 lbs. gross vehicle weight rating (LDDT34)

Table 3.10 CO MOBILE6.2 Emission Factors (grams/mile)

MY	LDGV	LDGT1	LDGT2	LDGT3	LDGT4	LDDV	LDDT12	LDDT34
2006	5.139	4.078	4.258	3.987	4.160	0.426	0.194	0.222
2005	7.608	6.012	5.513	5.158	5.385	0.426	0.194	0.222
2004	8.508	7.074	6.539	6.297	6.530	0.450	0.211	0.240
2003	10.202	13.249	12.173	12.464	12.722	0.945	0.568	0.751
2002	12.857	16.651	15.448	15.607	15.875	1.000	0.614	0.808
2001	15.396	19.709	18.395	19.191	19.473	1.055	0.660	0.865
2000	16.200	20.358	22.134	22.579	22.960	1.110	0.707	0.921
1999	18.144	22.652	24.580	25.106	25.503	1.166	0.755	0.979
1998	19.990	24.842	26.985	27.569	27.975	1.222	0.805	1.036
1997	21.736	26.954	29.327	29.922	30.338	1.279	0.857	1.095
1996	23.418	29.058	31.627	34.195	34.410	1.337	0.912	1.370
1995	26.627	33.305	35.525	38.988	38.988	1.396	1.128	1.669
1994	31.929	40.376	41.575	43.302	43.302	1.456	1.538	1.758
1993	37.257	51.455	51.455	51.267	51.267	1.517	1.997	1.850
1992	38.992	55.504	55.504	54.904	54.904	1.580	2.128	1.947
1991	41.633	64.093	64.093	62.769	62.769	1.645	2.270	2.049
1990	43.674	66.480	66.480	64.428	64.428	1.711	2.425	2.156
1989	48.898	71.807	71.807	68.666	68.666	1.779	2.594	2.270
1988	50.002	79.505	79.505	74.667	74.667	1.849	2.779	2.391
1987	67.059	103.708	103.708	96.919	96.919	1.921	2.983	2.520
1986	69.688	117.432	117.432	106.530	106.530	1.996	3.207	2.657
1985	80.756	148.505	148.505	130.146	130.146	2.074	3.454	2.804
1984	90.061	165.772	165.772	140.638	140.638	2.155	3.727	2.962
1983	94.737	145.134	145.134	127.904	127.904	2.239	4.027	3.131
1982	127.616	155.508	155.508	133.156	133.156	2.326	4.360	3.313
1981	131.205	167.067	167.067	138.579	138.579	2.416	4.728	3.509

Vehicle Types: Light-duty gas vehicles (LDV), Light-duty gas trucks 0 - 6,000 lbs. gross vehicle weight rating, 0 - 3,750 lbs. loaded vehicle weight (LDGT1), Light-duty gas trucks 0 - 6,000 lbs. gross vehicle weight rating, 3,751 - 5,750 lbs. loaded vehicle weight (LDGT2), Light-duty gas trucks 6,001 - 8,500 lbs. gross vehicle weight rating, 0 - 5,750 lbs. loaded vehicle weight (LDGT3), Light-duty gas trucks 6,001 - 8,500 lbs. gross vehicle weight rating, greater than 5,750 lbs. loaded vehicle weight (LDGT4), Light-duty diesel vehicles (LDDV), Light-duty diesel trucks 0 - 6,000 lbs. gross vehicle weight rating (LDDT12), Light-duty diesel trucks 6,001 - 8,500 lbs. gross vehicle weight rating (LDDT34)

Table 3.11 PM10 MOBILE6.2 Emission Factors (grams/mile)

MY	LDGV	LDGT1	LDGT2	LDGT3	LDGT4	LDDV	LDDT12	LDDT34
2006	0.1342	0.1336	0.1367	0.1396	0.1397	0.0396	0.0409	0.0422
2005	0.1489	0.1475	0.1561	0.1641	0.1645	0.1498	0.1974	0.2428
2004	0.1499	0.1507	0.1577	0.1683	0.1662	0.1632	0.2159	0.2613
2003	0.1509	0.1532	0.1588	0.1681	0.1681	0.2257	0.2801	0.3233
2002	0.1507	0.1525	0.1593	0.1662	0.1688	0.2257	0.2801	0.3233
2001	0.1513	0.1526	0.1589	0.1659	0.1680	0.2257	0.2801	0.3233
2000	0.1516	0.1522	0.1595	0.1653	0.1677	0.2257	0.2801	0.3233
1999	0.1519	0.1521	0.1593	0.1666	0.1686	0.2293	0.2801	0.3233
1998	0.1512	0.1525	0.1594	0.1668	0.1676	0.2192	0.2801	0.3233
1997	0.1511	0.1527	0.1597	0.1660	0.1679	0.2229	0.2801	0.3233
1996	0.1514	0.1556	0.1588	0.1662	0.1695	0.2226	0.3011	0.3443
1995	0.1517	0.1544	0.1608	0.1677	0.1698	0.2534	0.3011	0.3443
1994	0.1520	0.1542	0.1605	0.1672	0.1692	0.2534	0.3011	0.3443
1993	0.1520	0.1541	0.1604	0.1671	0.1692	0.2564	0.4652	0.5083
1992	0.1526	0.1533	0.1596	0.1664	0.1684	0.2564	0.4652	0.5083
1991	0.1525	0.1532	0.1594	0.1661	0.1681	0.2564	0.4652	0.5083
1990	0.1528	0.1528	0.1591	0.1658	0.1678	0.2574	0.4622	0.5053
1989	0.1521	0.1498	0.1561	0.1636	0.1657	0.2436	0.4718	0.5182
1988	0.1519	0.1493	0.1555	0.1631	0.1652	0.2592	0.4749	0.5220
1987	0.1531	0.1496	0.1557	0.1629	0.1649	0.2840	0.4972	0.5379
1986	0.1535	0.1230	0.1291	0.1389	0.1409	0.3747	0.5155	0.5544
1985	0.1547	0.1190	0.1254	0.1354	0.1375	0.3916	0.5188	0.5590
1984	0.1560	0.1129	0.1194	0.1294	0.1315	0.3861	0.5084	0.5459
1983	0.1469	0.1028	0.1091	0.1224	0.1245	0.4046	0.5099	0.5485
1982	0.1449	0.0955	0.1021	0.1149	0.1170	0.4055	0.5099	0.5485
1981	0.1450	0.0915	0.0982	0.1119	0.1140	0.4115	0.4452	0.4776

Vehicle Types: Light-duty gas vehicles (LDV), Light-duty gas trucks 0 - 6,000 lbs. gross vehicle weight rating, 0 - 3,750 lbs. loaded vehicle weight (LDGT1), Light-duty gas trucks 0 - 6,000 lbs. gross vehicle weight rating, 3,751 - 5,750 lbs. loaded vehicle weight (LDGT2), Light-duty gas trucks 6,001 - 8,500 lbs. gross vehicle weight rating, 0 - 5,750 lbs. loaded vehicle weight (LDGT3), Light-duty gas trucks 6,001 - 8,500 lbs. gross vehicle weight rating, greater than 5,750 lbs. loaded vehicle weight (LDGT4), Light-duty diesel vehicles (LDDV), Light-duty diesel trucks 0 - 6,000 lbs. gross vehicle weight rating (LDDT12), Light-duty diesel trucks 6,001 - 8,500 lbs. gross vehicle weight rating (LDDT34)

3.2.7. Greenhouse Gas Calculations

Vehicular GHG emissions are primarily made up of CO₂, NO_x, CO and CH₄¹⁰. MOBILE6 uses a simple formula based on fuel economy to estimate CO₂ emissions, the most abundant GHG in vehicular exhaust. EPA's method assumes that all carbon in motor fuel will eventually oxidize to form CO₂ in the atmosphere. Under this assumption, and ignoring fuel additives such as oxygenates, the following formulas are used to estimate CO₂ emissions.

$$3.1 \quad \text{Gasoline: } CO_2(g / mi) = \frac{8,868(g / gal)}{FE(mi / gal)}$$

$$3.2 \quad \text{Diesel: } CO_2(g / mi) = \frac{10,176(g / gal)}{FE(mi / gal)}$$

These relationships are used in MOBILE6 and were obtained through communications with the EPA. To make the best use of the rich data source, individual vehicle registrations and equations 3.1 and 3.2 are used to estimate CO₂ emissions for each individual vehicle, not MOBILE6. By using the above equations, CO₂ emissions of each vehicle are estimated from each vehicle's fuel economy. MOBILE6 estimates CO₂ emission based on the fuel economy of each vehicle class.

Under the assumption that all carbon in motor fuel becomes CO₂, then the only other GHG in vehicle exhaust is NO_x. NO_x emissions are a mixture of various oxides of nitrogen with the most important being N₂O for global warming. The 100 year global warming potential of N₂O is 296 times greater than that of CO₂ (EPA, 2002). That is, a unit of N₂O has the same potential to warm the atmosphere as 296 units of CO₂ over 100 years. Unfortunately, N₂O is not regulated and therefore the levels of N₂O in vehicle

¹⁰ Methane (CH₄)

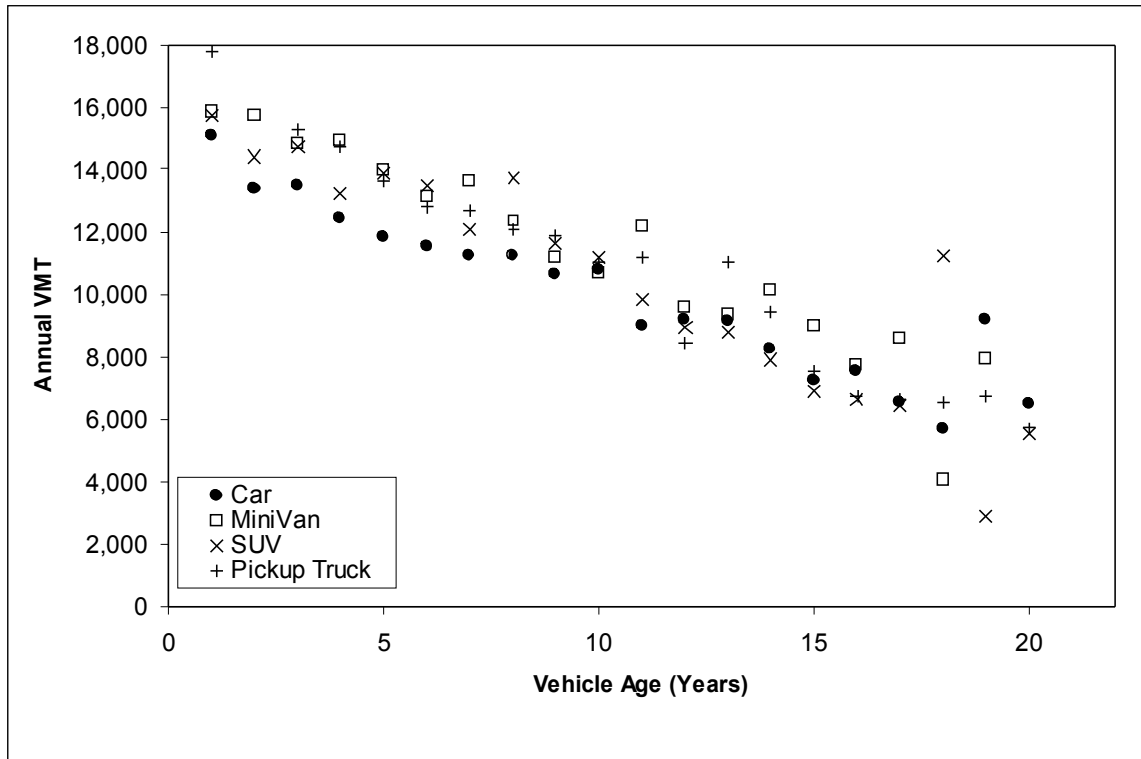
exhaust are poorly understood (and the topic of current research, see Behrentz, 2003) and not included in MOBILE6. This being the case, CO₂ is the only GHG gas considered in this research.

3.2.8. Annual Emissions

To estimate annual emission rates for each vehicle, information on annual VMT is required. Vehicle registration records contain self reported odometer readings, but with no time series data available the odometer readings cannot be used to determine annual VMT. As an alternative, a nationally representative federal survey is used. The 2001 National Household Transportation Survey (2001 NHTS) contains a wealth of information on the uses of various types of passenger vehicles by U.S. households. The survey is sponsored by the Federal Highway Administration (FHWA), the Bureau of Transportation Statistics (BTS), and the NHTSA and conducted by two private firms, Westat and Morpace. Oak Ridge National Laboratory (ORNL) maintains the data collected by the survey and provides online tools to access and analyze the data (ORNL, “2001 NHTS”).

The online data analysis tools were used to query data on VMT by vehicle age for cars, SUVs, pickup trucks, and vans from the 2001 NHTS. The relationship between VMT, vehicle age and vehicle type is show in Figure 3.2.

Figure 3.2 Annual Vehicle Miles Traveled vs. Vehicle Age



Annual mileage accumulation functions dependent on the type of vehicle are obtained using ordinary least squares (OLS). VMT accumulation is explained as a function of age. Vehicles zero to one year of age, model year 2005, are considered to be 1 year old. Table 3.12 provides mileage accumulation function parameters estimated by OLS which are intended to fit the data, not provide statistical estimates. The R^2 values indicate that the data fit well. The regression results also indicate that on average passenger vehicles are driven about 500 miles less each year.

Table 3.12 Annual VMT Accumulation OLS Regression Results

Parameter	Car	SUV	Pickup Truck	Minivan
intercept	14,380	16,258	17,504	16,692
age	-415.98	-551.04	-618.14	-537.34
R^2	0.89	0.83	0.94	0.9

These results are used to estimate the annual VMT for each passenger vehicle in Maine. The annual VMT is then multiplied by the emission factors to estimate annual emissions (grams/year) and divided by fuel economy (miles/gallon) to estimate annual fuel consumption for each passenger vehicle.

3.3. Policy Analysis: Impacts of Increasing CAFE Standards

The policy analysis estimates the costs and benefits of a 30 percent increase in CAFE standards over year 2000 levels. A 30 percent increase phased in over 10 years is the lower end of what the NRC (2002) in their report concluded was feasible with current technology. This increase would result in sales weighted fleet average fuel economy standards increasing from 27.5 MPG to 35.8 MPG for cars and 20.7 MPG to 26.9 MPG for trucks. Benefits are reduced private cost of driving from fuel savings, reduced CO₂ emissions and fuel consumption. Costs are the increased retail price of new vehicles and increased levels of criteria emissions due to the rebound effect. The private costs and benefits are combined and expressed as the NPV of an increase in CAFE standards. The NPV is the present value of fuel savings less the increased retail costs. The rebound effect is the increase in VMT caused by a reduction in the cost of driving, in this case due to greater fuel economy. As the results will show, the increase in annual criteria emissions resulting from the rebound effect is greater than the reduction in criteria emission resulting from increased fuel economy.

The policy analysis assumes that the sales mix (pickup trucks, SUVs, cars, and vans) and sales volume for each manufacture remains constant over the analysis period. However, manufacturers could attempt to meet CAFE standards by changing their sales mix though a combination of marketing and pricing strategies. A study on short-run

pricing strategies by Greene (1991) shows that this would be an expensive option to comply with CAFE standards as compared to adopting new fuel economizing technology. Similarly it is assumed that consumers continue to purchase the same types and amount of new vehicles each year. New vehicle registrations in Maine have been fairly constant over the past 4 years, as shown in Table 3.13, making the assumption of a constant sales volume reasonable. There is plenty of evidence indicating shifting demand for vehicle types, notably from cars to light-duty pickup trucks and SUVs (Davis and Diegel, 2004; Plaut, 2004; Davis and Truett, 2000; Kockelman and Zhao, 2000; Kockelman, 2000) but because time series registration data is unavailable the rate of this change is not known and so the change in demand for different vehicle types remains unaccounted for.

Table 3.13 Maine Motor Vehicle Registrations

Year	Registered Motor Vehicles
2005	1,198,445
2004	1,204,038
2003	1,233,564
2002	1,206,825
2001	1,160,977
2000	1,128,686
1999	1,124,517
1998	1,053,594

Source: Maine BMV (BMV, “statistics”)

3.3.1. Estimating Private Costs

The cost that consumers of new vehicles will face due to an increase in CAFE standards are estimated using fuel economizing technology cost curves created by Rubin et al. (2006). They use NRC (2002) data on fuel economizing technology and costs to create quadratic cost curves for 10 categories of passenger vehicles. The technologies included in the data are technology that is currently available and emergent technology that is fundamentally sound and expected to have significant market penetration by 2010

to 2015. The list of technologies and their costs were constructed by the National Research Council after interviewing vehicle and component manufactures. The technologies are ranked by cost effectiveness by Rubin et al. (2006), lowest to highest marginal cost of increasing fuel economy, and ordinary least squares is used to fit quadratic functions to the data. A study of automotive fuel economy potential by Greene and DeCicco (2000) finds that quadratic functions with zero intercept are appropriate for constructing fuel economy cost curves. Quadratic functions with a zero intercept ensure that there is no cost when no improvements are made and allows for increasing marginal costs of increasing fuel economy. The cost curves provide estimates of the increase in the retail price of new passenger vehicles due to a decrease in fuel intensity (increase in fuel economy) and have a quadratic form as show by equation 3.3.

$$3.3 \quad C(X)_{m,t,s} = b_{t,s}X_{m,t,s} + c_{t,s}X_{m,t,s}^2$$

The increased retail cost, $C_{t,s,m}$, is in 2001 dollars, the fractional change in fuel intensity, $X_{m,t,s}$, is in units of gallons per 100 miles, and $b_{t,s}$ and $c_{t,s}$ are cost curve parameter estimates. The subscripts m , t , and s , are indices for vehicle manufacturer, type and size. As equation 3.3 shows, costs can be estimated for each type and size of vehicle produced by each manufacturer. Table 3.14 provides the cost curve parameter estimates for each vehicle type and size. As Table 3.14 indicates, three sets of cost curves are estimated based on low, average and high efficiency assumptions. Here, efficiency refers to the potential for each technology to increase fuel economy. Lower efficiency cost curves therefore produce higher cost estimates for a given increase in fuel economy. The average of the low and high efficiency estimates is used.

Table 3.14 NAS Quadratic Fuel Economy Cost Curve Parameters

Class	Low Efficiency		Average Efficiency		High Efficiency	
	b	c	b	c	b	c
Car sub-compact	-4483.3	37917.2	-1540.3	15863.0	-156.7	7653.1
Car compact	-4977.3	34834.0	-1576.7	15119.5	2.6	7499.9
Car mid-size	-4156.2	33261.0	-1413.2	13824.5	129.9	7240.6
Car large	-4094.3	27185.2	-1111.9	12721.4	-83.1	5911.2
Small SUV	-6053.0	21895.7	-1092.4	13087.8	83.9	5756.3
Mid-size SUV	-5855.1	20007.2	-867.9	12744.2	-71.7	5101.0
Large SUV	-5410.3	21153.0	-739.4	13134.4	52.8	5432.6
Minivan	-5256.6	22686.7	-856.9	12969.7	53.2	5509.9
Small Pickup	-5530.0	20038.3	-988.0	11635.1	32.7	5178.0
Large Pickup	-5265.5	22737.7	-860.4	12997.9	50.3	5518.9

Cost curves provide estimates in 2001 Dollars

b and c are quadratic cost curve parameters used in equation 3.3

CAFE standards set three sales weighted average fuel economy standards that must be met by each manufacturer. One standard for domestic and imported light-duty trucks and two for cars; one for imported cars and one domestic cars. The two standards for cars require the same sales weighted average fuel economy to be met, but it must be met separately for imported and domestic vehicles. The separate standards for imported and domestic cars will not be taken into account because the registration data available does not provide information on whether a vehicle is domestic or imported. Therefore, there will be one truck and one car standard for each manufacturer to meet. The first step in determining the increase in retail cost due to an increase in CAFE standards is to determine how much each manufacturer will have to increase their car and truck fleet fuel economy to meet the stricter standards. Data on each manufacturer's production volume and fuel economy by vehicle type and size for the year 2003 are obtained from the National Highway Traffic Safety Administration (NHTSA) Manufacturer's Fuel Economy Reports (Rubin et al. 2006). Because the cost curves are in terms of fractional changes in fuel intensity (gallons per 100 miles), not fuel economy (miles per gallon), the

fuel economy data is transformed into fuel intensities. Equation 3.5 five provides the transformation from fuel economy, FE , to fuel intensity, I .

$$3.5 \quad I = \frac{100}{FE}.$$

Next, the difference between each manufacturer's fuel intensity, I_{mc} , where c is an index for CAFE class (car or truck), and the increased CAFE standard to be met (also transformed into fuel intensity), I_{cafe} , is calculated.

$$3.6 \quad \Delta I_{m,c} = I_{cafe} - I_{m,c}$$

The fractional change in fuel intensity required to meet a 30% increase in CAFE standards for each manufacturer and vehicle type is then calculated as:

$$3.7 \quad X_{m,c} = \frac{\Delta I_{m,c}}{I_{m,c}}.$$

Table 3.15 provides each manufacturer's 2003 car and truck sales weighted fleet average fuel intensity and the fractional change in fuel intensity needed to meet a 30 percent increase in CAFE standards. These estimates are used with Equation 3.3 specified with the average efficiency cost curve parameters from Table 3.14 to produce cost estimates for each of 10 vehicle type and size categories for each manufacturer, using the registration data from Maine. The cost estimates are provided in Table 3.16.

