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THE EFFECT OF AUTOMOTIVE FUEL CONSERVATION MEASURES ON AIR POLLUTION

by

Robin Landis
Charles River Associates Incorporated
Cambridge, Massachusetts 02138

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Project Officer
Steven E. Plotkin
Office of Energy, Minerals and Industry
Washington, D.C.

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20460

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FOREWORD

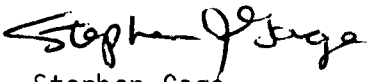
The continuing crisis in the supply of petroleum, the resulting call for strong measures to reduce consumption in the transportation sector and the potential effects such measures might have on the environment have caused the Office of Research and Development (ORD), U.S. Environmental Protection Agency to undertake studies of the effects that transportation-related energy conservation measures will have on petroleum demand and air quality.

The principal investigator of the study reported here was Robin Landis, Senior Research Associate, Charles River Associates (CRA), 1050 Massachusetts Avenue, Cambridge, Massachusetts. CRA Vice-President Harrison Campbell was Officer-in-Charge of the study. The EPA project officer was Steven E. Plotkin of the Office of Energy, Minerals and Industry.

This study attempts to predict the impact of four conservation measures designed to significantly reduce the consumpton of gasoline by automobiles. All four measures deal directly with the automotive sector, two by dealing directly with new automobiles (an excise tax that penalizes inefficient automobiles, and a mileage standard that directly regulates automobile efficiency) and two by changing the fuel marketplace (a gasoline rationing plan and a direct tax on gasoline sales). The report develops estimates of the response in fuel use, in vehicle miles traveled, and in the automobile sales marketplace to each of the measures, uses these results to project total automobile emissions, and uses simple diffusion models to predict changes in air quality resulting from the measures. Special care should obviously be used in interpreting the results for photo-chemical oxidants, since models which do not account for atmospheric reactions do a poor job of forecasting concentrations of reactive pollutants.

As with most analytical studies, there are points in the computations where important assumptions are made which influence the end results in ways that are not obvious. Although the author has conducted a sensitivity analysis on some variables, there are too many to allow him to do more than scratch the surface. I believe that the complexity of this analysis and the opportunity of second-guessing some of the analytical choices made are going to cause some readers to view the final results with some skepticism.

However, EPA is publishing this report with the belief that it is at least one man's competent and quite thorough approach to addressing an important policy question. We also hope that researchers will be able to use portions of the analysis in other studies; the richness of detail presented here is designed to facilitate this use.



Stephen Gage
Deputy Assistant Administrator
for Energy, Minerals and Industry

ABSTRACT

The energy crisis of the winter of 1973-1974 dramatized the risk of dependence on foreign sources of crude oil. In response to this crisis, government policies are being formulated to reduce our dependence on imports of crude oil. A number of these policies have been designed to reduce gasoline consumption by automobiles, including: gasoline rationing; increases in the federal excise tax on gasoline; excise taxes on new cars, in inverse proportion to their fuel economy; and regulations to set minimum levels on average fuel economy of new cars.

This study is addressed to two questions dealing with these proposed policies. First, what will be the impact on fuel consumption by automobiles and by other competing modes of transportation, if different levels of these policies are put into effect. Second, what impact would these policies have on emissions and concentrations of automotive pollutants.

The major conclusions of this study are:

- Increases in the federal excise tax on gasoline and gasoline rationing are considerably more effective in conserving fuel than excise taxes and fuel economy restrictions on new cars, especially in the early years of the policies.

- The policies aimed at new cars also lead, within several years of their adoption, to significant increases in emissions relative to base case emissions.

- The effect of any of the policies will be small in the first year, but will become more pronounced over time.

The rest of the study presents the background analysis and documentation - including quantitative estimates of gasoline consumption, automotive emissions and concentrations for several levels of the different policies - for these and other conclusions.

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TABLE OF CONTENTS

	Page
List of Figures	xvi
List of Tables	xx
Acknowledgements	xxxiv
Executive Summary	1

Chapter 1

INTRODUCTION	24
Background	24
The Form of the Policies Analyzed	26
Organization of the Study	29

Chapter 2

TRENDS IN GASOLINE CONSUMPTION, EMISSIONS, AND AIR QUALITY IN THE ABSENCE OF MAJOR POLICY CHANGES	30
Historical Trends in Gasoline Consumption, Pollutant Emissions, and Air Quality	31
Gasoline Consumption	32
Trends in Emissions of Pollutants	34
Forecasts of Gasoline Consumption and Emissions	36
Forecasts of Gasoline Consumption	37
Forecasts of Pollutant Emissions	39
Forecasts of Pollutant Concentrations	49
The Relationship of Light-Duty Vehicles to National Total Urban Emissions	51

Chapter 3

OVERVIEW OF METHODS	62

TABLE OF CONTENTS (Continued)

Page

Introduction 62
Base Case Forecasts 63
Gasoline Rationing and Increases in the Excise Tax 64
Excise Tax on New Cars Based on Fuel Consumption and Restrictions on Fuel Consumption of New Cars 64
Structure of the Analysis 65
Central Modules 68
Short-Run Demand for Gasoline 68
Price Elasticity 69
The Effect of the Stock of Cars 70
The Effect of Income 70
Effect of Pollution Control Devices 71
The Effect of Fuel Consumption Characteristics of the Car Stock 72
Disaggregation of Gasoline Consumption . . . 73
Emission Production Functions 75
Emission Rates 77
Vehicle Miles of Travel and Trip Frequency 82
The Air Quality Model 84
Concentrations of Carbon Monoxide and Nitrogen Oxides 86
Oxidant Concentrations 87

Chapter 4

POLICIES AFFECTING GASOLINE DEMAND DIRECTLY . . . 91
Introduction 91
Qualitative Analysis 92
An Increase in the Federal Excise Tax . . . 93
The Effects on Alternative Modes of Transportation 97

TABLE OF CONTENTS (Continued)

	Page
The Imposition of Gasoline Rationing . . .	99
Effects of a Tax Increase on the Price of Gasoline	105
Effect of Price Increase on Gasoline Consumption	109
Short-Run vs. Long-Run Gasoline Demand . .	111
Results	118
Gasoline Consumption	118
Carbon Monoxide	127
Hydrocarbons	131
Nitrogen Oxides	135
Concentrations of Pollutants	135
Changes in Fuel Consumption and Emissions by Alternative Modes	143
General Discussion of This Problem . . .	143
The Effect of Rationing and Gasoline Excise Tax Increases on Fuel Consumption by Public Transit	146
Increase in Emissions from Alternative Sources	153
Secondary Impacts	164
Administrative Costs	165
Income Distribution	167
Incentives for Efficiency and Technical Change	177

Chapter 5

POLICIES AFFECTING THE STOCK OF CARS	179
Introduction	179
Qualitative Analysis	180
Policy Impact on Gasoline Consumption . .	181
Policy Impact on Automotive Emissions and Ambient Air Quality	187

TABLE OF CONTENTS (Continued)

	Page
Practical Difficulties in the Quantitative Analysis of These Policies	195
Statement of the Problem	195
Previous Approaches	197
Methods Used to Analyze the Impact of Policies Affecting New-Car Sales	201
The Response of Fuel Economy to an Excise Tax Based on Fuel Economy	205
Change in New-Car Sales in Response to the Excise Tax	210
Change in Scrappage in Response to Tax	211
Change in Gasoline Consumption	215
Change in Emissions	216
Restrictions on the Fuel Economy of New Cars	217
Summary of Parameters	229
Results	229
Gasoline Consumption	232
Changes in Emission Factors	238
Changes in Emissions	242
Changes in Concentration	252
Fuel Consumption and Emissions by Alternative Modes	257
Increase in Emissions from Alternative Modes	262
Potential Changes in Structure and Secondary Impacts	263
Changes in Structure	263
The Effects of Lowering National Speed Limits	264
Change in the Mix of Vehicles Offered for Sale	265
Secondary Impacts	273
Income Distribution	274

TABLE OF CONTENTS (Continued)

	Page
Incentives for Efficiency and Technical Change	275
Impact on Automotive Employment	276
Chapter 6	
CONCLUSIONS	278
Policies Affecting Gasoline Demand Directly	278
Policies Affecting the Stock of Cars	282
Comparison of the Two Sets of Policies	284
APPENDIX A	287
The Demand for Gasoline	287
Short-Run Demand for Gasoline	287
Estimating Technique	288
Goodness of Fit	290
Description of the Variables and Their Sources	291
QGASLD	291
PGASD	292
RVLD	292
PCERVLD	294
MPG	296
Variables from the Supply Side	304
The Long-Run Adjustment Coefficient	306
Forecasting Methods	311
Variables Forecasted by Time Trends	311
Variables Forecasted by Other Methods	318
PGASD	318
PCERVLD	323
MPG	325

TABLE OF CONTENTS (Continued)

	Page
Disaggregation of Gasoline Consumption by City Size and Rural Area	331
Emission Production Functions	333
Introduction	333
Sources of LDV Emission Rates	333
Exhaust Emission Rates	334
Evaporative Sources	337
Crankcase Emissions	339
Required Inputs for the Determination of Selected Urban and National Average Emission Levels	341
Analysis Years	342
Analysis Areas	342
Prediction of Vehicle Miles of Travel by Analysis Year and Area	344
Prediction of Trip Frequency	348
Exhaust Emission Deterioration Factors	350
Averaging Period for the Prediction of Pollutant Emissions	353
The Emission Production Functions	358
Total Emissions	358
Running Exhausts	359
Cold Start Exhausts	360
Hot Soak Emissions (HC only)	360
Diurnal Evaporative Emissions (HC only)	361
Crankcase Emissions (HC only)	361
Air Quality Calculations and Validation of the Model	362
Modeling Calculation Procedure	362
1. LDV Component	365
2. Total Urban Emissions	365
Model Validation	368

TABLE OF CONTENTS (Continued)

	Page
APPENDIX B	375
Carbon Monoxide	375
Hydrocarbons	381
Nitrogen Oxides	381
Oxidants	385
Emissions Data for 1971 and 1972	390
APPENDIX C	393
A. Relationship Between a Tax Increase and the Equilibrium Price of Gasoline	394
B. Disaggregation of Gasoline Demand Elasticities	396
1. Precise Relations	397
2. Determining the Individual Elasticities	399
C. Determination of the Long-Run Demand Elasticities	411
APPENDIX D: POLICIES AFFECTING NEW CAR SALES	417
Qualitative Analysis of Policies Affecting Gasoline Consumption and Air Quality	417
A. Gasoline Consumption	417
1. Effect of a Tax on Fuel Economy of New Vehicles	417
2. Effect of Restrictions on the Fuel Economy of New Vehicles	431
B. Ambient Air Quality	433
1. Effect of a Tax on Fuel Economy of New Vehicles	433
2. Effect of Restrictions on the Fuel Economy of New Vehicles	440
Technical Details on Methods	441
Derivation of Change in Miles Per Gallon Resulting From Excise Taxes	441
Derivation of the Average Price Increase	444

Page

Derivation of the Average Fuel Economy of the Car Stock 448
Derivation of the Change in New Car Sales 450
Derivation of the Change in Scrappage . . 450
Derivation of the Change in the Car Stock 451
Derivation of the Change in the Proportion of Cars Produced After 1968 452
Derivation of the Change in Gasoline Consumption 452
Restrictions on Fuel Economy of New Cars . 452
Parameters and Sensitivity Analysis . . . 453
Sources of Data and Estimation Details . . . 459
Equation Relating Fuel Economy to Weight and Horsepower 459
Demand for Weight and Horsepower 464
Change in New Car Sales in Response to the Excise Tax 466
Scrappage of Used Cars 466
The Relationship Between the Price Indexes for Used Cars and New Cars 471
Sources of Other Data Used in the Analysis 474
Sales-Weighted Average Miles Per Gallon, Weight, and Horsepower 474
Sales-Weighted Average Price 477
1975 Pre-Tax Price of Weight and Horsepower 477
Share of Cars Subject to the Tax 477

APPENDIX E 479
Gasoline Consumption 482
Carbon Monoxide Emissions 493
Hydrocarbon Emissions 493

TABLE OF CONTENTS (Continued)

	Page
Nitrogen Oxide Emissions	493
Concentrations of Pollutants	512
APPENDIX F	521
Gasoline Consumption	521
Emissions	533
Concentrations	533

LIST OF FIGURES

		Page
EXECUTIVE SUMMARY		
Figure S-1	Consumption of Gasoline under Policies of Rationing and Different Tax Levels, 1975, 1981 and 1987	5
S-2	Urban Emissions of Carbon Monoxide, Hydrocarbons, and Nitrogen Oxides as Percentage of Base Forecasts 1975, 1981 and 1987 ...	6
S-3	Relative 8-Hour Carbon Monoxide Concentrations, 13 City Average, All Emissions Sources, 1975, 1981 and 1987	7
S-4a	Percent of Income on $0.10/Gallon Gasoline Excise Tax Increase	8
S-4b	Net Transfers per Household under Coupon Rationing, 1975 and 1981	8
S-5	Forecasts of Gasoline Consumption under Policies Affecting the Stock of Automobiles 1971, 1975 and 1987	9
S-6	Urban Emissions of Carbon Monoxide as Percentage of Base Forecasts, Policies Affecting Stock of Cars, 1975, 1981, 1987	10
S-7	Comparison of Emissions (in Grams per Passenger-Mile) from Autos and Buses, 1975, 1981 and 1987	11
S-8a	Gasoline Consumption as Percent of Base Forecast	13
S-8b	Carbon Monoxide Emissions as Percent of Base Forecast	13
S-9	Flowchart of the Analysis	14

LIST OF FIGURES (Continued)

Page

1. INTRODUCTION

No figures

2. TRENDS IN GASOLINE CONSUMPTION, EMISSIONS, AND AIR QUALITY IN THE ABSENCE OF MAJOR POLICY CHANGES

2-1 Nationwide Estimates of Pollutant Emissions, 10^6 Tons/Year..... 35

2-2 Emissions of Carbon Monoxide by Automobiles in Urban Areas..... 43

2-3 Emissions of Oxides of Nitrogen by Automobiles in Urban Areas..... 44

2-4 Emissions of Hydrocarbons by Automobiles in Urban Areas..... 45

2-5 Projected Urban Area Annual Emissions for Carbon Monoxide..... 57

2-6 Projected Annual Urban Area Nitrogen Oxide Emissions..... 58

2-7 Projected Annual Urban Area Total Hydrocarbon Emissions..... 59

3. OVERVIEW OF METHODS

3-1 Flowchart of the Analysis..... 66

3-2 Schematic Representation of Methodology for the Estimation of Emission Production Functions..... 79

3-3 Maximum Daily 1-Hour-Average Oxidant Concentrations as a Function of 6-to 9 a.m. Averages of Total Hydrocarbon Concentrations at CAMP Stations, June Through September, 1966 through 1968 and in Los Angeles, May through October 1967..... 88

4. POLICIES AFFECTING GASOLINE DEMAND DIRECTLY

4-1 Schematic Representation of the Short-Run and Long-Run Impacts on Gasoline Consumption of an Increase in the Gasoline Excise Tax..... 95

Figures (Continued)

Page

4. POLICIES AFFECTING GASOLINE DEMAND DIRECTLY - Continued

4-2 Schematic Representation of the Supply of and Demand for Coupons on the White Market..... 101

4-3 Schematic Representation of the Equivalence of a Given Rationing Scheme to the Appropriate Excise Tax Increase..... 103

4-4 Schematic Representation of the Effect of a Change in the Gasoline Tax on the Equilibrium Price of Gasoline, When Supply is Not Perfectly Elastic.... 106

4-5 Schematic Representation of the Effect of a Change in the Gasoline Tax on the Equilibrium Price of Gasoline, When Supply is Perfectly Elastic..... 107

4-6 Schematic Representation of the Time Path of Gasoline Consumption in Response to a Sustained Increase in the Excise Tax on Gasoline (All Other Things Equal). 113

4-7 Schematic Representation of Demand Curves Outside the Observed Range of Prices..... 126

5. POLICIES AFFECTING THE STOCK OF CARS

5-1 Schematic Representation of Manufacturers' Determination of Optimal Improvement in MPG..... 268

5-2 Schematic Representation of Manufacturers' Determination of Optimal Improvement in MPG: "Corner Solution."..... 272

6. CONCLUSIONS

No figures

Figures (Continued)

Page

APPENDIX A

A-1 Data and Isopleths of upper decile autumn morning χ/Q values for 10- and 100-km city sizes..... 364

A-2 Comparison of Predicted Vs. Observed Carbon Monoxide Concentrations for 1973..... 372

A-3 Comparison of Predicted Vs. Observed Nitrogen Oxide Concentrations for 1973..... 373

A-4 Comparison of Predicted Vs. Observed Oxide Concentrations for 1973..... 374

APPENDIX B

B-1 Normalized Carbon Monoxide Emission Curves for Selected Areas 1970-1973..... 379

B-2 Annual Average Percent of Values Above the 8-Hour Carbon Monoxide Standard for Selected Areas, 1970-1973..... 380

B-3 Trend Lines for NO_x Annual Averages in Five Camp Cities..... 387

B-4 Composite Averages of Second High Annual 1-Hour Oxidant Values for Various Areas Within California..... 389

APPENDIX C

No figures

APPENDIX D

No figures

APPENDIX E

No figures

APPENDIX F

No figures

LIST OF TABLES

EXECUTIVE SUMMARY

Table S-1 Base Forecasts of Gasoline Consumption, Urban Automotive Emissions, and Total Urban Concentrations . . . 16

S-2 National Average Elasticities of Number of Trips and Average Trip Length with Respect to Gasoline Price 17

S-3 Summary of Impacts of Policies Affecting Price or Availability of Gasoline 18

S-4 Summary of Coefficients and Elasticity Estimates used in Analyzing Excise Taxes on Fuel Economy 20

S-5 Summary of Impact Policies Affecting Gasoline Consumption of New Autos . 21

LIST OF TABLES (Continued)

Page

1. INTRODUCTION

No tables

2. TRENDS IN GASOLINE CONSUMPTION, EMISSIONS, AND AIR QUALITY IN THE ABSENCE OF MAJOR POLICY CHANGES

2-1 Highway Use of Gasoline, 1950-1973..... 33

2-2 Base Case Forecasts Gasoline Consumption..... 38

2-3 Base Case Forecasts (High Gasoline Prices) Annual National Urban Automotive Emissions..... 40

2-4 Base Case Forecasts (Low Gasoline Prices) Annual national Urban Automotive Emissions..... 41

2-5 Emissions as Fractions of 1975 Emissions. 46

2-6 Base Case Emissions Backcast to 1972..... 48

2-7 Base Forecasts of Pollutant Concentrations, 13-City Averages, 1975, 1981, 1987..... 50

2-8 Summary of Estimated Nationwide Urban Area Emissions for 1970..... 52

2-9 National Urban Area Carbon Monoxide Emission Projections..... 54

2-10 National Urban Area NO_x Emission Projections..... 55

2-11 National Urban Area Hydrocarbon Emission Projections..... 56

2-12 Ratio of Estimated Annual Light-Duty Vehicle Emissions ($\bar{Q}_{LDV}$) to Total Emissions ($\bar{Q}_{TOT}$)..... 61

3. OVERVIEW OF METHODS

3-1 Relative Contributions of Pollution Sources (percent of total emissions during one cycle of the CVS-CH Federal Test Procedures)..... 78

Tables (Continued)

Page

3. OVERVIEW OF METHODS - Continued

3-2 Scaled Exhaust Emission Rates..... 80

3-3 HC Evaporative Emission Rates..... 81

3-4 Carbon Monoxide, Exhaust Hydrocarbon, and Nitrogen Oxide Deterioration Factors for Light-Duty, Gasoline-Powered Vehicles in All Areas Except California..... 83

3-5 Baseline Gasoline Consumption Rates (National Average) by Analysis Year and Price Scenario..... 84

3-6 Pollutants and Averaging Times..... 85

4. POLICIES AFFECTING GASOLINE DEMAND DIRECTLY

4-1 National Average Disaggregated Urban Gasoline Demand Elasticities..... 116

4-2 National Average Elasticities of Number of Trips and Average Trip Length... 117

4-3 Medium Estimate of Gasoline Consumption Under Policies Affecting Gasoline Demand Directly..... 119

4-4 Urban Gasoline Consumption in 1975, Medium Sensitivity..... 121

4-5 Urban Gasoline Consumption in 1981, Medium Sensitivity..... 122

4-6 Urban Gasoline Consumption in 1987, Medium Sensitivity..... 123

4-7 Urban Carbon Monoxide Emissions in 1975, Medium Sensitivity..... 128

4-8 Urban Carbon Monoxide Emissions in 1981, Medium Sensitivity..... 129

4-9 Urban Carbon Monoxide Emissions in 1987, Medium Sensitivity..... 130

4-10 Urban Hydrocarbon Emissions in 1975, Medium Sensitivity..... 132

4-11 Urban Hydrocarbon Emissions in 1981, Medium Sensitivity..... 133

Tables (Continued)

Page

4. POLICIES AFFECTING GASOLINE DEMAND DIRECTLY - Continued

4-12 Urban Hydrocarbon Emissions in 1987, Medium Sensitivity..... 134

4-13 Urban Nitrogen Oxide Emissions in 1975, Medium Sensitivity..... 136

4-14 Urban Nitrogen Oxide Emissions in 1981, Medium Sensitivity..... 137

4-15 Urban Nitrogen Oxide Emissions in 1987, Medium Sensitivity..... 138

4-16 Relative One Hour Carbon Monoxide Concentrations for 13 City Averages..... 139

4-17 Relative Eight Hour Carbon Monoxide Concentrations for 13 City Averages (As a percentage of baseline concentrations).. 140

4-18 Relative Annual Nitrogen Oxide Concentrations for 13 City Averages (As a percentage of baseline concentrations).... 141

4-19 Relative One Hour Oxidant Concentrations for 13 City Averages (As a percentage of baseline concentrations)..... 142

4-20 Maximum Increases in Fuel Consumption by Public Transit in Response to Policies Reducing Automotive Consumption of Gasoline..... 152

4-21 Emissions Per Passenger Mile of Bus and Light-Duty Vehicles, 1975, 1981, and 1987..... 154

4-22 Emission Standards, Heavy-Duty Vehicles, 1975..... 157

4-23 Emission Rates Per Passenger Mile, Single-Occupant Light-Duty Vehicles..... 159

4-24 Maximum Increases In Emissions of Carbon Monoxide by Transit Buses in Response to Policies Reducing Automotive Consumption of Gasoline..... 161

4-25 Maximum Increases in Emissions of Hydrocarbons by Transit Buses in Response to Policies Reducing Automotive Consumption in Gasoline..... 162

Tables (Continued)

Page

4. POLICIES AFFECTING GASOLINE DEMAND DIRECTLY - Continued

4-26 Maximum Increases in Emissions of Nitrogen Oxides by Transit Buses in Response to Policies Reducing Automotive Consumption of Gasoline..... 163

4-27 Estimated Additional Tax Receipts for Excise Tax Policies in 1975, 1981, and 1987..... 169

4-28 Daily Vehicle Miles of Travel and Yearly Gasoline Consumption by Households in Different Income Classes..... 171

4-29 Estimated Value of Rationing Coupons for Different Sensitivity Assumptions in 1975, 1981, and 1987..... 173

4-30 Comparison of Desired Gasoline Consumption and Coupon Entitlements, by Income Class..... 175

4-31 Comparison of Estimated Household Consumption and Entitlements..... 176

4-32 Estimated Transfers per Household by Income Classes Under Coupon Rationing..... 178

5. POLICIES AFFECTING THE STOCK OF CARS

5-1 Equivalent Taxes on Weight and Horsepower Implied by a Tax on Each Mile Per Gallon Less than 20..... 207

5-2 1974 Sales and Market Shares of U.S. Models and 1974 and 1975 Fuel Economy of These Models..... 219

5-3 Present Discounted Value of Gasoline Savings Due to Improvements in Automotive Fuel Economy..... 223

5-4 Summary of Coefficients and Elasticity Estimates Used in Analyzing Excise Taxes on Fuel Economy..... 230

5-5 Medium Estimate of Gasoline Consumption Under Policies Affecting New Car Sales..... 233

5-6 Light-Duty Vehicle Carbon Monoxide Emission Factors for the Different Policies, 1975, 1981, and 1987..... 239

Tables (Continued)

Page

5. POLICIES AFFECTING THE STOCK OF CARS - Continued

5-7 Light-Duty Vehicle Hydrocarbon Emission Factors for the Different Policies, 1975, 1981, and 1987..... 240

5-8 Light-Duty Nitrogen Oxides Emission Factors for the Different Policies, 1975, 1981, and 1987..... 241

5-9 Urban Carbon Monoxide Emissions in 1975, Medium Sensitivity..... 243

5-10 Urban Carbon Monoxide Emissions in 1981, Medium Sensitivity..... 244

5-11 Urban Carbon Monoxide Emissions in 1987, Medium Sensitivity..... 245

5-12 Urban Hydrocarbon Emissions in 1975, Medium Sensitivity..... 246

5-13 Urban Hydrocarbon Emissions in 1981, Medium Sensitivity..... 247

5-14 Urban Hydrocarbon Emissions in 1987, Medium Sensitivity..... 248

5-15 Urban Nitrogen Oxides Emissions in 1975, Medium Sensitivity..... 249

5-16 Urban Nitrogen Oxides Emissions in 1981, Medium Sensitivity..... 250

5-17 Urban Nitrogen Oxides Emissions in 1987, Medium Sensitivity..... 251

5-18 Relative One-Hour Carbon Monoxide Concentrations for 13 City Averages (As Percentages of Baseline Concentrations).. 253

5-19 Relative Eight-Hour Carbon Monoxide Concentrations for 13 City Averages..... 254

5-20 Relative Annual Nitrogen Oxides Concentrations for 13 City Averages (As Percentages of Baseline Concentrations).. 255

5-21 Relative One-Hour Oxidant Concentrations for 13 City Averages (As Percentages of Baseline Concentrations)..... 256

5-22 Percentage Reduction in Size of Auto Stock Due to Enactment of Policies..... 258

Tables (Continued)

Page

5. POLICIES AFFECTING THE STOCK OF CARS - Continued

5-23 Reduction in Fuel Consumption by Automobiles Due to Enactment of Policies... 260

5-24 Increase in Fuel Consumption By Transit Due to Enactment of Policies..... 261

6. CONCLUSIONS

6-1 Gasoline Consumption and Pollutant Emissions as a Percentage of Base Case Levels: Policies Affecting Fuel Price and Availability..... 279

6-2 Gasoline Consumption and Pollutant Emissions as a Percentage of Base Case Levels: Policies Affecting the Stock of Cars..... 285

APPENDIX A

A-1 Models Used to Calculate Market Share of Compacts..... 299

A-2 Adjustment of Estimated Average Displacement of New Car Sales to Link With Dewees' Data..... 301

A-3 Average Curb Weight, Engine Displacement and Estimated Miles Per Gallon of the Stock of Automobiles, 1950-1971..... 302

A-4 Grouping of Observations by States For Forecasting Equations..... 312

A-5 Summary of Equations Used to Forecast Licensed Drivers, Registered Trucks, and Registered Autos..... 313

A-6 Growth Rates for Independent Variables in Gasoline Demand Equation..... 317

A-7 Low and High Prices for Gasoline Assumed in the Forecasts..... 320

A-8 Forecasts of Age Distribution of Automobile Stock, 1973-1975, 1981, 1987.... 326

Tables (Continued)

		Page
A-9	Equations Used to Forecast Average New-Car Weight and Displacement for "High" Gasoline Consumption Forecasts	328
A-10	Assumed Values for Average Weight and Engine Displacement of New Cars, 1973-1978	330
A-11	Carbon Monoxide, Hydrocarbon, and Nitrogen Oxide Emission Factors for Light-Duty Vehicles at Low and High Altitude	335
A-12	Scaled Exhaust Emission Rates	338
A-13	HC Evaporative Emission Rates	340
A-14	Sample Cities	343
A-15	Baseline Gasoline Consumption Rates (National Average) by Analysis Year and Price Scenario	345
A-16	Fractional Change from Baseline Gasoline Consumption Rates Associated with New Car Excise Taxes and Fuel Economy Restrictions	347
A-17	Variation in Average Trip Length by Size of Place	349
A-18	Average Trip Lengths (Across All Purposes) in Sample Cities	351
A-19	Carbon Monoxide, Exhaust Hydrocarbon, and Nitrogen Oxides Deterioration Factors for Light-Duty, Gasoline-Powered Vehicles in All Areas Except California	352
A-20	Diurnal Distribution of VMT and ATL	355
A-21	Urban Area Diameter and Interpolated $\overline{\chi}/\overline{Q}$	363
A-22	Ratio of Annual Average to Peak LDV Emission Rates (T)	367
A-23	Air Quality Monitoring Data for 1973	369
A-24	Predicted Air Quality Concentrations for 1973	370

Tables (Continued)

		Page
APPENDIX B		
B-1	Nationwide Estimates of Carbon Monoxide Emissions, 1940-1970.....	377
B-2	Nationwide Estimates of Carbon Monoxide Emissions, 1970.....	378
B-3	Nationwide Estimates of Hydrocarbon Emissions, 1940-1970.....	382
B-4	Nationwide Estimates of Hydrocarbon Emissions, 1970.....	383
B-5	Nationwide Estimates of Nitrogen Oxide Emissions, 1940-1970.....	384
B-6	Nationwide Estimates of Nitrogen Oxide Emissions, 1970.....	386
B-7	Estimated Emissions of Air Pollutants by Weight Nationwide 1971.....	391
B-8	National Emisssions Data System Emission Estimates.....	392
APPENDIX C		
C-1	Estimates of Parameters Used in Elasticity Disaggregation.....	407
C-2	Summary of Estimates of Disaggregate Urban Gasoline Demand Elasticities: Short-Run and Long-Run.....	410
APPENDIX D		
D-1	Summary of Coefficients and Elasticity Estimates Used in Analyzing Excise Taxes on Fuel Economy.....	454
D-2	1974 Age Distribution of the Automobile Stock.....	457
D-3	Base Forecasts of New Car Sales.....	458
D-4	Survey of Models of New-Car Demand.....	467
D-5	1975 Models For Which Fuel Economy Was Estimated.....	475
D-6	Options Whose Prices Were Included in Prices of New Cars.....	478

Tables (Continued)

Page

APPENDIX E

E-1 National Average Disaggregated Urban Gasoline Elasticities, Low Gasoline Consumption Forecasts..... 480

E-2 National Average Disaggregated Urban Gasoline Elasticities, High Gasoline Consumption Forecasts..... 481

E-3 Low Estimate of Gasoline Consumption Under Policies Affecting Gasoline Demand Directly..... 484

E-4 Urban Gasoline Consumption in 1975, High Sensitivity..... 485

E-5 Urban Gasoline Consumption in 1981, High Sensitivity..... 486

E-6 Urban Gasoline Consumption in 1987, High Sensitivity..... 487

E-7 High Estimate of Gasoline Consumption Under Policies Affecting Gasoline Demand Directly..... 488

E-8 Urban Gasoline Consumption in 1975, Low Sensitivity..... 489

E-9 Urban Gasoline Consumption in 1981, Low Sensitivity..... 490

E-10 Urban Gasoline Consumption in 1987, Low Sensitivity..... 491

E-11 Urban Carbon Monoxide Emissions in 1975, High Sensitivity..... 494

E-12 Urban Carbon Monoxide Emissions in 1981, High Sensitivity..... 495

E-13 Urban Carbon Monoxide Emissions in 1987, High Sensitivity..... 496

E-14 Urban Carbon Monoxide Emissions in 1975, Low Sensitivity..... 497

E-15 Urban Carbon Monoxide Emissions in 1981, Low Sensitivity..... 498

Tables (Continued)

		Page
E-16	Urban Carbon Monoxide Emissions in 1987, Low Sensitivity.....	499
E-17	Urban Hydrocarbon Emissions in 1975, High Sensitivity.....	500
E-18	Urban Hydrocarbon Emissions in 1981, High Sensitivity.....	501
E-19	Urban Hydrocarbon Emissions in 1987, High Sensitivity.....	502
E-20	Urban Hydrocarbon Emissions in 1975, Low Sensitivity.....	503
E-21	Urban Hydrocarbon Emissions in 1981, Low Sensitivity.....	504
E-22	Urban Hydrocarbon Emissions in 1987, Low Sensitivity.....	505
E-23	Urban Nitrogen Oxides Emissions in 1975, High Sensitivity.....	506
E-24	Urban Nitrogen Oxides Emissions in 1981, High Sensitivity.....	507
E-25	Urban Nitrogen Oxides Emissions in 1987, High Sensitivity.....	508
E-26	Urban Nitrogen Oxides Emissions in 1975, Low Sensitivity.....	509
E-27	Urban Nitrogen Oxides Emissions in 1981, Low Sensitivity.....	510
E-28	Urban Nitrogen Oxides Emissions in 1987, Low Sensitivity.....	511
E-29	Relative 1 Hour Carbon Monoxide Concentrations For 13 City Averages.....	513
E-30	Relative 8 Hour Carbon Monoxide Concentrations for 13 City Averages.....	514
E-31	Relative Annual Average Nitrogen Oxide Concentrations for 13 City Averages.....	515
E-32	Relative 1 Hour Oxidant Concentrations for 13 City Averages.....	516

Tables (Continued)

		Page
E-33	Relative 1 Hour Carbon Monoxide Concentrations for 13 City Averages.....	517
E-34	Relative 8 Hour Carbon Monoxide Concentrations for 13 City Averages.....	518
E-35	Relative Annual Average Nitrogen Oxide Concentrations for 13 City Averages.....	519
E-36	Relative 1 Hour Oxidant Concentrations For 13 City Averages.....	520
APPENDIX F		
F-1	Gasoline Consumption in 1975, Medium Sensitivity.....	522
F-2	Gasoline Consumption in 1981, Medium Sensitivity.....	523
F-3	Gasoline Consumption in 1987, Medium Sensitivity.....	524
F-4	Low Estimate of Gasoline Consumption Under Policies Affecting New-Car Sales...	525
F-5	Gasoline Consumption in 1975, High Sensitivity.....	526
F-6	Gasoline Consumption in 1981, High Sensitivity.....	527
F-7	Gasoline Consumption in 1987, High Sensitivity.....	528
F-8	High Estimate of Gasoline Consumption Under Policies Affecting New-Car Sales...	529
F-9	Gasoline Consumption in 1975, Low Sensitivity.....	530
F-10	Gasoline Consumption in 1981, Low Sensitivity.....	531
F-11	Gasoline Consumption in 1987, Low Sensitivity.....	532
F-12	Urban Carbon Monoxide Emissions in 1975, High Sensitivity.....	534

Tables (Continued)

		Page
F-13	Urban Carbon Monoxide Emissions in 1981, High Sensitivity.....	535
F-14	Urban Carbon Monoxide Emissions in 1987, High Sensitivity.....	536
F-15	Urban Carbon Monoxide Emissions in 1975, Low Sensitivity.....	537
F-16	Urban Carbon Monoxide Emissions in 1981, Low Sensitivity.....	538
F-17	Urban Carbon Monoxide Emissions in 1987, Low Sensitivity.....	539
F-18	Urban Hydrocarbon Emissions in 1975, High Sensitivity.....	540
F-19	Urban Hydrocarbon Emissions in 1981, High Sensitivity.....	541
F-20	Urban Hydrocarbon Emissions in 1987, High Sensitivity.....	542
F-21	Urban Hydrocarbon Emissions in 1975, Low Sensitivity.....	543
F-22	Urban Hydrocarbon Emissions in 1981, Low Sensitivity.....	544
F-23	Urban Hydrocarbon Emissions in 1987, Low Sensitivity.....	545
F-24	Urban Nitrogen Oxides Emissions in 1975, High Sensitivity.....	546
F-25	Urban Nitrogen Oxides Emissions in 1981, High Sensitivity.....	547
F-26	Urban Nitrogen Oxides Emissions in 1987, High Sensitivity.....	548
F-27	Urban Nitrogen Oxides Emissions in 1975, Low Sensitivity.....	549
F-28	Urban Nitrogen Oxides Emissions in 1981, Low Sensitivity.....	550
F-29	Urban Nitrogen Oxides Emissions in 1987, Low Sensitivity.....	551

Tables (Continued)

		Page
F-30	Relative 1 Hour Carbon Monoxide for 13 City Averages.....	552
F-31	Relative 8 Hour Carbon Monoxide for 13 City Averages.....	553
F-32	Relative Annual Average Nitrogen Oxides Concentrations for 13 City Averages.....	554
F-33	Relative 1 Hour Oxidant for 13 City Averages.....	555
F-34	Relative 1 Hour Carbon Monoxide for 13 City Averages.....	556
F-35	Relative 8 Hour Carbon Monoxide for 13 City Averages.....	557
F-36	Relative Annual Average Nitrogen Oxides Concentrations for 13 City Averages.....	558
F-37	Relative 1 Hour Oxidant for 13 City Averages.....	559

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EXECUTIVE SUMMARY

A number of fuel conservation policies have been proposed to reduce gasoline consumption by automobiles, including: gasoline rationing; increases in the federal excise tax on gasoline; excise taxes on new cars, in inverse proportion to their fuel economy; and regulations to set minimum levels on average fuel economy of new cars.

This study estimates the impacts on fuel consumption by automobiles and by other competing modes of transportation and on emissions and concentrations of automotive pollutants, if different levels of these automobile fuel conservation policies are implemented.

The major findings of this study are:

- Increases in the federal excise tax on gasoline and gasoline rationing are considerably more effective in conserving fuel than new car excise taxes or fuel economy restrictions on new cars, especially in the early years of the policies.

- The policies of taxing or regulating new cars also lead, within several years of the date of the policy, to significant increases in emissions relative to base case emissions.
- The effect of all of the policies will be small in the early years of the policy, but the effects will become more pronounced over time.

Background and Main Findings

This study examines the effect of four kinds of fuel conservation policies on gasoline consumption, automotive emissions, and concentrations of pollutants.

Two policies relating to the price and availability of gasoline were examined:

- Rationing gasoline, with each licensed driver entitled to 10 gallons per week.
- An increase in the federal excise tax on gasoline of
  - o $0.10 per gallon
  - o $0.25 per gallon
  - o $0.50 per gallon

In addition, two policies directed at improving the fuel economy of new cars were examined:

- Imposing a federal excise tax on new cars of
  - o $50 per MPG less than 20 MPG;
  - o $100 per MPG less than 20 MPG; and
  - o $200 per MPG less than 20 MPG

  No tax would be imposed on cars achieving 20 or more MPG.
- Requiring all manufacturers to achieve a target sales-weighted average miles per gallon of new cars of

- o 17.5 MPG;
- o 20.0 MPG;
- o 22.5 MPG;

The analysis assumes that a policy is enacted in early 1975, and its effects are examined for 1975, 1981 and 1987. The principal findings of this study are:

- In the first year after enactment, none of the policies except rationing has a large impact on gasoline consumption, on automotive emissions ,or on pollutant concentrations. By 1981, gasoline taxes and rationing reach nearly their maximum effectiveness (measured as percentage decrease from the base forecast). New car excise taxes and fuel economy restrictions reach their maximum effectiveness by 1987.
- Emissions and concentrations tend to correspond to gasoline consumption in the case of rationing and gasoline taxes. The policies affecting the stock of autos cause emissions and pollutant concentrations to be greater around 1981 than their forecasted levels in the absence of these policies.
- Emissions of nitrogen oxides per passenger-mile by buses exceed those of autos in all years considered by this study. Bus emissions of carbon monoxide per passenger-mile will exceed those of autos by 1987. Consequently, if policies are implemented that will shift auto travelers to transit, stricter bus emission standards should be considered for future years.

- The policies that affect gasoline price and availability result in lower emissions and better air quality than those that affect the stock of cars, when the entire 1975-1987 period is considered.
- The income distribution effects of both gasoline excise taxes and coupon rationing are mildly progressive. Excise tax payments as a percentage of income are slightly higher for high income groups than low income groups. Under coupon rationing, higher income households would, in effect, transfer income to lower income households, but households in the lowest income bracket would receive only between $20 and $100 per year from the sale of unused coupons.

The rest of this summary considers these findings in greater detail. The last section outlines the approach, presents key parameters, and summarizes the results in tabular form. In addition to the topics summarized here, the body of the study treats the sensitivity of the results to different assumptions and parameter estimates; the impact of these policies on employment; the impact on fuel use and emissions from buses; and the methodology used.

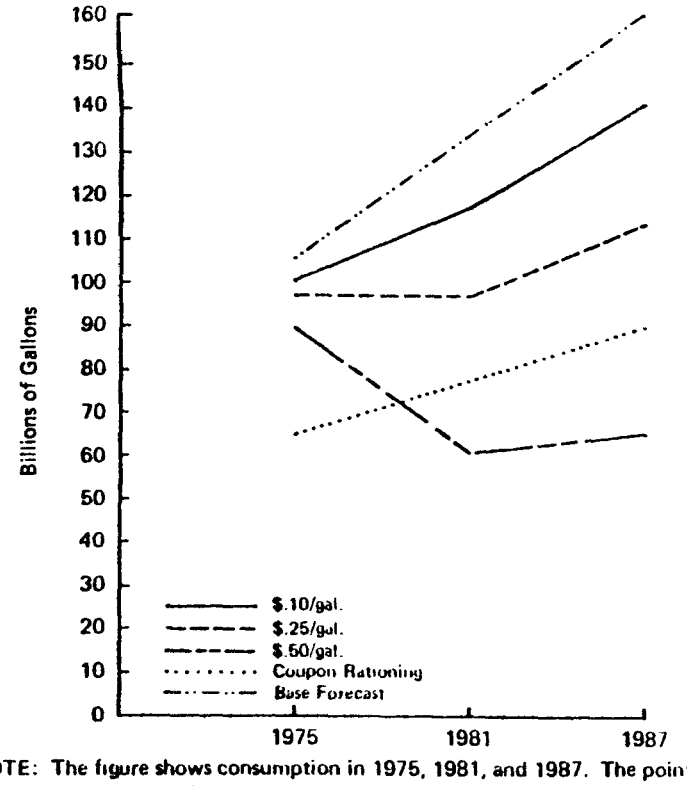
Impacts of Policies Affecting Price or Availability of Gasoline

Our estimates imply that gasoline consumption is, over a one-year period, relatively insensitive to changes

in the price of gasoline. A tax increase of $0.50 per gallon (almost doubling the 1974 price) leads to only a 15 percent reduction in consumption. Rationing licensed drivers to 10 gallons per week, on the other hand, reduces consumption by almost 40 percent. This is equivalent to a coupon price in the first year of about $1.30 per gallon.

Over time, as people adjust to the new policies, the effects of tax increases become more evident. After six years the same $0.50 per gallon increase leads to an estimated reduction of over 50 percent of base line consumption. Figure S-1 compares the expected impact of rationing and different tax increases on gasoline consumption in 1975, 1981, and 1987 with the base forecast.

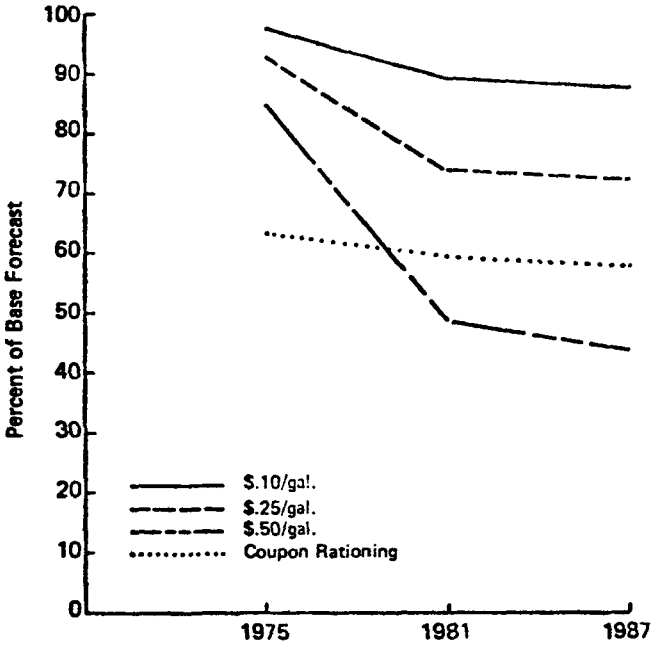
Figure S-1
CONSUMPTION OF GASOLINE UNDER POLICIES OF RATIONING AND DIFFERENT TAX LEVELS, 1975, 1981, AND 1987



NOTE: The figure shows consumption in 1975, 1981, and 1987. The points are connected for ease of interpretation but consumption in the intervening years cannot be read from the figure.

The percentage reduction in urban automotive emissions of carbon monoxide, hydrocarbons, and nitrogen oxides are almost exactly equal and are similar to the percentage reductions in gasoline consumption. Figure S-2 shows these percentage reductions for 1975, 1981, and 1987.

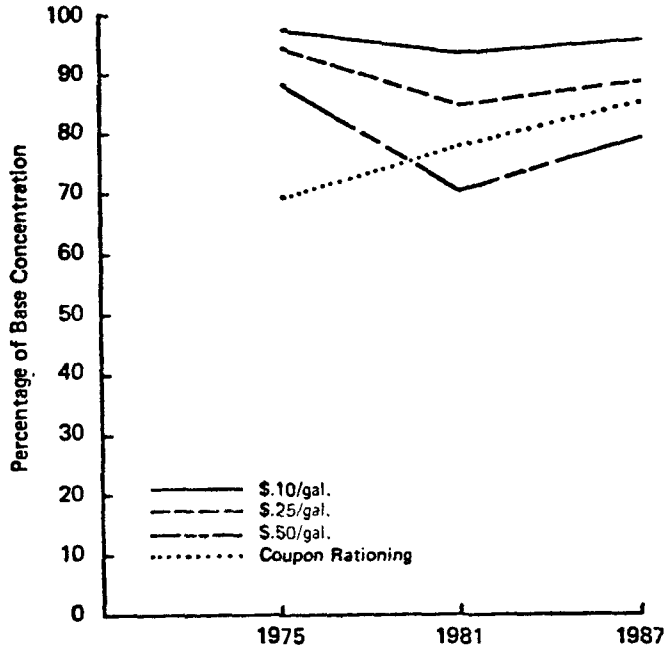
Figure S-2
URBAN EMISSIONS OF CARBON MONOXIDE, HYDROCARBONS, AND NITROGEN OXIDES AS PERCENTAGE OF BASE FORECASTS, 1975, 1981, AND 1987



NOTE: The figure shows emissions in 1975, 1981, and 1987. The points are connected for ease of interpretation, but emissions in the intervening years cannot be read from the figure.

The concentrations of the different pollutants all follow the same pattern; the eight-hour carbon monoxide concentrations as a percentage of base case concentrations are shown as a representative example in Figure S-3.

Figure S-3
RELATIVE 8-HOUR CARBON MONOXIDE CONCENTRATIONS,
13 CITY AVERAGE, ALL EMISSIONS SOURCES, 1975, 1981, AND 1987



NOTE: The figure shows concentrations in 1975, 1981, and 1987. The points are connected for ease of interpretation, but concentrations in the intervening years cannot be read from the figure.

The increases in the gasoline excise tax lead to an increase in gasoline tax payments as a percent of household income that is roughly the same for all income classes. Figure S-4a shows that households in different income classes would spend between 1.0 and 1.3 percent of their income in additional gasoline taxes if the excise tax increased by $0.10 per gallon and that households in the lower income brackets do not systematically pay a higher proportion of their income. Under a rationing plan that allocates 10 gallons of gasoline per licensed driver per week, households in the upper income brackets buy coupons (to obtain gasoline in addition to their allotment) while households in lower brackets sell coupons. As shown in Figure S-4b, the income transfers are small. Households in the lowest income bracket receive about $100 per year in 1975, but the amount they receive annually falls to about $30 by 1981.

Figure S-4a
PERCENT OF INCOME SPENT ON $0.10/GAL. GASOLINE EXCISE TAX INCREASE

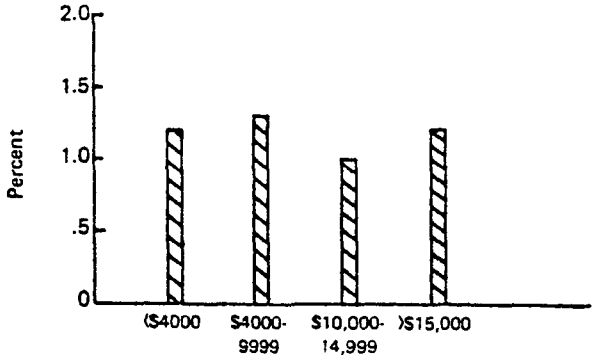
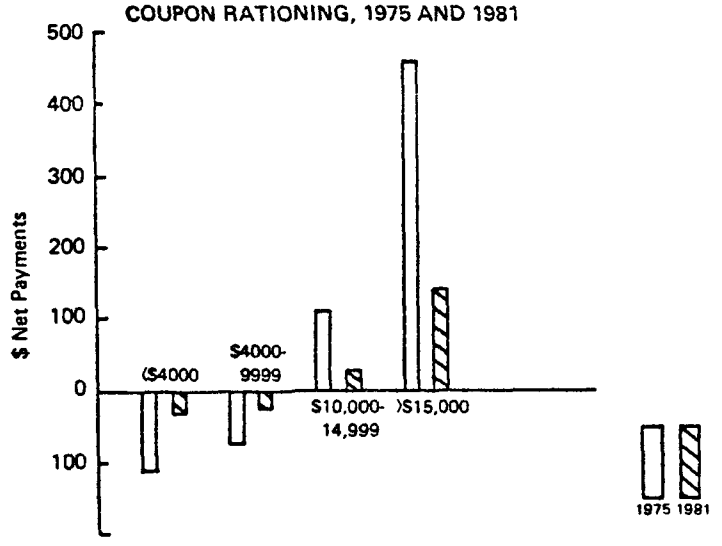


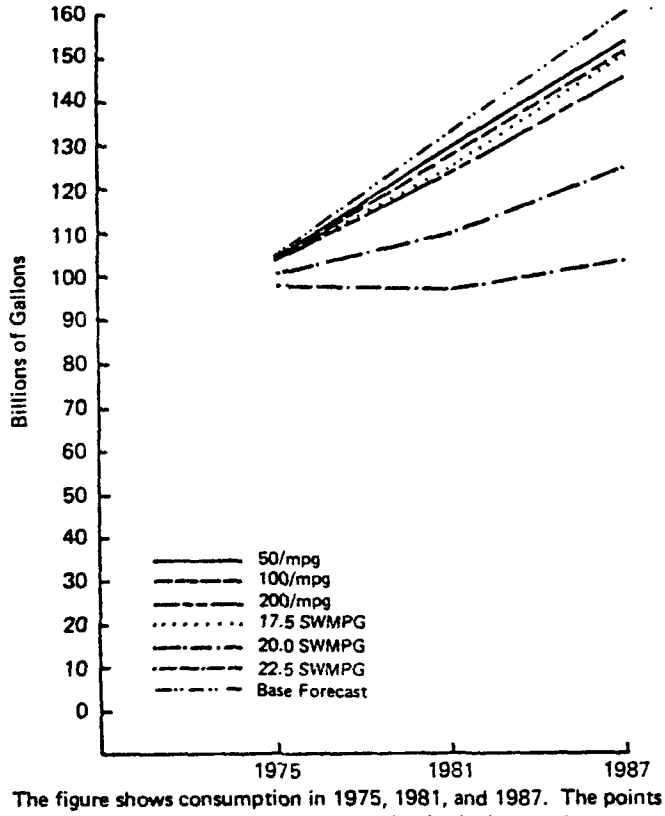
Figure S-4b
NET TRANSFERS PER HOUSEHOLD UNDER COUPON RATIONING, 1975 AND 1981



Impact of Policies Affecting the Stock of Automobiles

Our estimates show that policies directed toward automobile fuel economy lead to virtually no reduction in gasoline consumption in the first year they are in effect. In fact, only the most stringent policies lead to a substantial percentage reduction in gasoline consumption by 1987. Figure S-5 shows estimated gasoline consumption under these policies in 1975, 1981,and 1987.

Figure S-5
FORECASTS OF GASOLINE CONSUMPTION UNDER POLICIES AFFECTING THE STOCK OF AUTOMOBILES, 1971, 1975, AND 1987



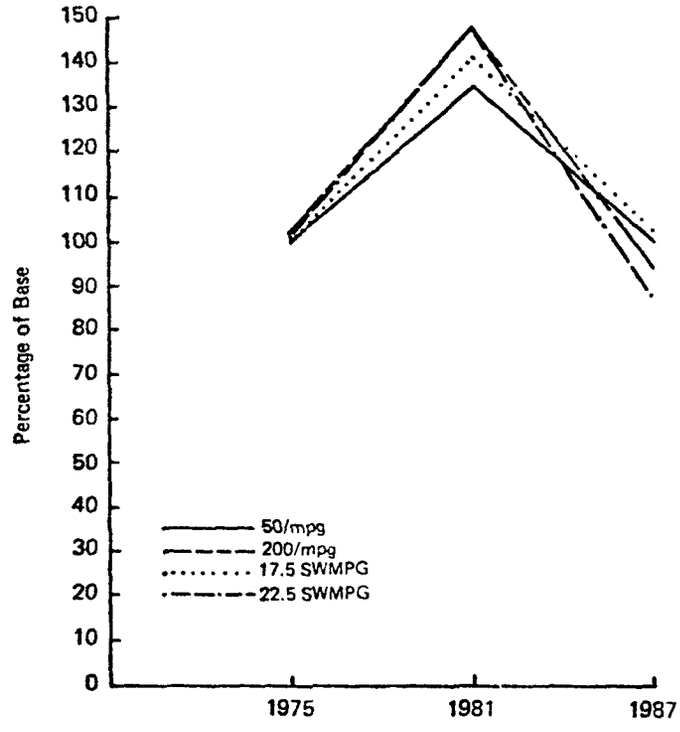
NOTE: The figure shows consumption in 1975, 1981, and 1987. The points are connected for ease of interpretation, but consumption in the intervening years cannot be read from the figure.

Even the most stringent policy, requiring manufacturers to improve fuel economy to an average of 22.5 miles per gallon, leads in 1975 to only a 6 percent decrease in gasoline consumption below the base line forecast.

The excise taxes on new cars and the least stringent policy considered, requiring a minimum sales-weighted average miles per gallon, lead only, at most, to a five percent reduction in gasoline consumption below the base forecast level. The policies with more severe requirements have appreciable impacts. The 1987 results are similar.

Because these policies slow down the turnover of the stock of cars, they raise fleet emission factors above what they would have been without the policies. Consequently, emissions and pollutant concentrations in 1975 and 1987 are roughly the same as in the base case, but in 1981 are much higher. This pattern is most pronounced for carbon monoxide emissions, shown in Figure S-6. Emissions of nitrogen oxides and hydrocarbons are higher for all years and for all policies except the requirement of average fuel economy of 22.5 miles per gallon. Urban concentrations of these pollutants follow the same general pattern.

Figure S-6
URBAN EMISSIONS OF CARBON MONOXIDE AS PERCENTAGE OF BASE FORECASTS, POLICIES AFFECTING STOCK OF CARS, 1975, 1981, AND 1987



NOTE: The figure shows emissions in 1975, 1981, and 1987. The points are connected for ease of interpretation, but emissions in the intervening years cannot be read from the figure.

Impact on Emissions from Other Modes

All of the policies, by reducing auto travel, tend to increase travel by public transportation, although no precise and reliable estimates of the increase in transit passenger-miles exist. Comparison of emissions per passenger-mile by autos and and buses shows how emissions change when a passenger is diverted from auto to bus (assuming constant average occupancy in both modes before and after the shift).

Figures S-7a, b, and c show, perhaps surprisingly, that under existing emission control standards shifting

Figure S-7
COMPARISON OF EMISSIONS (IN GRAMS PER PASSENGER-MILE) FROM AUTOS AND BUSES, 1975, 1981, AND 1987

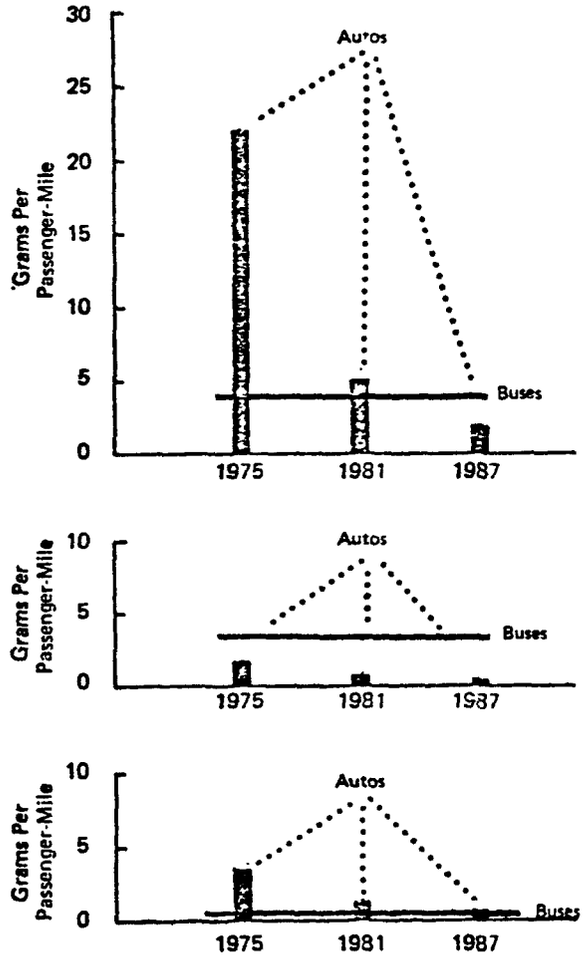


Figure S-7a
CARBON MONOXIDE

Figure S-7b
NITROGEN OXIDES

Figure S-7c
HYDROCARBONS

a traveler from auto to bus causes carbon monoxide and hydrocarbon emissions to fall but causes nitrogen oxide emissions to rise.

These figures suggest that, if fuel conservation policies lead to diversion of auto travel to bus, future emission standards for buses ought to be seriously considered for air quality control.

Comparison of the Different Policies

If policies are judged by their impacts on fuel consumption and emissions, then policies affecting the price or availability of gasoline are markedly preferable to those affecting the stock of automobiles. A $0.25 per gallon increase in the excise tax on gasoline, for example, has virtually the same impact on gasoline consumption as the most severe restriction on the sales-weighted average fuel economy of new cars, but the gasoline excise tax leads to a substantial decrease in emissions while the restriction on new car fuel economy leads to an increase in emissions for a number of years. Figures S-8a and S-8b compare gasoline consumption and urban carbon monoxide emissions for these two policies. Pollutant emissions and concentrations resulting from policies aimed at new cars are about the same as those in the base forecasts for the early and late years of the forecast period, but they increase substantially during the middle years. It appears, therefore, that policies designed to conserve fuel by improving the fuel economy of the auto stock have perverse effects on air quality, while the policies affecting price or availability of gasoline lead to both reductions in emissions and improvements in air quality.

Figure S-8a
GASOLINE CONSUMPTION AS PERCENT OF BASE FORECAST

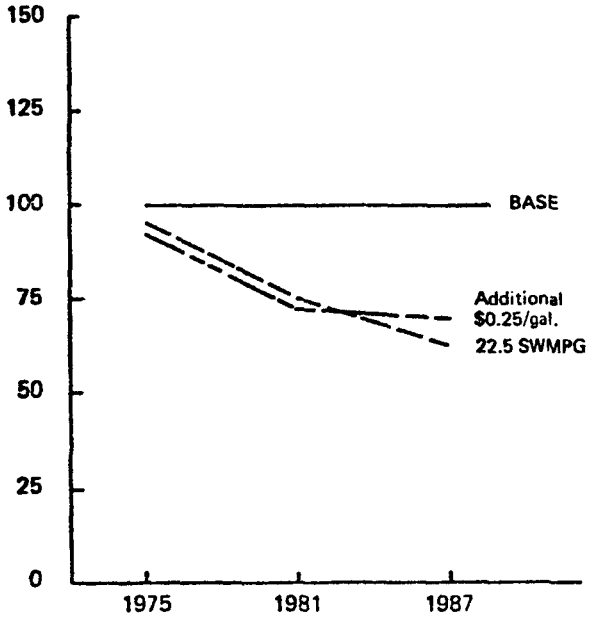
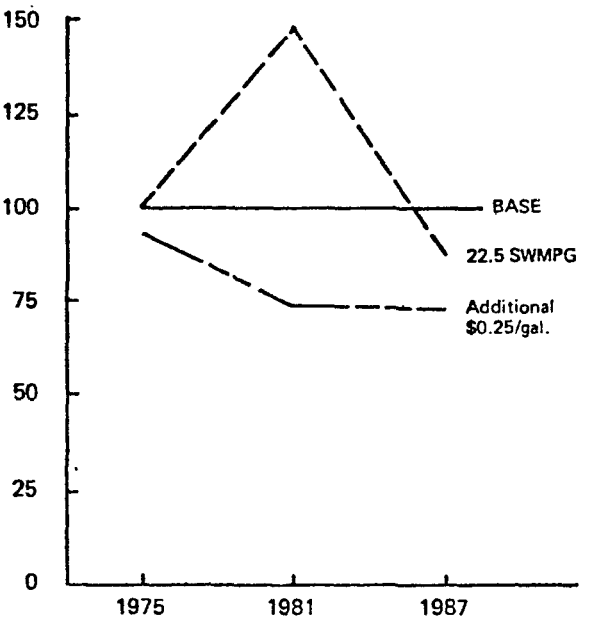


Figure S-8b
CARBON MONOXIDE EMISSIONS AS PERCENT OF BASE FORECAST



Comparison of Gasoline Consumption and Carbon Monoxide emissions from two policies – an added tax of $0.25 per gallon of gasoline, and requiring manufacturers to have their new cars average 22.5 miles per gallon.

NOTE: The figure shows emission in 1975, 1981, and 1987. The points are connected for ease of interpretation, but emissions in the intervening years cannot be read from the figure.

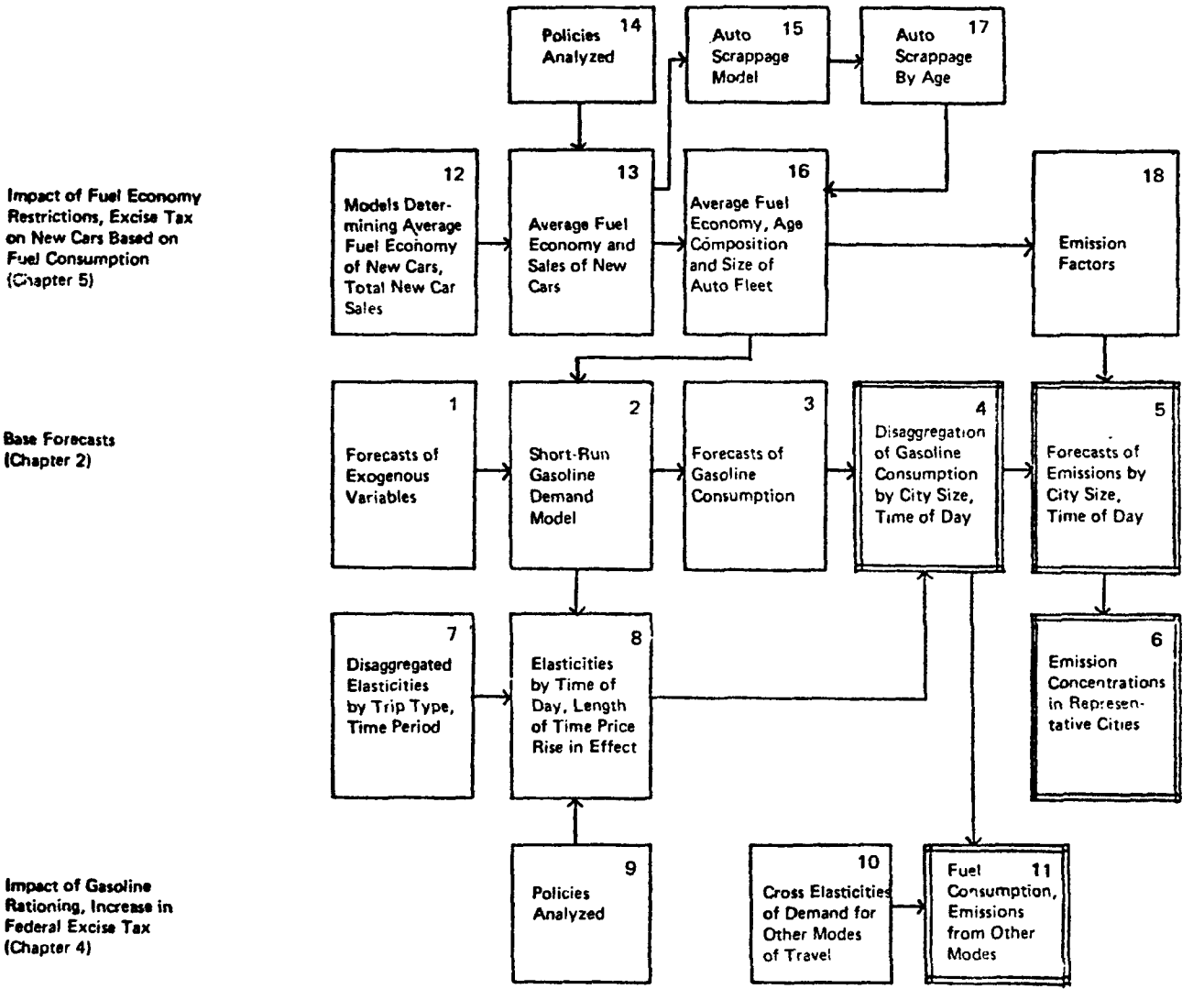
Outline of Approach and Key Assumptions and Parameters

The analysis consists of three main parts:

- base forecasts;
- analysis of policies affecting gasoline price or availability;
- analysis of policies affecting the stock of cars.

Figure S-9 shows a flow chart of the analysis. This section discusses very briefly the methods, key assumptions, and parameter values used. The boxes in Figure S-9 are numbered and are referred to by number.

Figure S-9
FLOWCHART OF THE ANALYSIS



Base Forecasts

In forecasting base case gasoline consumption we use a demand equation for gasoline (Box 2) that explains total highway consumption of gasoline by state. Forecasts of the

independent variables in this equation (Box 1) are substituted into this equation to forecast gasoline consumption in each state (Box 3). Emissions are estimated by a two-step procedure.

- Estimates of miles per gallon for the fleet as a whole are used to obtain vehicle miles of travel (VMT) from the gasoline consumption forecasts (Box 4);
- Forecasts of emission factors for the fleet translate VMT's into emissions (Box 18);

A simple atmospheric diffusion model is used to translate emissions (in terms of source strengths) into concentrations (Box 6). Table S-1 summarizes the base forecasts.

Approach to Analysis of Gasoline Rationing and Increases in the Fuel Excise Tax Policies

From the standpoint of fuel consumption and emissions, gasoline rationing is equivalent to an increase in the excise tax. To analyze the impact of increases in the federal excise tax on gasoline, we apply the price elasticity of demand to the increases in price due to the tax increases (Box 8).[1] The implied percentage decrease in consumption is then applied to the base forecasts (Box 4) and emissions and concentrations are estimated using the methods described above. The price elasticity is disaggregated into components specific to time of day, location, number of trips and trip length (Box 7). Table S-2 summarizes these elasticities. Table S-3 summarizes the main results of the analysis of policies affecting gasoline price or availability.

---

[1]The price elasticity of demand measures the percentage change in quantity demanded that will result from a one percent increase in the price.

Table S-1

Base Forecasts of Gasoline Consumption, Urban Automotive Emissions, and Total Urban Concentrations

	1975	1981	1987
Gasoline consumption[1] (billions of gallons)	104.8	131.1	160.9
Carbon monoxide emissions[2] (billions of kilograms)	30.3	8.9	4.5
Nitrogen oxides emissions[2] (billions of kilograms)	2.6	1.4	0.7
Hydrocarbon emissions[2] (billions of kilograms)	4.3	1.8	1.2
Carbon monoxide concentration, 1 hour[3] (milligrams per cubic meter)	4.9	1.9	1.1
Carbon monoxide concentration, 8 hours[3] (milligrams per cubic meter)	3.9	1.7	1.1
Nitrogen oxide concentration, annual avg.[3] (micrograms per cubic meter)	53.2	56.0	62.2
Oxidant concentration, 1 hour[3] (micrograms per cubic meter)	144.3	141.9	110.6

[1]Total highway consumption of gasoline

[2]Urban automotive emissions

[3]Urban total concentrations, 13-city average

Table S-2

NATIONAL AVERAGE ELASTICITIES OF
NUMBER OF TRIPS AND AVERAGE TRIP LENGTH
WITH RESPECT TO GASOLINE PRICE

Year	Peak	Offpeak	Total
	Number of Trips		
1975	-0.134	-0.167	-0.153
1981	-0.484	-0.604	-0.553
1987	-0.538	-0.672	-0.616
	Average Trip Length		
1975	-0.016	-0.006	-0.010
1981	-0.056	-0.023	-0.036
1987	-0.062	-0.025	-0.041
	Gasoline Consumption		
1975	-0.149	-0.173	-0.164
1981	-0.539	-0.626	-0.592
1987	-0.600	-0.697	-0.659

Table S-3

SUMMARY OF IMPACTS OF POLICIES
AFFECTING PRICE OR AVAILABILITY OF GASOLINE

Year	Policy	Total Gasoline Consumption		Urban Automotive Emissions As Percent of Base			Average Urban Concentrations (Including Emissions from Background Sources) As Percent of Base			
		Billion Gallons	Pct of Base	Carbon Monoxide	Hydro-Carbons	Nitrogen Oxides	Carbon Monoxide 1-Hour	Carbon Monoxide 8-Hour	Nitrogen Oxides Annual Avg.	Oxidants 1-Hour
1975	$0.10/gal	101.69	97.0	97.1	97.1	97.0	97.7	97.6	99.1	93.7
	$0.25/gal	97.01	92.6	92.3	92.7	92.6	94.2	94.0	97.8	88.2
	$0.50/gal	89.19	85.1	85.4	85.5	85.2	88.4	88.1	95.7	90.6
	Rationing	65.17	62.2	63.0	63.1	62.5	70.6	69.8	89.0	75.3
1981	$0.10/gal	117.09	89.4	89.7	89.7	89.4	93.8	94.4	98.4	83.0
	$0.25/gal	96.18	73.4	74.3	73.3	73.5	84.4	85.9	96.0	69.0
	$0.50/gal	61.29	46.8	48.6	48.2	47.1	68.8	71.6	92.0	68.1
	Rationing	76.62	58.5	59.9	59.6	58.7	75.6	77.9	93.8	73.0
1987	$0.10/gal	141.72	88.1	88.9	88.4	88.0	95.1	96.0	99.1	87.5
	$0.25/gal	113.24	70.4	72.1	71.0	70.1	87.7	89.9	97.7	75.0
	$0.50/gal	65.03	40.4	44.3	42.1	40.2	75.4	79.8	95.4	74.2
	Rationing	89.92	55.9	58.8	57.1	55.8	81.8	85.0	96.6	81.7

Excise Tax on New Cars Based on Fuel Consumption and Restrictions on Fuel Consumption of New Cars

Analysis of these policies requires a number of different parameter estimates and assumptions, including:

- The relationship of fuel economy (miles per gallon) to vehicle weight and horsepower (Box 12);
- The implicit price elasticity of demand for weight and horsepower (Box 12);
- The elasticity of new car sales with respect to new car prices (Box 12);
- The elasticity of used car scrappage with respect to new car sales and used car prices (Box 15);
- The relationship of used car prices to new car prices (Box 15); and
- The costs of meeting the requirements of sales-weighted average fuel economy (Box 14).

These pieces of information are sufficient to determine:

- Average fuel economy of new cars (Box 13);
- New car sales (Box 13); and
- Scrappage of used cars, by age class (Box 17).

In turn, this information can be used to determine:

- The age distribution and size of the fleet (Box 16);
- Average fuel economy of the fleet (Box 16);
- Average emission factors for the fleet (Box 18);
- Gasoline consumption (Boxes 2-4); and
- Emissions (Boxes 5-6).

Table S-4 shows the key parameter estimates and assumptions. Table S-5 summarizes the results of the analysis of these policies.

Table S-4

SUMMARY OF COEFFICIENTS AND ELASTICITY ESTIMATES
USED IN ANALYZING EXCISE TAXES ON FUEL ECONOMY

Stage of Analysis	Coefficient or Elasticity
Linear dependence of fuel economy (in miles per gallon) on vehicle weight and horsepower	
Weight (in hundreds of pounds)	-.270
Horsepower (in BHP)	-.0102
Elasticity of demand for weight with respect to the implicit price of wght.	
First year	-.0105
Second year	-.0211
Third year	-.0264
Elasticity of demand for horsepower with respect to the implicit price of horsepower	
First year	-.088
Second year	-.177
Third year	-.221
Elasticity of demand for new cars with respect to new car price	-1.0
Change in scrappage in response to tax on new cars	
Elasticity with respect to new car sales	.742
Elasticity with respect to used car sales	-.912
Elasticity of used car price index with respect to new car price index	
1975	.213
1976	.381
1977	.513
1978	.616
1979	.698
1980	.763
1981	.813
1982	.853
1983	.884
1984	.909
1985	.928
1986	.944
1987	.956
Assumed price increase, 17.5 mpg restriction	$ 365
Assumed price increase, 20.0 mpg restriction	$ 724
Assumed price increase, 22.5 mpg restriction	$1001

Table S-5

SUMMARY OF IMPACTS OF POLICIES
AFFECTING GASOLINE CONSUMPTION OF NEW AUTOS

Year	Policy	Total Gasoline Consumption		Urban Automotive Emissions As Percent of Base			Average Urban Concentrations (Including Emissions from Background Sources) As Percent of Base			
		Billion Gallons	Pct of Base	Carbon Monoxide	Hydro-Carbons	Nitrogen Oxides	Carbon Monoxide 1-Hour	Carbon Monoxide 8-Hour	Nitrogen Oxides Annual Avg.	Oxidants 1-Hour
1975	$50/MPG	104.76	100.0	101.3	101.2	101.0	98.4	96.1	99.5	102.3
	$100/MPG	104.76	100.0	101.6	101.4	101.0	98.7	96.3	99.5	102.4
	$200/MPG	104.55	99.8	102.4	101.8	101.1	99.4	96.9	99.5	102.8
	17.5 SWMPG	104.41	99.7	101.7	101.7	101.1	98.8	96.3	99.5	102.8
	20.0 SWMPG	101.71	97.1	100.9	100.4	99.8	98.1	95.8	99.2	101.6
	22.5 SWMPG	98.85	94.3	99.6	98.8	98.0	97.0	94.8	98.7	100.1
1981	$50/MPG	129.55	99.1	135.2	109.8	100.2	119.9	113.9	99.6	63.5
	$100/MPG	127.46	97.5	138.2	110.3	101.0	122.0	115.6	99.7	63.7
	$200/MPG	124.14	94.9	147.6	113.1	103.8	128.3	120.8	100.1	64.7
	17.5 SWMPG	125.46	96.0	141.6	120.4	103.4	124.2	117.4	100.1	63.6
	20.0 SWMPG	110.40	84.4	145.1	113.7	103.1	127.0	119.8	100.1	65.3
	22.5 SWMPG	97.79	74.8	147.8	111.0	101.8	129.3	121.7	99.9	64.2
1987	$50/MPG	155.91	97.3	99.2	108.7	105.2	96.3	93.4	100.3	85.4
	$100/MPG	152.25	95.0	97.5	106.8	103.7	95.5	92.8	100.2	84.6
	$200/MPG	146.32	91.3	94.7	104.4	102.0	94.2	92.0	100.1	83.7
	17.5 SWMPG	151.13	94.3	102.7	121.1	109.3	97.9	94.5	100.6	83.1
	20.0 SWMPG	124.75	77.8	96.2	107.2	103.1	95.2	92.7	100.2	84.8
	22.5 SWMPG	102.31	63.8	87.2	96.8	94.7	91.3	90.1	99.6	81.2

Cautionary Remarks

This summary and the accompanying tables reflect the main thrust and conclusions of *The Effects of Automotive Fuel Conservation Measures on Automotive Air Pollution.* For the sake of brevity, we have not set forth in detail underlying methods and assumptions, which are discussed in the full report. The estimates shown in the various tables represent our best estimates. Because of unavoidable uncertainties surrounding parameter estimates and assumptions, we also analyzed the sensitivity of our conclusions to various parameters and assumptions. The resulting forecasts are shown in the full report. Although specific estimates of gasoline consumption, emissions, and concentrations differ for different parameters and assumptions, the conclusions as outlined here are not substantially affected.

There are two broad classes of uncertainties that might affect these conclusions. First, the parameter estimates are, in almost all cases, based on observed ranges of variation in independent variables that do not include all of the values implied by the policies. For example, a $0.50 gallon increase in the excise tax roughly doubles the price of gasoline at the pump. Because the price has never doubled in a short period, our estimates of consumer response to such an event extrapolate their responses to much more modest changes.

Second, the course of technological change is unpredictable. New technologies providing both better fuel economy and lower emissions *might* be achievable at a very low cost, merely waiting to be discovered. If such

technologies exist and are rapidly implemented, the policies affecting the stock of cars will have little impact on air quality.

1. INTRODUCTION

Recent concern over fuel prices and supplies has prompted consideration of a number of policies designed to reduce gasoline consumption. These policies, through their impact on auto travel and on the size and age distribution of the auto fleet, will have important, if unintended, effects on automotive pollutant emissions and air quality. The first section of this chapter discusses this background more fully, while the second describes the policies analyzed in this study. The last section outlines the organization of the study.

Background

In the past several years, spot shortages of gasoline and threats of shortages have been relatively common. The energy crisis of 1973-1974, however, made such shortages seem even more probable, emphasizing the insecurity of our supply of Eastern Hemisphere crude oil. The Arab cutbacks in production, the embargo against the United States and the Netherlands, and the subsequent sharp increase in

the price of crude oil, coupled with the prospect of increasing U.S. dependence on imports of crude oil, have led policymakers to consider a number of alternatives to reduce energy consumption in the United States. Gasoline accounts for over 40 percent of U.S. refinery output.[1] About 90 percent of gasoline output is consumed by passenger cars and trucks in transportation uses.[2] As part of the effort to reduce our dependence on insecure supplies of foreign oil, therefore, a number of different policies have been suggested to reduce gasoline consumption.

Some of these policies are intended to reduce gasoline consumption directly, either through increases in the price of gasoline paid by consumers or through direct rationing of supplies. Others are intended to improve the fuel economy of new cars. Improved fuel economy might be induced by direct restrictions on average miles per gallon of new cars or by differential excise taxes that increase with fuel consumption per mile.

All of these policies affect not only gasoline consumption but also emissions of automotive pollutants. Changes in emissions affect air quality. Because the Environmental Protection Agency has responsibility for

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[1]Calculated from U.S. Bureau of Mines, *Mineral Industry Surveys*, "Petroleum Statements."

[2]"Transportation uses" are taken to be "highway consumption of gasoline," estimated as "highway use of motor fuel" less "highway use of special fuel." These figures were taken from Federal Highway Administration, *Highway Statistics*, Tables MF-22 and MF-24. U.S. production of gasoline was taken from U.S. Bureau of Mines, *Mineral Industry Surveys*, "Petroleum Statements."

seeing that the goals of the Clean Air Act are met, the impact of these different policies on emissions and on air quality is a matter of concern.

Moreover, the impact of these policies on air quality is not self-evident. For example, although increasing the excise tax on gasoline would lead to a decrease in gasoline consumption, it might not lead to a corresponding improvement in air quality. If carbon monoxide concentrations are worst during the hours when commuters are driving to or from work, and if commuters are very unresponsive to changes in the price of gasoline, air quality as measured by the one-hour standard might not improve at all. Worse still, if the policies aimed at increasing the fuel economy of new cars cause a sharp reduction in new car sales, with an attendant increase in the use of old cars, the greater pollution per mile from old cars might, for a few years, result in a slowdown in the emissions reductions caused by the emission standards for new cars. This study, therefore, examines how these different policies would affect fuel consumption, emissions, and ambient air quality.

The Form of the Policies Analyzed

Four kinds of policies are analyzed in this study: increases in the federal excise tax on gasoline; the imposition of coupon rationing of gasoline; restrictions on fuel consumption per mile achieved by new cars; and excise taxes on new cars based on their fuel consumption per mile. These policies are by no means the only possible policies that would affect gasoline consumption and emissions. However, they seem to be the policies which are most frequently suggested to reduce gasoline consumption.

The policies analyzed ought not to be construed as identical to any particular policy or legislation currently being considered. We have made no attempt to specify in detail the administrative workings of these policies or to tailor them to particular proposals. We make no judgment as to whether these policies are necessarily the most appropriate ones for their intended aims. Instead, the policies have been selected as reasonably representative of proposals currently being considered. We consider what *will* happen if these policies are put into effect, rather than whether they *ought* to be put into effect.

We analyze three different levels of every policy except gasoline rationing. The levels were chosen on the basis of three criteria. First, where a specific level has already been suggested or introduced into the legislative process, we analyzed that level. Second, we selected a much more severe level of each policy to see what its impact would be. Third, we also selected a level that either extended the range to include a low but significant level, or that bridged a substantial gap between the legislative proposal and the severe level. These three levels, it is hoped, provide a broad enough range to analyze, at least in a rough way, what the impact of intermediate levels of these policies would be.