Table 3.15 Fractional Decrease in Fuel Intensity with a 30% Increase in CAFE standards

Manufacturer	Car		Truck	
	<i>I</i>	<i>X</i>	<i>I</i>	<i>X</i>
BMW	3.775	-0.259	4.995	-0.256
Daimler Chrysler	3.523	-0.206	4.536	-0.181
Ford	3.614	-0.226	4.677	-0.205
Fuji Heavy Industries	3.713	-0.247	3.659	0.000
General Motors	3.504	-0.202	4.691	-0.208
Honda	3.081	-0.092	4.057	-0.084
Hyundai	3.312	-0.155	4.095	-0.093
Isuzu	-	-	4.519	-0.178
Kia	3.344	-0.164	5.069	-0.267
Mitsubishi	3.567	-0.216	4.316	-0.139
Nissan	3.587	-0.220	4.561	-0.185
Porsche	4.335	-0.355	-	-
Suzuki	3.066	-0.088	4.377	-0.151
Toyota	3.078	-0.091	4.553	-0.184
Volkswagen	3.388	-0.174	4.654	-0.202

Dashes (-) indicate a manufacturer did not produce vehicles in the indicated category during 2003.

Fuel Intensity (*I*), Fractional Decrease in Fuel Intensity (*X*)

Table 3.16 Technology Costs for a 30% Increase in CAFE Standards

Manufacturer	Car				SUV			Pickup Truck		Minivan
	Sub-compact	Compact	Mid-Size	Large	Small	Mid-Size	Large	Small	Large	
BMW	\$1,462	\$1,422	\$1,293	\$1,141	-	\$1,058	-	-	-	-
Daimler Chrysler	\$991	\$967	\$878	\$769	\$625	\$573	\$563	\$559	\$580	\$579
Ford	\$1,158	\$1,129	\$1,026	\$901	\$777	\$716	\$706	\$694	\$725	\$724
Fuji Heavy Ind.	\$1,345	\$1,309	\$1,190	-	\$0	\$0	\$0	-	-	-
General Motors	\$956	\$933	\$848	\$742	\$792	\$731	\$721	\$708	\$740	\$738
Honda	\$276	\$274	\$247	-	\$184	\$163	-	-	-	\$164
Hyundai	\$623	\$610	\$554	-	\$213	\$189	-	-	-	-
Isuzu	-	-	-	-	-	\$557	\$546	-	-	-
Kia	\$676	\$662	\$601	\$522	\$1,224	\$1,139	-	-	-	\$1,153
Mitsubishi	\$1,071	\$1,044	\$949	-	\$405	\$367	-	-	-	-
Nissan	\$1,108	\$1,080	\$981	-	-	\$598	\$588	\$582	\$605	\$604
Porsche	\$2,543	-	-	-	-	-	-	-	-	-
Suzuki	\$257	\$254	\$230	-	\$463	\$422	-	-	-	-
Toyota	\$273	\$270	\$244	\$207	\$643	\$590	\$580	\$575	\$597	\$596
Volkswagen	\$751	\$735	\$667	\$581	\$752	\$692	-	-	-	\$699

Costs are in 2001 Dollars

Dashes (-) indicate a manufacturer did not produce vehicles in the indicated category during 2003

The cost estimates in Table 3.16 may appear unintuitive in the way they vary over vehicle type, size and manufacturer. There are several factors involved that determine the increase in retail cost resulting from a decrease in fuel intensity. The difference between vehicle types, the cost for cars being greater than the cost for light-duty trucks, is due to cars being held to higher CAFE standards than trucks. This has two effects. First, cars have a higher level of fuel economy and so a percentage change in fuel economy standards requires a greater absolute increase in the level of fuel economy for cars than it does for trucks. Second, since cars are held to higher fuel economy standards they contain greater amounts of fuel economizing technology, further increases in fuel economy will require more technology at an increasing marginal cost.

There are also differences in costs between different sized vehicles of the same type. In general, small vehicles have higher cost estimates than do large vehicles. Again, this is explained by differences in the level of fuel economy. Smaller vehicles generally are more fuel efficient than larger vehicles, so a percentage increase in fuel economy standards will require a greater absolute increase in the level of fuel economy for smaller vehicles.

The costs of increasing the fuel economy of small and fuel efficient vehicles are higher than they are for large and less fuel efficient vehicles. This does not mean that an increase in CAFE standards will raise the costs of small and fuel efficient vehicles more than those of larger and less fuel efficient vehicles which would make the CAFE program appear to be a poor policy tool. This is because not all vehicles will require the same increase in fuel economy. The increase in fuel economy will be different for each manufacturers fleet of cars and trucks. The differences in cost estimates between

manufacturers depend on how much each manufacturer is required to increase their average fleet fuel economy to meet the increased CAFE standard and the level of fuel intensity already existing in the fleet. Some manufacturers like Toyota, that produce relatively fuel efficient vehicles, will not be required to make large improvements to meet the higher standards while other manufacturers that produce relatively inefficient vehicles, such as General Motors, will have to make large improvements.

3.3.2. Estimating Private Benefits

The private benefits of increasing CAFE standards considered in this thesis are reduced fuel costs over the life of the vehicle. Using the approach and parameter estimates of Rubin et al. (2006) the discounted present value of fuel savings over the lifetime of each vehicle is calculated as:

$$3.9 \quad PV(X)_{m,t,s} = \frac{K_t}{100} (I_{m,t,s} - I_{m,t,s} (1 + X_{m,c}))$$

where K_t is the present discounted lifetime value of fuel savings and is expressed as;

$$3.10 \quad K_t = \frac{P \cdot M_t}{\kappa} \left(\frac{1}{\gamma_t + \rho} \right) \left(1 - e^{-(\gamma_t + \rho)L_t} \right).$$

$I_{m,t,s}$	Initial fuel intensity of each vehicle type and size by manufacturer
P	Fuel price
M_t	Annual VMT for a new vehicle of each type
κ	EPA expected on-road fuel economy correction factor
γ_t	Annual VMT rate of decline
ρ	Consumer discount rate
L_t	Vehicle lifetime for each vehicle type

Equation 3.9 is the discounted present value of fuel savings multiplied by the decrease in the level of fuel intensity. The values chosen for the parameters in the present value equation can have a significant effect on the level of benefits estimated for a change in fuel intensity. The most current estimates available from federal government sources are

used for all the parameters except for the consumer discount rate and vehicle lifetime where two scenarios are considered; a low consumer valuation of fuel economy case where there is no discounting and fuel economy is only valued for the vehicles first three years, and a high consumer valuation for fuel economy case where the discounted fuel savings over the life of the vehicle are considered.

These two cases are considered because it is unclear how consumers trade off current dollars for future savings in fuel consumption and this has a large effect on the estimation of benefits. Estimates of consumer discount rates in the economic literature have show a large range of values from negative values to exceedingly large values well over 100 percent (Frederick et al., 2002; Train, 1985). Additionally, discount rates appear to be influenced by a number of factors including; the size of the investment, the length of repayment, the particular good in question, and education (Frederick et al., 2002), income (Houston, 1983; Hausman, 1979; Train, 1985), and experience with the particular investment problem (Houston, 1983).

While it would be appropriate for consumers to consider the present value of fuel savings over the life of the vehicle it is more likely that they only consider the non-discounted savings for the first few years of ownership (NRC, 2002). The two cases of fuel economy valuation follow those used by Rubin et al.(2006) and the NRC (2002). The parameters used in this thesis for each case are provided in Table 3.17.

Table 3.17 Parameter Values used in Equation 3.9

Vehicle Type	ρ	γ	P (2001 \$)	M (miles)	L (years)	κ	K (2001 \$/ ΔI)
High Consumer Valuation of Fuel Economy							
Car	0.12	0.038	\$1.46	14,380	16.9	0.85	123,678
SUV	0.12	0.046	\$1.46	16,258	15.5	0.85	132,081
Pickup Truck	0.12	0.049	\$1.46	17,504	15.5	0.85	140,203
Minivan	0.12	0.043	\$1.46	16,692	15.5	0.85	137,559
Low Consumer Valuation of Fuel Economy							
Car	0	0.038	\$1.46	14,380	3	0.85	59,527
SUV	0	0.046	\$1.46	16,258	3	0.85	66,515
Pickup Truck	0	0.049	\$1.46	17,504	3	0.85	71,299
Minivan	0	0.043	\$1.46	16,692	3	0.85	68,592

Consumer discount rate (ρ), Annual decline in vehicle miles traveled (γ), Estimated price of gasoline in 2015 (P), Annual miles traveled for a new vehicle (M), Vehicle lifetime (L), EPA on-road fuel economy discount factor (κ), present discounted lifetime value of fuel savings (K), change in fuel intensity (ΔI)

Higher or lower values of the consumer discount rate, ρ , which is assumed to be equal to 12 percent in this thesis, could be argued for based on the large amount of uncertainty and factors effecting estimates of discount rates as discussed above. However, a discount rate of 12 percent is within the range estimated by Dreyfus and Viscusi (1995) for automobile fuel economy decisions (see Section 2.3).

A factor of particular concern to this thesis is the possible influence of income on the discount rate because the benefits of an increase in fuel economy are distributed across towns with varying levels of median household income. If low income households have higher discount rates than high income households, low income households will realize fewer benefits than high income households from an equivalent change in fuel economy. If this is the case, then assuming a constant discount rate across the population will under estimate the benefits to high income households and over estimate the benefits to low income households. Hausman (1979) found that households with lower incomes had higher discount rates for an investment in an energy saving durable good. Discount rates ranged from 5% to 89% over a household income range of \$6,000 to \$50,000 for the

purchase of an air conditioner. The difference in discount rates are attributed to low income households having a larger uncertainty in future income, lack of savings, less education, and lower income tax rates which provide less of an incentive to invest in durable goods which provide tax free returns. However, Houston (1983) using the survey discussed in Section 2.3 found no significant effect of income on the discount rate for energy saving durables goods. Houston does caution that this may be due to correlation with education and house size variables and does find that income increases the probability of a respondent indicating that they are unsure of how to evaluate the investment decision. Train (1985) reviews a number of additional studies which find that increasing income leads to lower discount rates for a range of energy saving investments. The magnitude of the effect of income on discount rates varies substantially across the numerous studies. For a change in income from 10,000 dollars to 50,000 dollars, estimates of the change in discount rates due to this change in income range from zero to 88 percent. These studies suggest that income does play a role in the discount rate that households use, but there is little evidence to support choosing particular discount rates for different household income levels. This being the case, the discount rate used may be considered an average discount rate with the result being a tempering of the resulting distribution of benefits across towns of varying median household income.

The initial level of fuel intensity for each vehicle type, size and manufacturer is taken from the same 2003 production data used in Section 3.3.1 to estimate costs. The fuel price is an estimate of the year 2015 price, the year in which it is assumed a 30 percent CAFE increase could be fully phased in. The fuel price is obtained from the Energy Information Agency's Annual Energy Outlook 2005 (EIA, 2005). The annual

VT of new vehicles and annual rate of decline in annual VT are estimated from the 2001 NHTS. The vehicle life is obtained from Tables 3-9 and 3-10 in the Transportation Energy Data Book (Davis and Diegel, 2004).

Social externalities are also generated by increasing CAFE standards. These include a reduction in GHG emissions, reduction in oil dependency, and an increase in criteria air pollutant emissions. These externalities impact society, not just specific vehicle owners and may be spread over large geographic areas.

GHG emissions and a reduction in oil dependency effect large groups of individuals. The benefits of a reduction in GHG emissions are a reduction in global warming and the potential adverse effects that global warming may cause. Benefits from a reduction in GHG emissions by an individual are spread across the globe and so the benefit to any individual, including the individual responsible for the reduction in GHG emissions, are likely to be small. Similarly the benefits of a reduction in oil dependency are spread across the U.S. The spatial distribution of these benefits across Maine is therefore homogeneous. The NRC (2002) estimates the cost of these externalities associated with gasoline use to be from 5 cents to 50 cents per gallon of gasoline and concludes that estimates much higher or lower cannot be rejected.

Criteria air pollutants contribute to a wide range of negative environmental and health impacts according to the EPA (EPA, "Criteria Emissions"). NO_x, CO, and VOC emissions contribute to ground level ozone formation. Ozone formation depends on weather conditions and ambient levels of additional pollutants in the air and may be transported over long distances by wind. Ozone can cause lung damage and infection, reduce crop productivity, damage foliage of plants and trees, and reduce visibility in

cities as well as scenic parks. NO_x emissions also contribute to acid rain which damages metal and stone structures and monuments and increases the acidity of soil and water, negatively impacting trees and fish. CO is also a poisonous gas, which at low levels poses a threat to individuals with heart disease and and at high levels impacts the central nervous system of healthy individuals. Particulates, including PM₁₀, are suspected of having wide ranging health effects including heart and lung disease while also reducing visibility and damaging plants and trees.

The impacts of an increase in criteria pollutant emission rates depend on where and when vehicles are driven, ambient air pollutant levels, and where the emissions are transported by wind. Health effects will be greatest in urban areas and congested highways where there is potential to expose more individuals and a greater concentration of vehicles. Wind may transport emissions and ozone from these areas into rural areas where environmental damages will be greatest. A model of vehicle activity and an atmospheric model (such as that used by Bachman et al. (2000)) would be required to estimate the spatial distribution of an increase in ambient levels of air pollutants and thus the spatial distribution of impacts. The modeling of vehicle activity and ambient air pollutant levels is beyond the scope of this thesis.

Therefore, the reduction of GHG emissions, reduction in oil dependency and increase of criteria emission rates are estimated and the spatial distribution of these quantities are displayed but not valued. In this case the net present value (NPV) of increasing CAFE standards (decreasing fuel intensity) is the discounted present value of fuel savings less technology costs for each vehicle type, size and manufacturer.

$$3.11 \quad NPV(X)_{m,t,s} = PV(X)_{m,t,s} - C(X)_{m,t,s}$$

Tables 3.18 and 3.19 show the estimated NPV for each vehicle type, size and manufacturer for the two consumer fuel economy valuation cases. The tables indicate that the assumptions about how consumers trade off current dollars for future savings in fuel consumption have a significant effect on the level of benefits.

Table 3.18 NPV of a 30% Increase in CAFE Standards: High Consumer Valuation of Fuel Economy

Manufacturer	Car				SUV			Pickup Truck		Minivan
	Sub-compact	Compact	Mid-Size	Large	Small	Mid-Size	Large	Small	Large	
BMW	-\$213	-\$28	\$259	\$422	-	\$1,017	-	-	-	-
Daimler Chrysler	\$230	\$1	\$188	\$322	\$872	\$794	\$1,128	\$1,036	\$1,240	\$394
Ford	\$79	-\$103	\$25	\$375	\$759	\$623	\$1,232	\$750	\$1,131	\$758
Fuji Heavy Ind.	-\$59	-\$49	\$107	-	\$0	\$0	\$0	-	-	-
General Motors	-\$54	-\$31	\$186	\$355	\$495	\$915	\$702	\$923	\$1,213	\$702
Honda	\$149	\$74	\$177	-	\$306	\$411	-	-	-	\$422
Hyundai	\$195	\$48	\$269	-	\$401	\$425	-	-	-	-
Isuzu	-	-	-	-	-	\$736	\$949	-	-	-
Kia	\$15	\$124	\$225	\$304	\$1,011	\$1,095	-	-	-	\$1,081
Mitsubishi	\$22	-\$95	\$167	-	\$568	\$606	-	-	-	-
Nissan	-\$2	\$26	\$126	-	-	\$781	\$792	\$862	\$879	\$819
Porsche	-\$386	-	-	-	-	-	-	-	-	-
Suzuki	\$120	\$123	\$147	-	\$520	\$720	-	-	-	-
Toyota	\$201	\$80	\$183	\$261	\$368	\$736	\$1,082	\$847	\$1,079	\$650
Volkswagen	\$48	\$67	\$232	\$473	\$756	\$815	-	-	-	\$928

All values in 2001 Dollars

Dashes (-) indicate a manufacturer did not produce vehicles in the indicated category during 2003.

Table 3.19 NPV of a 30% Increase in CAFE Standards: Low Consumer Valuation of Fuel Economy

Manufacturer	Car				SUV			Pickup Truck		Minivan
	Sub-compact	Compact	Mid-Size	Large	Small	Mid-Size	Large	Small	Large	
BMW	-\$838	-\$726	-\$518	-\$360	-	-\$57	-	-	-	-
Daimler Chrysler	-\$381	-\$484	-\$345	-\$224	\$97	\$86	\$253	\$208	\$294	-\$110
Ford	-\$541	-\$616	-\$501	-\$264	-\$36	-\$70	\$229	\$0	\$166	-\$9
Fuji Heavy Ind.	-\$703	-\$680	-\$542	-	\$0	\$0	\$0	-	-	-
General Motors	-\$506	-\$483	-\$331	-\$194	-\$171	\$63	-\$35	\$76	\$198	-\$44
Honda	-\$64	-\$100	-\$36	-	\$52	\$114	-	-	-	\$119
Hyundai	-\$215	-\$282	-\$143	-	\$83	\$107	-	-	-	-
Isuzu	-	-	-	-\$109	-	\$67	\$175	-	-	-
Kia	-\$331	-\$270	-\$188	-	-\$146	-\$61	-	-	-	-\$76
Mitsubishi	-\$526	-\$570	-\$391	-	\$65	\$103	-	-	-	-
Nissan	-\$556	-\$528	-\$428	-	-	\$67	\$78	\$112	\$108	\$82
Porsche	-\$1,466	-	-	-	-	-	-	-	-	-
Suzuki	-\$69	-\$66	-\$42	\$27	\$11	\$129	-	-	-	-
Toyota	-\$36	-\$95	-\$31	-\$54	-\$155	\$50	\$222	\$108	\$208	\$5
Volkswagen	-\$352	-\$335	-\$218	-	-\$24	\$35	-	-	-	\$85

All values in 2001 Dollars

Dashes (-) indicate a manufacturer did not produce vehicles in the indicated category during 2003.

The NPV is the metric used to analyze the equity of the private costs and benefits of an increase in CAFE standards for consumers of new vehicles. The increased CAFE standards are assumed to take affect in 2015. Since the future demand for light-duty vehicles in Maine is unknown, the NPV estimates are applied to the current demand for new light-duty vehicles which is assumed to approximate the demand for new light-duty vehicles in the future. This presents another issue, what is the current demand for new light-duty vehicles in Maine? The registration database contains only a snapshot of the Maine vehicle fleet so it cannot be determined which vehicles were purchased in any given year. The number of model year 2004 vehicles is close to the number of new vehicle titles received in Maine. There were 70,296 model year 2004 vehicles in the registration database compared to 67,394 new vehicle titles issued in 2001, the most recent available title information (BMV, 2001). Therefore an approximation of new light-duty vehicle sales is used; model year 2004 light-duty vehicles. The NPV estimates are then merged with model year 2004 light-duty vehicle records in the database.

3.3.3. Estimating Changes in Emissions

The level of criteria and GHG emissions under the increased CAFE standards are estimated using the same methods as in Section 3.3, replacing the 2004 fuel economy levels with the increased fuel economy levels. Table 3.20 displays the emission factors for new model year 2015 light-duty vehicles in Maine. The emission factors estimated for the 30 percent increase in CAFE are multiplied by a larger VMT which has been adjusted upwards due to the rebound effect which is discussed below. The difference between the original levels of emissions and new levels is then easily calculated. Similarly, the change in fuel consumption is found by multiplying annual VMT by the reference levels of fuel

economy and the adjusted annual VMT by the increased levels of fuel economy and taking the difference.

Table 3.20 Model Year 2015 MOBILE6.2 Gram/Mile Emission Factors

	LDGV	LDGT1	LDGT2	LDGT3	LDGT4	LDDV	LDDT12	LDDT34
PM10								
CAFE	0.1316	0.1316	0.1333	0.1354	0.1349	0.0385	0.0398	0.0408
Reference	0.1335	0.133	0.1358	0.1384	0.1385	0.0396	0.0409	0.0422
VOC								
CAFE	0.107	0.101	0.102	0.1025	0.1015	0.051	0.036	0.036
Reference	0.1095	0.103	0.105	0.1065	0.1075	0.051	0.036	0.036
NO _x								
CAFE	0.048	0.048	0.0455	0.055	0.064	0.048	0.033	0.033
Reference	0.048	0.048	0.0455	0.055	0.064	0.048	0.033	0.033
CO								
CAFE	4.9605	3.9405	4.164	3.899	4.068	0.426	0.194	0.222
Reference	4.9605	3.9405	4.164	3.899	4.068	0.426	0.194	0.222

Particulates less than 10 µm in diameter (PM10), Volatile Organic Compounds (VOC), Nitrogen Oxides (NO_x), Carbon monoxide (CO)

Vehicle Types: Light-duty gas vehicles (LDV), Light-duty gas trucks 0 - 6,000 lbs. gross vehicle weight rating, 0 - 3,750 lbs. loaded vehicle weight (LDGT1), Light-duty gas trucks 0 - 6,000 lbs. gross vehicle weight rating, 3,751 - 5,750 lbs. loaded vehicle weight (LDGT2), Light-duty gas trucks 6,001 - 8,500 lbs. gross vehicle weight rating, 0 - 5,750 lbs. loaded vehicle weight (LDGT3), Light-duty gas trucks 6,001 - 8,500 lbs. gross vehicle weight rating, greater than 5,750 lbs. loaded vehicle weight (LDGT4), Light-duty diesel vehicles (LDDV), Light-duty diesel trucks 0 - 6,000 lbs. gross vehicle weight rating (LDDT12), Light-duty diesel trucks 6,001 - 8,500 lbs. gross vehicle weight rating (LDDT34)

The increase in fuel economy due to the increase in CAFE standards increases the annual VMT of each vehicle. This occurs because increasing the fuel economy of vehicles reduces the marginal cost of driving. The elasticity of VMT with respect to cost per mile of driving has been estimated to be -0.2 by Greene et al.(1999) and is the value cited in numerous other CAFE studies (Perry et. al. 2004; Klier, 2004; Harrington and McConnell, 2003; NRC, 2002). This elasticity indicates that a 10 percent decrease in the cost of driving will increase the number of VMT by 2 percent. The increase in VMT will increase the annual emissions of criteria air pollutants.

Formally the elasticity of VMT is defined as:

$$3.8 \quad \varepsilon_{VMT, Pm} = \frac{\partial VMT}{\partial Pm} \cdot \frac{Pm}{VMT} = \frac{\% \Delta VMT}{\% \Delta Pm}$$

where, Pm , the price per mile is:

$$3.9 \quad Pm = \frac{P}{FE}$$

To estimate the rebound effect ($\partial VMT/VMT$) the percent difference in the price per mile ($\partial Pm/Pm$) resulting from the increase in CAFE standards is estimated for each light-duty vehicle.

$$3.10 \quad \frac{\Delta Pm}{Pm} = \frac{Pm_{cafe} - Pm_{reference}}{Pm_{reference}}$$

The rebound effect for each vehicle is then estimated as:

$$3.10 \quad \frac{\Delta VMT}{VMT} = \frac{\Delta Pm}{Pm} \cdot \varepsilon_{VMT, Pm}$$

The percent increase in VMT for each vehicle is then multiplied by each vehicle's estimated annual VMT (refer back to Table 3.11) to estimate the new annual VMT due to the increase in CAFE standards for each vehicle.

3.4. Displaying the Data Spatially

Now that a database containing passenger vehicle attributes, emissions and geographic locations for each passenger vehicle in Maine and also the NPV, increased emission levels, and reduced fuel consumption estimates resulting from increased CAFE standards for new light-duty vehicles have been created it is time to analyze the data. There are 1,005,446 passenger vehicle records and 56,700 new (model year 2004) light-duty vehicle records in the database. The data are aggregated by town and thematic maps are created which display the spatial distribution of the results.

3.4.1. Creating Spatial Data

There are a number of methods available to display data spatially using a GIS. Each individual point can be plotted by geocoding street addresses or the data can be aggregated over some geographical extent. While viewing the individual data points may be useful for some studies, such as looking at trends within a neighborhood or travel cost studies, it is not useful for this thesis because of the large number of data and wide scope of the study. A convenient way to aggregate the data without losing too much spatial resolution, which is used in this thesis, is to aggregate the data by town. The data could also be aggregated using a grid in place of town boundaries.

Using a grid would enable the data to be viewed at larger or finer levels of aggregation. To use a grid, the records must be geocoded by street addresses and then spatially joined to the grid. This process assigns each data point to a grid cell. The points in each cell can then be aggregated and the sum, mean, standard deviation or some other metric can be displayed. This method suffers from one limiting factor, the availability of high quality road and street address data that is necessary to enable geocoding. Street address typos and misspellings are also an issue but they may be manually corrected. Unfortunately such high quality data is only partially developed for Maine at this time.

Aggregating the data by town limits the level of aggregation, but it has its benefits. All of the registration records contain town names but many do not include street address information¹¹. Many of the street addresses also contain typos which limit the effectiveness of geocoding. Therefore, aggregating by town allows more records to be

¹¹Post office box numbers and Rural Route numbers are provided in place of actual street addresses in many rural areas.

used and eliminates a possible bias in rural areas where street address information is less complete.

ESRI® ArcMap™ 9, has the ability to connect to Microsoft® Access database which is used to store the vehicle records. This enables data to be transferred and displayed by ArcMap™ without any conversion. Additionally, data can be easily updated and recalculated in the Access database and the updates will be reflected in ArcMap™. The records are aggregated by town in Microsoft® Access and then joined with a shapefile that defines the boundaries of each town in Maine using ArcMap™. The shapefile (metwp250poly.shp) was downloaded from the Maine Office of GIS (ME-GIS, “metwp250”). Joining the database records to the shapefile is the process that connects the database records to a geographic position on earth which is then displayed by ArcMap™.

3.4.2. Thematic Display

Tufte (2001) states that, “Excellence in statistical graphics consists of complex ideas communicated with clarity, precision, and efficiency.” and that, “Graphics *reveal* data.”. Thematic maps are the graphics used in this thesis to communicate and reveal the spatial distribution and patterns in the data and results. There are multiple cartographic methods to map data and care must be taken in choosing a method that accurately displays the data and efficiently communicates the desired information. In this case the data to be communicated is the spatial distribution of passenger vehicles, their attributes and the impacts, costs and benefits of increasing CAFE standards.

The choropleth map is the most common type of statistical map for displaying quantitative data and the type that is used in this thesis. A choropleth map displays

quantities for various areas using colors, shading or cross hatching. The choropleth maps used in the thesis display quantitative metrics by town. To efficiently display data using a choropleth map the data should be classified. Classification clarifies and reveals the data by removing noise and reducing the number of symbols used to show quantities.

Research has indicated that people can only distinguish between a limited number of gray tones, between 7 and 11 (Kraak, 2003; Dent,1999); the recommended number of classes is usually between 4 and 6 but may be more or less depending on the application.

Choosing the correct data classification method when using choropleth maps is also important in order to accurately display the data. The best classification methods will accurately reflect the statistical surface of the data (Kraak, 2003). The statistical surface can be thought of as a three dimensional map where the height of each area is equal to the magnitude of the quantity for that area. The most common classification methods are equal interval, quantiles, natural breaks, and standard deviations. Each method has its strengths and weaknesses.

Equal interval and quantile methods are considered to be the least useful since they may classify similar data into different classes or classify dissimilar data into similar classes, not accurately reflecting the statistical surface, resulting in a misleading map (MacEachren, 1994). However, these methods are useful when comparing multiple maps or a time series of maps since the classification does not change allowing differences in the maps to be easily detected.

The natural breaks method ranks the data and then groups similar data in each class by setting class breaks where there are discontinuities in the ranked data series. Jenks (1977) created an algorithm to find these natural breaks automatically using a

computer. The natural breaks method presents the most accurate representation of the data in the sense that it minimizes within class variation and maximizes variation between classes, accurately reflecting the statistical surface of the data, but the classification is different for each data set making comparison between different maps and time series difficult (MacEachren, 1994).

The standard deviation method, which is used in this thesis, determines the mean of all the values of the areas and classifies the data by standard deviations (or fractions of a standard deviation) from this mean. The method is susceptible to misrepresenting the statistical surface of the data if the data is not distributed normally. The mean of a skewed distribution would not accurately describe the central tendency of the data and the resulting classification would be misleading (Dent, 1999). However, the standard deviation classification method is useful when the data is close to normally distributed and the purpose is to show deviations from the mean. This classification method is ideal for this analysis of heterogeneity in the spatial distribution of passenger vehicles, their attributes and the impacts, costs and benefits of increasing CAFE standards; greater numbers of towns deviating from the mean indicate greater amounts of heterogeneity.

Choropleth maps are produced using ESRI® ArcMap™ 9.0. The data are aggregated by town and the towns are classified using standard deviations from the mean town. Classes are either a half standard deviation or one standard deviation in size. Each class is assigned a color; neutral colors representing classes near the mean and darker colors representing classes that deviate from the mean. This scheme produces maps highlighting which towns deviate from the mean town and clearly displays the extent, pattern and magnitude of any heterogeneity.

Maps depicting the spatial distribution of passenger vehicles and their attributes display the fraction of each attribute by town expressed as a percentage. For example: the percentage of all light-duty vehicles that are SUVs in each town. Maps depicting the environmental attributes, criteria and GHG emission rates and fuel economy, and the NPV of increasing CAFE standards display the level for the average light-duty vehicle in each town.

Towns with less than 10 registered vehicles are excluded from the analysis to reduce the impact of outliers. Out of a total of 525 towns and unorganized territories with registered vehicles, 29 had less than 10 registered vehicles. When estimating the impacts of increasing CAFE standards, where only new vehicle registrations are considered, an additional 81 towns and unorganized territories were excluded based on the above criteria. Towns with few vehicles, there are some with only one, produce extreme values which impact the standard deviation which determines the class size. For example, a town with only one vehicle which happens to be a pickup truck will be composed of 100 percent pickup trucks and 0 percent of cars, SUVs and minivans. This leads to a larger standard deviation in the prevalence of pickup trucks across towns and the result is a loss of resolution displayed in the maps.

3.5. Quantifying and Statistically Testing Heterogeneity

The amount of heterogeneity in the spatial distribution of passenger vehicles, their attributes and the impacts, costs and benefits of increasing CAFE standards is measured using Moran's I. Moran's I is used to quantify the amount of clustering in spatial data, in this case how similar a town is to neighboring towns, and the degree of clustering can be statistically tested. Greater amounts of spatial clustering indicate the presence of spatial

patterns and provides evidence of heterogeneity while lack of spatial clustering indicates a dispersed or random spatial distribution and provides evidence of homogeneity.

3.5.1. Calculating Moran's I

For each pair of towns, ij , the product of the difference in the value of each town, Q_i and Q_j , from the mean value of all towns, \bar{Q} , is calculated and then weighted by the inverse distance between the pair of towns, W_{ij} . These values are then summed over all towns.

$$3.11 \quad \sum_i \sum_j W_{ij} (Q_i - \bar{Q})(Q_j - \bar{Q})$$

Then the variance of the value of each town from the mean value of all towns is calculated and multiplied by the sum of the distance weights, W_{ij} , where, n , is the number of towns.

$$3.12 \quad \sum_i \sum_j W_{ij} \frac{\sum_i (Q_i - \bar{Q})^2}{n}$$

The value in 3.11 is then divided by the variance in 3.12 to get Moran's I.

$$3.13 \quad I_{\text{moran}} = \frac{n \sum_i \sum_j W_{ij} (Q_i - \bar{Q})(Q_j - \bar{Q})}{\sum_i \sum_j W_{ij} \sum_i (Q_i - \bar{Q})^2}$$

The value of Moran's I ranges from -1 to 1. The expected value of Moran's I if the spatial distribution is perfectly random is:

$$3.14 \quad I_{\text{expected}} = \frac{-1}{n-1}$$

Moran's I will be approximately zero if the spatial distribution is perfectly random. If more pairs of towns have similar values than not, indicating clustering, then the value in 3.11 will be positive and Moran's I will be greater than zero. Otherwise, if more pairs of

towns have dissimilar values then not, indicating a dispersed spatial distribution, the value in 3.11 will be negative and Moran's I will be less than zero. Therefore, the presence of spatial clustering and patterns and evidence of heterogeneity are indicated when the value of Moran's I is greater than zero. A random spatial distribution, when Moran's I is close to zero, provides evidence of a homogeneous spatial distribution.

Moran's I is calculated for each map displayed in the results using ESRI® ArcMap™ 9.0. The GIS makes this calculation possible by having the ability to measure the inverse distance between each pair of towns. The GIS uses the centroid of each town to measure the distance between each pair. It should be noted that various distance weights may be used when calculating Moran's I. Inverse distance weights used here give greater importance to closer towns than more distant towns.

3.5.2. Testing the Significance of Moran's I

The significance of Moran's I can be tested by calculating its Z-score.

$$3.15 \quad Z_I = \frac{I_{\text{moran}} - I_{\text{expected}}}{\sqrt{\sum_i \sum_j W_{ij} \frac{\sum_i (Q_i - \bar{Q})^2}{n}}}$$

The Z-score is the difference between the calculated value and the expected value divided by the weighted standard deviation of the calculated value. The level of significance can then be determined using a standard normal distribution. The null hypothesis is that the distribution is perfectly random, if the Z-score exceeds the critical value of the standard normal distribution the null hypothesis is rejected and evidence of significant clustering is provided. The patterns in this thesis are tested at the 1% confidence level, so that Z-scores greater than the critical value of 2.58 provide strong evidence of spatial clustering.

Chapter 4

RESULTS: A SPATIAL VIEW

This chapter presents a series of choropleth maps that show the spatial distribution of passenger vehicles registered in Maine and their characteristics. The data are aggregated by town and in most cases the relative level of a characteristic is shown as a percentage. The levels are grouped into classes and the classes are indicated on the map by a particular color level. The grouping of the classes for the majority of the maps is determined by standard deviations from the mean of all towns, each class being either one half or one standard deviation. In other words, these maps display which towns have higher or lower relative levels of each characteristic with respect to the average town. This chapter also presents the results of a spatial policy analysis, the impacts, costs and benefits of increasing CAFE standards by 30 percent. This chapter therefore addresses the questions of whether the passenger vehicle fleet and passenger vehicle attributes are distributed homogeneously or not and the impact this has on the distribution of environmental attributes and in turn the equity of transportation policies.

The spatial distributions displayed in the maps in this chapter are also statistically tested for the amount and significance of clustering. Greater spatial clustering of similar values indicates that the spatial distribution of the results is not random and provides evidence of a heterogeneous spatial distribution. The amount and significance of spatial clustering is estimated by Moran's I. Values of Moran's I greater than zero and less than one indicate clustering, while values less than zero and greater than negative one indicate a dispersed distribution, and values close to zero indicate a random distribution. The values of Moran's I can be statistically tested as described in Section 3.5.2.

The presentation of the results include a number of maps, but certainly not every possible map. The database-GIS system used is capable of displaying a multitude of characteristics, classified and grouped by many different methods. Each of the following sections displays a group of related maps preceded by a discussion of their policy significance and how they help answer the three research questions discussed in the first chapter.

4.1. The Spatial Distribution of Passenger Vehicles

The majority of the maps in this thesis display relative levels of vehicle types and their characteristics, but it is important to keep in mind the distribution of the level of vehicle ownership (the number of passenger vehicles per town) across the state. This distribution follows the distribution of population as one would expect in a country with almost as many cars as people. This is shown in Figures 4.1 and 4.2. The figures indicate that passenger vehicles as well as the population are concentrated in four areas of the state: Portland, Lewiston, Augusta and Bangor. Income is also another important factor to keep in mind while viewing the following results. Vehicles are expensive and so how much an individual earns may limit which types of vehicles they may be able to purchase. The distribution of income will be referred back to several times while discussing the results and is therefore provided in Figure 4.3.

Figure 4.1. Number of LDVs by Town.

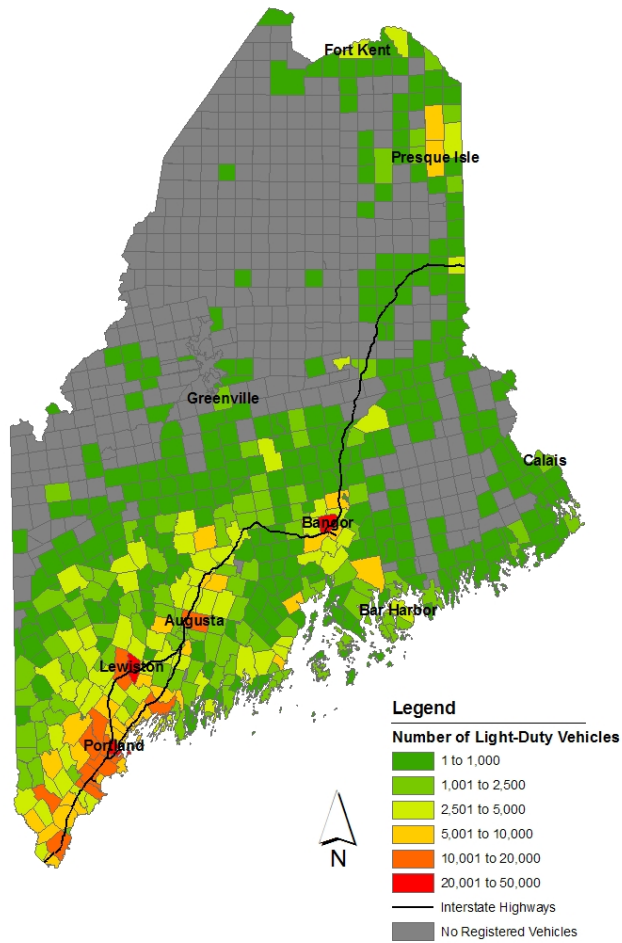


Figure 4.2. Year 2000 Population by Town.
 (Source: Maine Office of GIS)

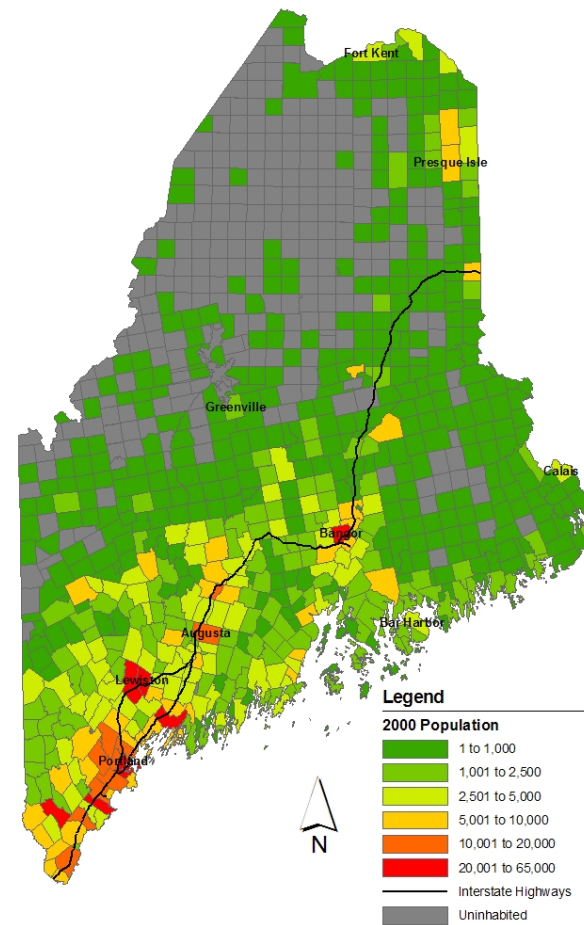
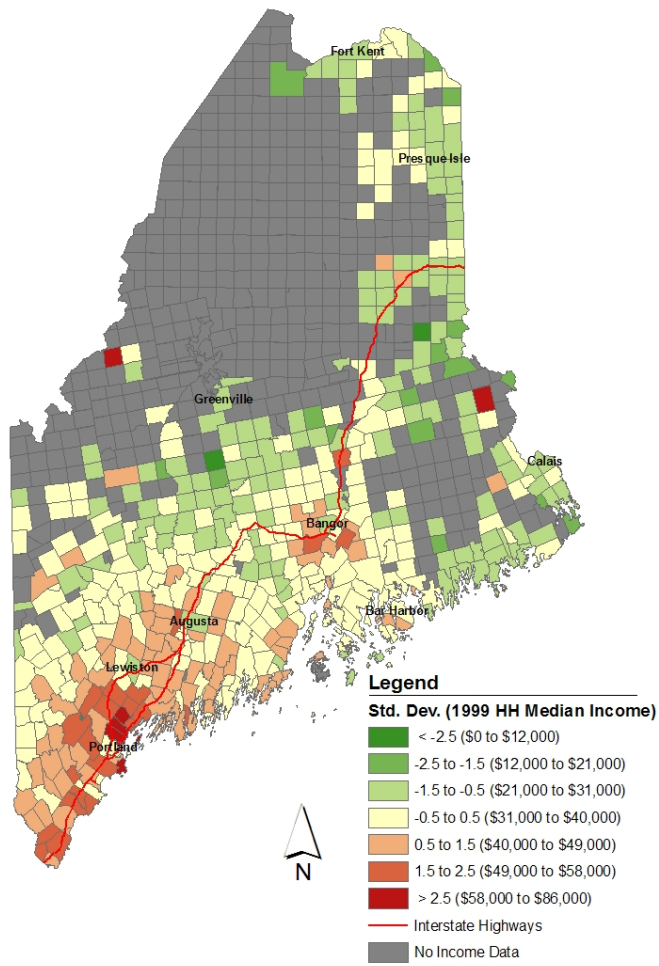


Figure 4.3. 1999 Household Median Income.
 (Source: Maine Office of GIS)



The remaining maps in this section, Figures 4.4 – 4.11, provide evidence of spatial variation in regards to vehicle size, type, age, make, and model across the state. The spatial distribution of these attributes is important to consider because they influence the spatial distribution of environmental attributes. This is the case because; larger vehicles often have lower fuel economy than smaller vehicles as shown in Figure 3.1, heavier light-duty trucks are held to lower emission standards than cars as shown in Table 3.7 and thus pollute more, older vehicles pollute more than newer vehicles as shown in Tables 3.8 -3.11, the fuel economy of each manufacturer's car and truck fleet varies as shown in Table 3.15, and fuel economy also varies widely across various makes and models of vehicles in the same size and type class.