Increases in the federal excise tax of $0.10 per gallon, $0.25 per gallon, and $0.50 per gallon are analyzed. A surtax of $0.10 is the one most frequently mentioned in the press, while $0.50 per gallon is a very stiff tax, roughly equal to the current price of gasoline. A tax of $0.25 per gallon has impacts in between these two extremes.

For the policy imposing gasoline rationing, we selected a level of 10 gallons per licensed driver per week. This level was the one most frequently mentioned during the energy crisis of the winter of 1973-74. Only one level of this policy was selected because, as shown in Chapter 4, coupon rationing has the same impact on gasoline consumption as an increase in the excise tax. Thus, from the standpoint of gasoline consumption, automotive emissions, and air quality, the three levels of the excise tax can be considered equivalent to coupon rationing, with the amount rationed equal to gasoline consumption after the increase in the excise tax.

The excise taxes on new cars based on fuel consumption were designed as follows. Any car achieving 20 or more miles per gallon would be subject to no additional tax. Any car achieving less than 20 miles per gallon would be subject to an excise tax in the amount of so many dollars for every mile per gallon less than 20. This policy, of course, penalizes cars that get poor gas mileage relative to those that get good gas mileage. The three levels analyzed are $50.00, $100.00, and $200.00 for every mile per gallon below 20. The high figure implies, for example, that a car achieving ten miles per gallon would pay an excise tax of $2,000. For 1975 model year cars getting 10 miles per gallon in city driving, this amount represents a percentage price increase of between 18 and 38 percent, with a sales-weighted average increase of about 22 percent.

The restrictions on new car fuel economy were structured so that each manufacturer's sales-weighted average fuel economy would have to achieve a certain minimum level,

where the weights would be the share of each model's sales in the preceding year. This policy might lead to the actual average miles per gallon (weighted by the eventual sales shares of that model year) being either more or less than the minimum set by the standard, but over time, the actual would tend to converge to the standard. The three levels of this policy analyzed are: 17.5 miles per gallon, 20 miles per gallon, and 22.5 miles per gallon. The middle estimate is the one most often discussed in connection with this policy. The low one represents a slight improvement over the actual sales-weighted average currently observed, while 22.5 miles per gallon represents a fairly stringent standard in the absence of radical engine or transmission design changes.

Organization of the Study

The rest of this report is organized as follows. In Chapter 2, we present historical trends in highway consumption of gasoline, automotive emissions, and concentrations of emissions. We also discuss the forecasts of gasoline consumption and emissions. In Chapter 3 we present the structure of the analysis and discuss methods used in both Chapter 4 and Chapter 5. In Chapter 4, we analyze increases in the excise tax on gasoline and the imposition of coupon rationing. In Chapter 5, we analyze excise taxes on new cars based on their fuel consumption and restrictions on fuel consumption of new cars. Conclusions are presented in Chapter 6. Appendices A through D contain those details on methods that were too technical for presentation in the text. Appendices E and F show how the results of Chapters 4 and 5 change when some of the assumptions and parameter estimates are altered.

2. TRENDS IN GASOLINE CONSUMPTION, EMISSIONS, AND AIR QUALITY IN THE ABSENCE OF MAJOR POLICY CHANGES

This chapter briefly reviews trends in gasoline consumption and in emissions and concentrations of carbon monoxide, nitrogen oxides, hydrocarbons, and oxidants.[1] It also discusses the projections of gasoline consumption by automobiles and emissions of these pollutants from automobiles as forecast for the base line case.[2]

These historical trends and projections place in perspective the analysis of the different gasoline consumption policies. That is, the base line forecasts provide an indication of what can be expected to happen if none of these policies (or any similar policy) is introduced. These forecasts also assume implicitly that past trends in gasoline consumption continue and that currently projected automotive emission standards take effect as scheduled.

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[1]Throughout this report, we measure air quality by concentration measures. Trends in concentration are therefore, for our purposes, equivalent to trends in air quality.

[2]The methods and technical details of these forecasts are discussed in Appendix A at the end of this study.

This chapter has two main sections. The first section discusses past trends in gasoline consumption, emissions, and concentrations of pollutants from automobiles. The second section discusses the projections of gasoline consumption, emissions, and concentrations. This section also discusses the relationship of light-duty vehicle emissions to national total urban emissions.

Historical Trends in Gasoline Consumption, Pollutant Emissions, and Air Quality

It is difficult to place in perspective both the base forecasts and results of policy changes without first examining historical trends in gasoline consumption, automotive emissions, and concentrations of pollutants. In this section, therefore, we consider trends in gasoline consumption and in emissions of carbon monoxide, nitrogen oxides, and hydrocarbons. We also look at available evidence on trends in concentrations of these pollutants and of oxidants in several cities for which data are available. Estimates of emissions and concentrations are subject to considerable uncertainty and, where more than one estimate is available, we have presented several estimates to establish broad trends. We have not attempted to estimate historical emissions and concentrations directly but have relied on

generally accepted sources. This section provides, therefore, a context for the base case forecasts and the impacts of the different policies.

Gasoline Consumption

Since World War II, gasoline consumption has grown at a remarkably steady rate. Table 2-1 shows the national highway use of gasoline from 1950 to 1973.[1] This table shows that in every year since 1950, highway consumption of gasoline has increased. The average annual growth rate over this period was about 4.6 percent. During this period, the stock of automobiles was steadily growing, while the real price of gasoline was, on the whole, falling. These factors led to this steady growth in highway gasoline consumption.

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[1]This study focuses on highway use of gasoline. Highway use of gasoline excludes agricultural and aviation uses. These quantities are relatively small. A different kind of problem is that this category includes gasoline consumed by gasoline-powered trucks, which may have different fuel use and emission characteristics from automobiles. However, the approach taken implicitly includes gasoline-powered trucks (of which the vast majority, along with automobiles, belong to the category of light-duty motor vehicles), and the emissions standards have historically been the same for all light-duty vehicles. Thus, the implicit inclusion of gasoline consumed by trucks will not seriously affect the methods or conclusions of the study.

Table 2-1

HIGHWAY USE OF GASOLINE, 1950-1973

(Billions of Gallons)

Year	Highway Consumption of Gasoline
1950	35.14
1951	37.45
1952	39.77
1953	41.82
1954	43.32
1955	46.53
1956	48.80
1957	50.23
1958	51.56
1959	54.10
1960	55.43
1961	56.61
1962	58.75
1963	61.28
1964	64.27
1965	66.97
1966	69.93
1967	72.64
1968	77.25
1969	81.79
1970	85.60
1971	89.98
1972	96.54
1973	100.64

SOURCE: Federal Highway Administration, *Highway Statistics*, various years (derived as highway use of motor fuels less highway use of special fuels).

Trends in Emissions of Pollutants

Overall trends of nationwide emissions are shown in Figure 2-1.[1] Emissions from nitrogen oxides (NO_x), hydrocarbons (HC), and carbon monoxide (CO) rose from 1940 to 1969, and, with the exception of NO_x, decreased in 1970. EPA reports that the ambient air quality for particulates and carbon monoxide has improved in some major urban areas from 1972 to the present.[2] This national summary may be somewhat misleading, since emissions and ambient air trend statistics for individual regions result from a variety of factors, including shifts in emission sources, population centers, meteorology, etc. The trends in individual communities, however, generally are poorly documented. A

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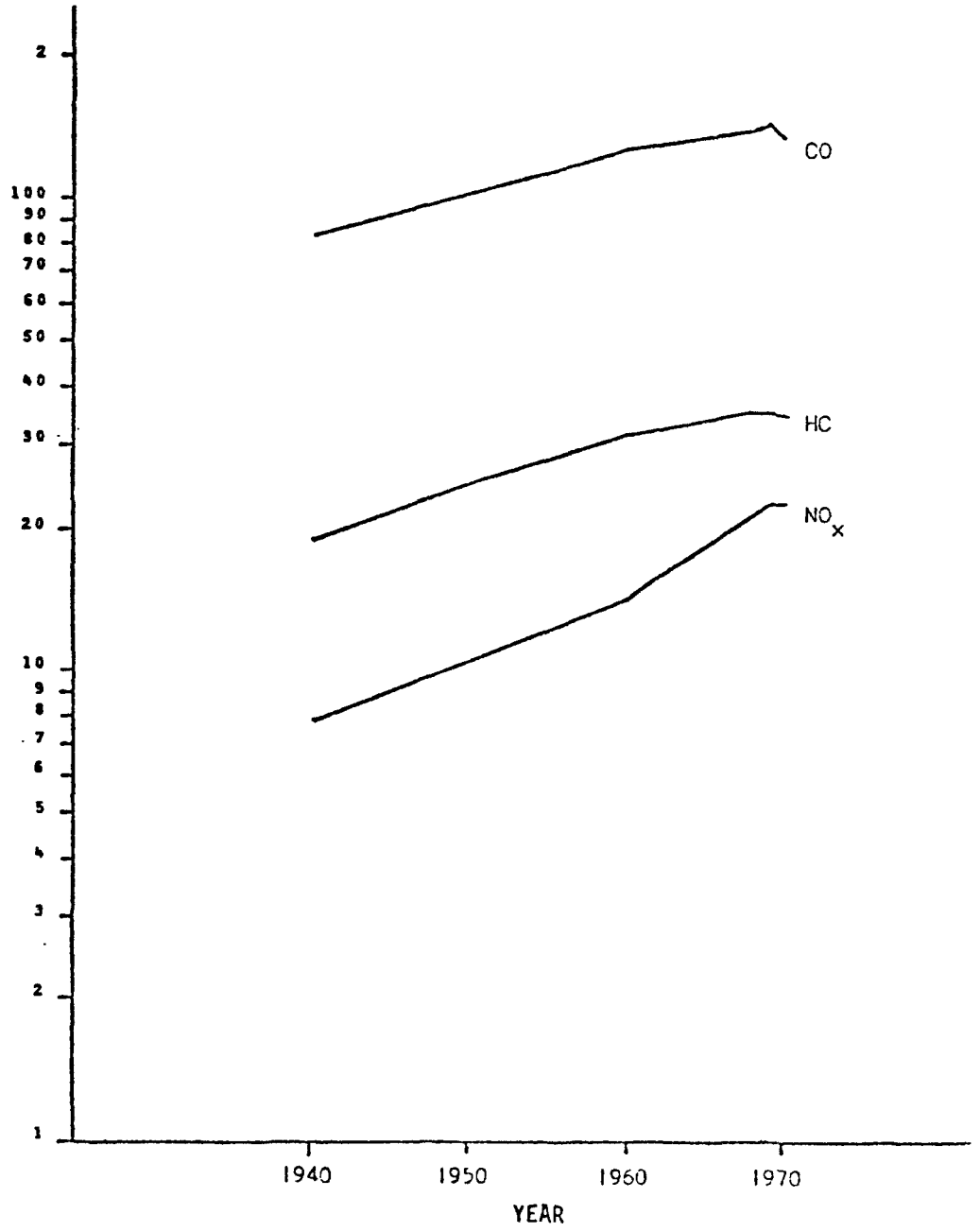
[1] In recent years, information on air quality has become more abundant with the development of a coordinated system of monitoring networks and data banks. Some of the principal sources of air quality information are ambient monitoring by the Continuous Air Monitoring Program (CAMP) system, the National Air Sampling Network (NASN), and other state and local monitoring systems, all of which are assembled by the National Aerometric Data Bank (NADB). These data have been published in a report of the National Air Monitoring Program that analyzes nationwide air quality trends for major pollutants through 1971 (*The National Air Monitoring Program: Air Quality and Emissions Trends, Annual Report,* EPA-450/1-73-001a and EPA-450/1-73-001b, Research Triangle Park, N.C., August 1973). This initial analysis of air quality data has been updated to include observations for the years 1972 and 1973 (*Monitoring and Air Quality Trends Report 1972,* EPA-450/1-73-004, December 1973 and *Monitoring and Air Quality Trends Report 1973,* EPA-450/1-74-007). Nationwide emissions estimates were published in *Nationwide Air Pollutant Emissions Trends -- 1940-1970* (EPA Publication AP-115, Research Triangle Park, N.C., January 1973). The most recent nationwide emissions estimates available are for 1972 (*The Fourth Annual Report of the Council on Environmental Quality,* Washington, D.C. 1973).

[2] *The Fifth Annual Report of the Council on Environmental Quality,* Washington, D.C., 1974.

Figure 2-1

NATIONWIDE ESTIMATES OF POLLUTANT EMISSIONS

10^6 TONS/YEAR



broad assessment of these data indicates an overall improvement in air quality where pollutant concentrations had been highest, but a degradation of air quality in areas that had previously had low pollutant concentrations. A more detailed discussion of these air quality trends for carbon monoxide, hydrocarbons, and nitrogen oxides can be found in Appendix B.

Forecasts of Gasoline Consumption and Emissions

Two sets of baseline forecasts of gasoline consumption and pollutant emissions have been calculated. (Details of these calculations can be found in Appendix A.) In view of the unpredictable variations in the price of gasoline and in the average fuel economy of new cars purchased after 1973, two sets were chosen to provide an upper and lower bound on gasoline consumption. For convenience, we refer to these forecasts as "high-price" and "low-price" scenarios, although the high-price scenario also assumes that new cars bought are quite fuel-economical, while the low-price forecast assumes that the fuel economy of new cars deteriorates along the trend line.

The forecasts have been made for three separate years, 1975, 1981, and 1987. Within each year the forecasts have been further disaggregated according to two different city sizes -- those having diameters approximately 10 kilometers across, and those having diameters closer to 35 kilometers across -- and rural.[1] In addition, the forecasts of

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[1]Urban diameters were estimated on the assumption that each Standard Metropolitan Statistical Area is circular, or that Diameter = $2\sqrt{\text{Area}/\pi}$. Examples of SMSA's in the 10 kilometer category are Portland, Maine (13.55) and Spokane, Washington (16.02). Examples of 35 kilometer cities are New York, New York (89.43), Nashville, Tennessee (33.66), Seattle, Washington (36.91), and San Francisco, California (47.39).

emissions have been further disaggregated for the two city sizes into peak and offpeak hours. These disaggregations were made with a view to the analysis of the policies in later chapters, time of day and city size being relevant factors in the determination of pollutant concentrations and air quality. In the discussion below, we largely ignore rural emissions, on the grounds that rural concentrations are generally well below critical levels. (We do consider rural emissions when comparing our base case estimates with aggregate national emissions from other sources, however.)

Forecasts of Gasoline Consumption

The base case forecasts of gasoline consumption for the three years are shown in Table 2-2. For 1975, total gasoline consumption is forecast to range between 104.8 billion gallons and 111.8 billion gallons, while by 1987 consumption is estimated to be between 160.9 and 179.2 billion gallons of gasoline. The low gasoline consumption forecasts, corresponding to high gasoline prices and high fuel economy, imply an annual average growth between 1975 and 1987 of about 3.6 percent per year.[1] The higher gasoline consumption forecasts, corresponding to low gasoline prices and low fuel economy of new cars, imply an annual average percentage growth rate of about 3.9 percent.[2] There is not a

[1]High gasoline prices were taken as those in effect as of July 16, 1974. The average price as of this date was $0.551 per gallon; deflated by the Implicit Price Deflator for Gross National Product during that quarter, the average value was $0.003293 per gallon. Details are shown in Appendix A.

[2]Low gasoline prices were assumed to be those in effect as of September 11, 1973. The average price at this date was $0.385 per gallon, or $0.002473 when divided by the Implicit Price Deflator for GNP during that quarter. Details are shown in Appendix A.

Table 2-2

BASE CASE FORECASTS

GASOLINE CONSUMPTION

(Billions of Gallons)

		1975	1981	1987	Annual Average Percentage Growth Rate, 1975-1987
High Gasoline Prices	10 KM Cities	18.08	22.65	27.86	3.6
	35 KM Cities	38.10	47.46	58.08	3.5
	Rural	48.63	60.94	74.96	3.6
	Grand Total	104.81	131.05	160.90	3.6
Low Gasoline Prices	10 KM Cities	19.29	24.87	31.01	4.0
	35 KM Cities	40.67	52.18	64.76	3.9
	Rural	51.87	66.88	83.38	4.0
	Grand Total	111.83	143.93	179.15	3.9

very large range between the high and low estimates, as, for example, the difference in 1975 is less than 7 percent of the low gasoline consumption forecast, while the difference by 1987 is only about 11 percent of the low gasoline consumption forecast. Both sets of forecasts imply a growth rate that is slightly less than the postwar historical average, but the difference is small.

Forecasts of Pollutant Emissions

Table 2-3 shows the base case forecasts of emissions of carbon monoxide, nitrogen oxides, and hydrocarbons for the three years, broken down by city size and by peak and offpeak. These forecasts, which were derived from the high-price gasoline consumption forecasts, are for urban emissions only. As can be seen from the table, the base forecast implies a substantial decrease in automotive emissions of each of these pollutants. This decrease is, of course, due to the changing emission standards for new cars, coupled with the turnover in the automobile stock over time, as new, less polluting automobiles replace the older, dirtier cars that are scrapped or retired. For each pollutant, the rate of decline within each of the categories (10 kilometer cities, 35 kilometer cities, broken down into peak and offpeak hours of the day) is substantially the same. That is, carbon monoxide emissions are forecast to decline at about 15 percent per year between 1975 and 1987 in each of the categories, while nitrogen oxides and hydrocarbons are forecast to decline at an average annual rate between 10 and 11 percent. Table 2-4 shows the corresponding forecasts of urban emissions for the scenarios with low gasoline prices (i.e., high gasoline consumption). It will be seen that the

Table 2-3

BASE CASE FORECASTS (HIGH GASOLINE PRICES)

ANNUAL NATIONAL URBAN AUTOMOTIVE EMISSIONS

(Millions of Kilograms)

Year		10 KM Cities			35 KM Cities			Urban Total
		Peak	Off-Peak	Total	Peak	Off-Peak	Total	
1975								
	CO	4403	5284	9687	9412	11250	20662	30349
	NO_x	362.8	469.8	832.6	767.7	992.8	1760.5	2593.1
	HC	586.0	766.8	1352.8	1257	1643	2900	4252.8
1981								
	CO	1335	1505	2840	2859	3206	6065	8905
	NO_x	196.6	257.6	454.3	412.9	540.7	953.6	1407.9
	HC	378.0	500.4	878.4	813.9	107.7	921.6	1800.0
1987								
	CO	730.7	702.0	1432.7	1585	1516	3101	4533.7
	NO_x	101.6	139.4	241.0	210.9	289.9	500.8	741.8
	HC	172.3	210.7	383.0	365.9	446.3	812.2	1195.2
Annual Average Percentage Growth Rates, 1975-1987								
	CO	-14.97	-16.82	-15.93	-14.85	-16.70	-15.80	-15.84
	NO_x	-10.61	-10.12	-10.33	-10.77	-10.26	-10.48	-10.43
	HC	-10.20	-10.76	-10.52	-10.28	-10.86	-10.61	-10.58

Table 2-4

BASE CASE FORECASTS (LOW GASOLINE PRICES)

ANNUAL NATIONAL URBAN AUTOMOTIVE EMISSIONS

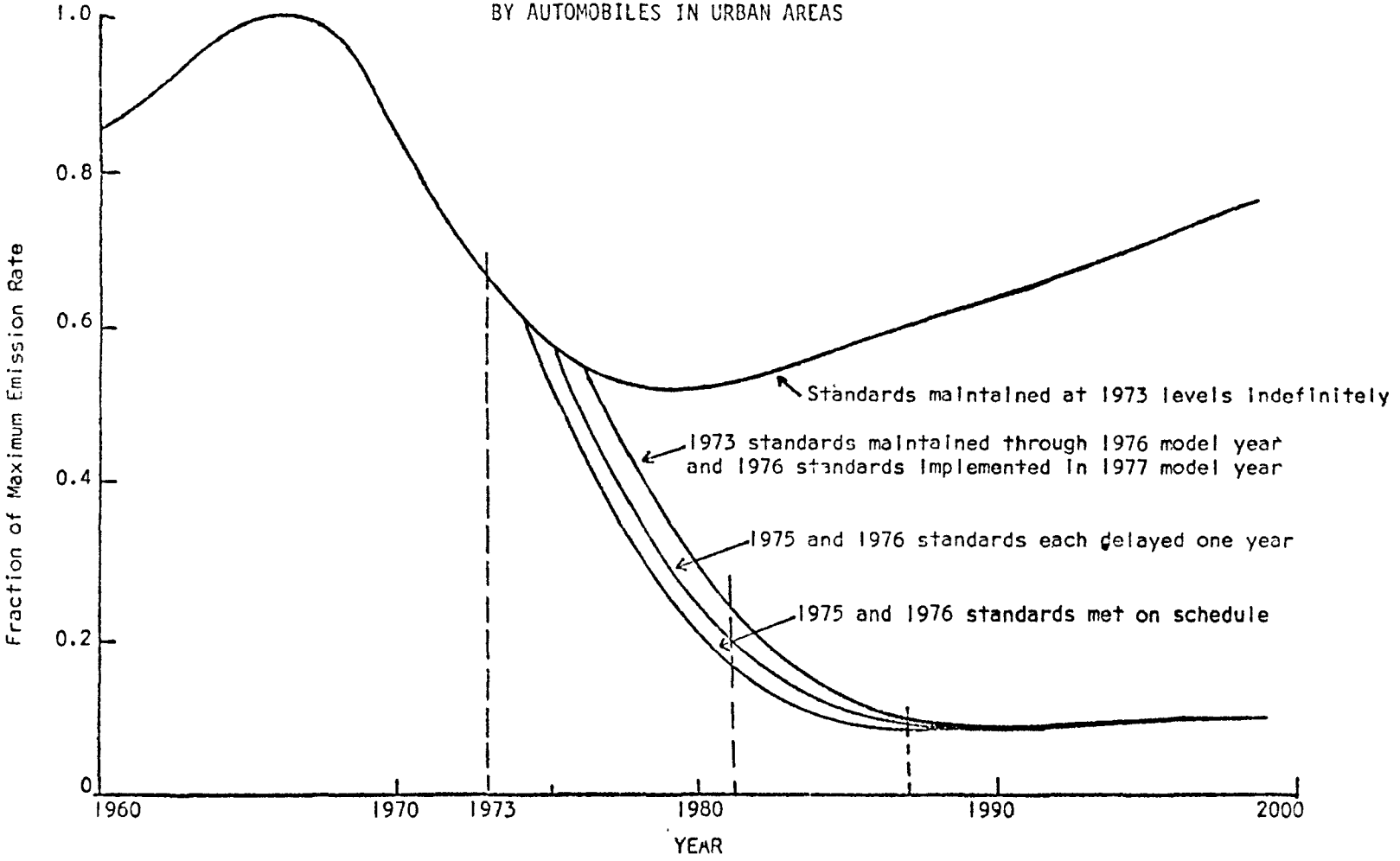
(Millions of Kilograms)

Year		10 KM Cities			35 KM Cities			Urban Total
		Peak	Off-Peak	Total	Peak	Off-Peak	Total	
1975								
	CO	4553	5464	10017	9737	11640	21377	31394
	NO_x	375.2	485.8	861	794.2	1027	1821.2	2682.2
	HC	606	792.9	1398.9	1300	1700	3000	4398.9
1981								
	CO	1357	1530	2887	2910	3263	6173	9060
	NO_x	199.9	261.9	461.8	420.3	550.3	970.6	1432.4
	HC	384.3	508.8	893.1	828.3	1096	1924.3	2817.4
1987								
	CO	732.8	704	1436.8	1592	1522	3114	4550.8
	NO_x	101.9	139.8	241.7	211.9	291.2	503.1	744.8
	HC	172.8	211.3	384.1	367.5	448.3	815.8	1199.9
Annual Average Percentage Growth Rates, 1975-1987								
	CO	-15.22	-17.08	-16.18	-15.09	-16.95	-16.05	-16.09
	NO_x	-10.86	-10.38	-10.59	-11.01	-10.50	-10.72	-10.68
	HC	-10.46	-11.02	-10.77	-10.53	-11.11	-10.85	-10.83

estimates of emissions are quite close, and, although the higher gasoline consumption implies a higher level of emissions, the forecasted rate of decline is virtually the same for the high and the low forecasts of emissions.

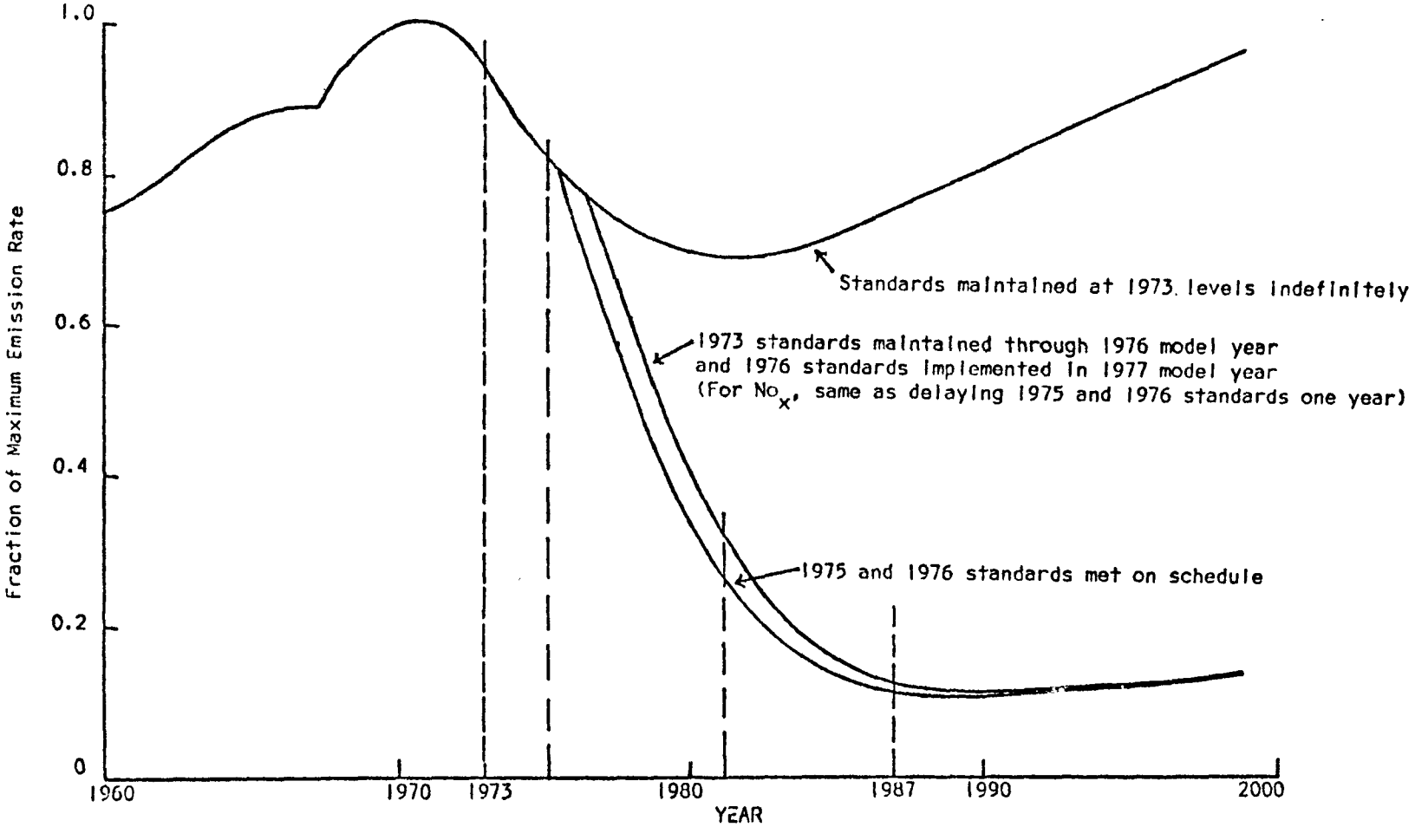
Although these base case forecasts are intended to be just that -- a reference point for the later analysis of policies -- it is interesting to see how closely these forecasts compare with other estimates of national emissions of these pollutants from automobiles. We made two kinds of comparisons. Figures 2-2 , 2-3 , and 2-4 show projections made by the National Academy of Sciences of emissions of carbon monoxide, nitrogen oxide, and hydrocarbons respectively in urban areas. For purposes of comparison, we used the curve that assumed 1973 standards were maintained through the 1976 model year and 1976 standards implemented in the 1977 model year. This curve is most appropriate to the carbon monoxide and hydrocarbon forecasts, but presumably it understates somewhat the forecast of nitrogen oxides (as these standards have been delayed until 1978). Table 2-5 compares the fraction of emissions of each of these pollutants in 1981 and 1987 as compared with their 1975 levels, both for the National Academy of Sciences projections and for our base line projections using high gasoline prices. This table shows that, in general, the two sets of forecasts are quite close, although the base line 1981 forecast for carbon monoxide is below that forecasted by the National Academy. We have not investigated in detail this discrepancy, but, given the difference in methods, it might have arisen from a number of different sources, including forecasts of the age distribution of the auto stock, forecasts of vehicle miles of travel, and the treatment of cold-start emissions.

Figure 2-2
EMISSIONS OF CARBON MONOXIDE
BY AUTOMOBILES IN URBAN AREAS



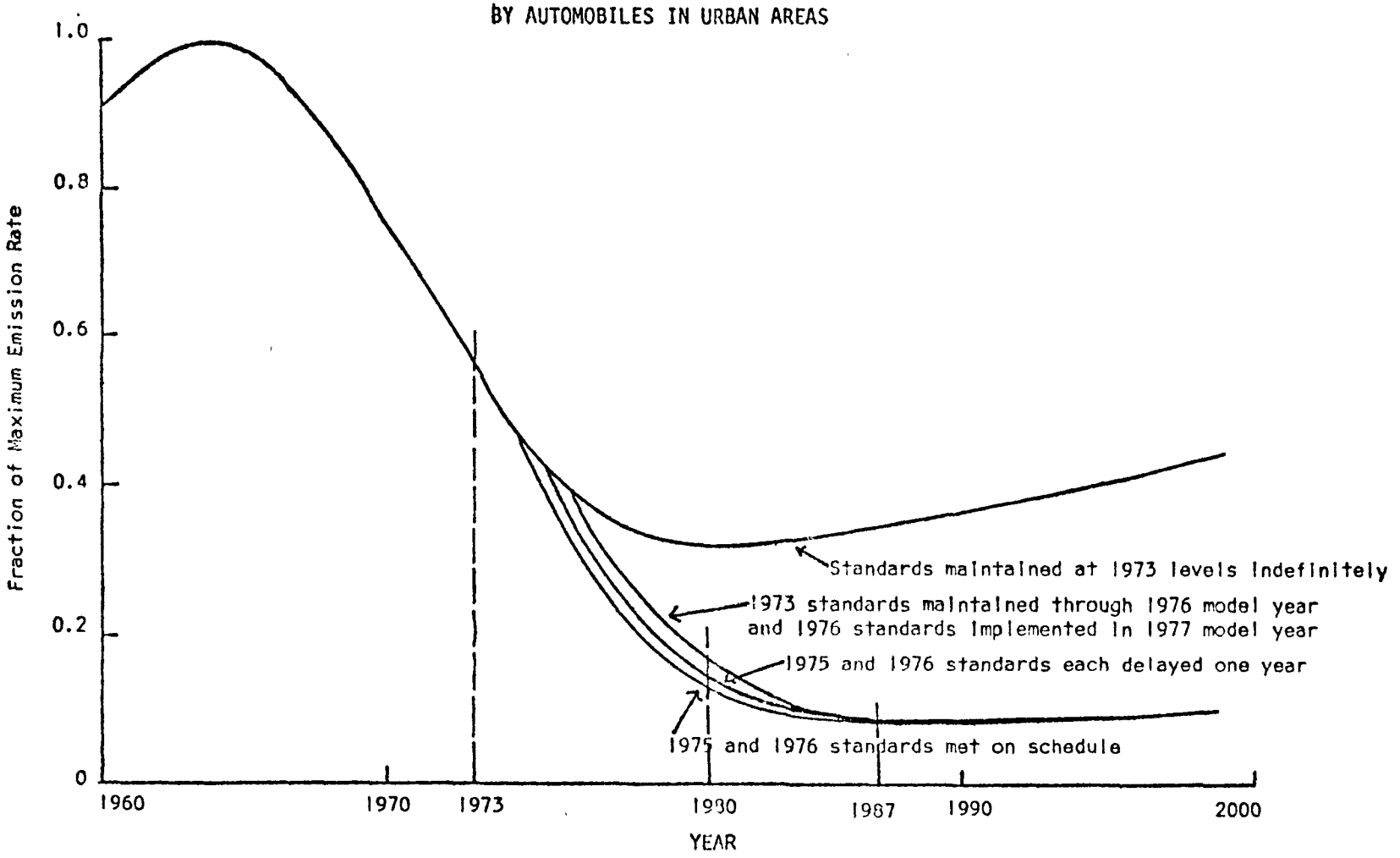
Source: National Academy of Sciences, *Report by the Committee on Motor Vehicle Emissions*, February 1973

Figure 2-3
EMISSIONS OF OXIDES OF NITROGEN
BY AUTOMOBILES IN URBAN AREAS



Source: National Academy of Sciences, *Report by the Committee on Motor Vehicle Emissions*, February 1973

Figure 2-4
EMISSIONS OF HYDROCARBONS
BY AUTOMOBILES IN URBAN AREAS



Source: National Academy of Sciences, *Report by the Committee on Motor Vehicle Emissions*, February 1973.

Table 2-5

EMISSIONS AS FRACTIONS OF 1975 EMISSIONS

		National Academy Of Sciences[1]	Baseline Forecast (High Gasoline Prices)
CO	1975	1.0	1.0
	1981	0.42	0.23
	1987	0.15	0.12
NO_x	1975	1.0	1.0
	1981	0.38	0.54
	1987	0.16	0.29
HC	1975	1.0	1.0
	1981	0.38	0.42
	1987	0.18	0.28

[1]National Academy of Sciences, *Report by the Committee on Motor Vehicle Emissions*, February 1973.

There is also the discrepancy in nitrogen oxides, which comes about because of the delay in imposing standards, reflected in our forecast but not in the National Academy forecast.

The base case forecasts were also checked by backcasting them. That is, using the proportions shown in the National Academy of Science's forecast, we backcast 1975 forecasts of emissions to 1972, so that they could be readily compared with the 1972 emissions estimates from the National Emissions Data System shown in Appendix B, Table B-8. Table 2-6 compares those figures and the base case figures, backcast to 1972. These figures show that, except for carbon monoxide (for which the base case overstates the NEDS figures), the figures agree quite closely. These two comparisons, rough as they are, indicate that the base case forecasts of emissions of the different pollutants seem to be quite close to the actual data and to other forecasts. Thus, even though we are primarily interested in the percentage changes in emissions that will result from the different policies, it is reassuring to note that the actual levels forecast appear to be quite close to those levels forecast by others.

These forecasts are, of course, subject to considerable uncertainty. This uncertainty derives from three main sources First, the equation used to forecast gasoline demand does not fit the historical observations perfectly. Second, the coefficients of that equation are also subject to sampling error. Third, the forecasts of the independent variables are themselves subject to error. Nevertheless, the forecasts shown above agree reasonably closely with the values for 1973, the only year for which data have since become available.

Table 2-6

BASECASE EMISSIONS BACKCAST TO 1972

AND COMPARED WITH NEDS ESTIMATES

(Millions of Tons)

	NEDS	Base Case 1972[2]	
	1972[1]	High Price	Low Price
CO	59.53	67.10	69.38
NO_x	5.16	5.65	5.86
HC	10.98	9.86	11.65

[1]Total emissions by gasoline land vehicles. For source, see Table B-8 in Appendix B.

[2]Base case forecasts for 1975 -- including *rural*, 10 KM and 35 KM city emissions -- converted from kilograms to tons and backcast to 1972, using the proportions of 1972 to 1975 emissions of each pollutant from National Academy of Sciences, *Report by the Committee on Motor Vehicle Emissions.*

We have not, however, provided confidence intervals for the forecasts of gasoline consumption and emissions. We have tried to make these forecasts as precise as possible in order to present an accurate estimate of total automotive emissions in each of these years. Because, however, of various difficulties in attempting to measure the total quantity of automotive emissions, we have focused our attention instead on the percentage changes in gasoline consumption, emissions, and concentrations of emissions. For this purpose, the actual level of the base forecasts is not critical. That is, the percentage change in emissions will not depend on the level of the base forecast. In this sense, therefore, the forecasts provide a convenient reference point and, to some extent, a validation of the methods used, but the analysis of policy does not depend in any important way on the precise forecasted levels.

Forecasts of Pollutant Concentrations

Table 2-7 shows the base forecasts of concentrations of carbon monoxide, nitrogen oxides, and oxidants, on the assumption that gasoline prices remain high. These figures include the contribution of sources other than light-duty vehicles. As can be seen from this table, the light-duty vehicle contribution to all three pollutants declines sharply between 1975 and 1987. Concentrations of carbon monoxide and oxidants are expected to decline as well, but concentrations of nitrogen oxides are forecast to increase slowly over this period.

Table 2-7

BASE FORECASTS OF POLLUTANT CONCENTRATIONS, 13-CITY AVERAGES,[1]
1975, 1981, 1987

	1975		1981		1987	
	LDV	Total	LDV	Total	LDV	Total
CO: 1 HOUR[2]	4.4	4.9	1.3	1.9	0.6	1.1
CO: 8 HOUR[3]	3.3	3.9	0.9	1.7	0.4	1.1
NO_x: Annual Average[4]	15.8	53.2	8.6	56.0	4.9	62.6
OXIDANT: 1 HOUR[5]	64.9	144.3	60.6	141.9	6.1	110.6

[1]The 13 cities are: Portland, ME; New York, NY; Nashville, TN; Pittsburgh, PA; Little Rock, AR; Oklahoma City, OK; Tampa, FL; Miami, FL; Spokane, WA; Denver, CO; Seattle, WA; San Francisco, CA; and Los Angeles, CA.

[2]Carbon monoxide, 1 hour concentrations, milligrams per cubic meter.

[3]Carbon monoxide, 8 hour concentrations, milligrams per cubic meter.

[4]Nitrogen oxides, annual average concentrations, micrograms per cubic meter.

[5]Oxidants, 1 hour concentrations, micrograms per cubic meter.

The Relationship of Light-Duty Vehicles to National Total Urban Emissions

In addition to light-duty vehicles, other sources contribute to the total pollutant burden. These other emission sources arise from such activities as fuel combustion for heat and power, losses from manufacturing process operations, solid waste disposal, and other miscellaneous sources. Contaminant emissions also arise from other transportation sources, such as heavy-duty vehicles, aircraft, ships, trains, etc. Therefore, the analysis of changes in ambient air quality from the changes in light-duty vehicle source emissions must be considered both separately and in the context of total emissions for the pollutants of interest.

An indication of the relative contribution from light-duty vehicles and from other sources is given in Table 2-8. These data show that on a national scale, light-duty vehicles contribute 77 percent of the carbon monoxide emissions, 55 percent of hydrocarbon emissions, but only 35 percent of nitrogen oxide emissions.[1] Consequently, non-LDV emissions constitute a major component of the total contaminant load. It should be noted that non-urban sources of emissions, such as forest fires, slash burning, etc., have not been included in Table 2-8.

For the current analysis, estimates of emissions from all other sources were constructed to correspond in time to the projected emissions from light-duty vehicles. The basic procedure used to develop these projections is derived

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[1] *Nationwide Air Pollutant Emission Trends 1940-1970*, U.S. EPA Publication AP-115, January 1973.

TABLE 2-8

SUMMARY OF ESTIMATED NATIONWIDE
URBAN AREA EMISSIONS FOR 1970

Source	Carbon Monoxide (10^6 tons/year)	Hydrocarbons (10^6 tons/year)	Nitrogen Oxides (10^6 tons/year)
Light-Duty Vehicle (LDV)	95.8	16.6	7.8
Other Sources*	28.3	13.4	14.2
TOTAL (TOT)	124.1	30.0	22.0
(LDV/TOT)	0.77	0.55	0.35

* Other sources include non-light-duty vehicle emissions and stationary sources.

from the methodology developed by EPA for Air Quality Maintenance Planning and Analysis.[1] This procedure applies growth factors (which account for economic and population growth) and emission reduction factors (which account for control brought about by the Clean Air Act and State regulations) to predict 1975 and future emissions. Projections derived by the Bureau of Economic Analysis are used as the indicators of growth in population and earnings for the nation.[2]

Emissions from light-duty vehicles were projected from the 1970 base year by a separate two-step procedure. For the period 1970-1975, normalized projections given in the Federal Register were applied to the 1970 LDV value.[3] Projections for the years 1981 and 1987 were taken from Table 2-3.