Figures 4.4 and 4.5 display the distribution of small and large cars across the state. The maps clearly indicate a pattern with respect to car size. Towns along the coast and Maine's four largest population centers have above average rates of small car ownership while inland areas, especially the north east, have above average rates of large car ownership. These patterns are not all unexpected. One would expect to find more small cars in cities, such as Portland, where it is more congested and on street parking spaces may make owning a small car more convenient. Large cars may be favored in the rural northeastern region because congestion and parking are not an issue but heavy snowfall and rough roads are. Interestingly though, large cars are not as popular in other rural regions of the state such as the western mountain region (a region stretching southwest from Greenville) and Downeast (the region south and east of Bangor). These results appear to agree with the current literature discussed in Chapter 2. Larger cars are found by Lave and Train (1979) to be preferred in more rural areas. It was also found by

Agarwal and Ratchford (1980) that greater levels of education reduce the willingness to pay for vehicle attributes. Smaller cars generally have lower levels of attributes that consumers desire and average levels of education are higher in Maine's larger cities and southern coastal region where small cars are most prominent.

The next two maps, Figures 4.6 and 4.7, display the distribution of pickup trucks and SUVs across the state. Once again, there are distinct patterns. The rate of pickup truck ownership is greatest in the northern half of the state with the exception of the extreme northeast corner where drivers appear to favor large cars. Above average rates of SUV ownership occurs in the western third of the state and around Greenville. It is no surprise that the rate of pickup truck ownership is highest in the most rural areas of the state where roads are often dirt or snow covered and many people work in agriculture or forestry. Pickup trucks are also useful for transporting outdoor recreation equipment such as ATVs, boats and snowmobiles which are popular in these regions. This result is consistent with the findings of Niemeier et al. (2001), Klockelman and Zhao (2000), and Bhat and Sen (2006) who find that light-duty trucks are favored in rural and low density regions. Residents of suburban and rural areas may also drive more which would also increase the demand for vehicle attributes such as comfort, performance and cargo space (Agarwal and Ratchford, 1980) which is provided by many of these vehicles.

SUV ownership is a bit more interesting. Above average rates of SUV ownership can be found in very rural areas, the western mountain region, and in densely populated areas along the south coast. SUVs are popular vehicles because of their multi-functionality and high level of valued attributes such as size, cargo space, and perception of safety, but they are also more expensive than cars. As shown by Bhat and Sen (2006),

Plaut (2004), Choo and Mokhtarian (2004), Niemeier et al. (2001) and Kockelman and Zhao (2000), wealthier households are more likely to own SUVs and so it is no surprise that the wealthier areas of the state, the southern coastal region as indicated in Figure 4.3, would have relatively high rates of SUV ownership. Suburban residents are also likely to drive more in addition to having higher incomes and so they desire higher levels of comfort and performance (Agarwal and Ratchford, 1980) which SUVs provide. SUVs may be popular in the western mountain, even though the median household income is lower, because this region is an area with many mountains, ski areas, lakes and rivers popular with those participating in outdoor recreation activities. SUVs are marketed as being particularly useful vehicles for participating in outdoor recreation activities because they can hold lots of cargo, tow heavy loads, and travel over rough roads and snow.

The next two maps, Figure 4.8 and 4.9, display the distribution of passenger vehicles manufactured by General Motors and Daimler Chrysler. Both of these domestic manufactures offer a wide range of vehicles including trucks, SUVs, cars and vans, but the rate of ownership of models produced by these manufactures varies dramatically across the state. In the case of General Motors the ownership per town ranges from 9.1 percent up to 86.7 percent, similarly for Daimler Chrysler the range is 0 percent to 46.4 percent. The rates of ownership of models produced by these manufactures also follow strong spatial patterns. Above average ownership rates of General Motors models are found in the eastern and central regions of the state while above average ownership rates of Daimler Chrysler models are found in the western mountain region and the south west.

Figure 4.10 takes a different approach at viewing the distribution of makes and models; the map displays the most popular make and model in each town. Towns with

less than 10 registered vehicles or ties for the most popular vehicle were excluded from this map. The map indicates that General Motor's Sierra pickup truck and Ford's F-150 pickup truck are by far the most popular vehicles in the state. The map also indicates the Sierra pickup truck is most popular in certain regions, particularly around the major cities, while the F-150 is most popular in the more rural areas. This pattern may be explained by the average age of vehicles in these regions which is displayed in Figure 4.11. The average age of the passenger vehicle fleet is lowest in the most populated, and wealthiest, areas of the state. These are towns where there is a greater fraction of new cars. The average age of the fleet is highest in rural and lower income areas. A review of the registration records indicates that the most popular new vehicle in almost every town in Maine is General Motor's Sierra pickup truck. Therefore, towns with a lower average vehicle fleet age are more likely to have the Sierra pickup truck as the most popular vehicle. It is also interesting to note that the Jeep Cherokee and Subaru Legacy are fairly popular in coastal towns.

Moran's I is calculated for the distributions displayed in Figures 4.4 – 4.9 and 4.11 in order to statistically test the significance of the patterns displayed. The values of Moran's I are all greater than zero and statistically significant at the 1 percent significance level indicating that there is significant spatial clustering in the quantities shown by the maps. These values are provided in Table 4.1.

Table 4.1 Spatial Cluster Analysis of Light-duty Vehicle Attributes

Parameter	Figure	Moran's I	Z-Score*
% Small Car	4.4	0.145	45.74
% Large Car	4.5	0.100	31.89
% Pickup Truck	4.6	0.189	59.60
% SUV	4.7	0.094	29.78
% General Motors	4.8	0.159	40.05
% Daimler Chrysler	4.9	0.062	16.07
Average Age	4.11	0.087	27.82

* Values in **bold** are significant at the 1% confidence level

Figures 4.4 – 4.11 and the values of Moran's I shown in Table 4.1 present strong evidence that there is significant spatial variation in the passenger vehicle fleet. The next section will look at how this variation effects the spatial variation in the environmental attributes of Maine's passenger vehicles.

Figure 4.4. Percent Small Car by Town; Departure from the Mean.

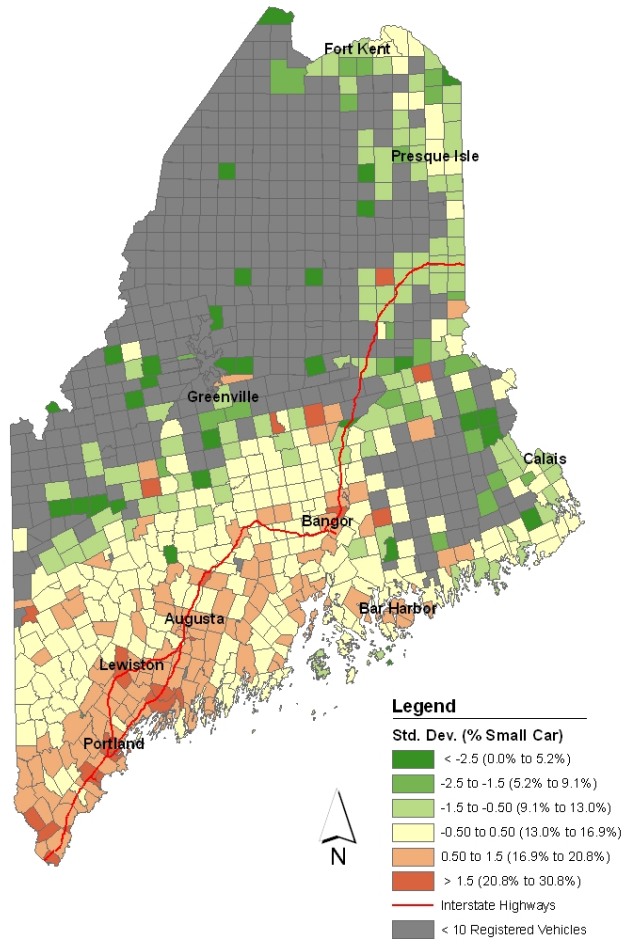


Figure 4.5. Percent Large Car by Town; Departure from the Mean.

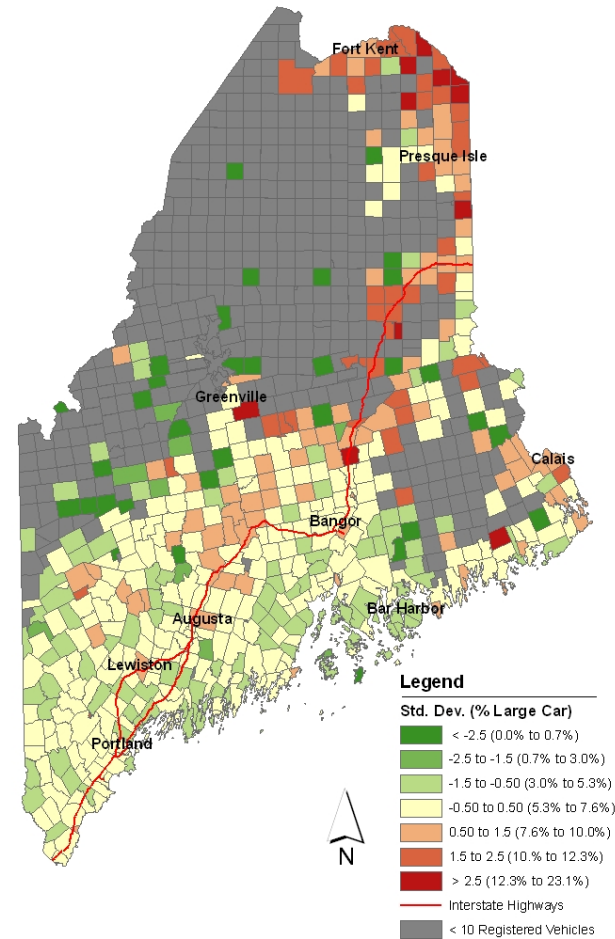


Figure 4.6. Percent Pickup Truck by Town; Departure from the Mean.

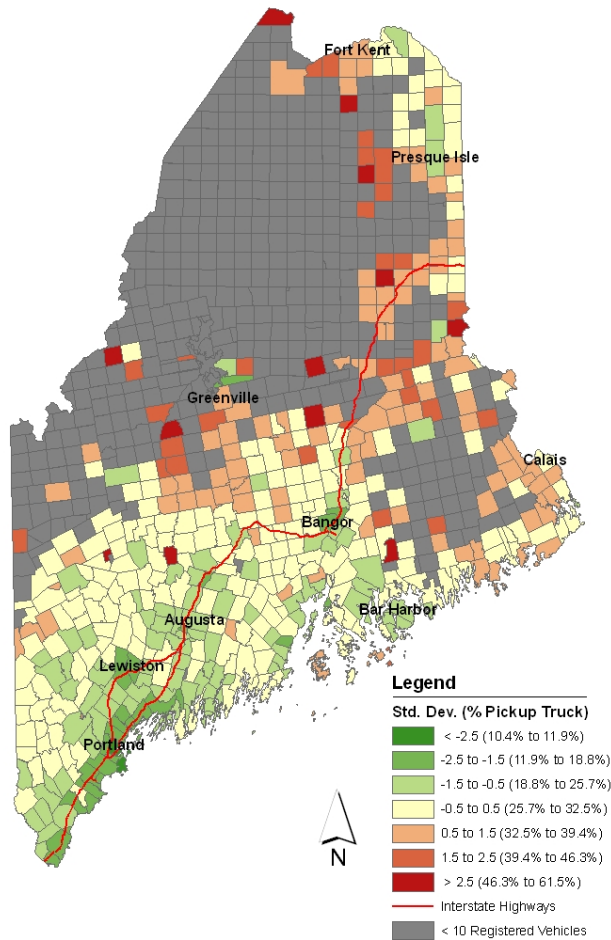


Figure 4.7. Percent SUV by Town; Departure from the Mean.

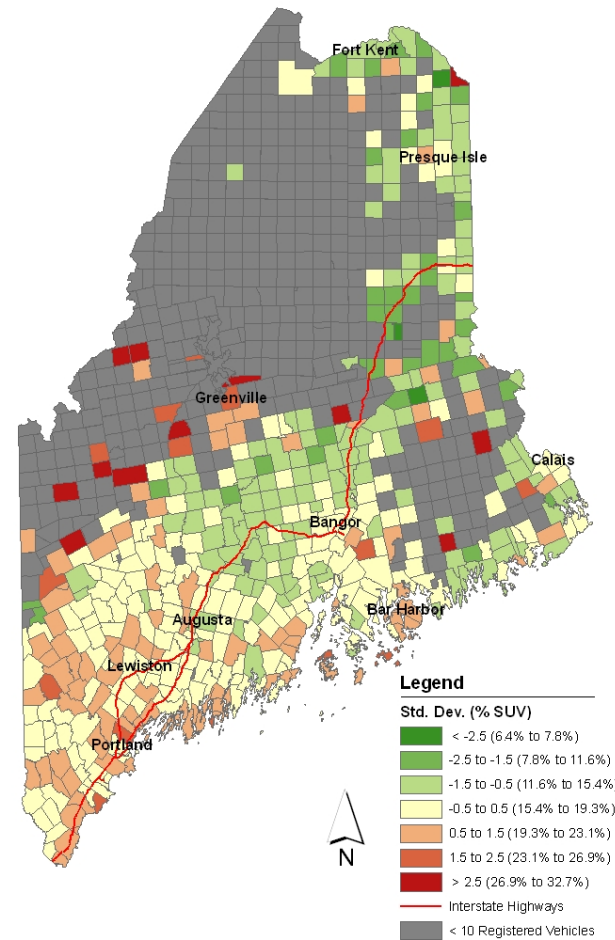


Figure 4.8. Percent General Motors (GM) by Town; Departure from the Mean.

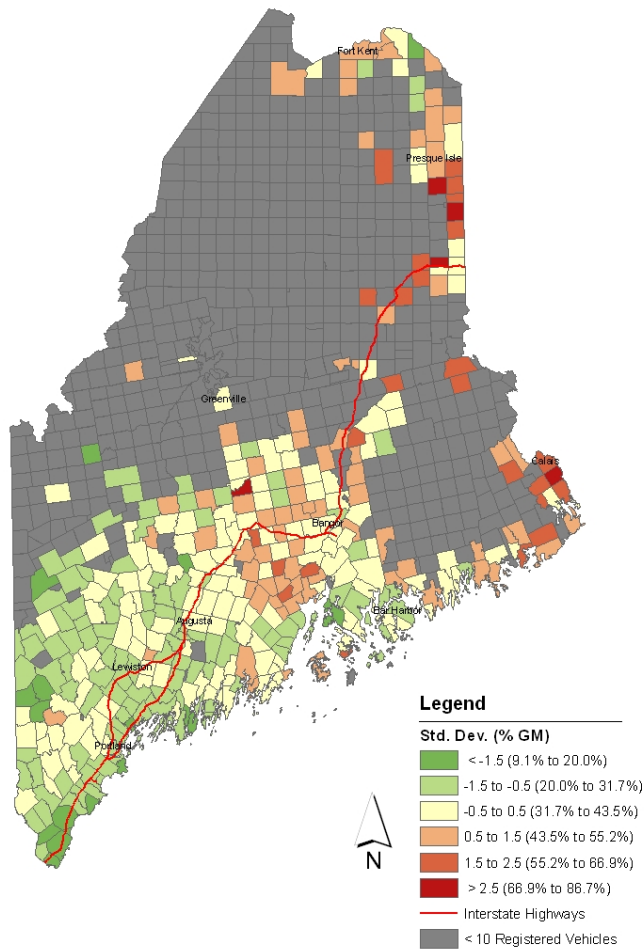


Figure 4.9. Percent Daimler Chrysler Corp. (DCC) by Town; Departure from the Mean.

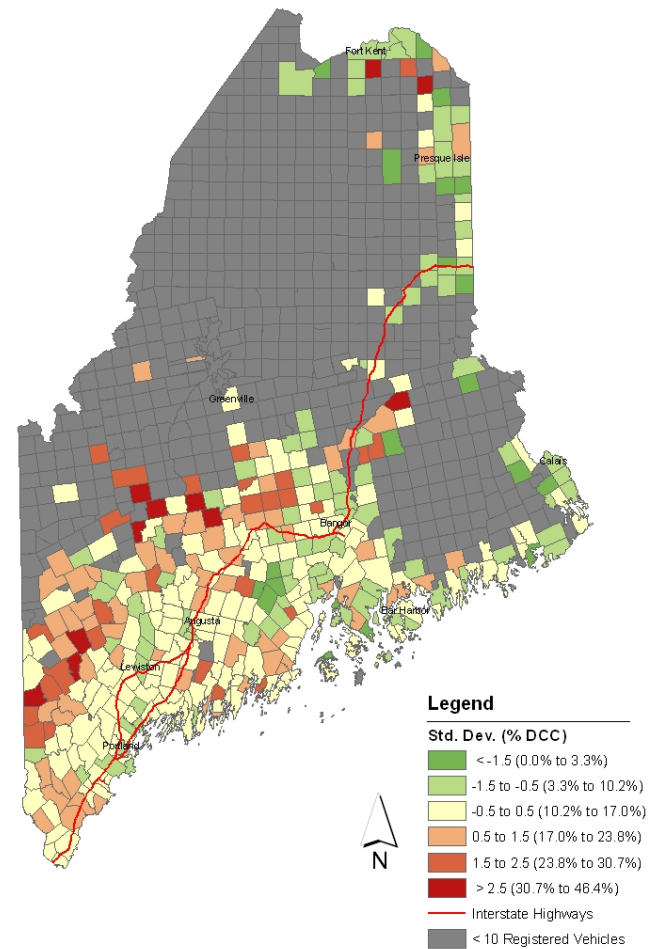


Figure 4.10. Most Popular LDV Model by Town.