The different factors used in the preparation of these projections and the results from this application are summarized in Tables 2-9 through 2-11. These data also are graphed in Figures 2-5 through 2-7 to show the character of temporal trends. These data show a continued nationwide decline in both LDV and total urban area carbon monoxide emissions. Nitrogen oxide emissions indicate a continued rise in total emissions, although the LDV component is pro-

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[1] *Guidelines for Air Quality Maintenance Planning and Analysis, Vol. 1: Designation of Air Quality Maintenance Areas*, U.S. EPA-450/4-74-001, September 1974.

[2] 1972 OBERS Projections, *Regional Economic Activity in the U.S.*, Series E Population, *Vol. 5: Standard Metropolitan Statistical Areas*, U.S. Government Printing Office, Stock No. 5245-00017, April 1974.

[3] *Federal Register*, Vol. 36, No. 158, p. 15,550, August 14, 1971.

TABLE 2-9

NATIONAL URBAN AREA CARBON MONOXIDE EMISSION PROJECTIONS

Source Class	1970 Emissions*	Reduction Factor	Growth Factor	1975 Emissions*	Reduction Factor	Growth Factor	1981 Emissions*	Reduction Factor	Growth Factor	1987 Emissions*
Fuel Combustion										
Point Sources	0.235	1.0	1.245	0.293	1.0	0.296	0.380	1.0	0.523	0.446
Area Sources	0.555	1.0	1.245	0.691	1.0	0.296	0.896	1.0	0.523	1.052
Industrial Processes	11.40	0.10	1.253	1.428	0.70	0.243	1.671	0.40	0.506	1.717
Solid Waste Disposal										
Point Sources	0.350	0.53	1.048	0.194	1.0	0.056	0.205	1.0	0.119	0.217
Area Sources	0.450	0.88	1.048	0.415	1.0	0.056	0.438	1.0	0.119	0.464
Transportation										
LDV	95.80			70.96			19.63			10.00
HDV	0.800	0.9	1.048	0.805	0.98	0.056	0.849	0.97	0.119	0.898
Other	14.30	1.0	1.048	14.99	1.0	0.056	15.83	1.0	0.119	16.77
Miscellaneous										
Point Sources	—	—	—	—	—	—	—	—	—	—
Area Sources	0.220	1.0	1.245	0.274	1.0	0.296	0.355	1.0	0.523	0.417
TOTAL	124.1			90.0			40.3			32.0

* (10^6 tons/year).

TABLE 2-10

NATIONAL URBAN AREA NO_x EMISSION PROJECTIONS

Source Class	1970 Emissions*	Reduction Factor	Growth Factor	1975 Emissions*	Reduction Factor	Growth Factor	1981 Emissions*	Reduction Factor	Growth Factor	1987 Emissions*
Fuel Combustion										
Point Sources	9.24	1.0	1.245	11.504	1.0	0.296	14.909	1.0	0.523	17.521
Area Sources	0.790	1.0	1.245	0.984	1.0	0.296	1.275	1.0	0.523	1.499
Industrial Processes	0.199	1.0	1.253	0.249	0.70	0.243	0.291	0.40	0.506	0.299
Solid Waste Disposal										
Point Sources	0.020	1.0	1.048	0.021	1.0	0.056	0.022	1.0	0.119	0.023
Area Sources	0.045	1.0	1.048	0.047	1.0	0.056	0.049	1.0	0.119	0.053
Transportation										
LDV	7.80	—	—	7.16	—	—	3.10	—	—	1.64
HDV	1.30	1.0	1.048	1.362	1.0	0.056	1.438	1.0	0.119	1.524
Other	2.588	1.0	1.048	2.712	1.0	0.056	2.864	1.0	0.119	3.035
Miscellaneous										
Point Sources	—	—	—	—	—	—	—	—	—	—
Area Sources	0.007	1.0	1.245	0.009	1.0	0.296	0.012	1.0	0.523	0.014
TOTAL	21.99			24.05			23.96			25.61

* (10^6 tons/year)

TABLE 2-11

NATIONAL URBAN AREA HYDROCARBON EMISSION PROJECTIONS

Source Class	1970 Emissions*	Reduction Factor	Growth Factor	1975 Emissions*	Reduction Factor	Growth Factor	1981 Emissions*	Reduction Factor	Growth Factor	1987 Emissions*
Fuel Combustion										
Point Sources	0.412	1.0	1.245	0.513	1.0	0.296	0.665	1.0	0.523	0.781
Area Sources	0.203	1.0	1.245	0.253	1.0	0.296	0.328	1.0	0.523	0.385
Industrial Processes	5.470	0.47	1.253	3.221	0.70	0.243	3.769	0.40	0.506	3.873
Solid Waste Disposal										
Point Sources	0.015	1.0	1.048	0.016	1.0	0.056	0.017	1.0	0.119	0.018
Area Sources	0.248	0.88	1.048	0.229	1.0	0.056	0.242	1.0	0.119	0.256
Transportation										
LDV	16.60	—	—	10.25	—	—	3.97	—	—	2.63
HDV	0.100	0.90	1.048	0.096	0.90	0.056	0.101	0.87	0.119	0.106
Other	2.830	1.0	1.048	2.966	1.0	0.056	3.132	1.0	0.119	3.319
Miscellaneous										
Point Sources	—	—	—	—	—	—	—	—	—	—
Area Sources	4.127	1.0	1.245	5.138	1.0	0.296	6.659	1.0	0.523	7.825
TOTAL	30.00			22.68			18.87			19.19

* (10^6 tons/year)

Figure 2-5

PROJECTED URBAN AREA ANNUAL EMISSIONS
FOR CARBON MONOXIDE

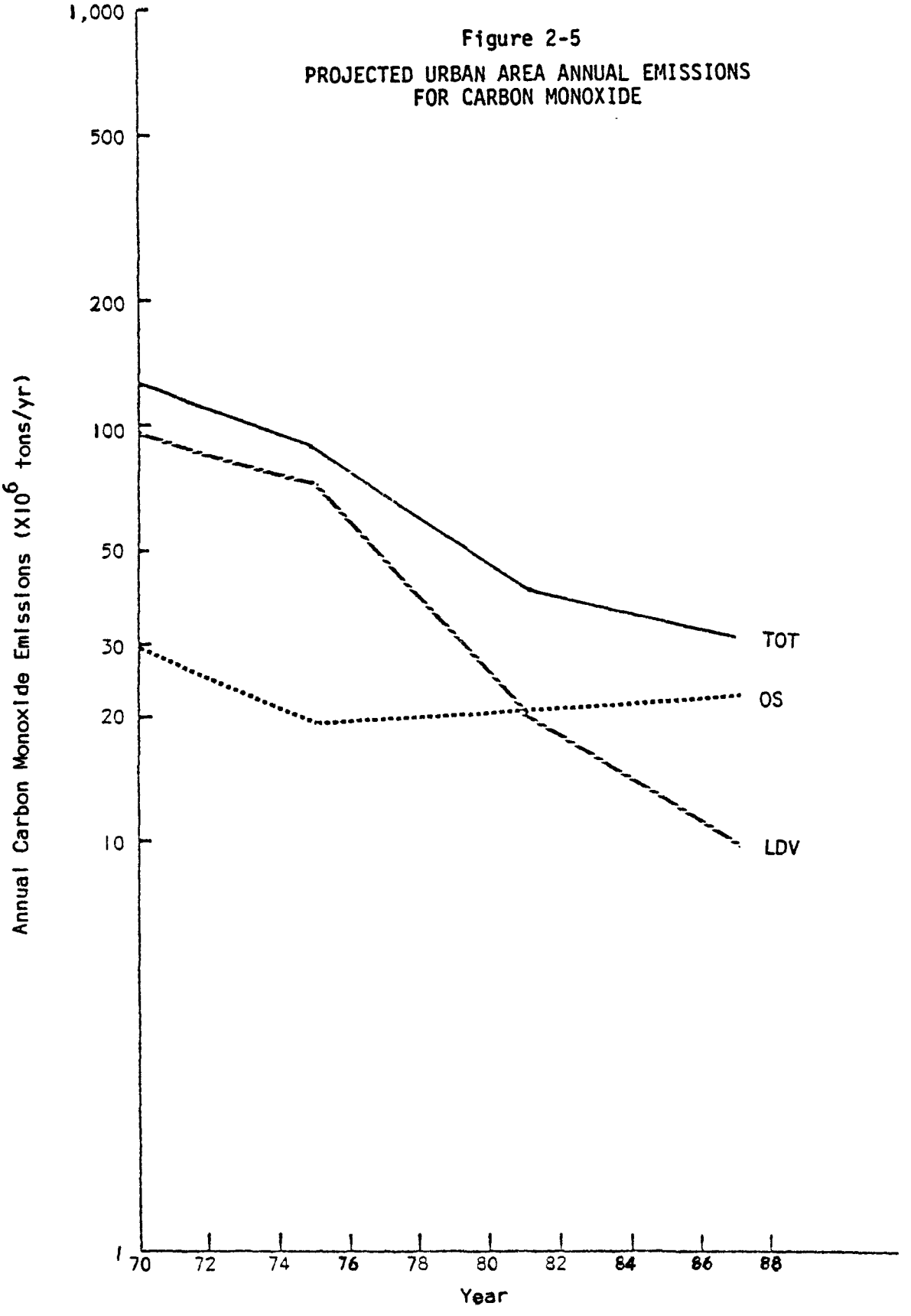


Figure 2-6

PROJECTED ANNUAL URBAN AREA NITROGEN OXIDE EMISSIONS

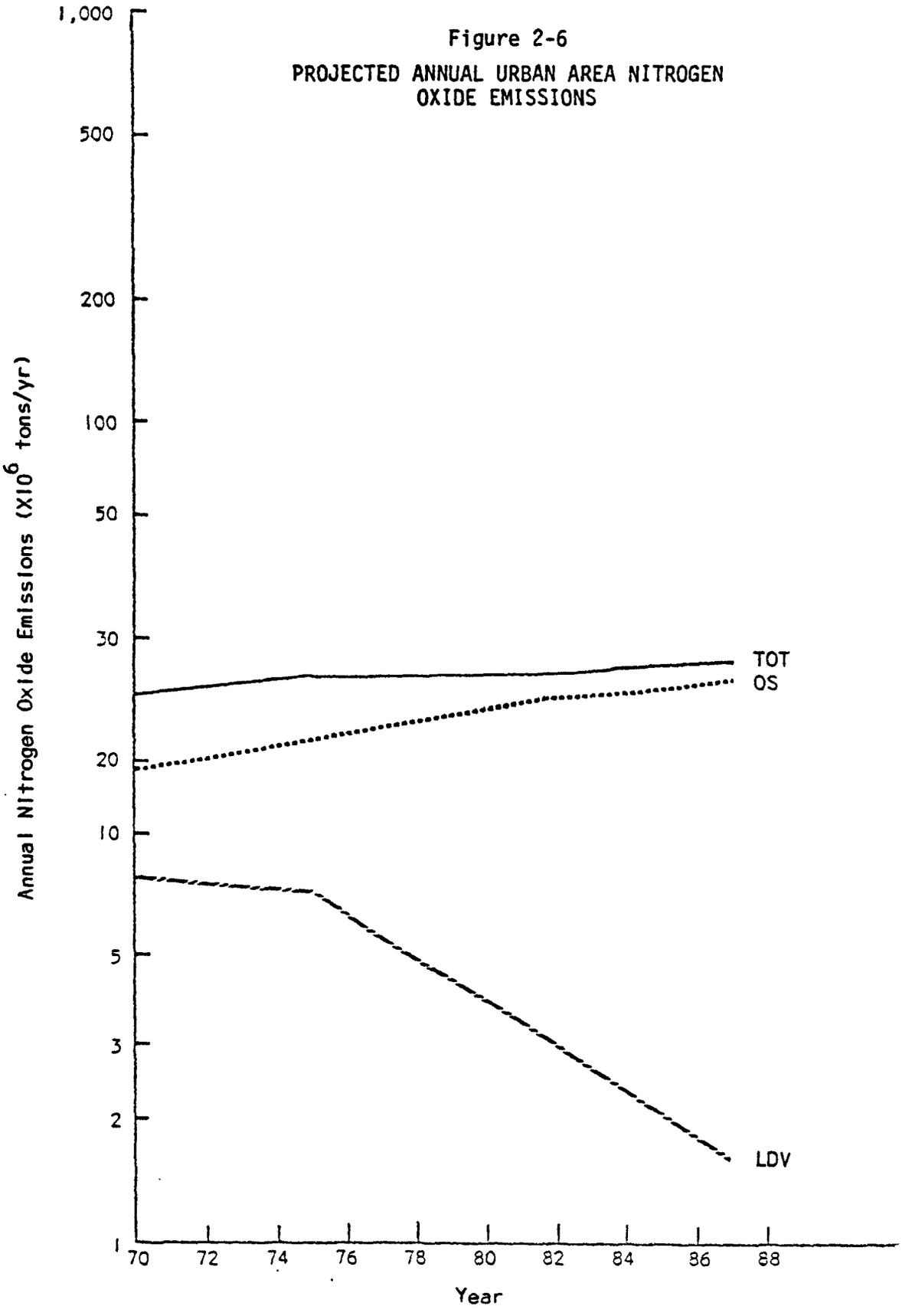
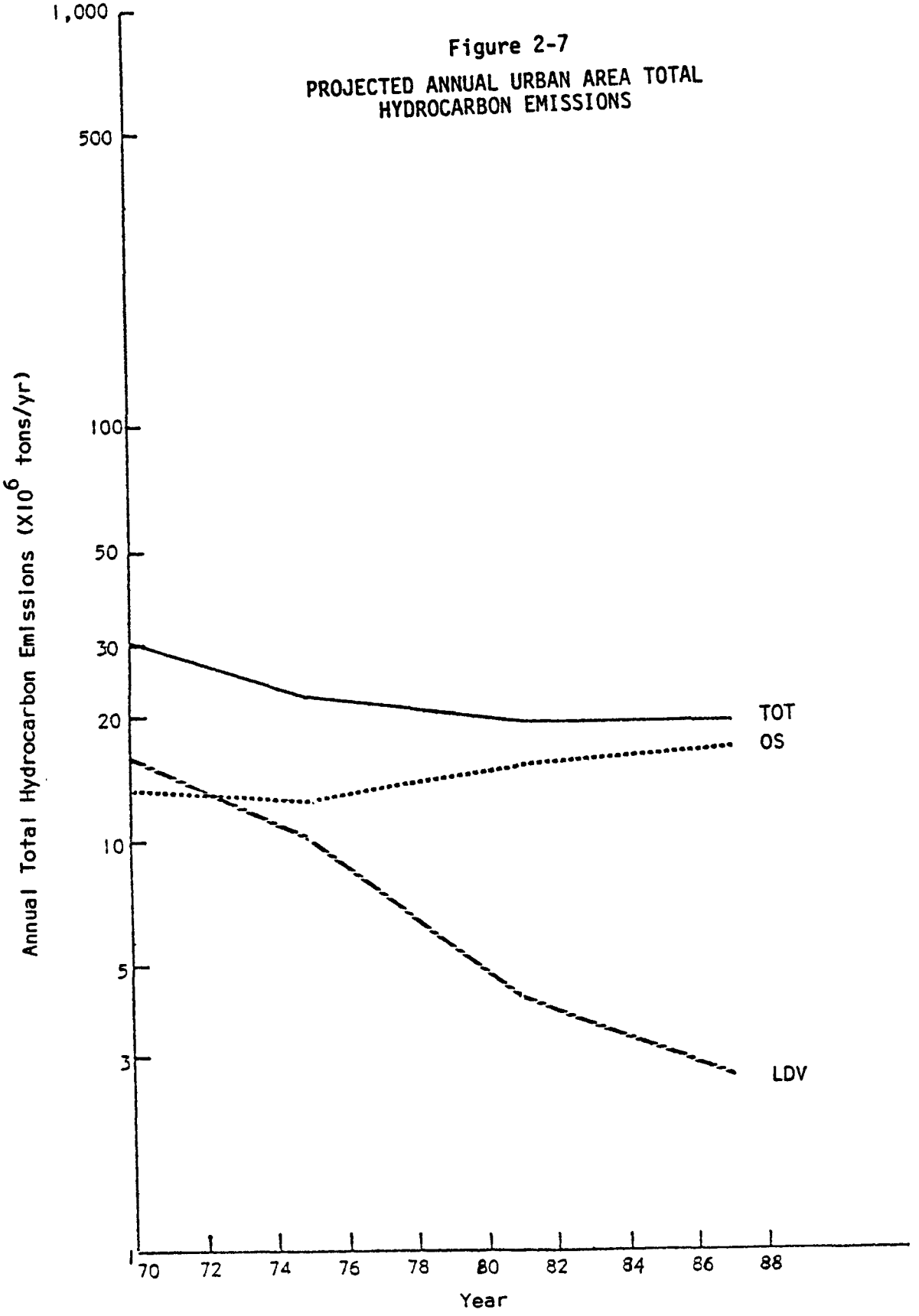


Figure 2-7

PROJECTED ANNUAL URBAN AREA TOTAL HYDROCARBON EMISSIONS



jected to decline sharply. The pattern of change in emissions of hydrocarbons is variable and more dependent on the time period of the projection.

A comparison of the projected change in the relative contribution by light-duty vehicles to total urban area pollutant emissions indicated by these data is given in Table 2-12. These data show almost uniformly that beyond 1975 the LDV component is projected to become an increasingly smaller fraction of total urban area emissions. For the purpose of the current study, the data in Table 2-12 were considered representative of a national model and subsequently applied to the analysis of individual regional areas. The details of this application are given in the following sections of this report.

TABLE 2-12

RATIO OF ESTIMATED ANNUAL LIGHT-DUTY VEHICLE EMISSIONS ($\overline{Q}_{LDV}$) TO TOTAL EMISSIONS ($\overline{Q}_{TOT}$)

Contaminant	Year 1970	1975	1981	1987
Carbon Monoxide	0.77	0.79	0.49	0.31
Nitrogen Oxides	0.35	0.30	0.13	0.06
Hydrocarbons	0.55	0.45	0.21	0.14

3. OVERVIEW OF METHODS

The analysis of the impacts of these policies on gasoline consumption, emissions,and air quality requires a large number of submodels, assumptions,and parameter estimates. Because of these many facets, in this chapter we present the structure of the analysis and some of the important parameter estimates used. Details on data, estimation techniques,and other methods can be found in Appendices A through D.

This chapter is divided into three major sections. A brief introduction is followed by a flow chart of the entire analysis. The third section discusses those aspects of the analysis that are common to both Chapters 4 and 5, while the methods specific to each chapter are discussed in the appropriate chapter.

Introduction

There are a number of issues that must be dealt with if the effects of the policies are to be thoroughly understood. These issues include, for example, how changes in

the price of gasoline affect gasoline consumption at different times of day and in rural and urban locations; how the demand for new cars, both in toto and by size class of car, is affected by differential excise taxes; and how the scrappage of old cars changes in response to higher prices for new cars.

Our approach contains three parts. First, we forecast gasoline consumption and emissions in the absence of any policy changes and on the assumption that past trends continue into the future. These are called the base case forecasts. Second, we analyze how these forecasted quantities change under the different policies of an increase in the excise tax and coupon rationing of gasoline. Third, we analyze how the base case forecasts would be altered by the policies involving an excise tax on new cars based on their fuel consumption and restrictions on the fuel consumption of new cars.

Base Case Forecasts

In forecasting base case gasoline consumption we use a demand equation for gasoline that explains total highway consumption of gasoline by state. Forecasts of the independent variables in this equation are substituted into this equation to forecast gasoline consumption in each state. This consumption is then disaggregated by time of day and by place (urban and rural, with urban consumption being broken down by two city sizes). The emissions associated with this disaggregated consumption are also forecast, and the forecasts of emissions are compared with other projections of emissions.

Gasoline Rationing and Increases in the Excise Tax

As discussed in Chapter 4, gasoline rationing is, from the primary point of view of this study, equivalent to an increase in the excise tax. To analyze the impact of increases in the Federal excise tax on gasoline, we disaggregate the overall price elasticity of demand into a number of different components. These component elasticities are specific to time of day, location, number of trips, and average trip length. These elasticities are then applied to the forecasted consumption to arrive at the change in gasoline consumption. Estimated gasoline consumption is then translated into emissions and air quality. Because some of the decrease in gasoline consumption, however, occurs because of a shift in choice of mode (that is, some auto travelers take public transportation instead of cars) we also examine the increase in fuel consumption and in emissions from other modes of travel.

Excise Tax on New Cars Based on Fuel Consumption and Restrictions on Fuel Consumption of New Cars

We may assume that, other things equal, people prefer cars that cost less to operate. Good fuel economy is, in itself, a desirable attribute of a car. The worsening of fuel economy in recent years has been due, at least in part, to a trend to heavier cars and more powerful engines. Presumably, because these heavier, more powerful cars were sold, consumers have been willing to pay the extra costs of buying and driving them. Consequently, in analyzing the impact of the tax based on fuel consumption per mile, we consider consumer preferences for weight and for horsepower to determine how the average fuel economy of new cars would

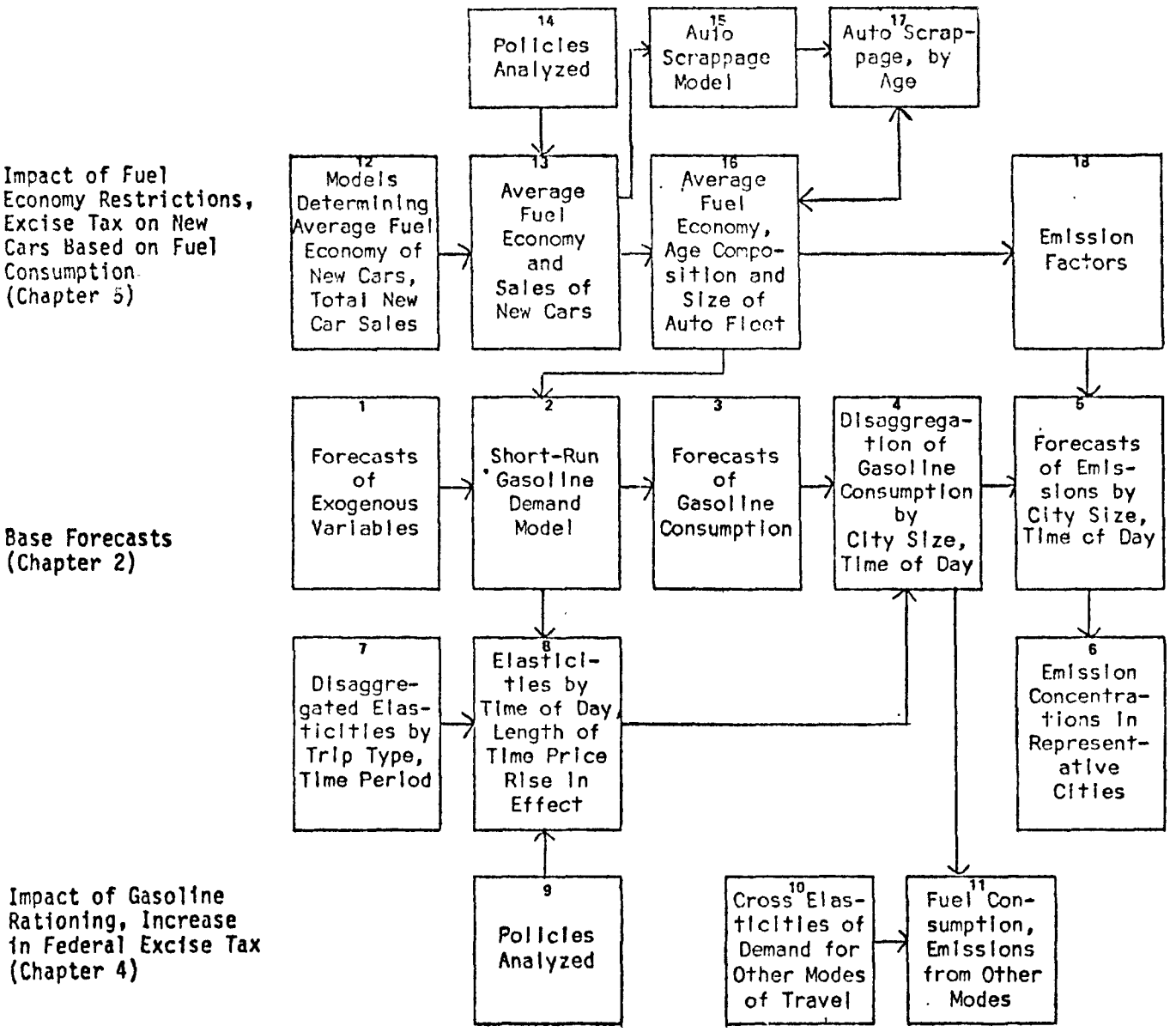
change in response to this tax. We also determine how new car sales would react to the higher prices resulting from increases in the excise tax, and how scrappage of old cars would respond to the higher prices and reduced sales of new cars.

This analysis generates new estimates of the stock of automobiles, average miles per gallon, and emission factors. These estimates are, in turn, used to calculate the change in gasoline consumption, emissions, and concentrations of pollutants under these different policies. In analyzing restrictions on new car fuel economy, average fuel economy is known, and assumptions are made about the implied increases in new car prices needed to cover the costs of improving fuel economy to meet the standard. Given the fuel economy of new cars and the average price increase, the analysis is quite similar to the analysis of excise taxes on new cars.

Structure of the Analysis

Figure 3-1 shows the different pieces of the analysis and how they relate to each other. A central unit is the short-run gasoline demand model (Box 2), which relates gasoline consumption to the number of licensed drivers, the real price of gasoline, average fuel economy of the stock of cars, the number of registered autos and gasoline-powered trucks, and a variable capturing the effects of emission controls. This model is short-run in that it estimates gasoline consumption during the first year following a change in the price of gasoline. In the analysis of policies affecting price and availability of gasoline, we use

Figure 3-1
FLOWCHART OF THE ANALYSIS



separate estimates of long-run elasticities and elasticities split up by time of day, length of trip, and number of trips (Boxes 7 and 8).

The longer-run effects are estimated by another equation, while a travel demand model supplies the decomposition of the overall price elasticity into elasticities of the number of trips and average length of trips, by time of day. These elasticities, along with the percentage price increases implied by the policies affecting gasoline price and availability, are then applied to the base forecasts (Box 4) to derive gasoline consumption by city size and by peak and offpeak times of day. The emission production functions are then used to translate the fuel consumption into emissions of the different pollutants (Box 5); the simple diffusion model, in turn, translates the emissions into concentrations in selected cities (Box 6).

A separate piece, not formally integrated with the rest of the analysis, estimates a range of additional fuel consumption and emissions due to the increase in travel by other modes (Boxes 10 and 11).

The analysis of policies affecting fuel economy of new cars uses many of these pieces. Once the average fuel economy and total size of the fleet are determined (Box 13), these values are substituted into the short-run demand equation (Box 2) to derive gasoline consumption (Boxes 3 and 4), emissions (Box 5), and concentrations (Box 6). These policies, however, by affecting the age distribution of the auto fleet, also affect emission factors (Box 18).

The models used to determine how average fuel economy, prices, and sales of new cars respond to taxes or restrictions on fuel consumption, in conjunction with the policies, lead to forecasts of new car sales and fuel economy.

New car sales and price increases feed into the auto scrappage model (Box 15) to determine fleet retirements. Scrappage, new car sales, and the previous year's fleet combine to yield the age distribution, number, and average fuel economy of the total auto fleet (Box 16).

Central Modules

The pieces or modules common to all of the analyses include, therefore, the short-run demand model, the method of disaggregating gasoline consumption by city size and by peak and offpeak hours, the emission production functions, and the air quality diffusion model. The rest of this chapter discusses each of these briefly.

Short-Run Demand for Gasoline

The demand for gasoline is estimated by an equation that is used both to forecast gasoline consumption by state and also to estimate the short-run elasticity of demand for gasoline. This equation, discussed in greater detail in Appendix A, relates gasoline consumption per licensed driver to the real price of gasoline, the number of registered vehicles, the gasoline consumption characteristics of the stock of automobiles, and the number of vehicles produced after 1968. The equation is as follows:

$$QGASLD = 1.14237 - 41.8367\ PGASD + .38298\ RVLD + .151965\ PCERVLD - .043262\ MPG$$

where:

QGASLD = thousands of gallons of gasoline consumed in highway uses per licensed driver;

PGASD = price of gasoline at the pump, divided by the Implicit Price Deflator for the Gross National Product;

RVLD = registered vehicles (a weighted sum of automobiles and trucks) per licensed driver;

PCERVLD= estimated registered vehicles per licensed driver that satisfy the 1968 exhaust emission standards; and

MPG = estimated miles per gallon of the stock of automobiles.

Price Elasticity

The equation is essentially linear in form. Consequently, the price elasticity of demand depends on the point on the demand curve at which it is evaluated. For example, the overall short-run elasticity, evaluated at the point of sample means, is -0.18. Evaluated at 1971 values, it is -0.13.

The estimates indicate that, at least for the observed historical ranges of the variables, demand is quite inelastic over the period of a year. It is not entirely inelastic, but the kinds of responses consumers make, given their location, and number and size of automobiles, do not lead to a significant drop in gasoline consumption when prices increase. These choices -- number of trips, length of trips, and auto occupancy -- do not appear to be very sensitive to gasoline prices. A 10 percent increase in the price of gasoline across the United States leads to a decrease in consumption of less than 2 percent.

The Effect of the Stock of Cars

The coefficient of *RVLD*, the number of car-equivalent vehicles per licensed driver, implies an elasticity of gasoline consumption with respect to the car stock of about .54. This elasticity implies that, other things equal, a 10 percent increase in the size of the car stock will lead to about a 5.4 percent increase in gasoline consumption.

This value is suspiciously low, as gasoline consumption might be expected to rise proportionately to the stock of cars. The available data tend to confirm this view. Two-car households average almost exactly twice as many vehicle-miles of travel as single-car households, and households with three or more cars average almost 2.9 times as many VMT's as single-car households.[1] This coefficient is, therefore, highly suspect, but we were unable, within the time and budget resources of this study, to determine the source of the problem.

The Effect of Income

One of the major effects of income on gasoline consumption is through the level of the car stock. The equation explicitly controls for this effect. Economic intuition suggests that an increase in per capita disposable income might lead to an increase in gasoline consumption

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[1]Nationwide Personal Transportation Study, Report No. 11, "Automobile Ownership," (December 1974), p. 45. The 1969 figures on average daily vehicle-miles per household are:

Automobile Ownership per Household	Average Daily Household Vehicle-Miles of Travel
One	28.5
Two	58.6
Three or More	82.1

in other ways, such as a shift from urban to suburban locations, longer automobile vacations, more activities using a car, or more leisure time in which to use a car. We were, however, unable to measure a separate income effect.

When per capita disposable income was included in an earlier equation (not reported here), its coefficient was estimated to be negative. This anomaly may have resulted from multicollinearity with the stock of cars or other variables, or it may be because such influences of income are not important. In any case, we excluded it from the equation reported here. Better measures of income or a different specification might produce a significant income effect, but, in our equations, income's only impact is through the stock of cars.[1]

Effect of Pollution Control Devices

With the 1968 model year, new standards on exhaust emissions went into effect. To comply with these standards, auto manufacturers installed devices that are thought to reduce fuel economy. If so, gasoline consumption would be higher in 1968-1971 than would be accounted for by the other variables in the model.

To measure these effects, we included a variable defined as the number of vehicles of 1968 model year and later, divided by the number of licensed drivers. This variable

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[1]Almost uniformly, studies of new car demand have found a large and statistically significant positive income effect. See Lawrence J. White, *The Automobile Industry Since 1945* (Cambridge, Mass.: Harvard University Press, 1971), pp. 94-95.

does not, therefore, necessarily capture only the effects of the pollution control devices but may pick up other influences associated with more recent model years. (Important influences such as vehicle weight and engine displacement are explicitly controlled for, as discussed in the next section.) The measure also assumes that the extra fuel consumption associated with the devices is the same for each auto and does not depend, for example, on engine size.

The coefficient implies that a car meeting the exhaust controls consumes about 152 gallons per year more than one that does not. Since the average passenger car consumed 746 gallons of gasoline in 1971, the extra gasoline burned by a car meeting environmental controls is about 20 percent of its yearly consumption.[1] This coefficient therefore undoubtedly measures other influences besides the effect of pollution control devices, since most other sources indicate that the additional consumption attributable to the pollution control devices is on the order of 10 to 12 percent.

The Effect of Fuel Consumption Characteristics of the Car Stock

The variable used to describe the fuel consumption characteristics of the stock of cars, *MPG*, is a constructed variable based on the average weight of cars on the road and their average engine displacement. The relationship between these variables and miles per gallon is one estimated by Dewees.[2] The details of the construction of this variable are described in Appendix A.

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[1]Federal Highway Administration, *Highway Statistics 1971*, p. 81.

[2]Donald N. Dewees, *Economics and Public Policy, The Automobile Pollution Case* (Cambridge, Mass.: MIT Press, 1974), p. 152.

The coefficient of this variable implies an elasticity of gasoline consumption with respect to fuel economy of about -1. This means that, other things equal, a decrease of one percent in the fuel economy of the stock of cars will result in a one percent increase in gasoline consumption. This result accords with what common sense suggests the coefficient of this variable ought to be. It should be noted that this variable does not measure the actual miles per gallon achieved by the cars on the road, which depends on the relative intensity and use of big cars and small cars as well as on their fuel consumption characteristics. Thus, this variable does not measure variations in driving behavior, which ought properly to be attributed to the influence of gasoline prices.

Disaggregation of Gasoline Consumption

Auto usage varies significantly across different city sizes as well as between cities with differing urban form. It has been observed[1] that vehicle miles of travel (VMT) per household tends to decrease monotonically with increasing city size. This pattern of travel behavior may be partly explained by:

- larger average household sizes in smaller cities and rural areas vis-à-vis large urban centers
- lack of convenient transit service in smaller cities and suburban areas.

The last two factors also serve to explain the effects of urban form on auto travel. Urbanized areas with a high degree of population decentralization tend to exhibit greater VMT (for a given city population) than cities with a high degree of population concentration in an urban core.

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[1] See National Personal Transportation Survey, *op. cit.*

Our methodology to disaggregate gasoline consumption by city size and rural area was designed to account for the VMT per household variation mentioned above. For each state, we have split gasoline consumption into five geographical categories: unincorporated areas, cities with 2500 to 5000 residents, cities with 5000 to 25,000 residents, cities with 25,000 to 50,000 residents and urbanized areas. In the last category, gasoline consumption was estimated for *each* urbanized area within the state. For the purposes of the analysis of national aggregate emission levels by city size,"rural" areas were taken to include unincorporated areas and all cities with fewer than 25,000 residents. Cities with 25,000 to 50,000 residents were included in our 10 kilometer city-size category.

The basic method for disaggregating gasoline consumption makes use of 1970 census data on household size variation by size of place and the distribution of urbanized area population by place size. This information is combined with data from the National Personal Transportation Survey on the variation of VMT per household by size of place to estimate VMT by geographical area within a state.[1] On the assumption that average automobile fuel economy does not vary from one geographical area to the next, the disaggregation of gasoline consumption is performed by finding the ratio of estimated VMT in a particular geographical area to the estimated statewide VMT.

Gasoline consumption was disaggregated by peak and off-peak times of day on the assumption that national averages

---

[1]Note that the VMT estimated by this procedure across all geographical areas within a state will not necessarily correspond to the independently estimated gas consumption figures.

for daily VMT's by hour of day are the same for all city sizes and rural areas.[1] Peak hour trips are taken to be those that start between 6:00 and 9:00 a.m. and 4:00 and 7:00 p.m. All others are offpeak trips. Peak hour VMT's account for 42 percent of total VMT's.[2] Thus peak hour gasoline consumption in the base forecasts is taken as 0.42 times total gasoline consumption.

Emission Production Functions

In Chapters 4 and 5, we trace out the differential impacts of the gasoline excise tax policies and the policies dealing with new car excise taxes and fuel economy restrictions on the size and vintage distribution of the auto stock, vehicle miles of travel,and frequency of auto travel. These policy impacts are important inasmuch as each of these dimensions of consumer response has a bearing on the production of light-duty vehicle pollutant emissions.

In this report, we have dealt with three pollutant types: carbon monoxide (CO), nitrogen oxides (NO_x), and hydrocarbons (HC). There are three major sources of automobile emissions of these pollutants: vehicle exhausts, evaporative losses,and crankcase emissions. Vehicle exhausts, responsible for the production of all three pollutant types, include running emissions, which depend on

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[1]Because disaggregation by time of day is important only for estimating urban emissions, its reasonableness for our purposes depends on the similarity of traffic distribution over time for different city sizes.

[2]Calculated from Nationwide Personal Transportation Study, Report No.8, Table A-27, p. 78.

vehicle miles of travel, and cold start emissions, which depend only on the frequency of auto travel (i.e., the number of vehicle cold starts). In addition to these sources, HC pollution is produced by crankcase emissions, which are a function of VMT and two evaporative sources: hot soaks, which depend on the frequency of travel, and diurnal losses, which depend only on the stock of automobiles.

It is clear that pollutant emission production functions depend critically on the relative intensity of auto use in different vehicle operating regimes. Policies that reduce VMT (through reductions in average trip length) but not the frequency of travel may be expected to have the greatest impact on running exhaust and crankcase emissions but little effect on the other emissions sources. Similarly, those policies which reduce the size of the auto stock will lower diurnal HC evaporative emissions as well as pollution from other sources (to the extent that VMT and trip frequency are correspondingly decreased).

Another important factor in considering emission production functions is the age distribution of the existing auto stock. The staged introduction of emission control devices since the early 1960's has resulted in significant reductions in vehicle emission pollution rates. And current EPA regulations governing vehicle pollution rates can be expected to continue the downward trend in vehicle emissions. In light of these facts, it is clear that any policies that serve to impede the scrappage of old model automobiles may well be counterproductive in terms of enhancing ambient air quality.

One additional point should be raised concerning the downward trend in recent model year vehicle emission

rates. The introduction of vehicle control devices has had varying degrees of success in controlling the different *sources* of automobile pollution. Table 3-1 presents the fraction of emissions of each pollutant type produced during one cycle of the CVS-CH Federal Test Procedure[1] for our three baseline analysis years (1975, 1981, and 1987). As can be seen, cold start emissions become an increasingly important component of vehicle emissions in future years for HC and CO.[2] This suggests that policies directed towards reducing the principal source of vehicle cold starts -- the urban automobile work trip -- will be most effective in reducing vehicle emission levels.

Figure 3-2 expands the section of Figure 3-1 dealing with emissions. Details of the methods and sources used are given in Appendix A, but it may be useful here to summarize some of the main assumptions and parameters.

Emission Rates

Table 3-2 shows the exhaust emission rates for different model years, broken up into cold start and running emissions. As can be seen, there is a sharp drop in emission rates between 1968 and 1975.

Hydrocarbon evaporative emission rates are shown in Table 3-3. Hot soak emissions depend on the number of trips, while diurnal depend on the total number of vehicles.

The equation used to estimate crankcase emissions of hydrocarbons, due to clogging of the positive crankcase

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[1]See Appendix A for a detailed description of the CVS-CH Federal Test Procedure.

[2]Cold start emissions of NO_x are relatively unimportant for all years.

Table 3-1

Relative Contributions of Pollution Sources
(percent of total emissions during one cycle of
the CVS-CH Federal Test Procedure)

Pollutant	Year	Running	Cold State	Hot Soak	Diurnal	Crankcase
HC	1975	58.9	7.6	26.8	.70	6.1
	1981	50.0	11.7	19.6	.255	17.85
	1987	33.4	20.7	12.9	.30	32.7
CO	1975	76.6	23.4			
	1981	62.5	37.5			
	1987	26.6	73.4			
NO_x	1975	93.8	6.2			
	1981	96.5	4.7			
	1987	100.0	0			

Figure 3-2

Schematic Representation of Methodology for the Estimation of Emission Production Functions

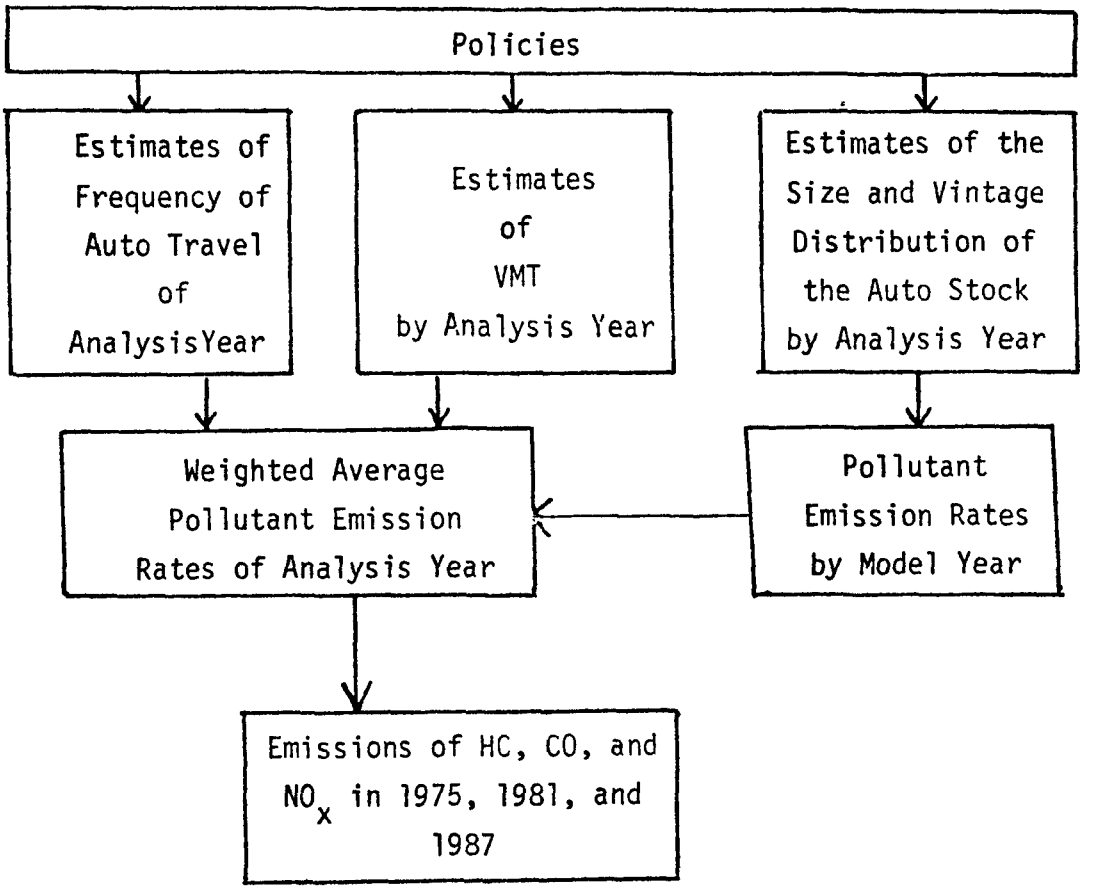

Table 3-2

SCALED EXHAUST EMISSION RATES

CO	Pre-1968	1968	1969	1970	1971	1972	1973	1974	1975	Post-1975
Running g/mile[1]										
High Altitude	91.91	53.09	37.29	52.75	63.56	36.38	36.38	36.38	.48	.48
Low Altitude	61.51	33.0	30.3	26.38	28.81	16.46	16.46	16.48	.48	.48
Cold Start g/cold start[2]										
High Altitude	659.92	362.33	185.5	333.46	198.27	97.29	97.29	97.29	22.9	22.9
Low Altitude	441.64	225.23	150.72	166.73	89.88	44.01	44.01	44.01	22.9	22.9
NO_x										
Running g/mile[1]										
High Altitude	1.80	2.07	2.39	2.63	2.86	2.85	1.29	1.29	1.49	.33
Low Altitude	3.40	4.05	5.06	4.80	4.43	4.41	2.11	2.11	2.45	.33
Cold Start g/cold start[2]										
High Altitude	1.80	2.19	3.57	2.88	4.13	4.31	1.95	1.95	-1.57	-0.35
Low Altitude	3.41	4.29	7.55	5.24	6.40	6.67	3.21	3.21	-2.57	-0.35
HC										
Running g/mile[1]										
High Altitude	8.918	5.067	4.668	4.932	4.701	4.482	4.482	4.482	.142	.142
Low Altitude	7.954	3.8	3.801	2.910	2.573	2.470	2.470	2.470	.142	.142
Cold Start g/cold start[2]										
High Altitude	16.471	16.181	12.688	20.248	10.376	7.242	7.242	7.242	1.522	1.522
Low Altitude	14.689	12.136	10.332	11.946	5.679	3.991	3.991	3.991	1.522	1.522

[1]Running emissions are divided into low and high altitude categories. They are measured in grams/mile.

[2]Cold start emissions are divided into low and high altitude categories. They are measured in grams/cold start.

Table 3-3

HC EVAPORATIVE EMISSION RATES

Model Year	Hot Soak Emissions[1] (g/Trip)		Diurnal Emissions[1] (g/Veh/Day)	
	Low Altitude	High Altitude	Low Altitude	High Altitude
Pre-1971	15	48	26	75.288
1971-1976	10.875	34.8	16.3	47.200
Post-1977[2]	0.75	2.4	1.3	3.764

[1]Values represent low-mileage emissions.

[2]Assumed 95 percent reduction from pre-1971 rates.

ventilation valve, is[1]

$$C_{mj} = 0.07344(j-m)$$

where

C_{mj} = crankcase emissions in grams per mile in calendar year j for autos of model year m.

This formula implies that crankcase emissions from new cars are zero, while those from ten-year-old cars are, on average, 0.73 grams per mile.

Because emission control systems deteriorate over time, the emission factors shown in Table 3-2 are adjusted for vehicle age by multiplication by the deterioration factors shown in Table 3-4. Since pre-1968 cars do not have exhaust emission control systems, their emissions do not vary systematically with vehicle age. For 1975 and later model cars, the average emission rates shown in Table 3-2 are more than doubled after three years on the road and tripled after six years. Thus the age distribution of the vehicle stock has considerable influence on the average emission rates of the fleet as a whole.

Vehicle Miles of Travel and Trip Frequency

The forecasts and different policies yield estimates of gasoline consumption, but emissions depend on VMT's. The average mile per gallon figures shown in Table 3-5 are used to convert fuel consumption into VMT's in the base case and in the policies discussed in Chapter 4. Average fuel economy is directly affected by the policies of Chapter 5.

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[1]This formula is adapted from that given in John B. Heywood and Michael K. Martin, "Aggregate Emissions from the Automobile Population," SAE Paper 740536 (June 1974), p. 6.

Table 3-4

CARBON MONOXIDE, EXHAUST HYDROCARBON, AND NITROGEN OXIDE DETERIORATION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES IN ALL AREAS EXCEPT CALIFORNIA

Pollutant and Model Year	Vehicle Age, Years									
	0	1	2	3	4	5	6	7	8	≥9
Carbon Monoxide										
Pre-1968	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1968	1.00	1.24	1.35	1.41	1.47	1.53	1.58	1.63	1.67	1.72
1969	1.00	1.42	1.53	1.59	1.63	1.68	1.71	1.75	1.79	1.82
1970 through 1974	1.00	1.18	1.32	1.38	1.40	1.44	1.47	1.50	1.51	1.56
1975	1.00	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48	3.77
Post-1975	1.00	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48	3.77
Exhaust Hydrocarbon										
Pre-1968	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1968	1.00	1.12	1.18	1.21	1.23	1.26	1.28	1.30	1.32	1.35
1969	1.00	1.10	1.16	1.18	1.21	1.23	1.25	1.28	1.29	1.31
1970 through 1974	1.00	1.05	1.10	1.13	1.15	1.17	1.20	1.22	1.24	1.26
1975	1.00	1.45	1.95	2.40	2.76	3.14	3.46	3.79	4.07	4.42
Post-1975	1.00	1.45	1.95	2.40	2.76	3.14	3.46	3.79	4.07	4.42
Nitrogen Oxides										
Pre-1973	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1973 through 1975	1.00	1.11	1.18	1.20	1.21	1.22	1.23	1.24	1.25	1.26
Post-1975	1.00	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48	3.77

SOURCE: U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors.*

Table 3-5

BASELINE GASOLINE CONSUMPTION RATES (NATIONAL AVERAGE)
BY ANALYSIS YEAR AND PRICE SCENARIO
(Miles Per Gallon)

Analysis Year	Low Price Scenario	High Price Scenario
1975	11.8564	12.2319
1981	11.6486	12.5835
1987	11.4413	12.7017

Trip frequency affects emission rates because of cold start and hot soak emissions. Trip frequency in the base case was estimated by dividing vehicle miles of travel by national average trip length. The implied number of trips is, in turn, affected by the fuel price and availability policies discussed in Chapter 4.

The policies analyzed in Chapter 4 are assumed not to influence the average emission factors of the auto stock over the forecast period,[1] while the ones analyzed in Chapter 5 are assumed not to influence average trip length. Thus, different policies affect different parts of the emissions model, although all of the policies affect VMT. The general model shown in Figure 3-2 is used for all of the policies analyzed in this study.

[1]This assumption is discussed in detail in Chapter 4.

The Air Quality Model

Estimates of the potential effect on urban air quality resulting from changes in LDV emissions were calculated by the application of simple atmospheric diffusion models. The calculations were performed for carbon monoxide, nitrogen oxides, total hydrocarbons,[1] and photochemical oxidants over averaging periods corresponding to the national primary air quality standards for these contaminants. These combinations of pollutant and averaging time are summarized in Table 3-6. For the 1-, 3-, and 8-hour averaging periods, the modeling calculations were based on the joint effects of adverse meterological dispersion conditions and projected peak LDV emissions during this time interval. Details on the methods used in the computations are presented in the following sections.

TABLE 3-6

POLLUTANTS AND AVERAGING TIMES

Pollutant	Averaging Times			
	1-Hour	3-Hour	8-Hour	Annual
Carbon Monoxide	X		X	
Nitrogen Oxides				X
Hydrocarbons*		X		
Oxidants	X			

* Hydrocarbon concentrations used to calculate photochemical oxidant concentrations

[1]The predicted total hydrocarbon concentrations were only used to calculate photochemical oxidant concentrations and are not reported separately.

Concentrations of Carbon Monoxide and Nitrogen Oxides

Predicted concentrations for carbon monoxide and nitrogen oxides were based on application of the Miller-Holzworth Model.[1] The predicted concentrations of photochemical oxidants were modeled using the Miller-Holzworth Model to determine total hydrocarbon concentrations and then the Criteria Document curve was applied to relate total hydrocarbon concentrations to maximum oxidant concentrations.[2]

The Miller-Holzworth Model relates pollutant concentrations to emissions and meteorological conditions through an integration of the Gaussian plume equation across an urban area. The spatially-averaged, normalized concentration $\overline{X}/\overline{Q}$ for the Miller-Holzworth Model, when the pollutants have not achieved a uniform vertical distribution, is expressed as:

$$\overline{X}/\overline{Q} = 3.994\ (S/U)^{0.115}$$

where $\overline{X}$ is the area average ambient pollutant concentration (g/m^3)

$\overline{Q}$ is the area average emission rate (g/m^2/sec)

U is the wind speed (m/sec)

S is the diameter of the urban area (km)

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[1] *Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States*, EPA Publication Number AP-101, Research Triangle Park, N.C., January 1972.

[2] *Air Quality Criteria for Hydrocarbons*, NAPCA Publication Number AP-64, Washington, D.C., pp. 5-7, March 1970.

When the pollutants have achieved a uniform vertical distribution, the model becomes:

$$\overline{X}/\overline{Q} = 3.613H^{0.130} + \frac{S}{2HU} - \frac{0.088UH^{1.26}}{S}$$

where H is the vertical mixing height (m).

The mathematical derivation of the Miller-Holzworth dispersion model is presented in EPA Publication AP-101. This document also provides values for $\overline{X}/\overline{Q}$ based on climatological frequencies for over 60 urban areas in the nation. Thus, pollutant concentrations can be estimated for a range of restrictive meteorological dispersion conditions. Although the $\overline{X}/\overline{Q}$ are presented as a function of region size, the model does not permit estimation of spatial variations in pollutant concentrations across the area. Consequently, any set of LDV scenarios which result in similar total area-wide pollutant emissions will be predicted to have the same air quality. This model has been calibrated by comparison of observed annual average concentrations of pollutants to predicted values for a wide sample of urban areas.[1] It can also be used to estimate shorter period regional average concentration for the area under consideration.

Oxidant Concentrations

Figure 3-3 presents the empirical relationship between 6-9 a.m. total hydrocarbon concentrations and peak one-hour

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[1] *Guidelines for Air Quality Maintenance Planning and Analysis, Vol. 12: Applying Atmospheric Simulation Models to Air Quality Maintenance Areas*, EPA-450/4-74-013, September 1974.

FIGURE 3-3

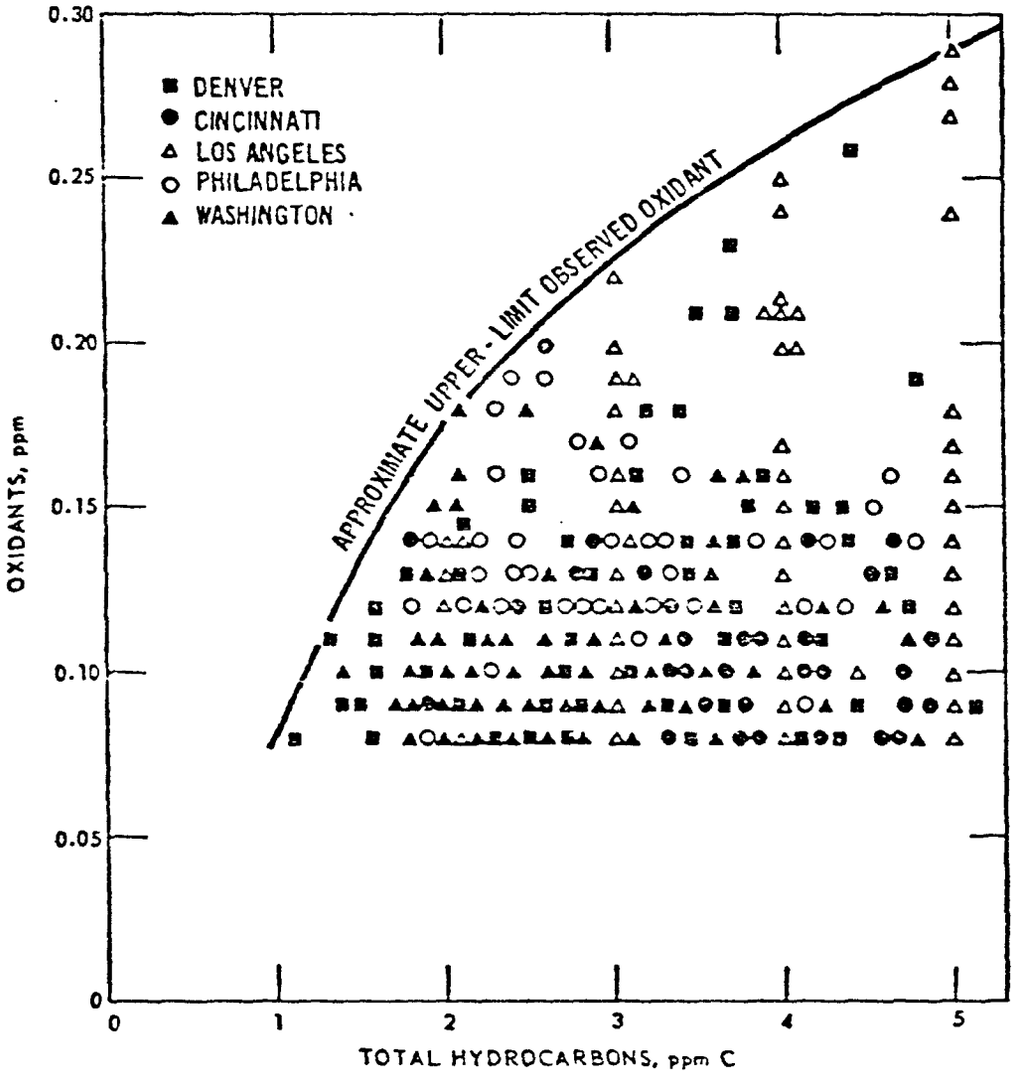

Figure 3-3. Maximum daily 1-hour-average oxidant concentrations as a function of 6-to 9-a.m. averages of total hydrocarbon concentrations at CAMP stations, June through September, 1966 through 1968 and in Los Angeles, May through October 1967.

SOURCE: *Air Quality Criteria for Hydrocarbons, op. cit.*

oxidant levels developed for the NAPCA criteria document on hydrocarbons.[1] Monitoring data from CAMP stations in various urban areas during the period June through September, 1966 through 1968, and in Los Angeles during May through October, 1967, formed the basis for this graph. It is significant to note that no data are presented for oxidant measurements below 0.075 ppm because of monitoring instrument accuracy limitations that existed circa 1967.

The envelope of these data, corresponding to the upper limit of observed oxidant concentrations, has been applied previously in metropolitan areas for the evaluation of transportation control strategies. It was applied in the current analysis for estimating changes in peak photochemical oxidant concentrations. To facilitate the computations, the bounding curve in Figure 3-3 was approximated by the following piece-wise empirical relationship:

$$\bar{X}_{Ox} = -1469 + 603.5 \log_{10} \bar{X}_{HC} \qquad \text{for } \bar{X}_{HC} > 500 \ \mu g/m^3$$

$$\bar{X}_{Ox} = -107 + 0.524 \, \bar{X}_{HC} \qquad \text{for } 204 \ \mu g/m^3 \leq \bar{X}_{HC} \leq 500 \mu g/m^3$$

$$\bar{X}_{Ox} = 0.0 \qquad \text{for } 204 \ \mu g/m^3 < \bar{X}_{XC}$$

where:

$\bar{X}_{Ox}$ is the peak 1-hour oxidant concentration

$\bar{X}_{HC}$ is the peak 3-hour total hydrocarbon concentration

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[1] *Air Quality Criteria for Hydrocarbons, op. cit.*

Implicit in these functions is the assumption of a linear extrapolation of the criteria data below the instrument accuracy threshold. This procedure does not permit estimating peak oxidant concentrations corresponding to hydrocarbon concentrations below 204 $\mu g/m^3$.

It should be noted that recent studies indicate that the oxidant-hydrocarbon relationship is an oversimplification of precursor influences. In particular, nitrogen oxide concentrations are a significant factor in peak oxidant formation. However, no simple model incorporating this effect is presently available for general application.

4. POLICIES AFFECTING GASOLINE DEMAND DIRECTLY

Introduction

In this chapter and the next we analyze the impact on automotive emissions and air quality of a range of policies affecting the consumption of gasoline both directly and indirectly. This chapter is devoted to the study of those policies which directly affect gasoline demand, i.e., varying the federal excise tax on gasoline and rationing a reduced supply of gasoline among consumers. We shall be concerned with the size of the effect of certain specific proposals (to be described in detail below) in the immediate future (1975), as well as the intermediate (1981) and longer-run effects (1987).

These estimates are based on statistical analysis of existing data on gasoline consumption and automobile use, basic results of economic theory, and where existing data and assumptions are inadequate, assumptions about behavioral relationships. This methodology is described

in detail in the text of this chapter and in Appendix C. Since any estimation of this sort is necessarily subject to error, Appendix C reports "confidence intervals" for the point estimates described in the text of this chapter. These intervals are generated by assuming that the statistical estimates of certain parameters used in the calculations deviate from the true values of those parameters in either direction by some specified amount. The implied range for the estimated effects of proposed policies then gives us some idea of the sensitivity of these estimates to error in the estimates on which they are based.

The rest of this chapter is organized as follows: First, we present a qualitative analysis of the effects of an increase in the federal excise tax on gasoline and of gasoline rationing on gasoline consumption and air quality. Second, we outline the approach taken in this chapter. Third, we estimate the quantitative impact on gasoline consumption, emissions, and air quality of an increase in the excise tax and imposition of gasoline rationing.

We then consider the cross effects of increased fuel prices on gasoline consumption and emissions by modes of travel other than the automobile. The implications of these policy-induced changes in gasoline consumption and automotive emissions for ambient air quality form the topic of the next section. We conclude the chapter with a discussion of the secondary impacts of the proposed policies. Technical details of the derivation of these results are relegated to Appendix C.

Qualitative Analysis

In this section we present a qualitative analysis of

the effects that the proposed policies are likely to have on gasoline consumption and on ambient air quality. The analysis is theoretical, based on conventional assumptions about the economic behavior of individuals.

There are two policy instruments whose effects are investigated here: an increase in the federal excise tax on gasoline and the imposition of gasoline rationing, with a legal market in the coupons needed to purchase gasoline.

For a given stock of cars with given polluting characteristics, a decrease in gasoline consumption results in a decrease of emissions (assuming that the decrease comes about both because of fewer trips and because of shorter average trips). The effect on air quality may thus be unambiguously determined, although the social benefits from the improvement in air quality may, to some extent, depend on where and at what time of day the reduction in emissions occurs.

An Increase in the Federal Excise Tax

Economic theory and common sense tell us that an increase in the excise tax on gasoline will lead, other things equal, to a reduction in gasoline consumption. This decrease, in the short run, results principally from a reduction in the aggregate use of automobiles, as individuals increase their use of carpooling and public transportation for work trips, and cut back on the number and length of shopping and recreational trips to economize on gasoline. In the long run, higher gasoline prices produce more basic changes. Changes will be induced in the fuel economy characteristics of the stock of automobiles on the road as individuals shift their new car demand to automobiles with better gasoline mileage and as automobile manufacturers develop cars that use gasoline more efficiently. Eventually, locational patterns may change as households locate themselves nearer to pla[illegible] of employment, shopping and service

centers, and to public transportation, further reducing consumption. However, locational effects are not treated in this report.

Figure 4-1 represents the short- and long-run effects of an increase in the gasoline tax schematically. With quantity of gasoline consumed measured on the abscissa and the price of gasoline on the ordinate, D_{LR} represents the long-run demand schedule for gasoline. It relates the aggregate quantity of gasoline which people desire to consume to the prevailing market price, assuming that enough time is allowed for the complete adjustment of the travel habits of individuals and the stock of registered automobiles to the price of gasoline. The downward slope of the schedule implies that an increase in price, other things equal, leads to a decrease in the desired consumption of the goods.

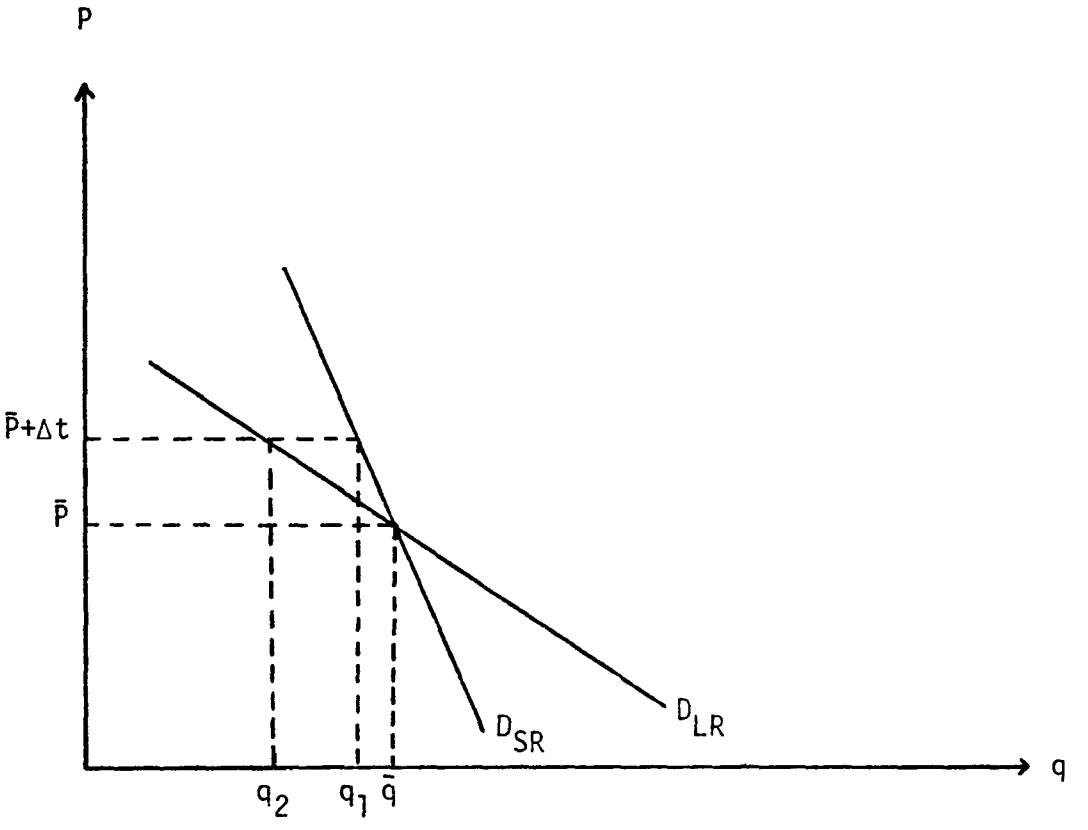
The long-run demand schedule D_{LR} is appropriate for analysis of time periods long enough for complete adjustment. To analyze consumption behavior in the period before the long-run equilibrium is reached, a short-run demand schedule pertinent to the length of the period of analysis may be constructed. One such schedule is exemplified by D_{SR} in Figure 4-1. Suppose that initially the market is in long-run equilibrium with tax-inclusive price $\bar{p}$ and quantity consumed $\bar{q}$, and that an increase of Δt in the excise tax on gasoline is contemplated. If increasing the tax by Δt leads to an increase in the market price of that amount,[1] then the eventual impact of that policy will be to reduce desired gasoline consumption to the level q_2, an ultimate consumption savings of $(\bar{q} - q_2)$ gallons.

---

[1]This implicitly involves the assumption of infinitely elastic supply of gasoline at the market price, which is maintained through this discussion for expositional ease.

Figure 4-1

SCHEMATIC REPRESENTATION OF THE SHORT-RUN AND LONG-RUN IMPACTS ON GASOLINE CONSUMPTION OF AN INCREASE IN THE GASOLINE EXCISE TAX



Suppose however that we desire to know the impact of the tax increase, say one year hence, and take D_{SR} as the demand schedule appropriate to a short run of this duration. Then such a policy will cause gasoline consumption to be reduced to the level q_1. The total reduction of desired gasoline consumption in this case is $[\bar{q} - q_1]$ which, of course, is less than before. That is, in the short run, when all the economic effects of the policy have not had time to work themselves out, a given tax increase will lead to a smaller reduction in consumption than in the long run. This expresses the basic economic result that demand is less price-elastic (i.e., price-sensitive) in the short run than in the long run.

Under the assumptions implicit in the above discussion, then, an increase in the federal excise tax on gasoline will result in reduced gasoline consumption and thus improved ambient air quality. The same argument also shows that the long-run effects of a "once and for all" tax increase are greater than the short-run effects. Both of these results are partial equilibrium results, in that they do not take account of all of the other factors influencing gasoline consumption. Because these other factors are constantly changing, it is often difficult in practice to observe directly and precisely the effects of a policy change. For example, in prosperous times more and larger cars tend to be sold, leading to an increase in gasoline consumption. If these times happen to coincide with an increase in the excise tax on gasoline, it might appear as though the tax had no effect. The difficulty of interpreting the data is compounded over longer time periods, as more extraneous influences are felt. The deliberately simplified analysis of the policy changes ought not to be regarded as directly applicable to

the prices and quantities observed in the market. In the empirical analysis, we use an econometric model to disentangle the different influences on gasoline consumption.

The Effects on Alternative Modes of Transportation

The discussion thus far has focused on the direct effects of these policies; that is, what happens to gasoline consumption and emissions by automobiles when the price of gasoline is increased. The reduction in gasoline consumption may arise from several different sources -- a decrease in trip length, an increase in auto occupancy, an increase in fuel economy of the fleet, and a decrease in the number of trips.[1]

Some of the reduction in auto trips comes about, however, because drivers and passengers shift to alternative modes of transportation -- buses, subways (in a few cities), trains, and (for intercity trips) airplanes. These other modes of transportation also consume energy and emit pollutants. As this study focuses on urban air quality, we will be concerned primarily with fuel consumption and emissions from buses.

Economic theory does not furnish any necessary conditions for the response of total (all modes) fuel consumption and emissions to an increase in the excise tax on gasoline (especially since over 80 percent of municipal bus system fuel consumption is diesel oil). In principle, that is, total fuel consumption might increase. This perverse

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[1]These responses are those predicted by economic theory as the underlying reasons for the responsiveness of gasoline consumption to increases in the price of gasoline. We do not, however, have quantitative estimates of their relative importance.

response might come about if certain very implausible conditions held; for example, if total fuel consumption per passenger mile was greater for buses than for autos and if all the reduction in passenger miles by auto was diverted onto buses.

For a number of reasons, however, such conditions are quite farfetched. Several of the consumer responses mentioned above -- a decrease in average trip length, an increase in average auto occupancy, and an increase in fleet fuel efficiency -- do not imply an increase in passenger miles by alternative modes. Moreover, some of the reduction in total trips probably comes about because people schedule their trips more carefully (deferring some trips to combine them with others, for example) or simply do not make some trips that they did at lower gasoline prices.

Finally, fuel consumption and emissions per passenger mile are, at present, lower for alternative modes than for autos, given current load factors (average proportion of vehicle capacity being used).[1] With an increase in the demand for public transportation, these load factors probably increase somewhat in the short run, before additional capacity can be added to the system. Higher load factors imply still lower gasoline consumption and emissions per passenger mile.

In summary, then, it seems most unlikely that, in the short run, the increase in fuel consumption and emissions

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[1]As discussed later in this chapter, however, emission factors for automobiles are projected to fall much faster than for buses. Consequently, current and expected exhaust emission standards imply that some pollutant emissions per passenger mile are likely to be higher for buses than for autos between 1981 and 1987, if the relative occupancy rates of buses and autos do not change.

from alternative modes will completely offset the reduction in fuel consumption and emissions from automobiles. These increases do, however, need to be taken into account, and they are considered later in this chapter.

The Imposition of Gasoline Rationing

We consider a policy of gasoline rationing with a "white" market in coupons. That is, the coupons necessary to purchase gasoline may be legally bought and sold. As will be shown below, this rationing scheme is quite similar to increasing the excise tax to allocate gasoline among users, except that the income from the effective increase in prices is retained by consumers of gasoline instead of the increased tax receipts accruing to the Treasury (and, assuming no increase in total tax collections, to the general taxpayer).

The impact of gasoline rationing on gasoline consumption and on ambient air quality follows directly if rationing is effective, that is, if the number of gasoline coupons (the size of the stock to be allocated) is less than the market-clearing quantity of gasoline which would be consumed in the absence of rationing. In this case, rationing leads to less gasoline consumption and, through reduced automotive emissions, to improved air quality. We show below that, for any quantity of gasoline to be rationed, there exists an excise tax increase which leads to an equivalent reduction in gasoline consumption. Furthermore, the white market price of coupons under the given rationing scheme will be equal to this excise tax increase.[1]

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[1]This equivalence assumes that the costs of buying and selling coupons are so small that these costs do not appreciably reduce the market value of the coupons.

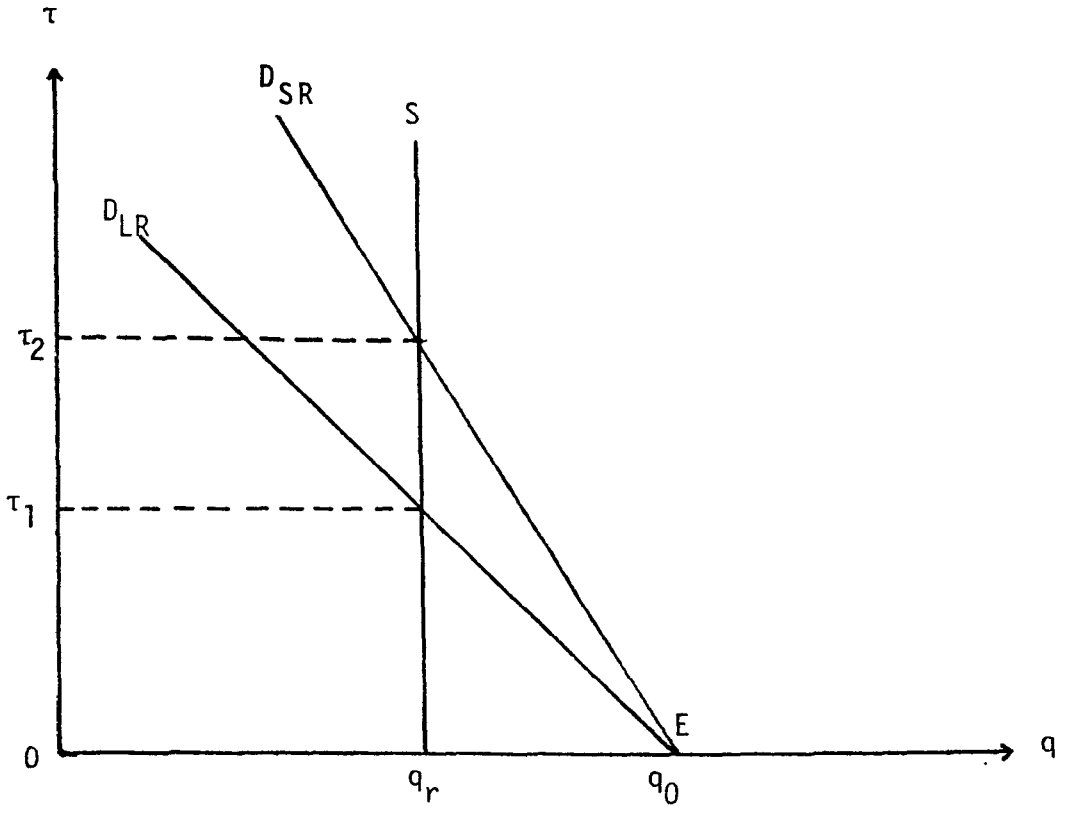
In order to see this, consider the diagrammatic representation of a rationing scheme given in Figure 4-2. Here the market is initially in equilibrium at point E, with the consumption of q_0 gallons of gasoline per year at the price P_0. Now suppose that a policy of gasoline rationing with a white market in coupons is imposed, and that the aggregate allotment is q_r gallons per year. As may be easily seen in the diagram, if D_{SR} represents the short-run demand for gasoline, then in the short run consumers would desire to purchase exactly the allotment q_r, if the price of gasoline were $P_0 + \tau_2$. Thus, increasing the excise tax on gasoline by the amount τ_2 will induce a reduction in consumption in the short run equivalent to that achieved by the rationing policy.

Notice however that while the tax increase of τ_2 is sufficient to achieve the desired reduction in consumption in the short run, it will continue to reduce consumption below the desired rate if maintained indefinitely. This is because, as noted above, the long-run demand schedule is more price-elastic than the short-run demand. Thus, if one desires to maintain consumption at the reduced rate of q_r for a prolonged period of time, the excise tax increase necessary to accomplish this must be reduced as time goes by. Let D_{LR} in Figure 4-2 represent the demand schedule corresponding to the indefinite long run. Then examination of Figure 4-2 reveals that the tax increase which sustains consumption at the rate q_r approaches the level τ_1 as time recedes indefinitely.

Let us now consider the determination of the white market price of the ration coupons. This price will in general be exactly equal to the excise tax necessary to effect a reduction in consumption equivalent to that achieved by the rationing policy. This means that the price of coupons will vary over

Figure 4-2

SCHEMATIC REPRESENTATION OF THE SUPPLY OF AND DEMAND FOR COUPONS ON THE WHITE MARKET



time, starting at the level τ_2 in the short run, but eventually approaching the long-run equilibrium level τ_1. We may substantiate this claim for the long run by examination of Figure 4-3. Here we depict the long-run supply and demand schedules for gas coupons, deduced from Figure 4-2. Supply is of course fixed at the level q_r, since the quantity of coupons available will equal the quantity of gasoline to be rationed. Demand for coupons at a given price, on the other hand, will equal the demand for gasoline at the effective price of gas implied by the coupon price. That is, if the price of gasoline at the pump remains constant at P_0 (as in Figure 4-2) after the rationing scheme is imposed, and if the price of a coupon is at some level τ_1, then the effective price of gasoline is $P_0+\tau_1$. This is so because when an individual buys a gallon of gasoline, he must pay $\$P_0$ in cash, and present a coupon worth $\$\tau_1$. Had he not purchased the gasoline, he could have sold the coupon on the open market for $\$\tau_1$. Symbolically,

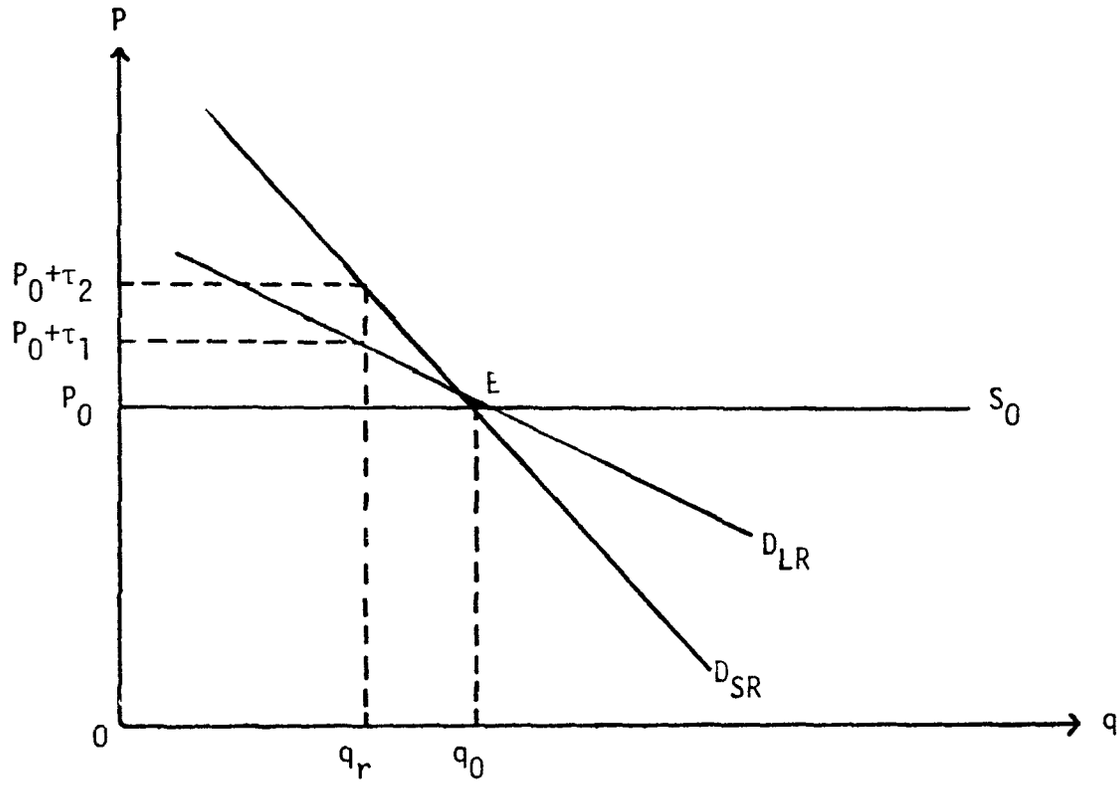
$$D_c(\tau) = D_g(P_0+\tau)$$

where D_c represents the demand for coupons (in gallon-entitlements) on the white market, and D_g is the demand for gasoline (in gallons). The white market will clear at price τ_1, if and only if the gasoline market clears at price $P_0+\tau_1$. However, this also means that an excise tax increase of τ_1 will reduce gas consumption to the rate q_r.

This conclusion holds in principle, but in practice it is impossible to know with certainty the demand curve for gasoline. Consequently, an excise tax allows us to estimate with reasonable precision the increase in price, but the quantity of consumption is subject to considerable uncertainty. Conversely, under rationing the amount of consumption is known with

Figure 4-3

SCHEMATIC REPRESENTATION OF THE EQUIVALENCE OF A GIVEN RATIONING SCHEME TO THE APPROPRIATE EXCISE TAX INCREASE



reasonable certainty, but the value of a coupon (and, hence, the effective price of gasoline) is subject to considerable uncertainty.[1] In addition to uncertainties about the shape of the demand curve, there are other determinants of demand besides price (such as the stock of cars and their average fuel economy), and variations in these determinants cause consumption to vary. Thus, the relative certainty about the quantity consumed under rationing may be an advantage, if uncertainty about effective price is less of a concern than uncertainty about quantity. (Administrative costs of rationing are discussed later in this chapter.)

Finally, one important difference between the rationing and equivalent excise tax schemes should be noted. While they have the same effect on gas consumption, the income distribution effects are, at least in principle, different. This difference is discussed in the section of this chapter entitled "Secondary Impacts."