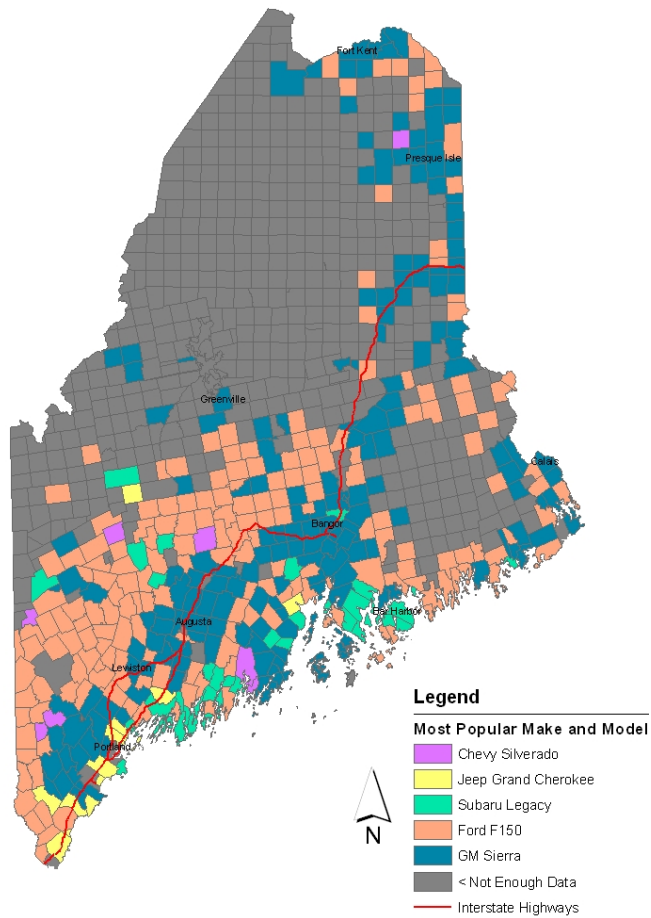
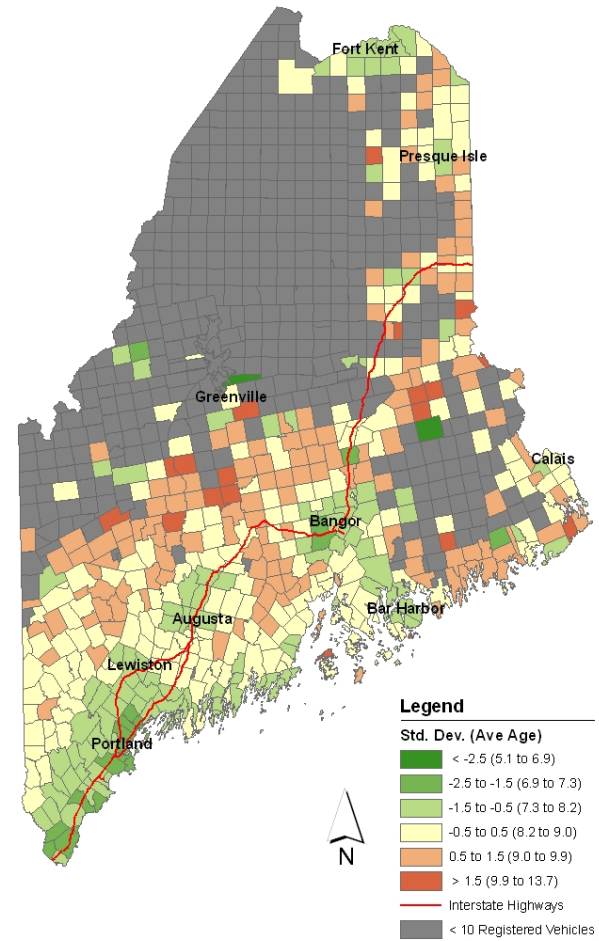


Figure 4.11. Average age of LDVs by Town; Departure from the Mean.



4.2. The Spatial Distribution of Passenger Vehicle Environmental Attributes

The next set of maps, Figures 4.12 – 4.17, display how the spatial variation in passenger vehicle characteristics described in section 4.1 leads to spatial variation in the environmental characteristics of vehicles. The environmental characteristics considered are EPA combined fuel economy adjusted for expected on road performance, annual criteria air emissions, and annual CO₂ emissions.

Figure 4.12 displays the distribution of fuel economy. One particular pattern that stands out is that fuel economy is highest in towns along the interstate system. This is likely due to these being commuter towns and that commuters choose more fuel efficient vehicles. Many of the towns with higher fuel economy are also more densely populated and less rural suggesting, based on the literature and the results presented in section 4.1, that these towns have relatively smaller cars which are more fuel efficient and less pickup trucks which are less fuel efficient. This pattern does not hold for the northern section of the interstate where there are few urban centers and agriculture and forestry jobs are more prevalent possibly making commutes shorter. These towns, and other towns located away from the interstate highways are also very rural, and therefore as previously discussed, contain relatively more pickup trucks, SUVs and larger cars which are less fuel efficient.

Figures 4.13 – 4.16 display the distribution of criteria air pollutant emissions. Figures 4.14 – 4.16 display the distributions of VOC, CO, and NO_x emissions respectively. The spatial distribution of these emissions generally follows the distribution of vehicle age presented in Figure 4.11. This is the case because age is a strong determinant of the level of these emissions for two reasons. First, emission standards have become more stringent over time so that new vehicles are designed to emit fewer

emissions in order to meet the standards. Second, technology added to vehicles to reduce emissions, such as catalytic converters, become less effective with use and so emissions increase with age. The oldest vehicles are in rural and low income areas and so are the highest emitters of VOC, CO and NO_x. Figure 4.13 displays the distribution of PM₁₀ emissions and indicates a different pattern of emissions than what is seen for the other criteria emissions. Very rural towns and towns around urban areas, but not the largest cities, have the highest PM₁₀ emission rates. This is caused by two factors. First there is an abundance of large pickup trucks in very rural areas and large SUVs in wealthy suburban towns which have higher emissions of PM₁₀ than cars and smaller light-duty trucks as shown in Table 3.11. Secondly, emissions of VOC, CO and NO_x experience large increases as vehicles age but this is not the case for PM₁₀ as shown in Table 3.11 so that the distribution of the age of vehicles has a smaller impact.

Figure 4.17 displays the distribution of annual CO₂ emissions. The pattern of emission levels is explained by several factors that determine annual fuel consumption which in turn determines CO₂ emission levels. The relationship between fuel consumption and CO₂ is provided by Equations 3.1 and 3.2. Annual fuel consumption is a factor of fuel type, annual VMT and fuel economy, and annual VMT is determined by vehicle type and age. The pattern of CO₂ emissions is therefore a composite of the spatial distribution of these factors: fuel type, vehicle type, age, and fuel economy. The map indicates that vehicles in low income regions and cities on average have the lowest annual emission rates of CO₂. Low income areas have older vehicles which according to data from the 2001 NHTS (Figure 3.2) accumulate less annual VMT than new vehicles. This reduces fuel consumption. Cities have newer vehicles which accumulate greater

annual VMT but they also have a greater share of small and fuel efficient vehicles which work to reduce fuel consumption.

Moran's I is calculated for the distributions displayed in Figures 4.12 – 4.17 in order to statistically test the significance of the patterns displayed. The values of Moran's I are all greater than zero and statistically significant at the 1 percent significance level indicating that there is significant spatial clustering in the quantities shown by the maps. These values are provided in Table 4.2.

Table 4.2 Spatial Cluster Analysis of Light-duty Vehicle Environmental Attributes

Parameter ¹	Figure	Moran's I	Z-Score*
Average Fuel Economy	4.12	0.108	34.22
Average Annual PM10	4.13	0.057	18.63
Average Annual VOC	4.14	0.105	33.47
Average Annual CO	4.15	0.113	35.94
Average Annual NO _x	4.16	0.091	28.85
Average Annual CO ₂	4.17	0.024	8.15

* Values in **bold** are significant at the 1% confidence level

¹ Particulate Matter less than 10µm in diameter (PM10), Volatile Organic Compounds (VOC), Nitrogen Oxides (NOX), Carbon Dioxide (CO2)

Figures 4.12 – 4.17 along with the values of Moran's I in Table 4.2 present strong evidence that there is significant spatial variation in the environmental attributes of passenger vehicles. The average fuel economy, fuel consumption and criteria and CO₂ emission rates are distributed in various patterns across the state. This spatial variation is driven by the spatial variation of passenger vehicle attributes shown in section 4.1. The next section will look at how the equity of a transportation policy, raising CAFE standards, is affected by the spatial distribution of passenger vehicles and their environmental attributes, specifically fuel economy.

Figure 4.12. Average LDV Fuel Economy (MPG) by Town; Departure from the Mean.

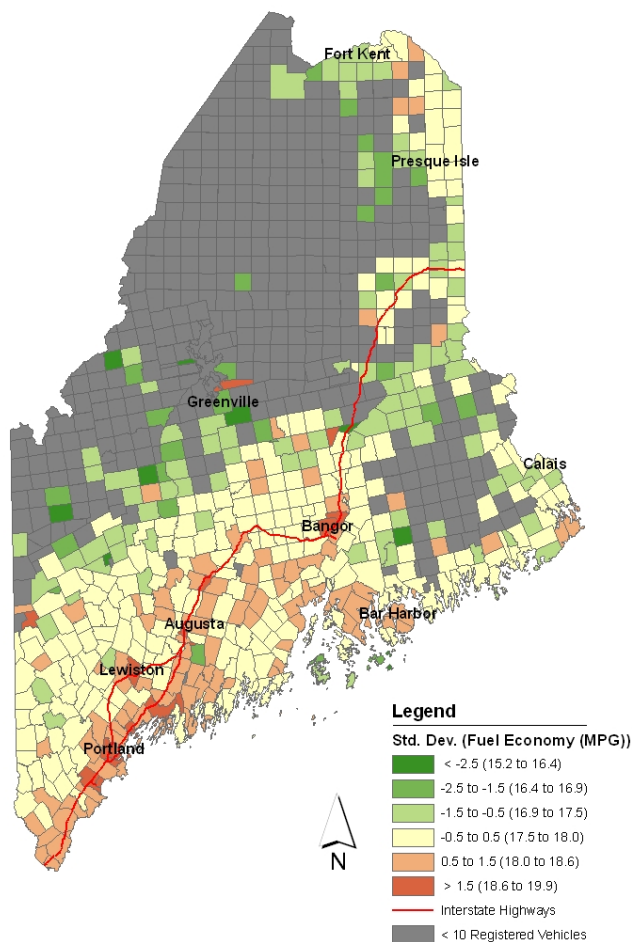


Figure 4.13. Average Annual LDV PM10 by Town; Departure from the Mean.

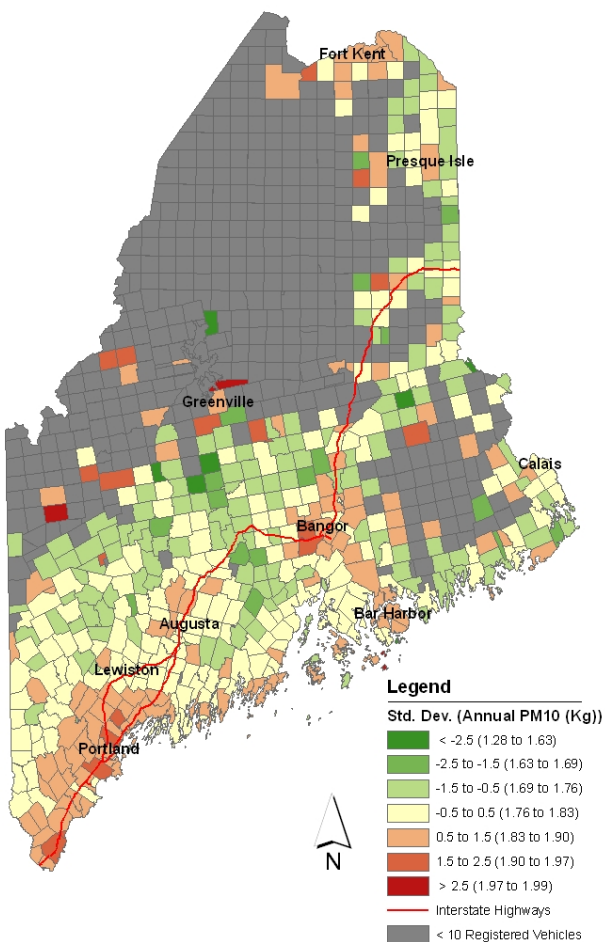


Figure 4.14. Average Annual LDV VOC Emissions by Town; Departure from the Mean.

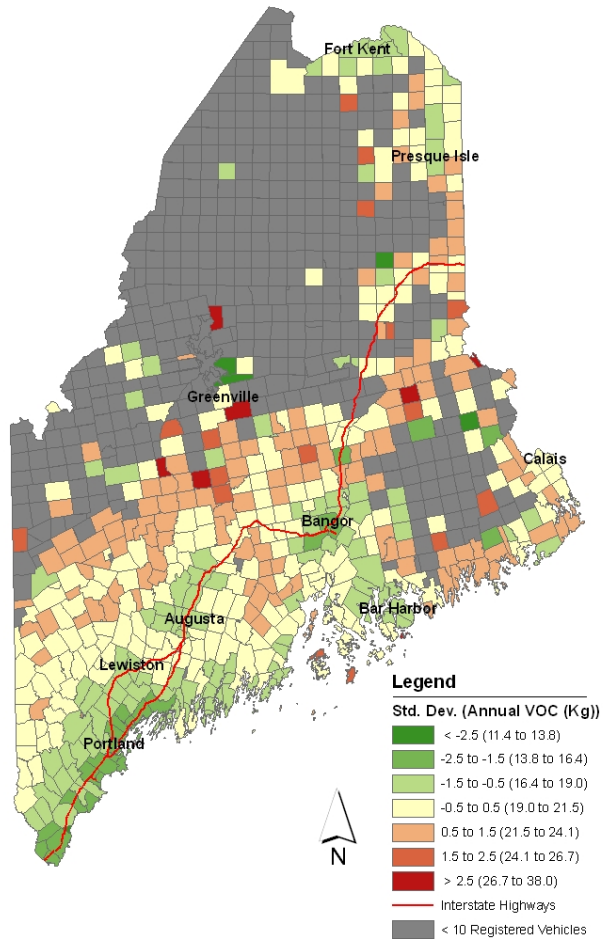


Figure 4.15. Average Annual LDV CO Emissions by Town; Departure from the Mean.

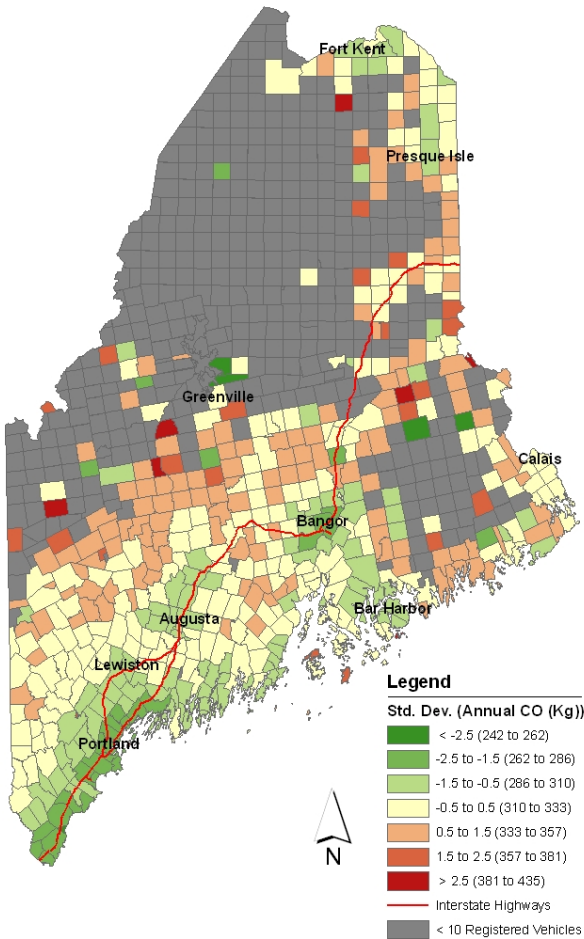


Figure 4.16. Average Annual LDV NO_x Emissions by Town; Departure from the Mean.

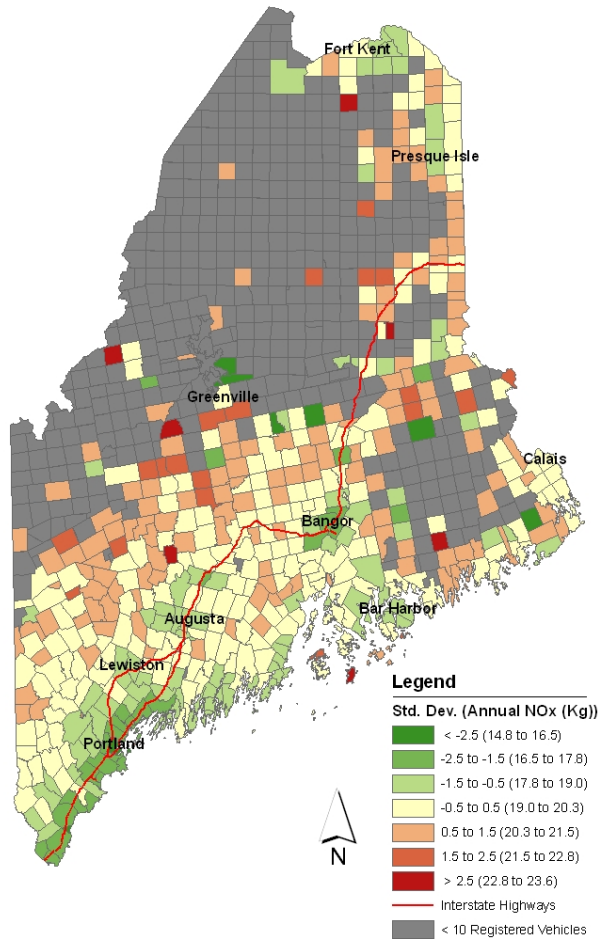
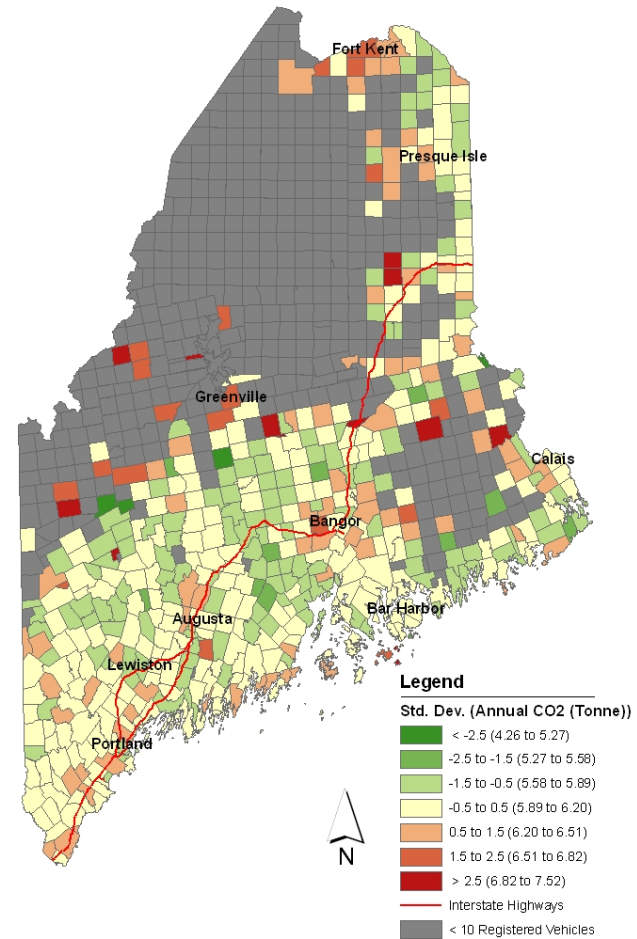


Figure 4.17. Average Annual LDV CO₂ Emissions by Town; Departure from the Mean.



4.3. Spatial Policy Analysis: Increasing CAFE Standards

This section presents the results of a hypothetical 30 percent increase in CAFE standards. Table 4.3 shows the average statewide impacts on new light-duty vehicles of increasing CAFE standards.

Table 4.3 Average Statewide Impacts of a 30% Increase in CAFE Standards

Quantity ¹	Units	State LDV Average		Average Change
		Reference	CAFE	
MPG	miles/gallon	17.72	21.65	22.22%
CO ₂	tonne/year	8.41	7.08	-15.77%
NO _x	Kg/year	0.76	0.79	3.70%
VOC	Kg/year	1.64	1.65	0.61%
CO	Kg/year	67.34	69.81	3.67%
PM10	Kg/year	2.08	2.12	1.82%
Fuel Consumption	gallons/year	948	799	-15.77%
VMT	miles/year	15,334	15,898	3.68%
NPV HV	2001 dollars		\$549.32	
NPV LV	2001 dollars		-\$70.98	

¹ Carbon Dioxide (CO₂), Nitrogen Oxides (NO_x), Volatile Organic Compounds (VOC), Carbon Monoxide (CO), Particulates less than 10µm in diameter (PM10), Vehicle Miles Traveled (VMT), Net Present Value: High Valuation Case (NPV HV), Net Present Value: Low Valuation Case (NPV, LV)

The fuel economy of Maine light-duty vehicles increases by 22.2 percent while annual CO₂ emissions and fuel consumption fall by 15.8 percent. Annual CO₂ emissions and fuel consumption do not fall as much as would be expected given the increase in fuel economy because of the rebound effect. Annual VMT increases by 3.68 percent. The rebound effect is also the reason that criteria emissions increase due to an increase in CAFE standards. Criteria emissions increase by 0.61 percent to 3.7 percent. The average NPV of an increase in CAFE standards depends on the assumption of how consumers trade off current dollars for future savings in fuel consumption as explained in Section 3.3.2. The first case assumes consumers have a high valuation of fuel economy, it is assumed that they consider the present discounted value of lifetime fuel savings. The

second case assumes consumers have a low valuation of fuel economy, it is assumed that they only consider the first 3 years of non-discounted fuel savings. The results are found to be sensitive to these assumptions. Under the high valuation assumption the average consumer receives a positive net benefit while under the low valuation assumption the average consumer experiences a negative net benefit. The increase in retail costs due to an increase in fuel economy are the same for both cases. In the high valuation case the NPV is positive because the savings due to an increase in fuel economy are considered over the entire lifetime of the vehicle as opposed to only the first three years in the low valuation case.