In the qualitative analysis, we observed that an increase in the federal excise tax on gasoline would increase the market price of this fuel, leading to a reduction in the consumption of gasoline by automobiles. It was further observed that reduced consumption of fuel by autos implies reduced automotive emissions of various pollutants and, as a consequence, improved air quality. Now we wish to quantify these effects. The linkage may be symbolically represented as

$$[\Delta t] \underset{1}{\rightarrow} [\Delta p] \underset{2}{\rightarrow} [\Delta g] \underset{3}{\rightarrow} [\Delta e] \underset{4}{\rightarrow} [\Delta a]$$

---

[1]Total consumption under rationing is not known precisely because the number of licensed drivers is not known with certainty. Indeed, rationing is likely to create incentives for eligible citizens without drivers' licenses to apply for them.

(where t = excise tax on gasoline, p = tax-inclusive price of gasoline, g = gallons of gas consumed by autos, e = quantity of automotive emissions into the atmosphere, a = some measure of ambient air quality, and Δ = change in).

Links 3 and 4 in this chain (the effect of a change in gasoline consumption on emissions, and the effect of a change in emissions on ambient air quality) were discussed in Chapter 3. The rest of this section deals with the first two links.

Effects of a Tax Increase on the Price of Gasoline

Link 1 embodies the effect of increasing the excise tax on gasoline on the market price of the fuel. In general, the relationship between a change in the tax and the change in the equilibrium price depends on both the demand and supply schedules for gasoline. We simplify the analysis, however, by assuming that the supply of gasoline is perfectly elastic. In this instance, an excise tax increase of any given size will lead to the same increase in the market price of gasoline.[1]

The effect of this assumption may be seen with the aid of Figures 4-4 and 4-5. Figure 4-5 depicts the case of perfectly elastic supply while Figure 4-4 shows the situation when this assumption does not hold. In each instance we assume the market initially in equilibrium at the intersection of the demand schedule D and the pre-tax schedule S_0. The

[1]We have made this assumption because, to our knowledge, there are no reliable estimates of the elasticity of supply of gasoline. Moreover, as shown in Section A of Appendix C, under reasonable assumptions about the elasticity of supply, almost the full amount of the tax is translated into the price. To the extent that supply is less elastic than assumed, however, the equilibrium price rises by less than the full amount of the tax increase, and our estimates of the change in gasoline consumption overstate the change that will occur.

Figure 4-4

SCHEMATIC REPRESENTATION OF THE EFFECT OF A CHANGE IN THE GASOLINE TAX ON THE EQUILIBRIUM PRICE OF GASOLINE, WHEN SUPPLY IS NOT PERFECTLY ELASTIC

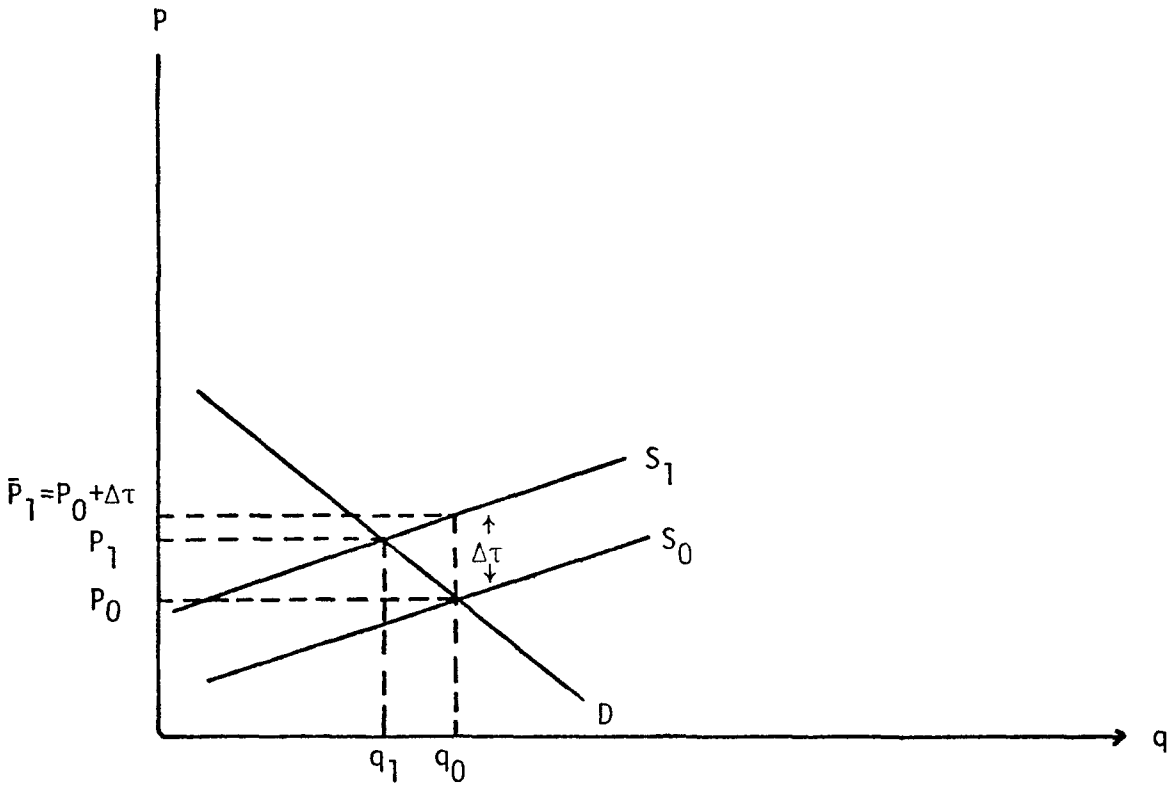
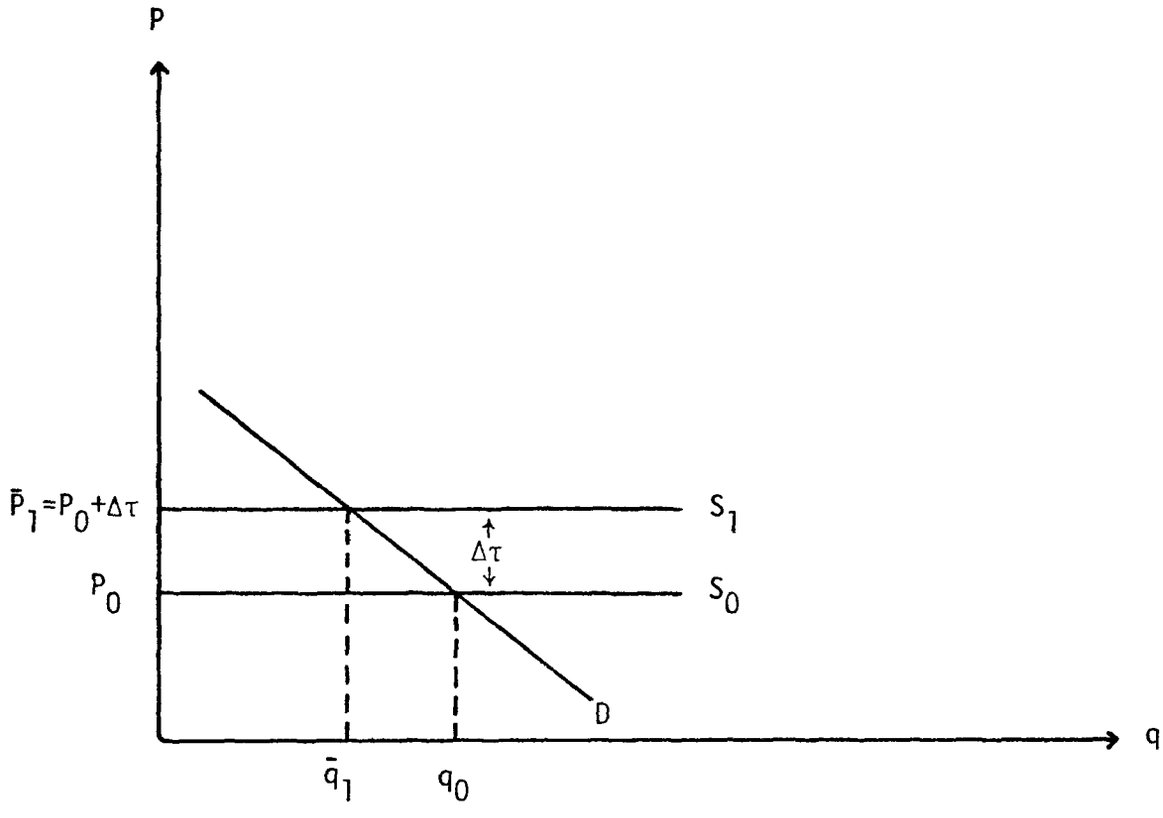


Figure 4-5

SCHEMATIC REPRESENTATION OF THE EFFECT OF A CHANGE IN THE GASOLINE TAX ON THE EQUILIBRIUM PRICE OF GASOLINE, WHEN SUPPLY IS PERFECTLY ELASTIC



market clearing price is P_0 and Q_0 is the quantity consumed. In Figure 4-4 the pre-tax supply schedule S_0 is less than perfectly elastic, having a positive slope. This reflects the assumption that an increase in the price of gasoline will increase the amount of fuel which producers desire to supply to the market. Figure 4-5, on the other hand, shows a horizontal pre-tax supply schedule which is perfectly elastic. In this case (corresponding to constant average production costs) producers are willing to supply at the price P_0 whatever amount is demanded.

In either case, we may think of an increase in the excise tax of Δt as shifting the supply schedule vertically by that amount at each point. This is so because producers will be willing to supply the same quantity after the tax increase as before if and only if the net price they receive for their product remains unchanged. But this is true only if the market (gross) price is increased by the amount of the tax increase. Thus at each quantity of the post-tax supply schedule, S_1 lies above the pre-tax supply schedule by the amount of the tax increase. The post-tax market clearing price and quantity under the respective assumptions about supply elasticity may be compared by observing the intersection of the post-tax supply schedules with the unchanged demand schedule in the two figures.

It is clear in Figure 4-5 that, when supply is perfectly elastic, a given increase in the excise tax leads to the same increase in the market clearing price, as asserted above. Similarly, from Figure 4-4 we can see that if the assumption of perfectly elastic supply fails, then an increase in the excise tax causes the market clearing price of gasoline to increase by less than the price amount

of the tax ($P_1 < \bar{P}_1$). It is also clear in this instance that the reduction in consumption caused by the tax increase is less than predicted under the assumption of perfect elasticity adopted for the purpose of our analysis. However, as is shown in Section A of Appendix C, as long as the elasticity of supply is "large" relative to the elasticity of demand, the size of these effects will be negligible. Since the demand for gasoline is notably inelastic in the short run,[1] and the supply is probably very elastic in the long run,[2] the assumption that price increases by the full amount of the tax should not give misleading results.

Effect of Price Increase on Gasoline Consumption

For the purpose of analyzing increases in the excise tax on gasoline, link 2, the effect of a price change on the quantity of gasoline demanded, is critical. This effect is embodied in the price elasticity of demand for gasoline.

Knowledge of this aggregate elasticity, however, is insufficient by itself to permit the further determination of the effects contained in links 3 and 4. This is because the effect which a given reduction in gasoline consumption

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[1]See the discussion of the price elasticity in Chapter 3.

[2]If, in the long run, refiners respond to permanent shifts in demand by increasing or shutting down refinery capacity (as the case may be), and if new and old refining capacities have similar costs, then the long-run supply schedule will be very elastic. Verification of these hypotheses is beyond the scope of this report, although the gradual decline in real gasoline prices during the 1960's suggests that the assumptions are reasonably correct.

has on the quantity of automotive emissions of various pollutants ($[\Delta g] \rightarrow [\Delta e]$), depends on the extent to which the initial drop in consumption results from a reduction in the number of automotive trips made as opposed to a reduction in the average length of such trips. Furthermore, the effect of reduced emissions on ambient air quality ($[\Delta e] \rightarrow [\Delta a]$) depends on where (urban vs. rural emissions) and when (peak hour vs. offpeak hour emissions) such a reduction in emissions takes place.

Consequently, analysis of the effect on air quality of a given excise tax increase requires disaggregation along three dimensions of the overall effect on consumption embodied in link 2. We must know the effect of $[\Delta p]$ on $[\Delta g]$ by time and place, and for each such subaggregate we must decompose the change in gasoline consumption into changes in the number of auto trips and changes in the average length of these trips.

For this purpose we assume two mutually exclusive and collectively exhaustive temporal and spatial categories of gasoline consumption: peak hour vs. offpeak hour consumption and urban vs. rural consumption, respectively.

This leaves eight parameters to be determined (a trip frequency and trip length elasticity for each time-of-day and place-of-consumption category). Unfortunately, not all of these disaggregated elasticities have been estimated. Various assumptions and implicit constraints must be used to make point estimates and define plausible ranges for these parameters. The procedures are described in detail in Section A of Appendix C. The net effect of the assumptions, however, is to increase the uncertainty about the urban trip-making elasticities that are central to the air quality problem. That is, these assumptions do not affect

the direction of the results, but the uncertainty about them increases the uncertainty about the exact size of the parameters of interest. This increased uncertainty is (partially) reflected in the size of the "confidence intervals" for the estimated effects given in Section B of Appendix C.

In general, urban peak gasoline demand is less price-elastic than urban offpeak gasoline demand, because peak travel contains relatively more work trips than offpeak travel, and work trips are less responsive to increased travel costs than are trips for other purposes. The estimated urban gasoline demand elasticities vary by state, depending on the price of gasoline in the state as well as the degree of urbanization. States in which the rural share of gasoline consumption is small generally have less elastic urban peak and offpeak gasoline demands than states with larger relative rural auto use.

Short-Run vs. Long-Run Gasoline Demand

We noted in the qualitative analysis that the demand for gasoline is likely to be more responsive to a given tax increase in the long run than in the short run, because changes in consumption habits and in the stock of cars in response to a change in the price of gasoline take time to occur. Thus, for a given increase in the excise tax on gasoline, annual consumption is reduced somewhat in the year following the tax increase as consumption partially adjusts to the price change. If the new, high price persists, in subsequent years gasoline consumption falls still further, reaching a floor as

complete adjustment is made.[1] This process is schematically shown in Figure 4-6. The initial (equilibrium) consumption of gasoline per unit of time is g_0. Imposition of a tax increase results in a new, lower long-run equilibrium quantity demanded, given by g_1. But since adjustment takes time, $g(t)$, the actual flow demand for gasoline at any time t after the tax increase, lies between g_0 and g_1. Gasoline consumption approaches g_1 as time goes by.

Under certain reasonable assumptions (described in Section C of Appendix C) it is possible to measure how quickly demand responds to a change in price. For example, if one assumes that each year demand adjusts from its current level toward the long-run equilibrium level by some constant fraction (s) of the difference,[2] then it is possible to estimate from time series data the size of s. Knowledge of this parameter, in conjunction with an estimate of the short-run price elasticity of demand, permits determination of the change in consumption for a given change in price over any duration. This parameter was estimated to be 0.788. It was used in the analysis of the effects of proposed policies in the years 1981 and 1987. This analysis proceeds (using disaggregation techniques described above) exactly as with the short-run analysis for 1975, replacing

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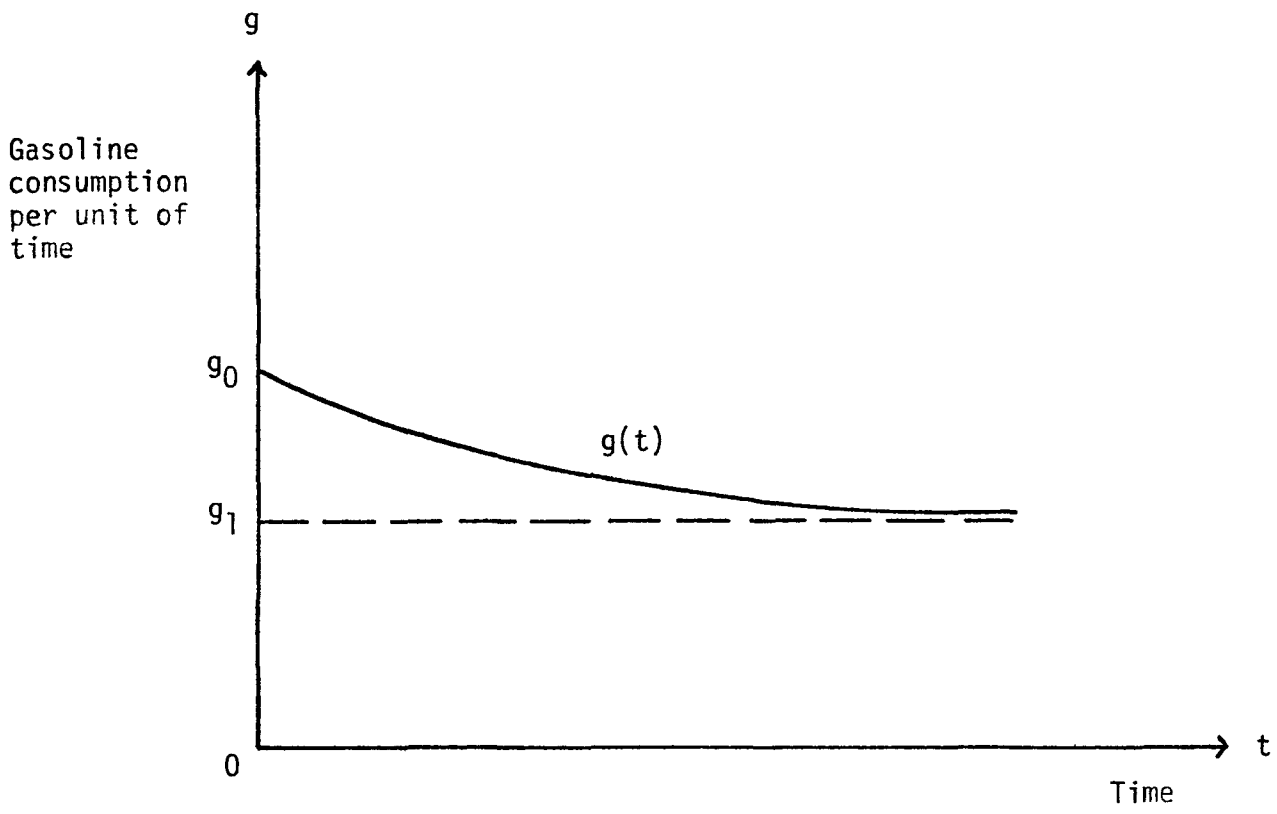
[1]For simplicity, we assume in this discussion that all other factors -- such as population, the number of automobiles, technology, fuel economy, and so forth -- are held constant. In the quantitative analysis, of course, base gasoline consumption is increasing over time, and the long-run elasticity is reflected in a reduced growth *rate*.

[2]In Figure 4-4, this implies the differential equation $\frac{dg}{dt} = [g(t)-g_1]$, with exponentially decaying consumption. The eventual solution is the asymptote, $g(\infty) = g_1$.

Figure 4-6

SCHEMATIC REPRESENTATION OF THE TIME PATH OF GASOLINE CONSUMPTION IN RESPONSE TO A SUSTAINED INCREASE IN THE EXCISE TAX ON GASOLINE (ALL OTHER THINGS EQUAL)



the short-run demand elasticity with a modified elasticity appropriate to the increased duration of the period of analysis.

The estimate of the long-run adjustment coefficient implicitly takes into account changes in the stock of cars in response to changes in gasoline prices. We also assume, however, that average emission factors of the stock of cars are not affected by these policies. In a strict sense, this assumption is probably not correct. Higher gasoline prices may cause the stock of cars to be replaced more rapidly, as older fuel-inefficient cars become less attractive relative to new, fuel-efficient models. Since new cars have lower emission factors than cars sold before the exhaust emission standards were implemented, the assumption made here probably overstates the average emission factors for the fleet. We expect this effect to be very small. Since the difference in gasoline costs between new and old cars is such a small fraction of the cost of car ownership and operation, it is unlikely that an increase in gasoline prices will cause the substantial change in scrappage rates that would be required to affect average emission factors significantly. In any case, the direction of the error is to overstate the emissions associated with gasoline taxes and rationing, and these policies are shown below to lead to a substantial reduction in emissions.

Table 4-1 shows the central elasticity estimates used in this study for 1975, 1981 and 1987. These estimates assume that the price change occurs at the beginning of 1975 and continues in effect to 1987. The elasticities for 1981 and 1987, therefore, reflect the long-run adjustment parameters. These elasticities are disaggregated into peak and offpeak components, which, in turn, are weighted averages of work and nonwork trip elasticities. The weights are the relative shares of each kind of trip during peak and offpeak hours.

We also disaggregate these elasticities by number of trips and average trip length, because the number of trips affects cold start and hot soak emissions. As can be seen in Table 4-2, most of the reduction in gasoline consumption can be attributed to a reduction in the number of trips. Because there are no separate long-run estimates of trip and average trip length elasticities, we assumed that the ratio of trip to average trip length elasticities was constant over time (although peak and offpeak ratios differ).

These elasticities are used in the next section to derive the impact of the different policies on gasoline consumption.[1]

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[1]For brevity, only national average elasticities are shown in Tables 4-1 and 4-2. The elasticities vary from state to state, however, and the actual computations used the state-by-state elasticities to derive gasoline consumption by city size and by the representative air quality cities.

Table 4-1

NATIONAL AVERAGE DISAGGREGATED
URBAN GASOLINE DEMAND ELASTICITIES[1]

Year	Peak	Offpeak	Total
1975	-0.149	-0.173	-0.164
1981[2]	-0.539	-0.626	-0.592
1987[2]	-0.600	-0.697	-0.659

[1]Elasticities assume gasoline prices at their post-embargo levels.

[2]All elasticities assume that the price change occurs at the beginning of 1975 and remains in effect throughout the period of analysis.

Table 4-2

NATIONAL AVERAGE ELASTICITIES OF
NUMBER OF TRIPS AND AVERAGE TRIP LENGTH

Number of Trips

Year	Peak	Offpeak	Total
1975	-0.134	-0.167	-0.153
1981	-0.484	-0.604	-0.553
1987	-0.538	-0.672	-0.616

Average Trip Length

Year	Peak	Offpeak	Total
1975	-0.016	-0.006	-0.010
1981	-0.056	-0.023	-0.036
1987	-0.062	-0.025	-0.041

Results

In this section, we discuss the results of the different policies affecting gasoline consumption directly. We discuss first the change in gasoline consumption, as measured from the base line forecast gasoline consumption, for the different policies. We next discuss the change in emissions, on a national level, for the different pollutants. We also discuss changes in concentrations of the different pollutants, by the appropriate time of day, as measured by an index of concentration of these pollutants in 13 different cities spread across the United States.

Gasoline Consumption

Table 4-3 presents a summary of our best estimates of gasoline consumption in 1975, 1981, and 1987 for each of the four policies. These forecasts assumed the policy goes into effect in 1975. The forecasts shown in Table 4-3 use the point estimates from the gasoline demand equation and the long-run adjustment equation. These estimates are based on high gasoline prices.

These estimates reflect the extreme insensitivity of gasoline consumption to changes in price in the very short run. For example, a tax of $0.10 per gallon (which is double the amount suggested in one recent policy) leads to only a 3 percent reduction in consumption in the base line forecast. A $0.50 per gallon tax on gasoline, which implies almost a doubling of the current price, leads only to a 15 percent reduction in consumption. Rationing, on the other hand, is much more effective in reducing consumption. The cost of this reduction of almost 40 percent

Table 4-3

MEDIUM ESTIMATE OF GASOLINE CONSUMPTION
UNDER POLICIES AFFECTING GASOLINE DEMAND DIRECTLY
(Billions of Gallons)

Year	Policy	10 Km Cities	35 Km Cities	Rural	Total	As Percentage of Baseline Forecast
1975	$0.10/gal.	17.54	36.97	47.18	101.69	97.0
	$0.25/gal.	16.74	35.27	45.00	97.01	92.6
	$0.50/gal.	15.39	32.44	41.36	89.19	85.1
	Rationing ($1.27/gal.)	11.26	23.73	30.18	65.17	62.2
1981	$0.10/gal.	20.24	42.42	54.43	117.09	89.4
	$0.25/gal.	16.64	34.86	44.68	96.18	73.4
	$0.50/gal.	10.62	22.26	28.41	61.29	46.8
	Rationing ($0.39/gal.)	13.27	27.80	35.55	76.62	58.5
1987	$0.10/gal.	24.55	51.17	66.00	141.72	88.1
	$0.25/gal.	19.848	40.820	52.57	113.24	70.4
	$0.50/gal.	11.30	23.56	30.17	65.03	40.4
	Rationing ($0.37/gal.)	15.60	32.53	41.79	89.92	55.9

Assumes (1) high gasoline prices; and (2) medium sensitivity assumptions.

is, however, a fairly high price per coupon. The estimated price of a coupon under a rationing scheme limiting licensed drivers to 10 gallons per week is almost $1.30, more than double the current price of gasoline.

In the longer run, however, as the drivers have time to adjust their patterns of consumption and as demand adjusts to the higher prices, demand becomes much more elastic. By 1981, for example, the same $0.10 per gallon increase in the excise tax has led to greater than a 10 percent reduction in gasoline consumption. The estimated reduction in consumption from a sustained increase in the excise tax of $0.50 per gallon is over 50 percent of base line consumption. The increasing elasticity of demand implies, however, that the price of a coupon falls over time. By 1981, the price of a coupon implied by policy restricting gasoline consumption to 10 gallons per licensed driver per week is about $0.39 per gallon. (It should be noted, of course, that the policy as we have defined it implies a growth in gasoline consumption concomitant with the growth of the number of licensed drivers.)

Tables 4-4, 4-5, and 4-6 show a more detailed disaggregation of gasoline consumption in 1975, 1981, and 1987, respectively, for the best estimates of these policies. These tables show that, for the point estimates used here, there is not much difference in the percentage reduction during peak hours as opposed to offpeak hours. For example, in 1975, for the most severe reduction in gasoline consumption, peak consumption falls by about 35 percent, while offpeak consumption falls by about 40 percent. This closeness arises from two factors. First, the less the overall percentage reduction in demand, the more narrow will be the spread between the peak and the offpeak reductions. For

Table 4-4

URBAN GASOLINE CONSUMPTION IN 1975, MEDIUM SENSITIVITY
(Billions of Gallons)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:$0.10				
PEAK:	7.54442	15.9016	23.446	0.972789
OFF-P:	9.99632	21.0695	31.0658	0.968398
TOTAL	17.5407	36.9711	54.5118	0.970282
TAX:$0.25				
PEAK:	7.22787	15.2344	22.4622	0.931972
OFF-P:	9.507	20.0382	29.5452	0.920995
TOTAL	16.7349	35.2725	52.0074	0.925704
TAX:$0.50				
PEAK:	6.70028	14.1224	20.8227	0.863945
OFF-P:	8.69147	18.3193	27.0107	0.841991
TOTAL	15.3918	32.4416	47.8334	0.851409
RATIONING				
PEAK:	5.07532	10.6974	15.7727	0.65442
OFF-P:	6.17965	13.025	19.2047	0.598656
TOTAL	11.255	23.7224	34.9774	0.622579

SENSITIVITY: MEDIUM

PRICE ASSUMPTION: HIGH

Table 4-5

URBAN GASOLINE CONSUMPTION IN 1981, MEDIUM SENSITIVITY

(Billions of Gallons)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:$0.10				
PEAK:	8.77114	18.3796	27.1503	0.90277
OFF-P:	11.4715	24.0382	35.5097	0.887082
TOTAL	20.2427	42.4178	62.6605	0.893812
TAX:$0.25				
PEAK:	7.35415	15.4104	22.7645	0.756926
OFF-P:	9.28117	19.4484	28.7296	0.717704
TOTAL	16.6353	34.8588	51.4941	0.73453
TAX:$0.50				
PEAK:	4.99249	10.4616	15.4541	0.513852
OFF-P:	5.63058	11.7967	17.4293	0.435407
TOTAL	10.6231	22.2603	32.8834	0.46906
RATIONING				
PEAK:	6.03162	12.6391	18.6707	0.620865
OFF-P:	7.23684	15.1646	22.4014	0.559618
TOTAL	13.2685	27.8036	41.0721	0.585867

SENSITIVITY: MEDIUM

PRICE ASSUMPTION: HIGH

Table 4-6

URBAN GASOLINE CONSUMPTION IN 1987, MEDIUM SENSITIVITY

(Billions of Gallons)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:$0.10				
PEAK:	10.6494	22.2043	32.8537	0.891156
OFF-P:	13.895	28.9715	42.8665	0.873593
TOTAL	24.5444	51.1758	75.7202	0.881127
TAX:$0.25				
PEAK:	8.69834	18.1363	26.8346	0.72789
OFF-P:	10.8791	22.6833	33.5624	0.683981
TOTAL	19.5775	40.8196	60.3971	0.702818
TAX:$0.50				
PEAK:	5.4466	11.3563	16.8029	0.455779
OFF-P:	5.85267	12.203	18.0557	0.367963
TOTAL	11.2993	23.5593	34.8586	0.405636
RATIONING				
PEAK:	7.13751	14.8819	22.0194	0.597277
OFF-P:	8.46643	17.6527	26.1192	0.532293
TOTAL	15.6039	32.5346	48.1386	0.560171

SENSITIVITY: MEDIUM

PRICE ASSUMPTION: HIGH

example, under a $0.10 per gallon tax, peak demand falls by 2.7 percent, while offpeak demand falls by 3.2 percent. Since, according to the way the peak and offpeak elasticity estimates have been constructed, the ratio of the percentage decrease in peak consumption to the percentage decrease in offpeak consumption will be the same for a given set of point estimates and price assumptions, the spread between the decreases will naturally increase with the decrease in total gasoline consumption. Second, although work trip demand is considerably less elastic than the demand for other kinds of trips (assumed to be similar to shopping trips in this analysis), not all work trips occur during peak hours, nor do all shopping trips occur during offpeak hours. This mixing of trip types at different times of the day tends to cause peak and offpeak elasticities to be closer to each other than if different trip types were rigidly made at different times of the day. Even for the most extreme percentage decrease in consumption -- that associated with a $0.50 per gallon tax in 1987 -- the reduction in peak demand is about 55 percent, while the reduction in offpeak demand is less than 65 percent.

This similarity in the elasticities of peak and offpeak demand suggests that, as a first approximation, it is not too misleading to assume that peak and offpeak demands have similar elasticities, from the point of view of determining the impact of changes in fuel consumption on air quality. That is, applying the overall elasticity of demand will give approximately right results for both peak and offpeak gasoline consumption. Certainly, the difference between the peak and the offpeak demand reduction is less than the uncertainty associated with the estimate of overall gasoline demand itself.

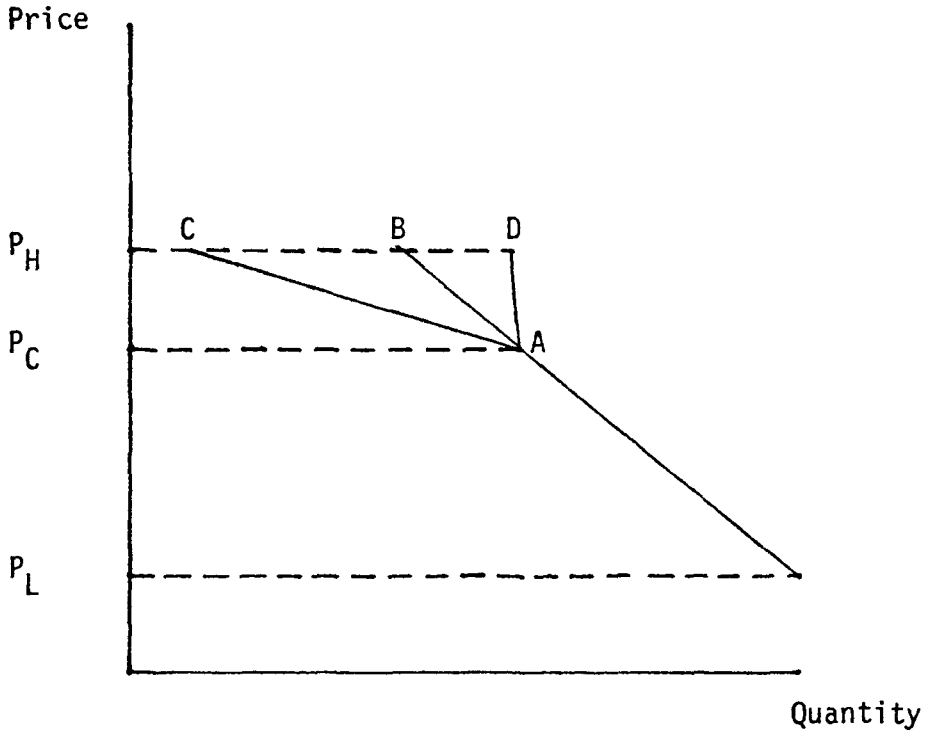
The central elasticities used here were estimated from historical data. Some of the policies considered (such as a $0.50 increase in the excise tax or rationing) imply price increases well outside the range of the sample. Consequently, these estimates may be especially subject to error for large price increases. Figure 4-7 illustrates the difficulties of extrapolating beyond the range of observed prices. The method used here assumes that the demand curve, estimated over the price range P_L to P_C, continues with the same slope over the range P_C to P_H (segment AB). In fact, however, it might very well become either more elastic or less elastic in this range, as represented by segments AC and AD, respectively.

There is no econometric method of estimating demand elasticities outside of the observed historical range; the economy has not performed the requisite experiments. One way to evaluate the uncertainty, however, is to use different elasticity estimates and determine how the results change. For this purpose, we assume that the true coefficients lie within one standard error on either side of the point estimates of the short-run price elasticity and of the long-run adjustment coefficient.

The 1975 results are not especially sensitive to which elasticity estimate is used; a $0.50 per gallon increase in price leads to a decrease in consumption between 8 and 22 percent of the base case level. The 1987 estimates vary markedly according to the elasticity assumed; a $0.50 per gallon tax surcharge leads to reductions in gasoline consumption between 90 and 24 percent of the base case. This wide range largely reflects relatively small differences in year-to-year adjustment

Figure 4-7

SCHEMATIC REPRESENTATION OF DEMAND CURVES
OUTSIDE THE OBSERVED RANGE OF PRICES



of gasoline consumption over a long period of time. The results of using different elasticities are presented in full in Appendix E.

Carbon Monoxide

The percentage reduction of emissions of carbon monoxide are quite similar to the percentage reductions in gasoline consumption, with some interesting exceptions. Our best estimates of urban carbon monoxide emissions, disaggregated into peak and offpeak for the two different size cities, are shown in Tables 4-7 to 4-9. The percentage reductions in 1975, shown in Table 4-7, are virtually identical to the percentage reductions shown in Table 4-4. By 1987, however, the percentage reductions in carbon monoxide (shown in Table 4-9) are not as great as the percentage reductions in gasoline consumption. The discrepancy, however, is quite small -- on the order of 2 percent. This difference arises because, as the price of gasoline goes up, the length of the average auto work trip tends to fall.[1] In the model from which this elasticity estimate was derived, average vehicle trip length falls for two reasons: (1) at higher gasoline prices, longer auto trips are more expensive than short trips, relative to the transit alternative; consequently, relatively more long auto work trips are diverted to transit; (2) those who live farthest away from work have the

[1]In the terminology of the transportation analyst, the average auto-driver trip length falls, while the average of auto-driver plus auto-passenger trips remains constant. Some additional effects will be introduced by the tendency of auto-owners to substitute fuel-economic cars in the longer trips.

Table 4-7

URBAN CARBON MONOXIDE EMISSIONS IN 1975, MEDIUM SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	4286.44	9163.02	13449.5	0.973574
OFF-P:	5118.26	10896.7	16015.	0.968626
TOTAL	9404.7	20059.7	29464.4	0.970879
TAX:$0.25				
PEAK:	4111.79	8790.08	12901.9	0.933935
OFF-P:	4869.52	10367.3	15236.8	0.921563
TOTAL	8981.31	19157.4	28138.7	0.927195
TAX:$0.50				
PEAK:	3820.71	8168.52	11989.2	0.867872
OFF-P:	4454.95	9484.94	13939.9	0.843121
TOTAL	8275.66	17653.5	25929.1	0.854387
RATIONING				
PEAK:	2924.16	6254.12	9178.28	0.664394
OFF-P:	3178.09	6767.34	9945.43	0.601526
TOTAL	6102.25	13021.5	19123.7	0.630143

SENSITIVITY: MEDIUM

PRICE ASSUMPTION: HIGH

Table 4-8

URBAN CARBON MONOXIDE EMISSIONS IN 1981, MEDIUM SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	1210.92	2593.78	3804.7	0.907114
OFF-P:	1337.06	2848.67	4185.73	0.888413
TOTAL	2547.98	5442.45	7990.43	0.89722
TAX:$0.25				
PEAK:	1024.74	2195.58	3220.32	0.767787
OFF-P:	1085.07	2312.05	3397.12	0.721032
TOTAL	2109.81	4507.63	6617.44	0.743052
TAX:$0.50				
PEAK:	714.442	1531.9	2246.34	0.535571
OFF-P:	665.093	1417.67	2082.76	0.442062
TOTAL	1379.54	2949.57	4329.11	0.486102
RATIONING				
PEAK:	850.973	1823.92	2674.89	0.637746
OFF-P:	849.884	1811.2	2661.08	0.56481
TOTAL	1700.86	3635.12	5335.98	0.59916

SENSITIVITY: MEDIUM

PRICE ASSUMPTION: HIGH

Table 4-9

URBAN CARBON MONOXIDE EMISSIONS IN 1987, MEDIUM SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX: $0.10				
PEAK:	657.513	1426.09	2083.6	0.899892
OFF-P:	615.436	1328.98	1944.42	0.876735
TOTAL	1272.95	2755.07	4028.02	0.888563
TAX: $0.25				
PEAK:	547.715	1188.21	1735.93	0.749733
OFF-P:	485.601	1048.74	1534.34	0.691832
TOTAL	1033.32	2236.95	3270.27	0.721406
TAX: $0.50				
PEAK:	364.717	791.738	1156.46	0.499464
OFF-P:	269.208	581.67	850.873	0.38366
TOTAL	633.925	1373.41	2007.33	0.442809
RATIONING				
PEAK:	459.876	997.902	1457.78	0.629603
OFF-P:	381.732	824.545	1206.28	0.543909
TOTAL	841.608	1822.45	2664.06	0.587678

SENSITIVITY: MEDIUM

PRICE ASSUMPTION: HIGH

greatest incentive to form carpools; in addition, longer trips are associated with greater freedom of route choice; this freedom tends to offset the greater density of potential ridership associated with shorter work trips to the central business district.[1] The fall in average auto trip length means, however, that average emissions per mile increase, because cold start emissions do not change with gasoline consumption. Therefore, the carbon monoxide emissions do not fall at the same rate as gasoline consumption. This argument, while of theoretical interest, is seen to be rather unimportant, at least for these estimates, because the difference between the fall in gasoline consumption and the fall in carbon monoxide emissions is very small.

Hydrocarbons

Tables 4-10 to 4-12 show the forecasted emissions of hydrocarbons for the medium estimate for 1975, 1981, and 1987 for the four policies. These emissions follow the same pattern relative to gasoline consumption as do the carbon monoxide emissions, except that, since cold start emissions are a smaller fraction of total emissions than in the case of carbon monoxide, the percentage reduction in hydrocarbons is closer to the percentage reduction in gasoline consumption.

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[1]The model and its results are described in Charles River Associates, *Economic Analysis of Policies for Controlling Automotive Air Pollution in the Los Angeles Region* (draft report to the Environmental Protection Agency, March 1975), Chapter 4 and Appendix A.

Table 4-10

URBAN HYDROCARBON EMISSIONS IN 1975, MEDIUM SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:$0.10				
PEAK:	570.603	1223.77	1794.37	0.973763
OFF-P:	742.836	1592.2	2335.04	0.968789
TOTAL	1313.44	2815.97	4129.41	0.970944
TAX:$0.25				
PEAK:	547.521	1174.33	1721.85	0.934407
OFF-P:	706.929	1515.26	2222.19	0.92197
TOTAL	1254.45	2689.59	3944.04	0.927359
TAX:$0.50				
PEAK:	509.051	1091.92	1600.97	0.868809
OFF-P:	647.085	1387.04	2034.13	0.843943
TOTAL	1156.14	2478.96	3635.1	0.854717
RATIONING				
PEAK:	390.565	838.121	1228.69	0.666778
OFF-P:	462.764	992.12	1454.88	0.60362
TOTAL	853.329	1830.24	2683.57	0.630985

SENSITIVITY: MEDIUM

PRICE ASSUMPTION: HIGH

Table 4-11

URBAN HYDROCARBON EMISSIONS IN 1981, MEDIUM SENSITIVITY

(Millions of Kilograms)

	10 km	35 km	Total	Fraction of Base
TAX: $0.10				
PEAK:	258.019	551.141	809.16	0.906720
OFF-PEAK:	326.229	696.307	1022.536	0.888886
TOTAL:	584.248	1247.448	1831.696	0.896677
TAX: $0.25				
PEAK:	218.102	466.006	684.108	0.766590
OFF-PEAK:	264.897	565.389	812.286	0.706117
TOTAL:	464.999	1031.395	1496.394	0.732535
TAX: $0.50				
PEAK:	151.589	324.128	475.7172	0.533074
OFF-PEAK:	162.558	347.159	509.717	0.443095
TOTAL:	314.1472	671.287	985.4342	0.482403
RATIONING:				
PEAK:	180.834	386.523	567.357	0.635763
OFF-PEAK:	207.622	443.138	650.76	0.565703
TOTAL:	388.456	829.661	1218.117	0.596309

SENSITIVITY: MEDIUM

PRICE ASSUMPTION: HIGH

Table 4-12

URBAN HYDROCARBON EMISSIONS IN 1987, MEDIUM SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	154.225	327.595	481.82	0.895277
OFF-P:	184.401	390.534	574.935	0.875017
TOTAL	338.626	718.129	1056.76	0.884139
TAX:$0.25				
PEAK:	127.139	270.141	397.28	0.738192
OFF-P:	144.882	306.873	451.755	0.687544
TOTAL	272.021	577.014	849.035	0.710349
TAX:$0.50				
PEAK:	81.9952	174.384	256.379	0.476382
OFF-P:	79.0158	167.439	246.455	0.375089
TOTAL	161.011	341.823	502.834	0.420699
RATIONING				
PEAK:	105.47	224.177	329.647	0.612522
OFF-P:	113.266	239.945	353.211	0.537566
TOTAL	218.736	464.122	682.858	0.571316

SENSITIVITY: MEDIUM

PRICE ASSUMPTION: HIGH

Nitrogen Oxides

Tables 4-13 to 4-15 show the best estimate of nitrogen oxide emissions for 1975, 1981, and 1987 under the four policies affecting gasoline demand directly. These emissions, not surprisingly, follow gasoline consumption quite closely. Cold start emissions account for only a small fraction of total nitrogen oxide emissions. Indeed, for recent model years, the estimated breakout between cold start and running emissions shows that running emissions per mile increase with average trip length.[1] That is, a decrease in average trip length leads to a decrease in nitrogen oxide emissions per mile. It is this relationship that, paradoxical as it may seem, leads to nitrogen oxide emissions falling more rapidly than gasoline consumption for each of the policies and years, although the difference is most pronounced for the $0.50 per gallon tax in 1987. This phenomenon is, of course, just the obverse of the phenomenon with cold start and hydrocarbon emissions, where, because of the large positive contribution of cold start emissions, total average emissions per mile fall with trip length.

Concentrations of Pollutants

Tables 4-16 to 4-19 show the national index of concentration for these pollutants. Because of the simple diffusion model used, the percentage change in the index of each nonreactive pollutant follows very closely the percentage change in the corresponding emissions. For

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[1]J. R. Martinez, R. A Nordsieck and A. Q. Eschenroeder, "Morning Vehicle Start Effects on Photochemical Smog," *Environmental Science and Technology*, Volume 7, Number 10 (October 1973), pp. 917-923.

Table 4-13

URBAN NITROGEN OXIDE EMISSIONS IN 1975, MEDIUM SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	353.011	746.965	1099.98	0.973006
OFF-P:	454.993	961.471	1416.46	0.968457
TOTAL	808.004	1708.44	2516.44	0.97044
TAX:$0.25				
PEAK:	338.317	715.886	1054.2	0.932517
OFF-P:	432.762	914.497	1347.26	0.92114
TOTAL	771.079	1630.38	2401.46	0.9261
TAX:$0.50				
PEAK:	313.828	664.086	977.914	0.865034
OFF-P:	399.71	836.209	1231.92	0.842281
TOTAL	709.538	1500.3	2209.83	0.8522
RATIONING				
PEAK:	238.4	504.544	742.944	0.657186
OFF-P:	281.591	595.08	876.671	0.599393
TOTAL	519.991	1099.62	1619.62	0.624589

SENSITIVITY: MEDIUM

PRICE ASSUMPTION: HIGH

Table 4-14

URBAN NITROGEN OXIDE EMISSIONS IN 1981, MEDIUM SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:$0.10				
PEAK:	177.59	372.976	550.566	0.903217
OFF-P:	228.58	479.683	708.263	0.887199
TOTAL	406.17	852.659	1258.83	0.894134
TAX:$0.25				
PEAK:	149.041	313.032	462.073	0.758042
OFF-P:	184.985	388.202	573.187	0.717997
TOTAL	334.026	701.234	1035.26	0.735335
TAX:$0.50				
PEAK:	101.46	213.125	314.585	0.516085
OFF-P:	112.326	235.734	348.06	0.435994
TOTAL	213.786	448.859	662.645	0.47067
RATIONING				
PEAK:	122.396	257.084	379.48	0.622546
OFF-P:	144.296	302.82	447.116	0.560075
TOTAL	266.692	559.904	826.596	0.587123

SENSITIVITY: MEDIUM

PRICE ASSUMPTION: HIGH

Table 4-15

URBAN NITROGEN OXIDE EMISSIONS IN 1987, MEDIUM SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	90.4661	187.771	278.237	0.890154
OFF-P:	121.787	253.222	375.009	0.873341
TOTAL	212.253	440.993	653.246	0.880424
TAX:$0.25				
PEAK:	73.7272	153.009	226.736	0.725389
OFF-P:	95.2959	198.134	293.43	0.683355
TOTAL	169.023	351.143	520.166	0.701063
TAX:$0.50				
PEAK:	45.8289	95.0706	140.9	0.450775
OFF-P:	51.1433	106.32	157.463	0.366709
TOTAL	96.9722	201.391	298.363	0.402124
RATIONING				
PEAK:	60.336	125.198	185.534	0.593572
OFF-P:	74.1026	154.063	228.166	0.531364
TOTAL	134.439	279.261	413.7	0.557571

SENSITIVITY: MEDIUM

PRICE ASSUMPTION: HIGH

Table 4-16

RELATIVE ONE HOUR CARBON MONOXIDE CONCENTRATIONS FOR 13 CITY AVERAGES
(As a Percentage of Baseline Concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$0.10/gal.	97.4	97.7
	$0.25/gal.	93.5	94.2
	$0.50/gal.	87.0	88.4
	Rationing ($1.27/gal)	67.0	70.6
1981	$0.10/gal.	90.9	93.8
	$0.25/gal.	77.2	84.4
	$0.50/gal.	54.3	68.8
	Rationing ($0.39/gal)	64.4	75.6
1987	$0.10/gal.	90.2	95.1
	$0.25/gal.	75.5	87.7
	$0.50/gal.	51.0	75.4
	Rationing ($0.37/gal)	63.7	81.8

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburgh, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and medium sensitivity assumptions.

Table 4-17

RELATIVE EIGHT HOUR CARBON MONOXIDE CONCENTRATIONS FOR 13 CITY AVERAGES
(As a Percentage of Baseline Concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$0.10/gal.	97.1	97.6
	$0.25/gal.	92.8	94.0
	$0.50/gal.	85.6	88.1
	Rationing ($1.27/gal)	63.6	69.8
1981	$0.10/gal.	89.9	94.4
	$0.25/gal.	74.7	85.9
	$0.50/gal.	49.2	71.6
	Rationing ($0.39/gal)	60.5	77.9
1987	$0.10/gal.	89.1	96.0
	$0.25/gal.	72.6	89.9
	$0.50/gal.	45.3	79.8
	Rationing ($0.37/gal)	59.5	85.0

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburgh, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and medium sensitivity assumptions.

Table 4-18

RELATIVE ANNUAL NITROGEN OXIDE CONCENTRATIONS FOR 13 CITY AVERAGES
(As a Percentage of Baseline Concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$0.10/gal.	97.1	99.1
	$0.25/gal.	92.8	97.8
	$0.50/gal.	85.5	95.7
	Rationing ($1.27/gal)	63.3	89.0
1981	$0.10/gal.	89.7	98.4
	$0.25/gal.	74.2	96.0
	$0.50/gal.	48.4	92.0
	Rationing ($0.39/gal)	59.7	93.8
1987	$0.10/gal.	88.4	99.1
	$0.25/gal.	71.0	97.7
	$0.50/gal.	41.9	95.4
	Rationing ($0.37/gal)	57.0	96.6

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburgh, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and medium sensitivity assumptions.

Table 4-19

RELATIVE ONE HOUR OXIDANT CONCENTRATIONS FOR 13 CITY AVERAGES
(As a Percentage of Baseline Concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$0.10/gal.	79.7	93.7
	$0.25/gal.	79.4	88.2
	$0.50/gal.	84.1	90.6
	Rationing ($1.27/gal)	41.7	75.3
1981	$0.10/gal.	68.7	83.0
	$0.25/gal.	40.1	69.0
	$0.50/gal.	38.9	68.1
	Rationing ($0.39/gal)	49.6	73.0
1987	$0.10/gal.	11.2	87.5
	$0.25/gal.	0.0*	75.0
	$0.50/gal.	0.0*	74.2
	Rationing ($0.37/gal)	0.0*	81.7

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburgh, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and medium sensitivity assumptions.
*Values of zero denote model limitations.

example, the percentage change in the index of one-hour concentrations of carbon monoxide under the different policies is almost exactly that of the percentage reduction in peak emissions of carbon monoxide. Similarly, the percentage in the eight-hour concentration levels of carbon monoxide is almost exactly that of the percentage reduction in total urban carbon monoxide emissions. Concentrations of nonreactive nitrogen oxides and hydrocarbons tend to follow the emissions of these pollutants equally closely.

Changes in Fuel Consumption and Emissions by Alternative Modes

So far in this study we have analyzed the impact of various policies on the consumption of gasoline by automobiles and automotive emissions. Little has been said about the cross-effects which these policies will have on fuel consumption by other transit modes, however. In this section we present analysis intended to suggest the magnitude of these effects. This discussion will proceed in three parts. First we will give a general statement of the problem, and review some attempts to measure these cross effects. Next, we will examine the impact of rationing and gasoline excise tax policies on fuel consumption by public transportation, indicating the assumptions and methodology used to infer our results. Third, we will consider increases in emissions from alternative urban modes.

General Discussion of This Problem

All of the policies analyzed in this study are aimed at reducing the automotive consumption of gasoline. Pursuing these methods to reduce automotive fuel consumption

will certainly affect the frequency with which individuals choose to use the public transportation services available in all urban areas. Consider an increase in the federal excise tax on gasoline, causing people to consume less gasoline. One way to economize on gasoline is to take the bus instead of a car to work.

Thus, analysis of the fuel conservation impact of these policies must take account of the effects which they have on non-automotive fuel consumption. Because a policy-induced reduction in auto use will lead to an increase in the use of public transportation, we have overstated the reduction in fuel consumption that will result from the policies in question. It is more difficult, however, to determine the size of this overstatement. This depends on how individuals choose among alternative transport modes for various kinds of trips, and how their choices are affected by changes in the relative costs and convenience of travel of alternative modes.

Estimation of the intra-city demand for travel on alternative modes as a function of the line-haul costs and travel times associated with these modes has been attempted in a previous CRA study.[1] Unfortunately, problems encountered in the course of the study prevented determination of estimates of the cross-effect which an increase in the cost of travel by auto has on demand for travel by public transit. These cross-elasticities were ultimately constrained to be zero. To our knowledge, there exist no direct estimates of these cross-effects

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[1]Thomas Domencich, Gerald Kraft, and Jean-Paul Valette, "Estimation of Urban Travel Behavior: An Economic Demand Model," *Highway Research Record* (No. 238, 1968).

for intra-city travel. While much work has been done on the modal shift effect in inter-city travel,[1] it is not directly applicable to this problem. Inter-city travel has quite different attributes from intra-city travel, including the relative costs in time and money of alternative modes, trip and occupancy patterns and, perhaps most important, availability of different modes. All of these considerations suggest that cross-elasticities for inter-city travel would be quite different from those for intra-city travel. The assumptions we make below to put bounds on the cross-elasticities for urban travel are also appropriate to inter-city travel. To the extent that alternative inter-city modes use more fuel or emit more pollutants per passenger mile than intra-city alternatives, the calculations below will understate somewhat the increase in fuel use and emissions from drivers changing modes. The error is likely to be small, however.

Another approach to this problem, which has been used by CRA in other work, is to infer cross-elasticity values from direct estimates of the own-elasticity and assumed invariance of overall travel demand. The basic idea is best illustrated by the case of work trips. It is reasonable to assume that no one quits a job or changes residence in response to an increase in the price of gasoline. Thus, the total passenger miles of travel on trips to work do not change with the price of gasoline. We may assume then that the reduction in passenger miles traveled by automobile is offset by a one-for-one increase in passenger miles traveled by public transit. Since we know the price

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[1]See, for example, Richard Quandt, ed., *The Demand for Travel: Theory and Measurement* (Lexington, Mass.: D. C. Heath and Company, 1970).

elasticity of demand for gasoline and the average fuel economy of the auto stock, we can translate a gasoline price increase into a decrease in vehicle miles traveled by auto. If the auto occupancy rate were constant, we could then determine the decrease in auto passenger miles traveled and the consequent increase in transit passenger miles traveled.[1] Assuming that the fuel efficiency of the transit system (measured in gallons per passenger mile) remains constant, we have a complete link from the initial gasoline price change to the resultant increase in transit fuel consumption. While some of these assumptions are relaxed below, this is the basic procedure we follow in analyzing the effect which the modal shift will have on gasoline consumption.

The Effect of Rationing and Gasoline Excise Tax Increases on Fuel Consumption by Public Transit

To a large extent the quantities of fuel consumed by automobiles and public transit systems are not directly comparable. Autos run almost exclusively on gasoline, whereas over 80 percent of urban buses use diesel fuel. Thus the modal shift in intra-urban travel resulting from these policies will cause a decline in gasoline consumption and an increase in diesel consumption.

In this section we give estimates which bound the size of the actual modal shift effect on transit fuel consumption. The bounds will be generated by making alternative assumptions about the response of the overall

[1]Auto occupancy rate will, in general, increase in response to these policies, and we use an estimate of this increase in the calculations below.

demand for travel to an increase in gasoline price. The actual response will be seen to lie between these two extremes. In this way we can determine the maximum amount by which our previously reported estimates of the policy-induced reduction in fuel consumption overstate the actual reduction that will occur.

We restrict our modal shift analysis to intra-urban travel, as discussed in the preceding section. Further, we assume that the shift of travel from auto to mass transit will cause an equivalent increase in the number of passenger miles of travel by buses alone. This assumption may be justified on the basis of two observations. First, fuel consumption per passenger mile by electric mass transit is only 10 percent higher than that by bus, while buses account for 1.8 times as many passenger miles of urban travel as does electric transit.[1] Consequently, this assumption understates energy use per passenger mile by, at most, less than 4 percent. Second, the increased ridership of public transit will require expansion of capacity. Although subway systems may add trains, no new subway systems will be constructed by 1987 in response to these policies. Thus, the bulk of increased passenger miles of travel will be absorbed by increasing the size of the intra-urban commercial bus fleets.

If the price of gasoline increases, we can put two bounds on the response of total travel. First, the total demand for travel cannot increase. That is, an increase

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[1]Eric Hirst, *Energy Intensiveness of Passenger and Freight Transport Modes: 1950-1970* (Oak Ridge, Tennessee: Oak Ridge National Laboratory, April 1973).

in the price of gasoline could not lead to people desiring to make more frequent or longer trips than they made before. This follows both from common sense and basic economic theory. Secondly, the reduction in total travel will not exceed the reduction in auto travel resulting from the tax increase. This is plausible because the cost of other travel modes has not changed, so there is no reason that they should lose ridership by virtue of auto travel becoming more expensive.

Therefore, the reduction in total passenger miles of travel must be between zero and that quantity implied by the fall in auto fuel consumption. From this conclusion we may infer bounds on the size of the increase in transit fuel consumption resulting from the modal shift in the following way: If the reduction in total travel is equal to the reduction in auto travel, then there is no modal shift and consequently no increase in transit fuel consumption. Conversely, if the reduction in total travel is zero, then the increase in transit travel is equal to the reduction in auto travel.

From the previous analysis, we estimated the reduction in VMT's due to these policies. The increased price of gasoline will encourage car pooling, increasing the average auto occupancy rate. However, the elasticity of auto occupancy (by trip purpose) with respect to increased auto travel costs has been estimated elsewhere by CRA.[1] By adopting this estimate, we can determine the reduction in passenger miles of auto travel resulting

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[1]The overall elasticity of auto occupancy is -0.11. See Charles River Associates Inc., "Study of Alternatives to Gas Rationing in the Los Angeles Area," in preparation for the Environmental Protection Agency under Contract #68-01-2235.

from the policies, and hence the equivalent increase in passenger miles of transit travel.

At this point, we can convert the increase in transit ridership into an increase in fuel consumption by using the fuel efficiency of the public transit mode. In 1970 buses consumed about 0.027 gallons of fuel per passenger mile, using an average load factor of 18 percent.[1] It is necessary to assume that bus fuel efficiency remains constant after the increase in ridership. It is likely that the fuel efficiency will increase however, since increased ridership will probably mean a greater load factor for intra-urban bus travel. Nonetheless, this possible understatement of transit fuel efficiency is consistent with our desire to give an upper bound on the size of increase in transit fuel consumption.

On the basis of the above observations, we can now calculate an upper bound on the fraction of fuel savings stemming from reduced auto use which is offset by the modal shift effect. Our assumption of no reduction in total travel demand requires that total passenger miles of travel be conserved. Thus the reduction in auto passenger miles leads to an equivalent increase in transit passenger miles. Assuming both fuel efficiency parameters constant (in gallons of fuel per auto or transit passenger mile of travel), the ratio of the quantity of fuel conserved in auto travel to the quantity of increased fuel usage in transit travel is simply the ratio of gallons per passenger mile in transit to gallons per passenger mile in auto travel. Since transit is more fuel-efficient than auto travel, fuel is still conserved, even though total travel remains constant. As indicated

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[1]Eric Hirst, *op. cit.*, Table 6, p. 14.

earlier, 0.027 gallons per passenger mile are consumed in urban bus transit, while the averate auto fuel efficiency for urban travel is approximately 0.048 gallons per passenger mile.[1] Thus the shift effect could offset fuel conservation from reduced auto use by as much as 56 percent. Note that this percentage increase is independent of the size of the reduction in gasoline consumption by auto, because of the assumption of conservation of passenger miles. It should be emphasized that this figure almost certainly overstates the offsetting effect of the modal shift, but a tighter estimate is not possible without further empirical investigation.

Using the methods described above, we can also give upper bounds on the increase in fuel consumption by transit associated with each of the excise tax policies and the rationing policy. The rationing policy is, of course, equivalent for purposes of this calculation to an excise tax policy achieving the same reduction in fuel consumption. Since these calculations depend on the base price of gasoline assumed and the value of the elasticity of gasoline demand utilized, Table 4-20 presents results for all four policies under the pre-embargo and post-embargo base gaso-

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[1]Using an average fuel efficiency for all auto travel of 13.5 vehicle miles per gallon with a relative gallons per mile in urban vs. rural travel of 1.42, a rural share of VMT of 0.57, and an average urban occupancy rate of 1.9 passengers per vehicle, one arrives at the cited figure. For overall fuel efficiency, see FHWA, *Highway Statistics*, 1972, Table VM-1, p. 52; the relative urban auto fuel efficiency is taken from *1975 Gas Mileage Guide for New Car Buyers*, EPA; the rural share is given in *Nationwide Personal Transportation Study*, Vol. 8, 1969; finally, one finds urban and rural vehicle occupancy rates in Eric Hirst, *op. cit.*, p. 32.

line price assumptions, using the low, medium, and high sensitivity estimates of the gasoline demand elasticity. We assume that base transit fuel consumption remains constant at 548.3 million gallons per year.[1] While the rapid growth of the auto as a means of intra-urban travel has caused a steady decline in the total passenger miles of travel by transit, it seems rather unsafe to project such a continued relative growth of auto transit for future years. For this reason, we assume constancy of the absolute level of transit ridership. Though transit's relative share of total urban travel is thus assumed to continue to decline, it declines at a slower rate than has historically been the case.

Because only 7.5 percent of all urban passenger miles of travel occur on public transit, even a small relative decline in auto travel will cause a large percentage increase in transit fuel consumption. Thus, Table 4-20 indicates that a $0.10 excise tax could have the effect of more than doubling transit fuel consumption by 1981. With a $0.50 increase in the price of gasoline, fuel consumption by public transit could be as much as 10 times greater by 1987 than it is now. It would seem that more precise estimates of these effects would have a substantial payoff in terms of more intelligent policy making in the near future.

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[1]This number was derived by summing the gallons of fossil fuel and the gallon-equivalents of electricity consumed by transit in 1974. Electricity used was converted by multiplying by 10,500 BTU/kwh (average heat rate in 1971, from *Steam-Electric Plant Construction Cost and Annual Production Expenses*, 1971, p. XXVIII) and dividing the result by 136,000 BTU/gal. Fuel use was taken from American Public Transit Association, *'74-'75 Transit Fact Book* (March 1975), p. 29.

Table 4-20

MAXIMUM INCREASES IN FUEL CONSUMPTION BY PUBLIC TRANSIT IN RESPONSE TO POLICIES REDUCING AUTOMOTIVE CONSUMPTION OF GASOLINE
(Millions of Gallons)

Policy on Gasoline	Low Gasoline Consumption[1]	Medium Gasoline Consumption[2]	High Gasoline Consumption[3]
$0.10/gal. surtax			
1975	163.7	66.1	0
1981	1227.5	757.0	11.0
1987	1699.6	1074.2	199.9
$0.25/gal. surtax			
1975	410.7	173.1	0
1981	3079.8	1897.9	339.9
1987	4392.3	2697.4	497.3
$0.50/gal. surtax			
1975	818.4	335.2	0
1981	6154.9	3789.6	678.3
1987	8775.2	5391.7	996.2
Rationing			
1975	1410.1	849.8	0
1981	3202.6	2958.7	1438.4
1987	4392.3	3994.2	2108.8

NOTES:

[1]Assumes post-embargo gasoline prices and high elasticity estimates;

[2]Assumes post-embargo gasoline prices and medium elasticity estimates;

[3]Assumes pre-embargo gasoline prices and low elasticity estimates.
Fuel consumption by transit is in units of diesel fuel; electricity consumed has been converted to diesel equivalents as described in footnote 1 on page 4-60.

Increase in Emissions from Alternative Sources

Because so little is known about cross elasticities between travel by automobile and by other kinds of transportation, there is a wide range in the possible increase of emissions due to travelers shifting from auto to alternative types of transportation. On the one hand, if these cross elasticities are zero, there will be no increase in fuel consumption by alternative transportation modes and, hence, no increase in emissions from these modes. At the other extreme, if the entire reduction in automobile passenger miles is diverted onto public transportation, the increase in fuel consumption will be as shown in Table 4-3, while the increase in emissions will depend on the relative emissions per passenger mile of buses and automobiles. These emission factors, in grams per passenger mile, are shown in Table 4-21. The values for light-duty vehicles are shown for 1975, 1981 and 1987, based on the base forecasts. The bus emissions per passenger mile assume that average occupancy (defined as passenger miles divided by vehicle miles) was 9.29, its value in 1970.[1] The emissions

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[1]This figure was derived by dividing total bus passenger miles (Eric Hirst, *op. cit.*, p. 14) by total bus vehicle miles (American Public Transit Association, *'74-'75 Transit Fact Book*, p. 26). This estimate agrees quite closely with a figure derived for 1969, 8.99, according to the following procedure. We subtracted intercity bus passenger miles from total bus passenger miles (*Automobile Facts and Figures, 1973-74*, pp. 34-36) to obtain an estimate of urban bus passenger miles. This estimate was then divided by total urban commercial bus miles, taken from the Federal Highway Administration, *Highway Statistics*, 1969 Edition, p. 73.

Average occupancy was slowly declining over the 1960-1970 period, so that use of a 1970 figure probably overstates the base period occupancy rate. The occupancy rate would, of course, tend to rise with an increase in bus ridership.

Table 4-21

EMISSIONS PER PASSENGER MILE OF BUS AND LIGHT-DUTY VEHICLES. 1975, 1981 and 1987 (Grams Per Mile)

	Bus (All Years)	Light-Duty Vehicles		
		1975	1981	1987
CO	3.63	23.18	5.29	2.17
NO_x	3.34	1.98	0.84	0.36
HC[1]	0.49	3.28	1.22	0.58

[1]Excludes diurnal evaporative emissions.

SOURCES:

Heavy-duty gasoline emission factors: *Compilation of Air Pollutant Emission Factors,* p. 3.1.5-2.

Heavy-duty diesel emission factors: *Ibid.*, p. 3.1.4-3.

Share of bus emissions from diesel: calculated as diesel fuel as fraction of total fuel * diesel emission factors plus (1 - diesel fuel fraction) * gasoline emission factors; 1972 fuel breakdown from American Transit Association, *'73-'74 Transit Fact Book,* Table No. 16, p. 19.

Passenger miles per vehicle mile:

Buses: Average occupancy of 9.29 derived by dividing 1970 bus passenger-miles, from Hirst, *op. cit.*, p. 14, by 1970 bus vehicle miles, from *'74-'75 Transit Fact Book,* p. 26.

per passenger mile for light-duty vehicles assume an average occupancy of 1.9, the average for all urban automobile trips in 1969.[1]

Average emission and occupancy rates are used here because they reflect what can be expected from policy changes that, in large measure, affect urban gasoline consumption proportionately at all times of day. These figures would not necessarily, therefore, be appropriate for evaluating policies that affect, say, rush-hour traffic only, when bus occupancy rates are very high. Diversion of a single-passenger trip to transit at peak hours might have quite different implications from one during offpeak hours.

These numbers suggest, surprisingly, that the reduction in emissions from diverting a passenger from auto to bus is not very great, assuming that the passenger travels the same number of miles by both modes. For example, the emissions per passenger mile of nitrogen oxides are greater for buses than for automobiles in every forecast year.

The short-run effects on carbon monoxide and hydrocarbon emissions, however, favor bus over auto. By 1981, carbon monoxide emissions per passenger mile by bus are about 70 percent of those by light-duty vehicles, but by 1987 buses will have higher emission rates of carbon monoxide per passenger mile than light-duty vehicles. Hydrocarbon emissions per passenger mile are roughly the same by 1987. This shift over time occurs because the emission standards for light-duty vehicles are reduced sharply over

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[1]This number was taken from the *Nationwide Personal Transportation Study*, Report No. 1, Table 2, p. 10.

the forecast period, while the emission standards for heavy-duty gasoline and diesel powered vehicles do not change.

Even if the 1975 California standards for heavy-duty vehicles were adopted nationally, the conclusions presented here would not require substantial revision. Only the nitrogen oxide standard is substantially stricter than the U.S. standard; even that standard implies that bus emissions of nitrogen oxides per passenger mile will be above those of autos throughout the forecast period. Table 4-22 presents a comparison of the California and U.S. standards from 1975 on.

Use of the average auto occupancy rate is based on the assumption that the reduction in auto trips comes about from a proportionate reduction in all trips at all occupancy levels. On intuitive grounds, it is not clear whether single-passenger or multi-passenger auto trips are most likely to be diverted to transit. On the one hand, it might be that those who value the convenience and privacy of driving alone will continue to do so at higher gasoline prices, while carpoolers will shift to transit. On the other hand, a given increase in the cost of an auto trip represents a greater cost per person for the single-occupant trip than for the carpool member, leading to a disproportionate reduction in single-occupant trips. We are not aware of any studies that provide evidence on the substitution of transit trips for auto trips with different numbers of passengers. It seems reasonable to assume, however, that the appropriate occupancy rate to use in calculating the change in emissions lies somewhere between the average occupancy rate and single

Table 4-22

EMISSION STANDARDS, HEAVY-DUTY VEHICLES, 1975

	Grams Per Vehicle Mile						Grams Per Passenger Mile	
	Gasoline		Diesel		Weighted Average			
	U.S.	CA	U.S.	CA	U.S.	CA	U.S.	CA
CO	130	81	20.4	20	33.7	27.4	3.63	2.95
HC	13	4.1	3.4	4.1	4.6	3.1	0.49	0.33
NO_x	9.2	2.8	34	15	31.0	13.5	3.34	1.45

SOURCES AND ASSUMPTIONS:

(1) U.S. and California gasoline standards: Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors*, p. 3.1.4-3.

(2) U.S. diesel standards: *ibid.*, p. 3.1.5-2

(3) California diesel standards: telephone conversation with Joel Horowitz of the Environmental Protection Agency, March 20, 1975. Horowitz disaggregated the combined standard for HC and NO_x.

(4) In the computation of the weighted average, diesel was weighted by 0.879 and gasoline by 0.121. These weights represent the share of fuel consumption in 1973 by each type of bus (propane assumed to be included with gasoline). *'74-'75 Transit Fact Book*, p. 29.

(5) Vehicle occupancy rate of 9.29 was assumed.

occupancy. Using both rates will, at least, provide bounds on the likely range.[1] If, therefore, we assume that all of the reduction in automobile passenger miles occurs from single-occupant vehicles, the relevant emission rates for automobiles, for purposes of comparison, are those per vehicle mile. These rates for the different pollutants for the forecast periods are shown in Table 4-23. Under the assumption that all of the diversion in automobile passenger miles is from single-occupant automobiles, the comparison is much less ambiguous. The emissions per passenger mile of buses are about the same as those of single-occupant autos by 1987 for carbon monoxide and hydrocarbons. Emissions of nitrogen oxides are higher for both 1981 and 1987. There is, however, a dramatic contrast between the short-run carbon monoxide emissions of automobiles and those of buses.

Of course, if the demand for bus transportation increases, average occupancy will tend to increase, particularly in the short run. After the bus system has had time to add additional vehicles, the average occupancy rate will fall, although it may still be above the level before the change. From 1950 to 1970, for example, when bus passenger miles fell from 29 to 13 billion, the average occupancy rate fell only from 12.63 to 9.29.[2] If we assume that, once

[1] If those who switch from autos to transit are carpoolers with an average occupancy rate higher than 1.9, then bus emissions per passenger-mile will be even greater relative to those from the reduced auto trips. For purposes of illustration, if the average auto occupancy rate of those switching to transit is 3, the relevant auto emission rates per passenger-mile become:

	1975	1981	1987
Carbon monoxide	14.67	3.35	1.37
Nitrogen oxides	1.26	0.53	0.23
Hydrocarbons	2.08	0.77	0.37

Comparison of these figures with those in Table 4-22 shows that bus emissions per passenger-mile of carbon monoxide and nitrogen oxides exceed those of autos by 1981. However, this assumption about auto occupancy seems implausible.

[2] Calculated from Hirst, *loc. cit.*, and American Public Transit Association, *loc. cit.*

Table 4-23

EMISSION RATES PER PASSENGER MILE, SINGLE-OCCUPANT LIGHT-DUTY VEHICLES
(Grams Per Mile)

	1975	1981	1987
Carbon Monoxide	44	10.05	4.12
Nitrogen Oxides	3.77	1.60	0.68
Hydrocarbons[1]	6.23	2.31	1.10

[1]Excludes diurnal evaporative emissions.

SOURCE: Base line forecasts.

adjustments to bus capacity are made, the maximum occupancy rate is 12.63, the bus emission rates per passenger mile become:

	g/passenger mile
Carbon Monoxide	2.67
Hydrocarbons	2.45
Nitrogen Oxides	0.36.

Hence none of the qualitative assertions made above are affected, although quantitatively the lower rates per passenger mile reduce bus emissions relative to autos.

The increases in emissions of carbon monoxide, hydrocarbons and nitrogen oxides by buses are shown in Tables 4-24, 4-25, and 4-26, respectively. These increases are based on the assumption that total passenger miles are conserved, and hence represent the maximum increase in bus emissions. They do not include emissions from electricity generation needed to power subway lines, since these emissions occur at stationary sources and include different pollutant types. The overall impact of these policies on air quality depends critically on the cross elasticity of demand between automobiles and other modes of transportation. We were unable, within the scope of this study, to do original research into this question, but it is important to determine both emissions and fuel use from alternative modes of transportation. Moreover, the numbers presented suggest that it might be useful to control exhaust emissions from heavy-duty vehicles as well, particularly if any policy is contemplated that will divert substantial amounts of travel from automobiles to public transportation. Since World War II, public transportation as a fraction of total passenger miles has been falling sharply and steadily, so that, in the absence of policies to reverse this trend, controlling emissions from these vehicles more strictly would probably not make

Table 4-24

MAXIMUM INCREASES IN EMISSIONS OF CARBON MONOXIDE BY TRANSIT BUSES IN RESPONSE TO POLICIES REDUCING AUTOMOTIVE CONSUMPTION OF GASOLINE

(Millions of Kilograms)

Policy on Gasoline	Low Gasoline Consumption[1]	Medium Gasoline Consumption[2]	High Gasoline Consumption[3]
$0.10/gal. surtax			
1975	13.09	5.29	0
1981	98.18	60.54	0.88
1987	135.93	85.91	15.99
$0.25/gal. surtax			
1975	32.85	13.84	0
1981	246.32	151.79	27.19
1987	351.30	215.74	39.77
$0.50/gal. surtax			
1975	65.46	26.81	0
1981	492.27	303.09	54.25
1987	701.84	431.23	79.68
Rationing			
1975	112.78	67.97	0
1981	256.14	236.64	115.04
1987	351.30	319.46	168.66

NOTES:

[1]Assumes post-embargo gasoline prices and high elasticities;

[2]Assumes post-embargo gasoline prices and medium elasticities;

[3]Assumes pre-embargo gasoline prices and low elasticities.

SOURCES AND ASSUMPTIONS:

(1) Fuel consumption is by buses only; bus fuel consumption is assumed to be the same proportion of total transit fuel consumption as in 1974;

(2) Total increase in transit fuel consumption taken from Table 4-20;

(3) Miles per gallon was assumed to be 4.10 (American Public Transit Association, *'74-'75 Transit Fact Book*, p. 30); and

(4) Emissions per vehicle mile were derived from Table 4-21.

Table 4-25

MAXIMUM INCREASES IN EMISSIONS OF HYDROCARBONS BY TRANSIT BUSES IN RESPONSE TO POLICIES REDUCING AUTOMOTIVE CONSUMPTION OF GASOLINE

(Millions of Kilograms)

Policy on Gasoline	Low Gasoline Consumption[1]	Medium Gasoline Consumption[2]	High Gasoline Consumption[3]
$0.10/gal. surtax			
1975	1.60	0.65	0
1981	11.98	7.39	0.11
1987	16.59	10.48	1.95
$0.25/gal. surtax			
1975	4.01	1.69	0
1981	30.06	18.52	3.32
1987	42.87	26.33	4.85
$0.50/gal. surtax			
1975	7.99	3.27	0
1981	60.07	36.99	6.62
1987	85.65	52.62	9.72
Rationing			
1975	13.76	8.29	0
1981	31.26	28.88	14.04
1987	42.87	38.98	20.58

NOTES:

[1]Assumes post-embargo gasoline prices and high elasticities;

[2]Assumes post-embargo gasoline prices and medium elasticities;

[3]Assumes pre-embargo gasoline prices and low elasticities.

SOURCES AND ASSUMPTIONS:

(1) Fuel consumption is by buses only; bus fuel consumption is assumed to be the same proportion of total transit fuel consumption as in 1974;

(2) Total increase in transit fuel consumption taken from Table 4-20;

(3) Miles per gallon was assumed to be 4.10 (American Public Transit Association, *'74-'75 Transit Fact Book*, p. 30); and

(4) Emissions per vehicle mile were derived from Table 4-21.

Table 4-26

MAXIMUM INCREASES IN EMISSIONS OF NITROGEN OXIDES BY TRANSIT BUSES IN RESPONSE TO POLICIES REDUCING AUTOMOTIVE CONSUMPTION OF GASOLINE

(Millions of Kilograms)

Policy on Gasoline	Low Gasoline Consumption[1]	Medium Gasoline Consumption[2]	High Gasoline Consumption[3]
$0.10/gal. surtax			
1975	12.08	4.88	0
1981	90.58	55.86	0.81
1987	125.41	79.27	14.75
$0.25/gal. surtax			
1975	30.31	12.77	0
1981	227.26	140.05	25.08
1987	324.11	199.04	36.70
$0.50/gal. surtax			
1975	60.39	24.73	0
1981	454.17	279.63	50.05
1987	647.52	397.85	73.51
Rationing			
1975	104.05	62.71	0
1981	236.32	218.32	106.14
1987	324.11	294.73	155.61

NOTES:

[1]Assumes post-embargo gasoline prices and high elasticities;

[2]Assumes post-embargo gasoline prices and medium elasticities;

[3]Assumes pre-embargo gasoline prices and low elasticities.

SOURCES AND ASSUMPTIONS:

(1) Fuel consumption is by buses only; bus fuel consumption is assumed to be the same proportion of total transit fuel consumption as in 1974;

(2) Total increase in transit fuel consumption taken from Table 4-20;

(3) Miles per gallon was assumed to be 4.10 (American Public Transit Association, *'74-'75 Transit Fact Book*, p. 30); and

(4) Emissions per vehicle mile were derived from Table 4-21.

much difference. With rising fuel prices, however, the absolute decline in transit passengers stopped in 1973. In 1974, transit passengers actually increased; total passengers rose above the 1971 level.[1] If policies are undertaken that will divert substantial traffic to these modes, it is important to control their emissions better, as the emissions per passenger mile are by no means negligible, even compared with those from automobiles.

Secondary Impacts

For the purposes of this report, the primary impacts of the policies considered have been the changes in gasoline consumption, emissions, and ambient air quality. There are, however, secondary impacts associated with these different policies. In particular, we discuss in this section differences in the secondary impacts associated with increases in the excise tax and gasoline rationing. We consider three secondary impacts: administrative costs associated with each policy; changes in the distribution of income due to these policies; and incentives for efficiency and technical change associated with each of these policies. Accurate measurement of the quantitative importance of each of these impacts is a difficult and complex job, and it is beyond the scope of this study. However, where magnitudes can be roughly quantified, we present these estimates.

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[1]American Public Transit Association, *'74-'75 Transit Fact Book*, pp. 16-17.

Administrative Costs

We are interested here in the marginal administrative cost of the different policies, that is, what additional administrative cost will be imposed if these policies are adopted. The question is posed this way because, to the extent that the administrative machinery has already been set up for other purposes, it does not seem appropriate to attribute the cost of the existing structure to the changes in policy.

There is already a federal excise tax on gasoline, with an administrative structure to collect the tax and ensure compliance. For this reason, it seems probable that an increase in the level of this tax would lead to, at most, trivial changes in the cost of administering the increase. There might be some increase because, at higher tax levels, there would be greater incentives to evade or to cheat on tax, but it seems probable that the existing apparatus could collect the additional federal excise tax revenues.

There does not exist, at present, an equivalent apparatus for coupon rationing. Administrative costs would be incurred in performing several functions associated with coupon rationing. First, the coupons would have to be printed and policed. That is, the same kinds of safeguards against counterfeiting U.S. currency would, to a lesser extent, be necessary to ensure that the coupons (with an estimated market value in 1975 between $0.86 and $2.64 per gallon) would not be counterfeited. Second, there would have to be a distribution network, with provisions to ensure that people entitled to receive coupons receive their exact allotment. Third, with coupons legally transferable, there would need to be a mechanism to ensure that, once used, they could not be reused. These and other difficulties associated with coupon rationing can, in principle, be resolved. However, they do impose additional administrative costs.

When coupon rationing was being considered during the gasoline shortage of the winter of 1973-74, it was estimated that the scheme then considered would have an annual cost of at least $1.25 billion. This amount is roughly equivalent to a surcharge of about $0.015 to $0.02 per gallon, or, on another basis, an annual cost of between $12 and $13 per licensed driver. These costs are real costs, in the sense that they represent resources used, rather than a transfer of income from one group in society to another.

In addition to the administrative costs, there would also be transaction costs associated with the buying and selling of coupons. Markets for buying and selling coupons would not arise and function smoothly without some individuals or agencies undertaking what amounts to a brokerage function, that is, standing ready to buy or sell coupons.

It is obviously impossible to predict the costs of organizing and operating a system of coupon exchanges and hence what the costs of coupon transactions will be. However, it is perhaps worth noting in this context the costs of transactions for exchanges with some similarities to coupon exchanges.