While the statewide impacts are interesting, the focus of this thesis is on the distribution of the private benefits and costs, reduced GHG emissions and increased criteria emissions. As the following results show, the impacts of increasing CAFE standards varies spatially across the state.

Figures 4.18 and 4.19 show the distribution of the average private costs and private benefits, under the high valuation of fuel economy assumption, a consumer purchasing a new light-duty vehicle would receive from a 30 percent increase in CAFE standards respectively. The figures indicate that regions with the highest level of costs also have the highest level of benefits. Towns with higher costs have relatively more vehicles from manufacturers which will need to make larger increases in fuel economy to meet the increased CAFE standards. These towns are mostly rural with the exception of Portland. Costs are high in Portland due to the large number of small vehicles which have a relatively high marginal cost of improving fuel economy. Benefits are largest in rural areas where the largest increases in fuel economy occur.

Figures 4.20 and 4.21 show the distribution of the average net present value (NPV) a consumer purchasing a new light-duty vehicle would receive from an increase in CAFE standards. The maps consider the two cases of how consumer may trade off current dollars for future savings in fuel consumption as explained above and in Section 3.3.2. The maps indicate that the average consumer in towns along the interstate system and in urban areas receive the lowest NPV from an increase in CAFE standards. This is due to on average smaller increases in fuel economy and higher marginal costs of improving the fuel economy of vehicles in these towns. The average consumer in very rural areas receives the greatest NPV. This is due to on average larger increases in fuel economy and lower marginal costs of improving the fuel economy of vehicles in these towns. There are exceptions to these two generalizations though because of the many factors involved. The two fuel economy valuation cases create similar spatial patterns, the major difference is in the level of NPV. The high valuation case produces a wider range of values which are all positive while the low valuation case produces a compressed range of values with the majority being negative. The increase in retail costs due to an increase in fuel economy are the same for both cases. In the high valuation case the NPV is generally positive because the savings due to an increase in fuel economy are considered over the entire lifetime of the vehicle as opposed to only the first three years in the low valuation case. The NPV calculation is therefore sensitive to assumptions about consumer valuation of fuel economy, but the spatial distribution of the NPV is not as sensitive.

Figures 4.22 and 4.23 display the distribution of the average percent increase in fuel economy and percent decrease in CO₂ emissions that the average new light-duty

vehicle would achieve if CAFE standards were increased. The decrease in CO₂ emissions is analogous to the decrease in fuel consumption due to the direct relationship between these two quantities (see Equations 3.1 and 3.2). These are social benefits since reduced CO₂ emissions benefit everyone and reduced fuel consumption (excluding private cost savings which were accounted for in the NPV calculation) may benefit the country by increasing energy security. Again, average new light-duty vehicles in towns along the interstate system and in urban areas have a smaller reduction in CO₂ emissions and fuel consumption. The average new light-duty vehicle in very rural areas has the largest reduction of CO₂ emissions and fuel consumption. This pattern is a result of how CAFE standards are applied to each manufacturer's fleet. Manufacturers that produce a relatively fuel efficient fleet of cars and trucks, usually smaller vehicles, will not have to increase fuel economy as much to meet the increased CAFE standards (see Table 3.15). Smaller vehicles are found in urban areas and in towns along the interstate system with many of these vehicles being produced by manufacturers that have a relatively fuel efficient vehicle fleet such as Toyota and Honda. Larger, less fuel efficient vehicles are more common in rural areas and are produced by manufacturers that have a relatively less fuel efficient fleet such as General Motors and Ford. Therefore, the largest increases in fuel economy and decreases in CO₂ emissions are found in regions where there are relatively more vehicles from inefficient manufacturers which will be required to make the largest increases in fuel economy. As shown in Figures 4.8 – 4.10 the composition of the vehicle fleet by manufacturer varies by town.

Figures 4.24 – 4.27 display the distribution of percent increase in criteria emissions due to the increase in CAFE standards and the rebound effect. The spatial

patterns vary for each emission due to the interplay between reduced emissions from increasing fuel economy (for PM10 and VOC) and increased emissions due to the rebound effect. The results for VOC emissions displayed in Figure 4.24 indicate that increasing CAFE standards has little effect on VOC emissions. The change in VOC emissions vary from a reduction of 0.2 percent in some areas to an increase of 0.9 percent in other areas. The results do not indicate any general patterns though urban areas tend to have larger increases in VOC emissions than other areas and many rural areas have decreased VOC emissions or no change in VOC emissions. The results for PM10 displayed in Figure 4.25 display no clear patterns. The results indicate a general 1.4 percent to 2.0 percent increase in PM10 emissions across the state. The results for CO and NO_x displayed in Figures 4.26 and 4.27 respectively show the same results because CO and NO_x emissions are not effected by fuel economy in MOBILE6 (see Table 3.19). Therefore the results for CO and NO_x are only a result of the rebound effect. The results indicate that the largest increases in CO and NO_x emissions are in rural areas and the smallest reductions are in areas along interstate highways and urban areas.

The values of Moran's I calculated for the distributions displayed in Figures 4.20 – 4.23 and 4.25 – 4.27, which are all greater than zero and statistically significant at the 1 percent significance level, indicate there is significant spatial clustering in the quantities shown by the maps. The value of Moran's I for the spatial distribution of the percent change in VOC emissions displayed in Figure 4.24 is greater than zero and statistically significant at the 5% significance level indicating significant clustering, but less clustering than in the other figures. These values are provided in Table 4.4.

Table 4.4 Spatial Cluster Analysis of the Impacts, Costs and Benefits of Increasing CAFE Standards

Parameter ¹	Figure	Moran's I	Z-Score*
NPVHV	4.20	0.052	13.55
NPVLV	4.21	0.022	6.06
Average % Increase in Fuel Economy	4.22	0.048	12.57
Average % Increase in CO ₂	4.23	0.065	16.64
Average % Increase in VOC	4.24	0.006	2.15
Average % Increase in PM10	4.25	0.034	9.02
Average % Increase in CO	4.26	0.050	12.95
Average % Increase in NO _x	4.27	0.057	14.76

* Values in **bold** are significant at the 1% confidence level

¹ Net Present Value: High Valuation Case (NPVHV), Net Present Value: Low Valuation Case (NPV, LV), Particulate Matter less than 10µm in diameter (PM10), Volatile Organic Compounds (VOC), Nitrogen Oxides (NOX), Carbon Dioxide (CO2)

Section 4.1 provides evidence of significant spatial variation in the passenger vehicle fleet. Section 4.2 indicates that this variation leads to spatial variation in the environmental attributes of passenger vehicles. This section has provided evidence that the spatial variation indicated in Sections 4.1 and 4.2 leads to spatial variation in the impacts of a transportation policy; an increase in CAFE standards. The passenger vehicle fleet is not homogeneous, there is significant spatial variation, and it does have an effect on the spatial equity of private costs and benefits stemming from a change in transportation policy.

Figure 4.18. Private Costs of a 30% Increase in CAFE Standards.

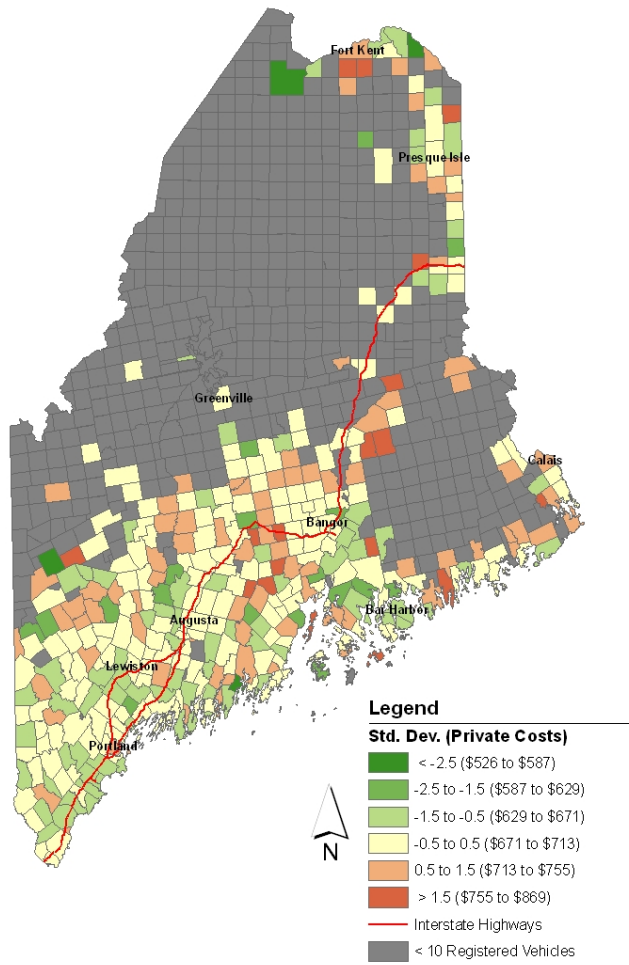


Figure 4.19. Private Benefits of a 30% Increase in CAFE Standards: High Fuel Economy Valuation Case.

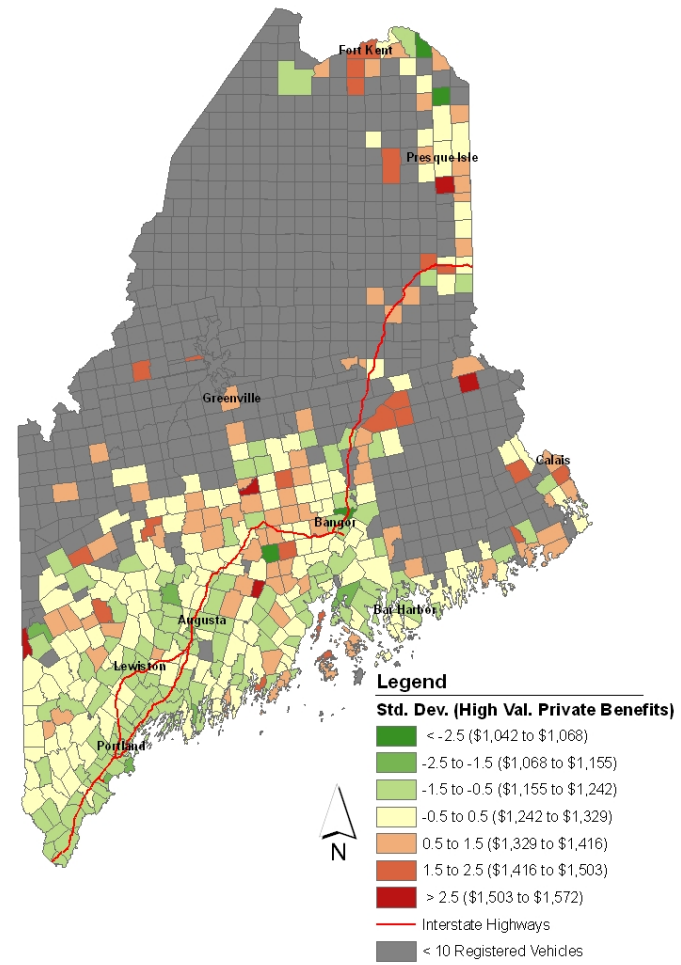


Figure 4.20. NPV of a 30% Increase in CAFE Standards: High Fuel Economy Valuation Case.

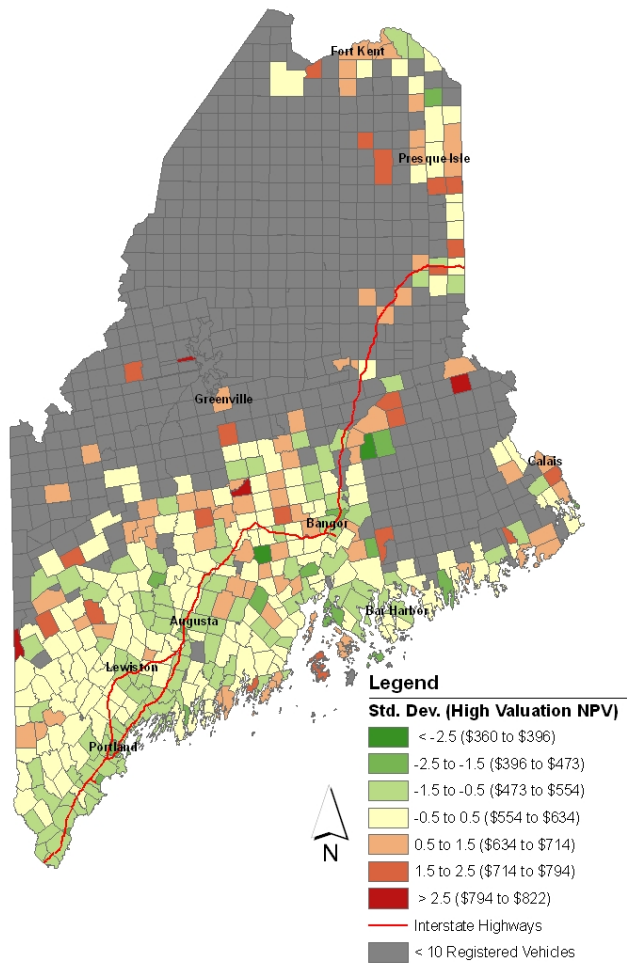


Figure 4.21. NPV of a 30% Increase in CAFE Standards: Low Fuel Economy Valuation Case.

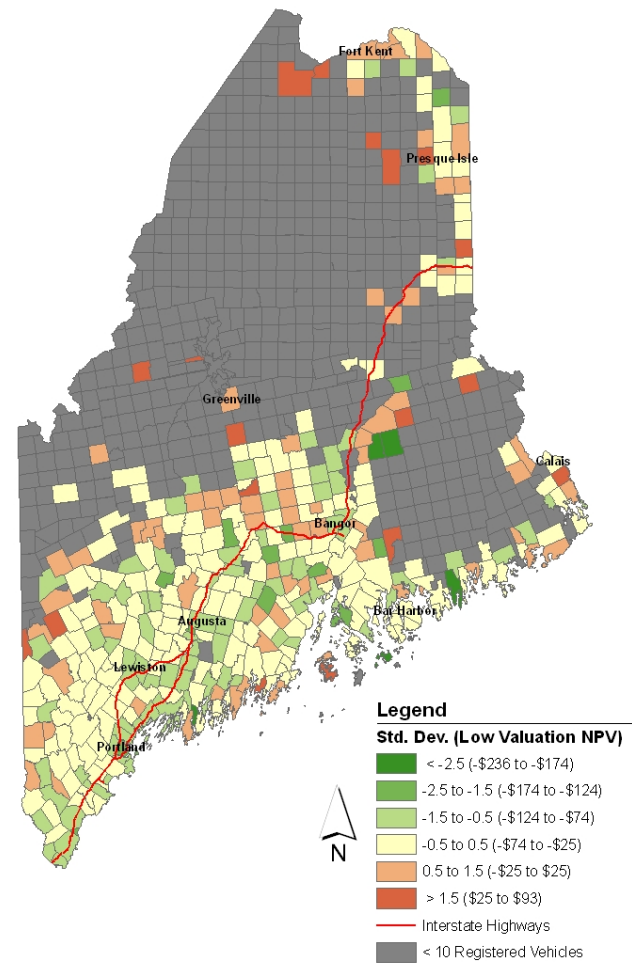


Figure 4.22. Average Percent Increase in Fuel Economy from a 30% Increase in CAFE Standards.

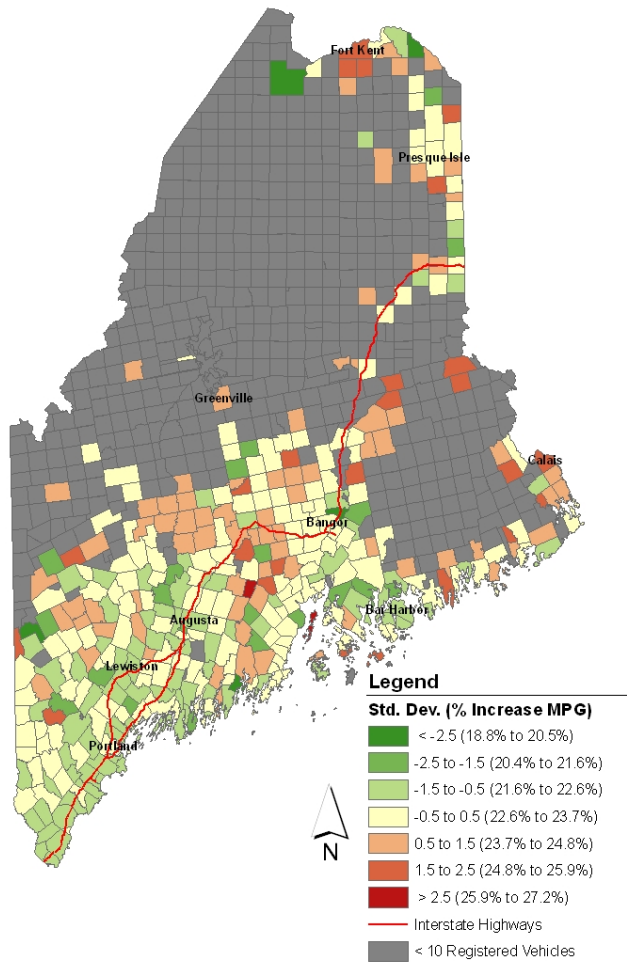


Figure 4.23. Average Increase in Annual CO₂ Emissions from a 30% Increase in CAFE Standards.

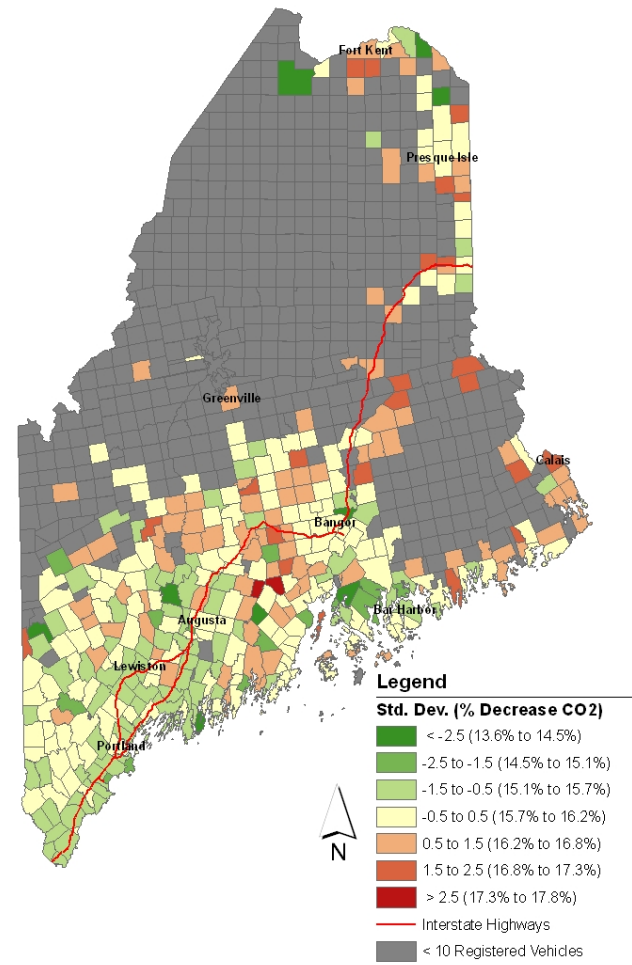


Figure 4.24. Average Increase in Annual VOC Emissions from a 30% Increase in CAFE Standards.

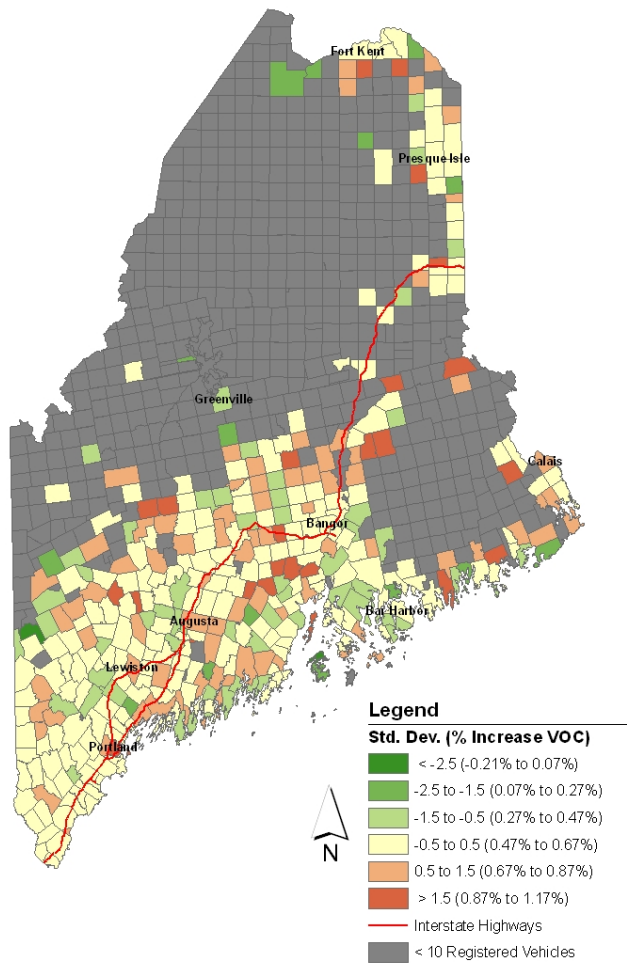


Figure 4.25. Average Increase in Annual PM10 Emissions from a 30% Increase in CAFE Standards.

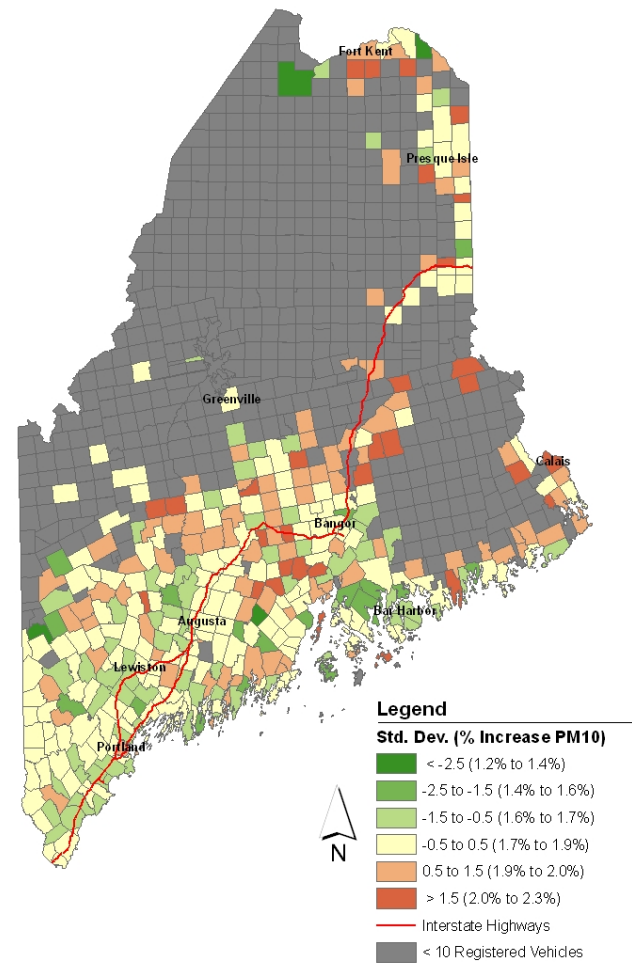


Figure 4.26. Average Increase in Annual CO Emissions from a 30% Increase in CAFE Standards.

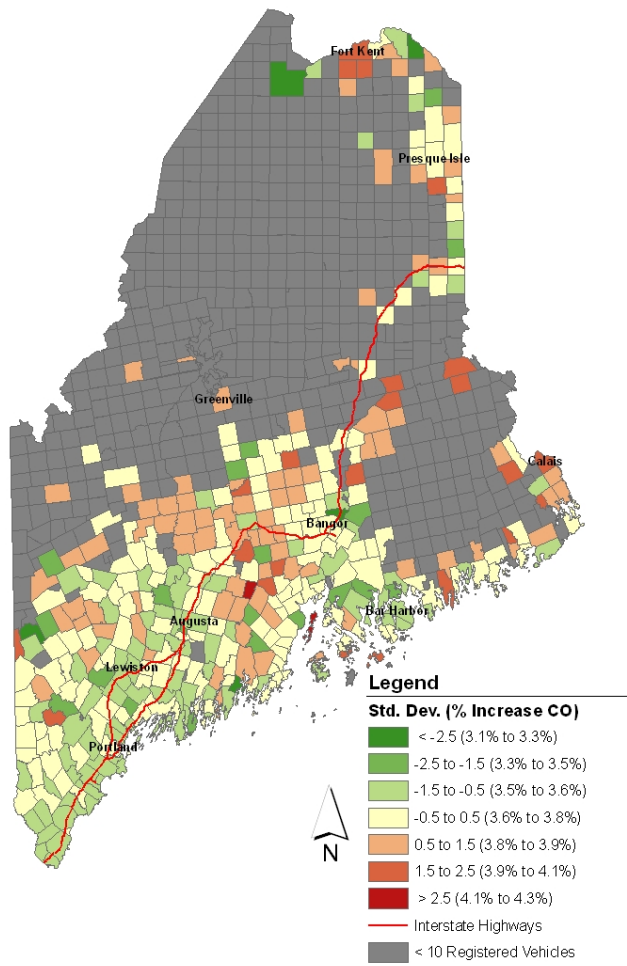
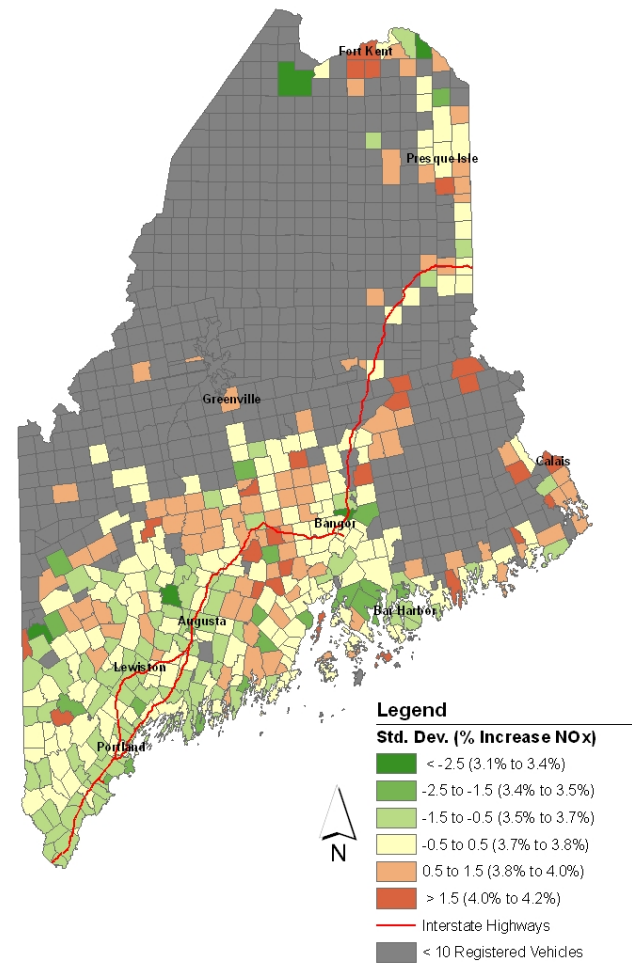


Figure 4.27. Average Increase in Annual NO_x Emissions from a 30% Increase in CAFE Standards.



Chapter 5

SUMMARY AND CONCLUSIONS

The literature review discussed evidence from recent studies that suggests there is substantial spatial variation in the passenger vehicle fleet with respect to physical and environmental attributes. There was also a discussion of studies that have incorporated spatial vehicle data into their analyses. The discussion concluded that there has been no explicit study of the spatial variation present in the passenger vehicle fleet. More importantly, it was found that little consideration has been given to the possible consequences that the spatial variation of the passenger vehicle fleet has on policy outcomes. A brief discussion of the current debate over increasing CAFE standards was presented where it was made clear that the debate has focused mainly on the costs and benefits of such a policy. As Arrow et al. (1996) stated, a good policy analysis will also identify distributional effects. This thesis begins to address the research needs in these two areas.

The objectives of this thesis are to analyze the spatial distribution of the passenger vehicle fleet with respect to physical and environmental attributes and the effects this spatial variation has on the impacts, costs and benefits of increasing CAFE standards. The following three research questions were addressed:

1. Is the spatial distribution of passenger vehicles heterogeneous?
2. If the spatial distribution of the passenger vehicle fleet is heterogeneous, then is the spatial distribution of the environmental attributes of the passenger vehicle fleet also heterogeneous?

3. If the spatial distribution of the passenger vehicle fleet is heterogeneous with respect to the physical and environmental attributes in (1) and (2), then will the impact, costs, and benefits of a policy targeting an environmental attribute of passenger vehicles, such as increasing fuel economy standards, vary across regions?

These research questions are addressed by providing evidence of significant spatial variation and patterns in the Maine passenger vehicle fleet. A series of choropleth maps depicting the spatial variation present in the Maine passenger vehicle fleet and the spatial variation of the impacts, costs and benefits of increasing CAFE standards are presented. The statistical significance of the spatial variation and patterns is tested using Moran's I and found to be significant at the 1 percent significance level in all but one case.

5.1. Spatial Variation in the Passenger Vehicle Fleet

The first set of maps depicting the spatial variation of the Maine passenger vehicle fleet, Figures 4.4 – 4.11, and the values of Moran's I, Table 4.1, provide strong evidence of significant spatial variation in the passenger vehicle fleet. The maps indicate that the percentage of vehicles of different size, type, age, make and manufacturer by town varies substantially across the state. The spatial variation of these attributes is not random, but follows interesting patterns and is found to be statistically significant. Small cars are found to be popular in the south while large cars are popular in the northeast corner of the state. As expected, pickup trucks are popular in very rural areas. SUVs are also found to be popular in rural areas but also in densely populated coastal areas in the southern portion of the state. Spatial patterns of vehicle ownership by make and manufacture are also found. GM vehicles are most popular in eastern Maine while

Daimler Chrysler vehicles are most popular in western Maine. The most popular vehicles in Maine are the Ford F-150 pickup truck and the GM Sierra pickup truck, but this varies by region. Regions around Portland, Augusta and Bangor have higher percentages of the Sierra pickup truck while outlying areas have higher percentages of F-150's. The average age of the vehicle fleet also varies by town following patterns of population density and median household income as shown in Figures 4.2 and 4.3.

The second set of maps depicting the spatial variation of the environmental attributes of the Maine passenger vehicle fleet, Figures 4.12 – 4.17, and the values of Moran's I, Table 4.2, provide strong evidence of significant spatial variation in the environmental attributes of passenger vehicles. The maps indicate that the average fuel economy, CO₂ emissions and criteria air pollutant emissions vary by town across the state. Again, the variation is not random, there are significant spatial patterns. Fuel economy is highest in urban areas and along the interstate system. CO₂ emissions which depend on fuel economy, but also on annual VMT, are found to be lowest in cities and low income areas. NO_x, CO and VOC emissions also exhibit spatial patterns. These emissions are strongly influenced by vehicle age and therefore generally correspond to the spatial distribution of vehicle age; emissions are highest in rural and low income areas. PM₁₀ emissions are an exception. PM₁₀ emissions are highest in very rural areas and urban areas surrounding cities, but not in the cities. This result is likely due to the popularity of pickup trucks in very rural areas and SUVs in towns surrounding cities. Both of these vehicle classes emit relatively higher levels of PM₁₀.

5.2. Policy Implications

The results indicate that a 30 percent increase in CAFE standards for model year 2015 light-duty vehicles would increase the fuel economy of light-duty vehicles in Maine by 22.2 percent while reducing CO₂ emissions and fuel consumption by 15.8 percent. The rebound effect, which increases annual VMT by 3.68 percent, is responsible for an increase in criteria emissions and reducing the magnitude of the benefits of increased fuel economy; reduced CO₂ emissions and fuel consumption. Criteria emissions increase by 0.61 percent to 3.7 percent. The NPV of increasing CAFE standards is sensitive to the assumption about how consumers trade off current dollars for future savings in fuel consumption. The NPV ranges from \$549 when consumers are assumed to have a high valuation of fuel economy to -\$71 under low valuation assumptions.

The spatial variation present in the passenger vehicle fleet results in significant spatial variation in the impacts, costs and benefits of increasing CAFE standards. These results are shown by Figures 4.18 – 4.27, and the values of Moran's I, Table 4.4. The maps displayed in the figures indicate that there is spatial variation in the average NPV of increasing CAFE standards. The variation is not random. Rural towns receive a higher NPV than urban towns and also areas along the interstate system. The spatial patterns are independent of the two cases of consumer valuation of fuel economy.

The pattern of NPV may be effected by the distribution of median household income. Evidence from the literature indicates that lower income households have a higher time discount rate or do not understand how to evaluate an investment in energy efficiency. This thesis has used a single value for the discount rate across all towns. If the discount rate varies significantly with income, the effect would be to reduce the NPV of

low income households and increase the NPV of high income households, assuming the value used is representative of the median household's discount rate. The income effect on the discount rate would therefore temper the results presented here. Alternatively, different discount rates could be used for towns with different median household incomes. The difficulty with this is the large amount of uncertainty in the magnitude of the income effect on the discount rate and on the large amount of uncertainty in the discount rate itself.

Spatial patterns found in the maps displaying the increase in fuel economy and reductions in CO₂ emissions are similar to those displayed by the NPV. The NPV is influenced by the magnitude of change in fuel economy. Some spatial patterns are also found in the increase of criteria emissions due to the rebound effect. CO and NO_x emissions are not effected by fuel economy in MOBILE6 and therefore the increase in these emissions is only a function of the rebound effect. Since this is the case, the spatial patterns of the increase of these emissions are the same as those of increasing fuel economy. VOC emissions are reduced by increasing fuel economy. The results generally indicate that the effect of reduced emissions due to increased fuel economy tend to cancel out the effects of the rebound effect. There is little variation in the increase of VOC emissions across the state. The results are similar for the increase in PM₁₀ emissions. The increase in PM₁₀ emissions due to the rebound effect are partially offset by the reduction in PM₁₀ emissions due to increased fuel economy.

5.2.1. Equity

The results raise questions about the equity of the impacts, costs and benefits of increasing CAFE standards. The NPV and change in criteria emissions are not distributed

equally, but is this good or bad for society? There has been little success in increasing CAFE standards or adopting an alternative policy to curb passenger vehicle fuel consumption. While there are multiple reasons for this, including concerns over the costs and benefits of a policy change, an often overlooked concern is how the benefits and costs are distributed. Policies often run into trouble over distributional concerns as previously discussed.

Referring back to Figure 4.3, the distribution of household median income, the towns that received on average the greatest NPV are among those with the lowest median household incomes. The wealthiest areas of the state received the lowest or even negative NPVs. This distribution of the private costs and benefits may be favorable if equity is a concern. The poorest towns receive on average the greatest private benefits from a 30 percent increase in CAFE standards. It should be kept in mind that the possible effect of income on the discount rate used to estimate the NPV may temper these results by reducing the benefits of low income towns and increasing the benefits of high income towns. The magnitude of this effect and whether it would have equal impacts on the NPV estimates of high and low income towns is unknown based on the current literature.

An alternative policy tool to increase passenger vehicle fuel economy advocated by some (Kleit, 2004; Espey and Nair, 2005) is to increase the gas tax. A gas tax, in theory, would increase the cost of driving, reducing the amount of driving and increasing the demand for fuel efficient vehicles. A gas tax has the benefit over CAFE standards that it does not reduce the cost of driving leading to the rebound effect and covers all vehicles, not just new vehicles. An increase in the gas tax though may be regressive (CBO, 2002). An increase in the gas tax would place the largest burden on those who drive the least

fuel efficient vehicles and those who have the fewest options to reduce their amount of driving. In Maine, the least fuel efficient vehicles are on average located in the areas of the state with the lowest income. Additionally, there are few alternative options for transportation in these areas whereas there is some public transportation in the larger cities and the relatively urban southern coastal region.

In comparison to an increase in gas tax, increasing CAFE standards could be considered a progressive policy and the more favorable of the two for Maine. Rural and low income towns, where on average the least fuel efficient vehicles are located, on average receive the greatest private benefits of increasing CAFE standards. Fuel economy would be increased state-wide with the least fuel efficient regions making the largest increases. Increasing the gas tax would place the largest costs on these rural and low income towns. Additionally, an increase in the gas tax would not necessarily improve fuel economy or reduce fuel consumption. Rural residents have few alternative options for transportation and sometimes rely on their inefficient vehicles, such as pickup trucks, for employment in agriculture and forestry and to travel over rough roads and through snow. Also, Greene et al. (2005), and Plotkin and Greene (1997) argue that there may be a market failure in fuel economy (see Section 2.3) which would reduce the effectiveness of a gas tax.

The distribution of changes (mostly increases) in criteria emission rates is a trickier question. Vehicles are mobile sources so the concentration of criteria pollutants in a particular area is a complex function of many factors. As mentioned previously, the analysis of criteria emissions in this thesis does not reflect ambient air concentrations. However, the results do indicate that increasing CAFE standards will generally increase

NO_x, CO, and VOC emissions and to a much lesser extent PM₁₀ emissions across the state. VOC emissions increase the most in urban areas while the largest increases in NO_x and CO are in rural areas. These findings emphasize the need to realize the spatial distribution of the vehicle fleet when estimating local air quality or local emission inventories. The increase in criteria emission rates across the state certainly has a cost but its magnitude is unclear. An increase in criteria emissions in rural areas is not a large concern, most concern is focused on urban areas and congested highways where exposure levels are highest and smog is a problem. Two recent studies have concluded that the cost of increased emissions and congestion due to the rebound effect outweigh the benefits of reduced fuel consumption; increased oil security and reduced levels of GHG emissions (Kleit, 2004 and Parry et al., 2004).

Of potentially greater concern is the increase in VMT which will increase congestion and accidents. The costs of congestion could be high, although additional tax revenue collected through gas tax could be used to offset these costs. The increase in the number of accidents will result in a greater number of fatalities and injuries. These costs could be quite substantial. An additional concern is that the increase in VMT in rural areas could increase sprawl. Whether or not the costs of the externalities associated with the rebound effect outweigh the benefits of reduced fuel consumption and oil security remains ambiguous in this case.

5.2.2. Policy Improvements

These results can be used to design more effective policies and to better inform policy makers and the public about the impacts of policy changes. The spatial distribution of private costs and benefits (NPV) appears to be progressive. The distribution of

externalities caused by the rebound effect may be regressive or undesirable. Armed with this information actions can be taken to address these externalities.

The major weakness of increasing CAFE standards is the rebound effect. Though a gas tax could be used to reduce this effect or entirely replace the CAFE standards it may be regressive or not efficient as previously discussed. An alternative would be a policy that sought to charge by distance traveled. There are several schemes that could possibly accomplish this. A distance based tax or registration fee could be charged or pay as you drive car insurance. These policies could be designed to take into account the transportation needs and limitations of alternatives in various regions of the state. Heavier taxes or fees could be levied on areas that have viable public transportation systems that could substitute for some driving. These types of policies would reduce the private benefits of increasing CAFE standards since the savings from increased fuel economy would be offset by distance taxes or fees. Alternatively, a yearly budget of untaxed VMT could be allocated to different regions based on the observed VMT present before an increase in CAFE standards.

A different solution to part of the rebound effect would be to introduce congestion charging in urban and high traffic areas. Congestion charging, which has been successful in central London, charges a daily fee for entering a particular high traffic urban area. The fees can be reduced during low congestion times such as evenings and weekends. Though Maine does not have many large urban areas with large traffic problems, some highways do have heavy congestion at certain times. Varying tolls can be collected on highways as traffic conditions change. As traffic increases tolls can be increased to provide an incentive to travel during a different time, take an alternative route or use an

alternative form of transportation. These types of policies could reduce congestion and some driving thus reducing the impacts of the rebound effect when and where they may be most harmful and costly.

5.3. Generalization of the Results

This thesis focused on Maine passenger vehicles and the effect of an increase in CAFE standards as they exist at present. In general the results are only applicable to Maine, but the finding that spatial patterns in the passenger vehicle fleet impact the outcome of policies can be generalized. The studies discussed in the literature review clearly find spatial patterns of vehicle ownership across the country. The patterns may vary from place to place, but they are just as likely to be important to policy analysis and design. Additional policies can also be analyzed using a similar framework. The impacts of increasing the gas tax, expanding the gas guzzler tax to include light-duty trucks, or modeling changes to the CAFE program, such as allowing permit trading, can be expected to have spatial patterns.

The methods used to view the spatial distribution of the vehicle fleet can be applied to any area provided the underlying registration data is available. Different states have various rules concerning the use of this data. If registration data were not available a survey could provide the necessary information.

5.4. Limitations and Future Research

This research has some important limitations that should be acknowledged. Assumptions have been made about future gasoline prices based on official EIA forecasts. In light of the current record high gasoline prices, the prices used may not be realistic. Higher gasoline prices would increase the NPV of the increase in CAFE

standards but the patterns will remain similar. It has also been assumed that the make up of the vehicle fleet will not change. That is in 2015 there will be the same number of vehicles and the fleet will be composed of the same number of car, pickup trucks, SUVs and minivans as it does today. This is an unrealistic assumption, but a necessary one given the lack times series data available for the Maine vehicle fleet. A spatial analysis of the temporal changes in the vehicle fleet would be an interesting extension to the present research. Finally, the current research has ignored hybrid technology and advanced diesel technology. Currently there are very few of these vehicles in Maine; 1,218 as of March 2005. Manufactures such as Toyota have recently announced ambitious plans to increase the number of hybrids on the market. This could have implications on the technology cost estimates used.

As discussed previously, this analysis did not include activity models (travel demand) or atmospheric models so ambient air quality could not be estimated. The addition of these models using techniques similar to those used by Bachman et al.(2003) would provide for a more complete analysis of the environmental impacts of a policy. Similarly, an activity model would provide information about how the volume of traffic on specific roads may change in response to a policy. Estimation of local changes in highway traffic and ambient air quality would provide data for the quantification of the costs or benefits of these changes. These externalities could then be compared to the private costs and benefits.

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APPENDIX

The appendix contains MOBILE6.2 input files which have been altered from default values in order to produced the results found in this thesis. Also included is visual basic computer code that was used to retrieve and aggregate MOBILE6.2 output data.

The following 4 files specify California LEV and LEVII emission standards for Maine.

File: T2CERT.D

T2 CERT

0.000, 0.000, 0.000, 0.000, 0.000,
0.007, 0.007, 0.007, 0.007, 0.007,
0.040, 0.040, 0.040, 0.040, 0.040,
0.051, 0.051, 0.051, 0.051, 0.051,
0.075, 0.075, 0.075, 0.075, 0.075,
0.075, 0.075, 0.075, 0.075, 0.075,
0.075, 0.075, 0.075, 0.075, 0.075,
0.100, 0.100, 0.100, 0.125, 0.125,
0.075, 0.075, 0.100, 0.140, 0.140,
0.125, 0.125, 0.125, 0.100, 0.100,
0.000, 0.000, 0.000, 0.100, 0.100,
0.000, 0.000, 0.000, 0.000, 0.000,

0.000, 0.000, 0.000, 0.000, 0.000,
1.700, 1.700, 1.700, 1.700, 1.700,
1.700, 1.700, 1.700, 1.700, 1.700,
1.700, 1.700, 1.700, 1.700, 1.700,
3.400, 3.400, 3.400, 3.400, 3.400,
3.400, 3.400, 3.400, 3.400, 3.400,
3.400, 3.400, 3.400, 3.400, 3.400,
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3.400, 3.400, 3.400, 4.400, 4.400,
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0.000, 0.000, 0.000, 0.000, 0.000,

0.000, 0.000, 0.000, 0.000, 0.000,
0.014, 0.014, 0.014, 0.014, 0.014,
0.021, 0.021, 0.021, 0.021, 0.021,
0.029, 0.029, 0.029, 0.029, 0.029,
0.050, 0.050, 0.050, 0.050, 0.050,
0.080, 0.080, 0.080, 0.080, 0.080,
0.110, 0.110, 0.110, 0.110, 0.110,
0.140, 0.140, 0.140, 0.140, 0.140,

126

127

128

0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000
0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000
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0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000
0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000
0.250,0.500,0.750,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000,1.000
0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000
0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000
0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000
0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000
0.750,0.500,0.250,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000
0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000
0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000,0.000

File: P94IMP.D

- * This is now a standard Mobile6 external data file.
- * The header 94+ LDG IMPLEMENTATION is now required.
- * Comments and blank lines are allowed in the header
- * and between the blocks of data.

- * this phase-in schedule reflects MOBILE6 default for
- * Tier 1, NLEV (non-OTC), and Tier 2

94+ LDG IMPLEMENTATION

- * The data is divided into 5 blocks, one each for LDGV, LDGT1, LDGT2, LDGT3, and LDGT4. In each data block there is one data line for each
- * calendar year from 1994 to 2025. Each line contains the phase-in
- * values for that year for 11 different vehicle standards categories.
- * The first column is Tier0 the second is intermediate Tier1, the third
- * is Tier1, and the fourth column is Tier2. The remaining columns are
- * intermediate TLEV, TLEV, intermediate LEV, LEV, intermediate ULEV, ULEV,
- * and ZEV. These are the standards categories defined by the California
- * LEV program.

* LDGV

* T0	T1	T1	T2	TLEV	TLEV	LEV	LEV	ULEV	ULEV	ZEV
*(int)			(int)	(int)	(int)					
0.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

* LDGT1

130

* LDGT2

131

[illegible]

The following file and 24 similar files were created and used in the model runs, one for each model year. This file is representative of the file used to estimate current model year emission factors. To estimate previous model year emission factors the second value under each vehicle type heading would be changed to 1.000 and the first value changed to 0.000. This process would be continued for each subsequently older model year.

File: Regdata.D

REG DIST

✻

- * This file contains the default MOBILE6 values for the distribution of
* vehicles by age for July of any calendar year. There are sixteen (16)
* sets of values representing 16 combined gasoline/diesel vehicle class
* distributions. These distributions are split for gasoline and diesel
* using the separate input (or default) values for diesel sales fractions.
* Each distribution contains 25 values which represent the fraction of
* all vehicles in that class (gasoline and diesel) of that age in July.
* The first number is for age 1 (calendar year minus model year plus one)
* and the last number is for age 25. The last age includes all vehicles

* of age 25 or older. The first number in each distribution is an integer
 * which indicates which of the 16 vehicle classes are represented by the
 * distribution. The sixteen vehicle classes are:
 *
 * 1 LDV Light-Duty Vehicles (Passenger Cars)
 * 2 LDT1 Light-Duty Trucks 1 (0-6,000 lbs. GVWR, 0-3750 lbs. LVW)
 * 3 LDT2 Light Duty Trucks 2 (0-6,001 lbs. GVWR, 3751-5750 lbs. LVW)
 * 4 LDT3 Light Duty Trucks 3 (6,001-8500 lbs. GVWR, 0-3750 lbs. LVW)
 * 5 LDT4 Light Duty Trucks 4 (6,001-8500 lbs. GVWR, 3751-5750 lbs. LVW)
 * 6 HDV2B Class 2b Heavy Duty Vehicles (8501-10,000 lbs. GVWR)
 * 7 HDV3 Class 3 Heavy Duty Vehicles (10,001-14,000 lbs. GVWR)
 * 8 HDV4 Class 4 Heavy Duty Vehicles (14,001-16,000 lbs. GVWR)
 * 9 HDV5 Class 5 Heavy Duty Vehicles (16,001-19,500 lbs. GVWR)
 * 10 HDV6 Class 6 Heavy Duty Vehicles (19,501-26,000 lbs. GVWR)
 * 11 HDV7 Class 7 Heavy Duty Vehicles (26,001-33,000 lbs. GVWR)
 * 12 HDV8A Class 8a Heavy Duty Vehicles (33,001-60,000 lbs. GVWR)
 * 13 HDV8B Class 8b Heavy Duty Vehicles (>60,000 lbs. GVWR)
 * 14 HDBS School Busses
 * 15 HDBT Transit and Urban Busses
 * 16 MC Motorcycles (All)
 *
 * The 25 age values are arranged in two rows of 10 values followed by a row
 * with the last 5 values. Comments (such as this one) are indicated by
 * an asterisk in the first column. Empty rows are ignored. Values are
 * read "free format," meaning any number may appear in any row with as
 * many characters as needed (including a decimal) as long as 25 values
 * follow the initial integer value separated by a space.
 *
 * If all 28 vehicle classes do not need to be altered from the default
 * values, then only the vehicle classes that need to be changed need to
 * be included in this file. The order in which the vehicle classes are
 * read does not matter, however each vehicle class set must contain 25
 * values and be in the proper age order.
 *
 * LDV
 1 1.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.0000 0.0000 0.0000
 * LDT1
 2 1.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.0000 0.0000 0.0000
 * LDT2
 3 1.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
 0.0000 0.0000 0.0000 0.0000 0.0000

[illegible][illegible][illegible][illegible][illegible][illegible][illegible][illegible][illegible][illegible][illegible]

15 1.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

```

0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000
* Motorcycles
16 1.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000

```

The following file is a sample of the input files used for each model run.

File: Ref1.in

```

MOBILE6 INPUT FILE :
> Maine Reference Case: 15% Adjusted EPA Fuel Economy
> Year 2005 Maine Fuel Data
> Cal LEV and LEVII standards
* Updated: 5/26/2006
POLLUTANTS      : HC CO NOx CO2
REPORT FILE     : reflx.txt
SPREADSHEET     : reflx
PARTICULATES    :

```

RUN DATA

```

EXPRESS HC AS VOC :
REG DIST          : Rdata1.d
EXPAND HDDV EFS   :
EXPAND HDGV EFS   :
EXPAND LDT EFS    :
EXPAND EVAPORATIVE :
T2 EVAP PHASE-IN  : T2EVAP.d
T2 EXH PHASE-IN   : T2EXH.d
T2 CERT          : T2CERT.d
94+ LDG IMP       : P94IMP.d

```

SCENARIO RECORD : Scenario Title : Maine Reference Winter, MY = 2005

```

CALENDAR YEAR    : 2005
FUEL PROGRAM     : 1
EVALUATION MONTH : 7
MIN/MAX TEMP     : 6.1 25.1
ALTITUDE         : 1
FUEL RVP         : 12.7
OXYGENATED FUELS : 1.000 0.000 0.0045 0.000 1
ABSOLUTE HUMIDITY : 20

```

137

0.0032 0.0097 0.0162 0.0241 0.0510 0.0706 0.0390 0.0269 0.0114 0.0093
0.0137 0.0155 0.0067 0.0067 0.0067

SCENARIO RECORD : Scenario Title : Maine Reference Summer, MY = 2005

CALENDAR YEAR : 2005
FUEL PROGRAM : 1
EVALUATION MONTH : 7
MIN/MAX TEMP : 56.7 77.6
ALTITUDE : 1
FUEL RVP : 8.26
OXYGENATED FUELS : 1.000 0.000 0.0033 0.000 1
ABSOLUTE HUMIDITY : 69
MPG ESTIMATES : MPGref.CSV
PARTICULATE EF : PMGZML.CSV PMGDR1.CSV PMGDR2.CSV
PMDZML.CSV PMDDR1.CSV PMDDR2.CSV
PARTICLE SIZE : 10
DIESEL SULFUR : 500
DIESEL FRACTIONS :
0.0009 0.0006 0.0001 0.0003 0.0006 0.0013 0.0004 0.0004 0.0001 0.0027
0.0032 0.0097 0.0162 0.0241 0.0510 0.0706 0.0390 0.0269 0.0114 0.0093
0.0137 0.0155 0.0067 0.0067 0.0067
0.0009 0.0006 0.0001 0.0003 0.0006 0.0013 0.0004 0.0004 0.0001 0.0027
0.0032 0.0097 0.0162 0.0241 0.0510 0.0706 0.0390 0.0269 0.0114 0.0093
0.0137 0.0155 0.0067 0.0067 0.0067
0.0009 0.0006 0.0001 0.0003 0.0006 0.0013 0.0004 0.0004 0.0001 0.0027
0.0032 0.0097 0.0162 0.0241 0.0510 0.0706 0.0390 0.0269 0.0114 0.0093
0.0137 0.0155 0.0067 0.0067 0.0067
0.0009 0.0006 0.0001 0.0003 0.0006 0.0013 0.0004 0.0004 0.0001 0.0027
0.0032 0.0097 0.0162 0.0241 0.0510 0.0706 0.0390 0.0269 0.0114 0.0093
0.0137 0.0155 0.0067 0.0067 0.0067
0.0009 0.0006 0.0001 0.0003 0.0006 0.0013 0.0004 0.0004 0.0001 0.0027
0.0032 0.0097 0.0162 0.0241 0.0510 0.0706 0.0390 0.0269 0.0114 0.0093
0.0137 0.0155 0.0067 0.0067 0.0067
0.0009 0.0006 0.0001 0.0003 0.0006 0.0013 0.0004 0.0004 0.0001 0.0027
0.0032 0.0097 0.0162 0.0241 0.0510 0.0706 0.0390 0.0269 0.0114 0.0093
0.0137 0.0155 0.0067 0.0067 0.0067
0.0009 0.0006 0.0001 0.0003 0.0006 0.0013 0.0004 0.0004 0.0001 0.0027
0.0032 0.0097 0.0162 0.0241 0.0510 0.0706 0.0390 0.0269 0.0114 0.0093
0.0137 0.0155 0.0067 0.0067 0.0067
0.0009 0.0006 0.0001 0.0003 0.0006 0.0013 0.0004 0.0004 0.0001 0.0027

0.0032 0.0097 0.0162 0.0241 0.0510 0.0706 0.0390 0.0269 0.0114 0.0093
 0.0137 0.0155 0.0067 0.0067 0.0067
 0.0009 0.0006 0.0001 0.0003 0.0006 0.0013 0.0004 0.0004 0.0001 0.0027
 0.0032 0.0097 0.0162 0.0241 0.0510 0.0706 0.0390 0.0269 0.0114 0.0093
 0.0137 0.0155 0.0067 0.0067 0.0067
 0.0009 0.0006 0.0001 0.0003 0.0006 0.0013 0.0004 0.0004 0.0001 0.0027
 0.0032 0.0097 0.0162 0.0241 0.0510 0.0706 0.0390 0.0269 0.0114 0.0093
 0.0137 0.0155 0.0067 0.0067 0.0067
 0.0009 0.0006 0.0001 0.0003 0.0006 0.0013 0.0004 0.0004 0.0001 0.0027
 0.0032 0.0097 0.0162 0.0241 0.0510 0.0706 0.0390 0.0269 0.0114 0.0093
 0.0137 0.0155 0.0067 0.0067 0.0067
 0.0009 0.0006 0.0001 0.0003 0.0006 0.0013 0.0004 0.0004 0.0001 0.0027
 0.0032 0.0097 0.0162 0.0241 0.0510 0.0706 0.0390 0.0269 0.0114 0.0093
 0.0137 0.0155 0.0067 0.0067 0.0067
 0.0009 0.0006 0.0001 0.0003 0.0006 0.0013 0.0004 0.0004 0.0001 0.0027
 0.0032 0.0097 0.0162 0.0241 0.0510 0.0706 0.0390 0.0269 0.0114 0.0093
 0.0137 0.0155 0.0067 0.0067 0.0067

END OF RUN

The following File is the Batch file used to call each input file.

File: Refrun.in

MOBILE6 BATCH FILE

ref1.in
 ref2.in
 ref3.in
 ref4.in
 ref5.in
 ref6.in
 ref7.in
 ref8.in
 ref9.in
 ref10.in
 ref11.in
 ref12.in
 ref13.in
 ref14.in
 ref15.in
 ref16.in
 ref17.in
 ref18.in
 ref19.in
 ref20.in
 ref21.in

```

ref22.in
ref23.in
ref24.in
ref25.in
ref06.in
ref07.in
ref08.in
ref09.in
ref010.in
ref011.in
ref012.in
ref013.in
ref014.in
ref015.in
cafe5.in
cafe6.in
cafe7.in
cafe8.in
cafe9.in
cafe10.in
cafe11.in
cafe12.in
cafe13.in
cafe14.in
cafe15.in

```

The following is a sample of the Visual Basic code used within Microsoft® Excel to retrieve, organize and aggregate the model output data which is in tab delimited text files. Manual data entry would require coping and pasting 2,880 values from 45 separate files.

```
Private Sub CommandButton1_Click()
```

```

,
+++++
++
' CAFE CASE RESULTS
'++++++
+++

```

```

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\CAFE5x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

```

```

Sheets("CAFE5x").Select
Sheets("CAFE5x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\CAFE6x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("CAFE6x").Select
Sheets("CAFE6x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\CAFE7x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("CAFE7x").Select
Sheets("CAFE7x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\CAFE8x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("CAFE8x").Select
Sheets("CAFE8x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\CAFE9x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("CAFE9x").Select
Sheets("CAFE9x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\CAFE10x.TAB",

```



```

Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("CAFE10x").Select
Sheets("CAFE10x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\CAFE11x.TAB",
-
Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("CAFE11x").Select
Sheets("CAFE11x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\CAFE12x.TAB",
-
Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("CAFE12x").Select
Sheets("CAFE12x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\CAFE13x.TAB",
-
Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("CAFE13x").Select
Sheets("CAFE13x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\CAFE14x.TAB",
-
Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _

```

```

        Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
        Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

    Sheets("CAFE14x").Select
    Sheets("CAFE14x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\CAFE15x.TAB",
-
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

    Sheets("CAFE15x").Select
    Sheets("CAFE15x").Move After:=Workbooks("Results.xls").Sheets(1)

End Sub

Private Sub CommandButton2_Click()
'
+++++
++
' REFERENCE CASE RESULTS
'++++++
+++

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref1x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

    Sheets("ref1x").Select
    Sheets("ref1x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref2x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

    Sheets("ref2x").Select

```

```

Sheets("ref2x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref3x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref3x").Select
Sheets("ref3x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref4x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref4x").Select
Sheets("ref4x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref5x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref5x").Select
Sheets("ref5x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref6x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref6x").Select
Sheets("ref6x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref7x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _

```

```

        Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
        Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

    Sheets("ref7x").Select
    Sheets("ref7x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref8x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

    Sheets("ref8x").Select
    Sheets("ref8x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref9x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

    Sheets("ref9x").Select
    Sheets("ref9x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref10x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

    Sheets("ref10x").Select
    Sheets("ref10x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref11x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

    Sheets("ref11x").Select
    Sheets("ref11x").Move After:=Workbooks("Results.xls").Sheets(1)

```

```

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref12x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref12x").Select
Sheets("ref12x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref13x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref13x").Select
Sheets("ref13x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref14x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref14x").Select
Sheets("ref14x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref15x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref15x").Select
Sheets("ref15x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref16x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

```

```

Sheets("ref16x").Select
Sheets("ref16x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref17x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref17x").Select
Sheets("ref17x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref18x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref18x").Select
Sheets("ref18x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref19x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref19x").Select
Sheets("ref19x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref20x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref20x").Select
Sheets("ref20x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref21x.TAB", _

```

```

Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref21x").Select
Sheets("ref21x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref22x.TAB", _
Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref22x").Select
Sheets("ref22x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref23x.TAB", _
Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref23x").Select
Sheets("ref23x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref24x.TAB", _
Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref24x").Select
Sheets("ref24x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref25x.TAB", _
Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref25x").Select

```

```

Sheets("ref25x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref06x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref06x").Select
Sheets("ref06x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref07x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref07x").Select
Sheets("ref07x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref08x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref08x").Select
Sheets("ref08x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref09x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

Sheets("ref09x").Select
Sheets("ref09x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref010x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _

```



```

        Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
        Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

    Sheets("ref010x").Select
    Sheets("ref010x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref011x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

    Sheets("ref011x").Select
    Sheets("ref011x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref012x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

    Sheets("ref012x").Select
    Sheets("ref012x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref013x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

    Sheets("ref013x").Select
    Sheets("ref013x").Move After:=Workbooks("Results.xls").Sheets(1)

' *****

Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref014x.TAB", _
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True

    Sheets("ref014x").Select
    Sheets("ref014x").Move After:=Workbooks("Results.xls").Sheets(1)

```

' *****

```
Workbooks.OpenText Filename:="C:\MOBILE6\Mobile6\Run Maine\ref015x.TAB", _  
    Origin:=437, StartRow:=1, DataType:=xlDelimited, TextQualifier:= _  
    xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=True, Semicolon:=False, _  
    Comma:=False, Space:=False, Other:=False, FieldInfo:=Array(Array(1, 1), _  
    Array(2, 1), Array(3, 1)), TrailingMinusNumbers:=True
```

```
    Sheets("ref015x").Select
```

```
    Sheets("ref015x").Move After:=Workbooks("Results.xls").Sheets(1)
```

```
End Sub
```

```
Private Sub CommandButton3_Click()
```

```
UserForm1.Show
```

```
End Sub
```

BIOGRAPHY OF THE AUTHOR

Gregory Matthew Gould was born in Revere, Massachusetts and later moved to Londonderry, New Hampshire where he graduated from Londonderry High School in 1998. He enrolled in the University of Maine the following fall where he graduated in 2003 with a Bachelor of Science degree in Chemical Engineering. During his course of studies at the University of Maine Greg completed three cooperative work experiences at National Semiconductor Corporation's South Portland, Maine manufacturing facility and an additional cooperative work experience at Fairchild Semiconductor Corporation's South Portland, Maine manufacturing facility. He worked as a process engineer for both companies where he helped to improve process throughput, product quality and developed, tested and implemented a new production process that reduced criteria air pollutant emissions while also reducing production costs.

After graduation Greg entered the Chemical Engineering graduate program at Washington State University where he began to study fuel cell catalysis. He would later leave Washington State University and enroll in the Resource Economics and Policy graduate program at the University of Maine which better fit his current interests. While in the department of Resource Economics and Policy he worked as a graduate research assistant.

After receiving his degree, Greg plans to pursue a PhD in Transportation Technology and Policy at the University of California, Davis. Greg is a candidate for the Master of Science degree in Resource Economics and Policy from The University of Maine in August, 2006.