At one extreme, transaction costs may be independent of the size of the transaction. An example of such a transaction is the purchase of postal money orders for which the current charge is $0.25 per order. At the other extreme, charges for transactions are often a simple percentage of the value of the transaction. Examples of such charges are the 1 percent service charge for American Express Travelers Checks and the 2 to 3 percent service charge to buy or sell small quantities of foreign currencies at commercial banks. Intermediate between these extremes are instances where the transaction charges are a flat fee plus a percentage of the value of the transaction.

Although it is difficult to estimate the administrative and transaction costs of a coupon rationing scheme, the foregoing considerations suggest the costs could be substantial and much greater than the costs of noncoupon schemes. This in turn suggests that if rationing is expected to be required only for a short period of time, the costs of mounting the necessary administrative machinery may detract seriously from the benefits of coupon rationing relative to alternative schemes. On the other hand, if it is expected that rationing will be necessary for an extended period of time, say substantially more than a year, then the benefits of coupon rationing may well be worth its administrative burden.

Income Distribution

Both coupon rationing and an increase in the excise tax on gasoline result in higher effective prices paid by the consumers of gasoline. The increase in price is direct and immediate in the case of an increase in the excise tax, while, in the case of coupon rationing, it is implicit in the market value of a coupon. As with any transaction, someone pays the higher price and someone else receives it. The distribution of these revenues is different for coupon rationing than for an increase in the excise tax.

With an increase in the excise tax on gasoline, it is clear that the consumers of gasoline are subject to a loss in income that is equal to the increase in the excise tax times the quantity of gasoline consumed after equilibrium is reached.[1] Assuming that this increase in tax revenues is balanced by a

[1]This result is strictly true only if the supply curve is horizontal. If, however, the supply curve is very close to horizontal, then this result holds approximately.

decrease in other taxes, such as the personal income tax, the excise tax redistributes income away from gasoline consumers to the general taxpayer. Of course, in many, perhaps most, cases, the general taxpayer and the consumer of gasoline are the same person, but the principle of redistribution remains the same.

On the other hand, gasoline rationing also involves a redistribution of income, albeit implicit. That is, if it turned out to be the case that each licensed driver consumed exactly his allotted ration of 10 gallons per week, then no income redistribution at all would occur. Because the coupons have a market value, however, gasoline rationing implicitly gives to each licensed driver the value of the coupons (in the policy analyzed here, 520 gallons per year times the coupon price). In this case, therefore, although there is a redistribution of income among the consumers of gasoline (from those who use more than the rationed amount to those who use less), there is no redistribution of income between the gasoline consumers in general and any other category. That is, through the issuing of coupons, the entire value of the increased price of gasoline (due to the mandated reduction in supply) is received by licensed drivers.

As discussed above, the amount of income transferred under increases in the excise tax can be determined by multiplying the excise tax times the gallons of gasoline consumed after the increase is put into effect. This amount will, of course, be different for different years of the forecast period, both because of the exogenous growth in gasoline consumption, on the one hand, and because of the lagged response to price over a period of years. Table 4-27 shows the amount of tax revenues that would be collected from the increase in the excise tax for each of the three forecast years -- 1975, 1981, and 1987 -- under each of the three levels of increase in excise tax analyzed

Table 4-27

ESTIMATED ADDITIONAL TAX RECEIPTS FOR EXCISE TAX POLICIES
IN 1975, 1981, AND 1987
(Billions of Dollars)

Year	Increase in Excise Tax	Sensitivity		
		Low[1]	Medium[2]	High[3]
1975	$0.10/gallon	$10.02	$10.17	$11.01
	$0.25/gallon	$23.33	$24.25	$26.86
	$0.50/gallon	$40.91	$44.59	$51.50
1981	$0.10/gallon	$11.03	$11.71	$13.75
	$0.25/gallon	$18.63	$24.05	$31.97
	$0.50/gallon	$14.98	$30.65	$56.16
1987	$0.10/gallon	$13.17	$14.17	$17.07
	$0.25/gallon	$21.97	$28.31	$39.49
	$0.50/gallon	$ 7.43	$32.52	$68.39

Notes:

[1]Assumes high gasoline prices, high elasticity assumptions.

[2]Assumes high gasoline prices, medium elasticity assumptions.

[3]Assumes high gasoline prices, low elasticity assumptions.

and for the three sensitivity assumptions. This table shows that a tax increase of $0.10 per gallon would result in additional tax receipts of about $10 billion in 1975, $12 billion in 1981, and $14 billion in 1987. A tax increase of $0.25 per gallon roughly doubles these amounts, while an increase of $0.50 per gallon results in much higher tax receipts in 1975 but, for the central estimate, roughly the same receipts in 1981 and 1987. (It should be noted that estimates of receipts under a $0.50 per gallon increase are quite sensitive to price/sensitivity assumptions in the later years. For example, in 1981 the range is between $15 and $56 billion, while by 1987 the range spreads from $7 billion to $68 billion.)

From the available data, it appears that these increases in gasoline tax revenues would be paid by all households roughly in proportion to their incomes. Table 4-28 shows the average daily vehicle miles by households in different income classes.[1] If we assume that average fuel economy per vehicle is roughly the same across income classes, we can estimate gallons of gasoline bought per year by households in each class, also shown in Table 4-28. A $0.10 per gallon surtax would cost those in the lowest income bracket about $35 per year, or roughly 1.2 percent of their income. It would cost those in the $4000 to $9999 bracket about $90 per year, or about 1.3 percent of their income, while those in the next higher bracket would have to pay about $129, or 1.0 percent

[1]The figures used in this section are based on the 1969-1970 *Nationwide Personal Transportation Study*. Both the income ranges and household VMT estimates are understated due to inflation and the growth in real income and in travel. For our purposes, therefore, these ranges should be interpreted as *relative* income classes, rather than as current absolute income classes.

Table 4-28

DAILY VEHICLE MILES OF TRAVEL AND YEARLY GASOLINE CONSUMPTION BY HOUSEHOLDS IN DIFFERENT INCOME CLASSES

Income Class	(1) Average Daily Vehicle Miles, Earning a Living	(2) Average Daily Vehicle Miles, All Purposes	(3) Yearly Gasoline Consumption, in Gallons
<$4000	4.0	12.9	346.2
$4000-9999	13.3	33.5	899.1
$10,000-14,999	21.1	47.9	1285.5
>$15,000	31.7	66.9	1795.5

SOURCES:

(1) and (2): *Nationwide Personal Transportation Study*, Report No. 7, "Household Travel in the United States," (December 1972), p. 21.

(3): Translation of daily vehicle miles of travel into yearly gallons of gasoline consumption assumed (1) 365 days per year, and (2) 13.6 miles per gallon (Federal Highway Administration, *Highway Statistics 1969*, p. 73).

of their income. Those in the highest bracket would have to pay about $180 per year, or 1.2 percent.[1]

Gasoline taxes higher than $0.10 per gallon would take a proportionately larger share of income, but the distribution across income classes would not be affected. It does not appear, therefore, that increases in the gasoline taxes would be regressive, except slightly as between the two middle-income classes.

The implicit amount of income granted to consumers of gasoline via a coupon rationing scheme can be computed as the market price of the coupon times the allowed gasoline consumption. For a rationed amount of 10 gallons per licensed driver per week, Table 4-29 shows the implicit income for each of the three forecasted years. These amounts are different in each year, both because of the increase in licensed drivers and because the coupon price changes over time, as gasoline consumers respond to the higher gasoline prices in a delayed fashion.

Note that, because demand is much more elastic in the long run, the coupon price falls sharply from 1975 to 1981 (and only

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[1]This discussion ignores the decrease in consumption brought about by higher gasoline prices. We are not aware of any data on elasticities by income class but if, as seems reasonable, those in the lower brackets cut back their purchases proportionately more than those in the higher brackets, the tax might even exact a larger percentage of upper-bracket income than lower-bracket income. The calculations are also somewhat confused by the large width of the income classes -- it is hard to know, for example, what the average income of those in the highest and lowest brackets is. In calculating these percentages, we have assumed the following average household incomes for the different classes: $3000, $7000, $12,500 and $16,000.

Table 4-29

ESTIMATED VALUE OF RATIONING COUPONS FOR DIFFERENT SENSITIVITY ASSUMPTIONS IN 1975, 1981, AND 1987

Year		Low[1]	Medium[2]	High[3]
1975	Coupon Price[4]	$ 0.86	$ 1.27	$ 2.64
	Aggregate value of coupons[5]	$56.10	$82.77	$172.15
1981	Coupon Price[4]	$ 0.26	$ 0.39	$ 1.06
	Aggregate value of coupons[5]	$16.42	$29.88	$ 80.49
1987	Coupon Price[4]	$ 0.25	$ 0.37	$ 1.06
	Aggregate value of coupons[5]	$21.97	$33.27	$94.66

Notes:

[1]Assumes high gasoline prices, high sensitivity.

[2]Assumes high gasoline prices, medium sensitivity.

[3]Assumes low gasoline prices, low sensitivity.

[4]In dollars per gallon, 1975 prices.

[5]In billions of dollars per year.

very slightly from 1981 to 1987), as does the aggregate value of the coupons. After 1981, however, the aggregate value of the coupons increases as the growth in gasoline consumption outweighs the slight decline in the coupon price. For the medium elasticity assumptions, the total value of the coupons distributed to licensed drivers falls from about $83 billion in 1975 to about $30 billion after 1981. The estimated aggregate value of the coupons does, however, vary substantially with the elasticity/price combination assumed, as does the value of the coupons themselves.

As shown above, households in higher income classes drive more. Households in the higher income classes also tend to have more licensed drivers.[1] The net impact of coupon rationing on income distribution is not immediately apparent. Table 4-30 shows desired gasoline consumption and coupon entitlements for households in different income classes, while Table 4-31 relates actual consumption under rationing to entitlements, on the assumption that all households reduce their desired consumption by the same proportion.[2]

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[1]The sharp increase in licensed drivers per household as income increases is presumably because the expense of learning to drive is incurred only if a car is likely to be available, and the number of cars per household increases sharply with income. Another source of this correlation may be that those physically unable to drive (because of age or infirmities) also tend to have lower incomes. If coupon rationing is adopted on the basis of licensed drivers, the value of the coupons will provide an incentive for those without licenses but capable of driving to obtain them. In this case, coupon rationing will lead to a greater redistribution of income from the upper to the lower income classes than estimated below.

[2]If those in the lower brackets reduce their consumption more than proportionately, then the income redistribution from upper to lower classes will be greater than estimated below.

Table 4-30

COMPARISON OF DESIRED GASOLINE CONSUMPTION AND COUPON ENTITLEMENTS, BY INCOME CLASS
(Gallons of Gasoline Per Household Per Year)

Income Class	(1) 1969 Consumption	(2) 1975 Desired Consumption	(3) Average Number of Licensed Drivers per Household	(4) Entitlements per Household	(2)/(4)
<$4000	346.2	443.5	0.75	390.0	1.14
$4000-9999	899.1	1151.7	1.64	852.8	1.35
$10,000-14,999	1285.5	1646.7	2.03	1055.6	1.56
>$15,000	1795.5	2300.0	2.36	1227.2	1.87

SOURCES:

(1): Col. (3) of Table 4-28.

(2): Estimated as 1969 consumption times the ratio of 1975 forecasted consumption (post-embargo prices) to 1969 consumption. Forecasted consumption of 104.81 billion gallons is shown in Table 3-10; 1969 consumption of 81.79 billion gallons is shown in Table 3-1.

(3): Average number of licensed drivers per household was derived from *Nationwide Personal Transportation Study*, Report No. 11, "Automobile Ownership" (December 1974), p. 22.

(4): Estimated as Col. (3) times 520 gallons per year.

Table 4-31

COMPARISON OF ESTIMATED
HOUSEHOLD CONSUMPTION AND ENTITLEMENTS
(Gallons per Household per Year)

Income Class	(1) Consumption under Coupon Rationing	(2) Coupon Entitlements	(1)/(2)
<$4000	306.5	390	0.785
$4000-9999	795.8	852.8	0.933
$10,000-14,999	1137.9	1055.6	1.077
>$15,000	1589.3	1227.2	1.295

SOURCES:

(1): Estimated on the assumption that all households reduce their desired consumption in the same proportion. Average licensed drivers per household are 1.41, so that average household entitlements are 734.9 gallons per year, while average desired consumption in 1975 is 1062.2 gallons. The entries in Col. (2) of Table 4-30 were multiplied by (734.9/1062.2), or 0.691, to arrive at the entries in Col. (1).

(2): Taken from Col. (4) of Table 4-30.

Table 4-32 shows the estimated household payments and receipts for coupons by income class. The amounts do not appear large. Households in the two lower income classes would receive, on average, $40 to $100 from the sale of their unused coupons in 1975, but $20 to $30 by 1981. Those in the highest bracket would pay about $450 in 1975 for additional coupons, but less than $150 by 1981. In summary, then, coupon rationing would redistribute income from the upper to the lower income brackets, but the amounts are not significant.

Incentives for Efficiency and Technical Change

For equivalent levels of gasoline rationing and excise tax increases -- that is, for levels of rationing for which the market price of the coupon (disregarding transaction costs) is the same as the increase in the excise tax -- both coupon rationing and an increase in the excise tax provide similar incentives for efficiency and technical change. Under both sorts of policy, drivers have incentives to use gasoline efficiently and to cut back on their consumption. Further, under both sets of policies, automobile manufacturers have an incentive to provide more efficient engines and technologies that use less fuel per mile, as, at higher prices, drivers naturally tend to be more concerned about fuel economy of new cars. This concern may also lead manufacturers to invest resources in discovering improvements in existing engine designs or, perhaps, even radical new designs, that will lead to more efficient fuel consumption. It is clear that quantification of these incentives is a very difficult job, beyond the scope of this report. However, it also seems clear that these policies provide incentives for efficiency in technical change that move in the direction of reduced fuel consumption. They do not provide incentives for reducing emissions below the level required by legislated standards.

Table 4-32

ESTIMATED TRANSFERS PER HOUSEHOLD BY
INCOME CLASSES UNDER COUPON RATIONING

Income Class	(1) Net Coupons Bought[1]	(2) 1975 Net Payments	(3) 1981 Net Payments	(4) 1987 Net Payments
<$4000	-83.5	-$106	-$ 33	-$ 31
$4000-9999	-57.0	-$ 72	-$ 22	-$ 21
$10,000-14,999	82.3	$105	$ 32	$ 30
>$15,000	362.1	$460	$141	$134
Price per Coupon		$ 1.27	$ 0.39	$ 0.37

NOTES:

[1]Each coupon is assumed to represent one gallon of gasoline. Negative numbers mean a net *sale* of coupons, while positive numbers mean a net *purchase*. Similarly for dollar receipts and payments.

SOURCES:

(1) Table 4-31, Col. (1) - Col. (2).

(2) - (4): Col. (1) times the estimated coupon price, based on post-embargo gasoline prices and medium elasticity estimates; shown in Table 4-28.

5. POLICIES AFFECTING THE STOCK OF CARS

Introduction

In this chapter, we consider two sets of policies, both of which affect fuel consumption, emissions, and air quality through their direct impact on new car sales and their indirect impact on the size and composition of the stock of autos. One set of policies imposes an excise tax on new cars in inverse proportion to their fuel economy. That is, for each mile per gallon less than 20 that an auto achieves in a certain test, it is subject to an excise tax of so many dollars.[1] The second set of policies requires manufacturers to achieve a certain average miles per gallon of their models, where the average is computed as a weighted average based on the share of sales in the preceding year. This latter set of policies directly affects the models offered by automobile manufacturers, while the former set has its immediate impact on the relative prices paid by consumers for different fuel economy classes of automobiles.

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[1]For convenience, we frequently refer in this chapter to these policies as excise taxes based on fuel economy, even though the relationship is an inverse one. We also refer to them as policies based on fuel consumption of new autos, since fuel consumption is the inverse of fuel economy, and the taxes may be thought of as being directly related to fuel consumption. We use these descriptions interchangeably, although we are talking about the same set of policies in both cases.

The rest of this chapter has five main sections. First, we present a qualitative analysis of the effects of these policies. That is, without attempting to assess their impact quantitatively, we explore what can be unambiguously determined about the direction of the effect of these policies. Second, we discuss some practical difficulties in determining the impact quantitatively, along with different approaches that might be used. Third, we present the methods used to determine the quantitative impact. The fourth section presents the results of this analysis. The last section discusses in qualitative terms the impact of potential changes in the structure and the secondary impacts of these policies.

Qualitative Analysis

In this section we present a qualitative analysis of policies which affect new car sales. These policies will have an indirect effect on gasoline consumption and ambient air quality because they will change the fuel economy and emissions characteristics of the stock of automobiles on the road, as well as the size of this stock, after they are put into effect. This analysis traces through the effects which the above policies will have over time, indicating where possible the direction of change in future gasoline consumption and automotive emissions as a consequence of enacting these policies.

In this analysis it will be necessary to distinguish between the qualitative effects which the policies have on gasoline consumption and their effects on automobile emissions. In these policies, unlike those analyzed in Chapter 4,

it is not true that a decline in gasoline consumption will necessarily ensure a decline in emissions. This ambiguity arises because the policies discussed in this chapter alter the vintage distribution of the stock of automobiles. That is, the policies lead to a stock of automobiles with relatively more older cars and relatively fewer new cars than would have been the case in their absence. Since older vehicles emit substantially more pollutants per mile than newer vehicles, this effect will tend to increase automotive emissions, in spite of reduced gasoline consumption.[1] For this reason we shall consider the policies' qualitative impact on gasoline consumption and ambient air quality separately.

Policy Impact on Gasoline Consumption

The results of the qualitative analysis of the policy impact on gasoline consumption differ depending upon whether a short-run or long-run horizon is considered. In the short run, it may be the case that taxing poor fuel economy of new cars will lead to more gasoline being consumed than in the absence of the tax. However, this somewhat counter-intuitive result cannot arise in the long run. Given enough time for all cars sold prior to the policy change to be retired, such policies will lead to decreased gasoline consumption. For example, a tax on those new cars which do not

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[1]For example, the EPA estimates that a car manufactured after 1975 will emit 4.42 times as much hydrocarbon pollutant when it is nine years old as when it is new. See "Compilation of Air Pollutant Emission Factors," 2nd edition, U.S. Environmental Protection Agency, April 1973, Table 3.1.2-5. Moreover, during the period when the emission standards are in transition, the older model years have much higher emission factors when new than more recent models. Increasing the proportion of these older cars further worsens the average emission factors of cars on the road.

achieve a certain minimum number of miles per gallon will increase the price of these new automobiles relative to those which meet the minimum requirement. This will cause a shift in consumers' demand for new cars, leading to the purchase of relatively fewer new cars with fuel economy below the minimum level. It follows from this that the average fuel economy of the new cars added to the stock of automobiles in each year will improve. Over time the average miles per gallon of the stock of automobiles on the road will improve, leading to less gasoline being consumed than would otherwise be the case.

In the short run, as mentioned above, the effects may be perverse. An increase in the price of new cars leads to reduced scrappage of used cars. Used cars are driven more miles and maintained in the fleet longer. This leads to greater gasoline consumption by these autos than would have occurred in the absence of these policies. The overall impact depends, therefore, on the relative importance of a number of different factors -- the sensitivity of new-car sales and average fuel economy to the tax or restriction and the change in used-car longevity and use in response to the decrease in new-car sales. The analysis is formalized in Appendix D, but the main results (under a number of simplifying but not essential assumptions) may be summarized as follows:

1) A tax on poor fuel economy in new cars causes an increase in the relative price of new cars with miles per gallon below the minimum vis-à-vis those with better than minimum fuel economy. As a result, in each subsequent year the fraction of total new car purchases belonging to the class of autos with miles per gallon above the minimum will increase. This *causes an increase in the average miles per gallon of cars joining the auto stock in each year after the policy is initiated.*

2) However, the imposition of a tax on some new vehicles causes the average price of new vehicles as a whole to rise, leading to a reduction in the total number of new cars sold.[1] That is, increasing the price of low mileage autos causes people to buy less of them. Some of these people buy better mileage cars instead, giving the effect discussed in 1) above. Others decide not to purchase a new car at all, causing new car sales to drop. Thus, *while the policy will lead to an improvement in the average fuel economy of new autos, fewer of these autos will be added to the stock of those already on the road.*

3) At the same time, this rise in the price of new cars causes used car prices to rise (since new and used cars are substitutes). For example, some of the people who decide not to purchase a new car, after introduction of the tax causes new cars prices to rise, will purchase used cars instead. This shifts the demand for used cars upward leading to a rise in used car prices. But this increases the economic life of older autos. Used-car dealers will now find it profitable to repair and market older vehicles which otherwise would have been scrapped. Hence *the policy will cause fewer older vehicles to be scrapped than would have been scrapped in its absence.*

4) Whether or not in the short run the improvement in average fuel economy of cars on the road due to the higher average miles per gallon of new cars is more than offset by the effect of the increased use and economic life of

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[1] This assertion cannot, in general, be proven on *a priori* grounds, It might be the case, to take a hypothetical example, that a tax on fuel consumption would cause sales of expensive cars with poor fuel economy to fall so sharply that the sales-weighted average price after the tax was less than before the tax. In the technical appendix to this chapter, we rule out this kind of behavior by assumption. For this kind of behavior to occur, the cross-elasticities of demand among different classes of car would have to be very high, but the quantitative estimates of the implicit cross-elasticities (discussed below) suggest that these cross-elasticities are quite low. Available empirical evidence, therefore, supports the assumption made here.

the less fuel-economical older cars is an empirical question.[1] Under reasonable assumptions, we can state unambiguously that *the policy under consideration will eventually lead to an improvement in the average fuel economy of all cars on the road, and thus to a reduction in gasoline consumption* from what it would have been in the absence of the policy. In the long run, less gas consumption will ensue.

This result is intuitively reasonable if one considers that from year to year the stock of autos changes through the addition of newly purchased automobiles and the retirement of older vehicles. For all practical purposes, all vehicles are eventually retired. Since, as we have already seen above, the proposed tax on new autos with low mileage will lead to better average fuel economy for the new autos added to the stock in any year subsequent to the enactment of the policy, it must eventually lead to a stock of automobiles with higher average miles per gallon than would have occurred without the tax. This is so because in some subsequent year, all cars on the road when the tax was first instituted will have been retired. At this point the stock of cars consists of surviving autos manufactured in years after the tax was imposed. But the tax would have improved the average fuel economy for autos sold in these years, and thus would eventually lead to a reduction in gasoline consumption below the level it otherwise would have obtained.

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[1]This short-run ambiguity arises because we cannot ensure *a priori* that the combination of the improved fuel economy of the new additions to the auto stock plus their diminished number will outweigh the increase in the number of older vehicles due to reduced scrappage. However, economic intuition suggests (and estimation would no doubt confirm) that total automobile use could hardly increase in response to an increase in new car prices. The qualitative analysis alone does not guarantee, therefore, that in the short run these policies would reduce fuel consumption below the level in the absence of these policies. The empirical results, discussed below, imply that these policies reduce gasoline consumption throughout the forecast period.

We next analyze the effect of a fuel economy restriction, imposed by the federal government on auto manufacturers, requiring the "average" car manufactured by each auto producer to achieve some minimum number of miles per gallon. By "average" we mean the weighted average miles per gallon across each manufacturer's entire line, where the fuel economy of each model is weighted by that model's share of the manufacturer's sales in the previous year.

For ease of exposition, we assume that each manufacturer will respond to such restrictions by increasing the fuel economy of some or all of his models so that average miles per gallon rises to the minimum level required by law.[1] We further assume that the imposed minimum fuel economy standard is not currently being met (or otherwise it would have no effect) and that auto producers will succeed in just meeting the standard rather than exceeding it. This latter assumption follows from cost-minimizing behavior on the part of auto manufacturers.

Since each manufacturer acts so as to just meet the minimum fuel economy requirement, the actual average fuel economy of new cars will be equal to the minimum level imposed

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[1]The introduction of completely new models creates some difficulties of interpretation, because the sales-weighted method for determining average fuel economy cannot be directly applied. This difficulty might be taken care of by the following rule: any model for which sales data for the previous year do not exist must meet the minimum miles per gallon standard; the sales weighted average miles per gallon of models for which sales data do exist must also meet this standard. This rule ensures that the sales-weighted average meets the standard and also allows for the introduction of new fuel-efficient models (although such models contribute to the manufacturer's weighted average only in subsequent years).

by the government, if sales of new cars occur in the same relative proportions as in the preceding year. Under further assumptions detailed in Appendix D, this will occur if the increased cost due to the government restriction is spread across all models in such a way that their prices rise in the same proportion. Thus, if firms spread their increased costs in this manner (and henceforth we assume that they actually do), the government can legislate the level of the average fuel economy of the additions to the stock of autos in any given year.

These assumptions imply that the average fuel economy of the new-car additions to the stock of automobiles will increase and that new car prices will also rise. Prices, in this context, should be interpreted as prices per unit of quality. That is, a manufacturer might increase fuel economy without increasing his costs by such methods as decreasing vehicle weight, lowering horsepower, and so forth. In this case, even though money prices stay constant, the amount of quality supplied has decreased and the price per unit of quality increased.[1]

It can be readily shown, under plausible assumptions, that the restrictions must lead to an increase in the quality-corrected prices of new cars. Improved fuel economy, other things equal, is viewed by consumers as an attractive characteristic of a car. Consequently, if an auto manufacturer could improve the fuel economy of his models at no cost he would do so, since he could thereby improve his competitive

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[1]Quality, in this context, is used narrowly to refer to attributes of automobiles valued by consumers and has no normative significance.

position. To improve fuel economy to meet the restrictions, therefore, a manufacturer must either use a more costly known technology or make investments in the research and development of improved technology. Either strategy will result in increased costs and since all U.S. manufacturers are affected (by assumption, their model mix prior to the restrictions does not meet the standards), these costs will lead to higher prices for new cars.

A key assumption here is that the restrictions are *effective*, in the sense that manufacturers would not make the improvements unless compelled to. That they haven't already done so is not necessarily conclusive, because it is possible that, given sufficient time, higher gasoline prices will induce them to make the improvements in fuel economy. If so, then these policies, at the levels of stringency considered, have no impact either on gasoline consumption or automotive emissions.

From this point on, the analysis follows the same lines as that of the policies placing excise taxes on new cars in relation to their fuel economy. The increase in price of new cars leads to fewer new cars being sold and fewer old cars being scrapped. The long-run effect on fuel consumption is an unambiguous decrease, but the short-run impact on fuel consumption cannot be unambiguously determined on theoretical grounds alone.[1] The empirical impacts of these policies are discussed below.

Policy Impact on Automotive Emissions and Ambient Air Quality

We consider the qualitative impact of the proposed policies on air quality separately because its analysis is complicated by the dependence of a vehicle's emission factor

[1]The remarks of footnote 1, p. 5-6, apply with equal force here.

on its age.[1] Since both a tax on poor fuel economy and federal restrictions on average fuel economy of new vehicles will tend to shift the age distribution of the stock of vehicles, analysis of these policies should take explicit account of this dependence.

In the analysis that follows we make the assumption that for a given vehicle, automotive emissions per year are proportional to the annual miles traveled by the vehicle.[2] Furthermore, this emissions factor is assumed to be the same for all autos manufactured in the same

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[1]An emission factor is the grams of a given pollutant emitted per mile. Thus, the factor times a vehicle's miles of travel measures the total output of the pollutant from that vehicle. We also use "emission factor" to refer to the weighted average emission factor of the entire stock of vehicles (i.e., that factor which, when multiplied by total vehicle miles of travel, results in total automobile emissions of a given pollutant).

[2]This assumption differs, at least at first glance, from the analysis in Chapter 4, where emissions were taken to depend on the number of trips as well as on the number of vehicle miles of travel. The source of the difference is our assumption that changes in the stock of cars or in its age distribution do not change average urban trip length. In this case, there is a direct correspondence between the two approaches. We have no way of verifying this assumption, but it seems plausible. Although a shift in the age distribution toward older cars might reduce the number of long trips (vacations, for example), this reduction would have only a negligible impact on average *urban* trip length. As these policies do not substantially affect automobile operating costs, there is no reason to think that the *pattern* of urban auto use should change in one direction or another.

calendar year.[1,2] New autos of a given year are equipped with emissions control devices that keep emissions per mile at (or below) the EPA standards in effect for the year model.[3] Since these standards become progressively more strict for vehicles manufactured in future years, we may presume that the initial emissions factors for new vehicles added to the fleet in future years will be less than the emissions factors that were applicable to currently existing autos when new.[4]

Average emissions per mile by an automobile tend to increase with the age of the vehicle.[5] This results

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[1]We ignore the slight overlap between a model year and preceding calendar year.

[2]This assumption is not strictly true for automobiles manufactured before 1968. Prior to exhaust emission controls, pollutant emission factors varied considerably among different makes of automobiles, but variations were not closely correlated with fuel economy. This assumption is, moreover, innocuous. Use of an average emission factor instead of the distribution of individual emission factors for pre-1968 cars could make a difference only if vehicle weight and horsepower were systematically correlated with emission factors, which does not appear to be the case. Moreover, the effect would, in any case, be negligible, as pre-1968 autos are estimated to account for less than 30 percent of the stock of cars in 1975 and about 5 percent by 1981.

[3]It is irrelevant, for our purposes, that cars are designed to meet the standards on average over a driving span of 50,000 miles. We assume that, except for the deterioration factor, the emission factor is constant over the life of the car.

[4]For a further discussion of the variability of initial emissions factors over time, see Section B of Appendix D.

[5]C.f. U.S. Environmental Protection Agency, "Compilation of Air Pollutant Emissions Factors," 2nd Edition, April 1973.

principally from the deterioration or malfunction of the emissions control devices installed on new autos.[1] The extent of deterioration and frequency or incidence of malfunction will, of course, be greater for older vehicles. This phenomenon is captured by assuming that the emissions factor appropriate to a given vehicle increases by a constant multiplicative factor with each additional year that the vehicle remains in the auto stock.[2] Thus, to know the initial emissions per mile of an automobile is to know its lifetime profile of emissions rates. However, these profiles will be different (perhaps drastically so) for automobiles manufactured in different years.

By virtue of the assumed dependence of automotive emissions on vehicle miles traveled, the policy impact on the average fuel economy of the fleet is not an issue in this section of the analysis. However, we must concern ourselves with how the policy affects the number of automobiles of each vintage which will be on the road in future years. In order to concentrate on this important question we will neglect the policy impact on vehicle miles travelled. We assume that in each future year every vehicle remaining in the auto stock in that year is driven the same number of

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[1]We have not analyzed or considered possible policies requiring maintenance, inspecting, and testing of emission control devices on old cars. These policies are not directly related to fuel conservation, but their impact on emissions could be readily analyzed with the models developed in this study.

[2]The assumption of exponential growth of emissions factors with age at a constant rate is discussed more fully in Appendix D.

miles, though this intensity of vehicle usage may vary from year to year.[1] We also assume that instituting the policies under study will not affect the number of miles drive by a vehicle in subsequent years.[2]

Given the framework described above, we can identify three factors crucial in determining the policy impact on air quality. These are: 1) the effect of the policy on new car sales; 2) the policy impact on the rate of retirement of older vehicles; and 3) the projected emissions factors for new automobiles manufactured in years subsequent to the policy initiation. Since annual emissions of autos manufactured in a given year are proportional to vehicle miles travelled, (VMT) and since VMT are in turn proportional to the number of such autos on the road, the quantity of emissions will depend on the size of the auto stock.

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[1]This assumption of constant mileage for all vehicles on the road in a given year is, of course, at variance with the facts. It is made only to simplify the qualitative analysis of the policies under study here, but does not affect our basic results. As one might suspect, the intensity of vehicle usage is a decreasing function of vehicle age. Older cars are less reliable and more costly to operate, and thus will be used less frequently for long trips. For example, in 1969, the average VMT of a five-year-old car was 56.8 percent that of a new vehicle, while a ten-year-old auto on average was driven 37.5 percent as many miles as a new car (*Nationwide Personal Transportation Study*, Report No.2, "Annual Miles of Automobile Travel," Federal Highway Administration, April 1972, Table 4). Since the policies under study tend to increase the relative number of older cars on the road, explicit recognition of the decrease in vehicle usage with vehicle age would only strengthen the conclusion that the long run impact of the policies is to decrease automotive emissions.

[2]The reasoning in footnote 2, p. 5-10, can be used to support this assumption. Again, this assumption is made only for the qualitative analysis.

As discussed in the previous section, a tax on poor fuel economy will cause an increase in the average price of new cars, leading to a decline in new car sales. This tends to diminish the size of the stock of cars on the road in subsequent years, causing a decline in emissions. On the other hand, new car prices rising will cause used car prices to increase, leading to fewer used cars being scrapped and increasing the number of used cars on the road in subsequent years. Thus the impact of the tax policy on the size of the auto stock depends on which of these two effects dominates.

Furthermore, since the emissions rates of older vehicles exceed those of more recent vintage autos, this tendency to keep older vehicles in the stock longer will have the effect of increasing the average emissions rate of the fleet. Thus, even if the size of the auto stock decreases, absolute emissions could still increase. In qualitative analysis of the short run effects it is not possible to resolve this ambiguity, and we must rely on the empirical study carried out in this report to determine the direction of the policy impact on automotive emissions. Observe, however, that if the emissions factors for older vehicles exceed by a substantial margin those for new vehicles manufactured shortly after the policy is imposed, then this tendency of the tax to cause older vehicles to be maintained longer and to diminish the number of new (less polluting) vehicles added to the stock, may increase significantly the average emissions per mile of the auto stock as a whole. The short-run effect thus depends critically on the extent to which emission factors of new cars are lower than those of cars manufactured prior to the policy. Ironically, the more rapid is the decrease in emission factors of new vehicles, the more likely it is that a tax

policy aimed at increasing the fuel efficiency of the auto fleet will increase emissions and concentrations of pollutants in the short run, relative to the emissions and concentrations that would have occurred without the policy. If, to take a hypothetical example, emission factors were identical for all past and future vintages, these policies would, by reducing VMTs, also lower emissions. The lower the emission factors of vintages after the policy (relative to emission factors of vintages before the policy), the greater will be the increase in emissions from a given shift in the age distribution resulting from the policy.

Once enough time has elapsed for the permanent EPA emission standards to be achieved, however, we can rule out the troublesome effects describe above. Thus the long-run qualitative impact of the proposed policies depends only on the first two of the three crucial factors mentioned above. To the extent that a tax on poor fuel economy diminishes the size of the long-run auto stock, better air quality will ensue. However, since emissions per mile grow with vehicle age, the policy's effect of increasing the average lifetime of an automobile will tend to worsen long-run air quality. If we could assume that in the long run the policy would decrease not only the overall size of the auto stock, but also the number of autos of each age that remain on the road, then we could be sure that the eventual policy effect on air quality would be a beneficial one. Whether or not this is the case depends (in a rather complex fashion) on the relative sensitivities of new car demand and used car scrappage rates to increases in new car prices. In Appendix D we state a condition (A7) which guarantees the long-run compatibility of the goal of improved air quality with a tax policy aimed

at increasing the fuel economy of the auto fleet. Under this condition (and the other assumptions of Proposition 5) we may be sure that taxing the poor fuel economy of new vehicles will also have the effect of reducing long-run automotive emissions and improving air quality.

Finally, we note that the above analysis applies directly to the qualitative effect of federal restrictions on the sales weighted average fuel economy of new cars. This is because, as observed earlier in this section, the policy impact on air quality works entirely through its effect on new car prices. In the qualitative analysis of the policy impact on gasoline consumption, we concluded that the increase in auto manufacturers' costs necessitated to meet federal standards for fuel efficiency would cause an increase in new car prices. Thus the qualitative analysis of the impact on air quality of fuel economy restrictions is the same as that of taxing poor fuel economy[1],[2]

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[1] The direction of the effects is identical, but the size of the effects could differ substantially, depending on which policy requires the greater increase in new car prices to meet the same fuel efficiency objective. We cannot answer this question a priori. The size of the price increase due to fuel-efficiency restrictions depends on technological considerations external to automobile demand, such as research and development costs. With the tax on poor fuel economy, however, the increase in new car prices is determined by the characteristics of consumers' demand for autos of different fuel economy classes. This increase depends on the amount by which the prices of low fuel efficiency cars have to be raised in order to cause a shift in demand to better mileage cars sufficient to achieve the desired increase in average fuel economy.

[2] This result assumes that the research and development efforts necessary to meet federal restrictions will not produce spinoff effects of better emissions control devices. To the extent that this occurs, fuel economy restrictions, which encourage research activity by auto manufacturers, could lead to better air quality even when taxing poor fuel economy has the opposite effect.

Practical Difficulties in the Quantitative Analysis of These Policies

The policies considered in this chapter are oriented toward one particular aspect of automobile performance, fuel consumption. Analysis of these policies, therefore, requires an understanding of the relationship between this characteristic of automobiles and consumer behavior, such as demand for new cars and the composition of the demand for new cars. This section of the chapter explores the question from a theoretical point of view. It is divided into two parts. The first part states the problem. The second part discusses briefly other work related to this problem. The next section presents the approach used in this report.

Statement of the Problem

Both sets of policies considered in this section have two kinds of effects. First, they change the prices of cars relative to each other, according to their fuel consumption characteristics.[1] Second, these policies tend to raise the prices of new cars relative to all other goods, including the prices of used cars before the imposition of these policies.

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[1] This assertion is probably, although not necessarly, true for the policy restricting the fuel consumption of new cars. As manufacturers are required to increase the fuel economy of their average car, it seems quite probable that the costs incurred in increasing the fuel economy of different models will be passed along to the consumer, and that these costs will be different for different models. It is, in principle, possible that manufacturers would choose to increase fuel economy of all models by the same percentage, and that this increase will be associated with the same percentage increase in price of all models. This outcome seems unlikely, but it does not substantively affect the analysis in what follows.

As shown in the qualitative analysis section of this chapter, reasonable assumptions about economic behavior tell us how consumers will react to these policies. There are two kinds of effects. First, we expect consumers to buy relatively fewer of the cars whose prices have been increased more (i.e., the cars with worse gas mileage or higher fuel consumption per mile) and relatively more of those cars whose prices have increased less (i.e., those cars with relatively good gas mileage or low fuel consumption per mile). This substitution will occur because, with the change in relative prices, some consumers will prefer to buy a smaller car that gets better gas mileage because of its lower initial price, when previously they would have preferred to buy a larger car in spite of its worse gas mileage.

Second, fewer new cars will be bought, because some consumers with large old cars, which they were considering trading in, will prefer to maintain these cars and make the necessary repairs rather than pay the increased price for a new car. That is, those customers who, for one reason or another, need or prefer large cars that get low gas mileage, faced with the increased prices due to the excise tax will, on average, buy fewer large new cars. This kind of behavior can be expected to affect the sales of every size class of car whose price has increased due to the excise tax (after allowing for the shift to more fuel-economical cars as a result in change of relative prices).

Although the qualitative effects of these policies are relatively straightforward, it is difficult to determine the quantitative importance of these shifts. However, the second effect is, in principle, simpler to determine. If, for example, we know the average increase in price implied by the excise tax, we can use existing estimates of the price elasticity of new car demand to estimate how many fewer new cars would be bought.

The question of the average increase in price, however, is not simple. For example, if consumers were indifferent between all different sizes of cars, then a shift in the relative prices would mean that no cars with miles per gallon less than 20 would be bought and all consumer demand would shift to those cars not subject to the tax. This kind of consumer behavior is, clearly, quite unlikely. At the other extreme, suppose that each consumer has in mind a particular size of car to buy. He plans to buy this car or no car at all. If the excise tax increases the price too much, the consumer will buy no car. Otherwise, he will buy the same size of car as he was planning to buy. This kind of behavior implies no increase in the sales of smaller cars at the expense of larger cars. The percentage increase in price could be easily calculated from the shares prior to the imposition of the tax increase, and the shares after the tax could be readily estimated. Neither of these extreme assumptions is, however, appealing. Consumer behavior almost certainly lies between these two extremes. We now turn to a brief review of different studies that, directly or indirectly, provide some measure of the way consumers will choose among different models when the prices of these models have increased differentially in response to excise taxes based on fuel consumption.

Previous Approaches

We are aware of at least two studies in progress that bear on this question, but that were not available in time to be of use in this study. First, Charlotte Chamberlain at the Transportation Systems Center in Cambridge has been working on a related problem.[1] As this work is still in progress

[1]Charlotte Chamberlain, "A Preliminary Model of Auto Choice by Class of Car: Aggregate State Data," (unpublished paper), January 31, 1974.

and was not available to us, we do not comment on it further here. Second, Charles River Associates, in connection with a study for the United States Department of Labor, is estimating a model that describes the distribution, across consumers, of tastes for different attributes of automobiles. The model is designed to predict the share of sales of U.S. autos as either the prices of different models of cars change or as their attributes change. This model is, therefore, perfectly matched to the questions raised in this chapter, as the increase in the excise tax could readily be translated into an increase in the price of the different models affected, and these new prices would then yield predictions of the change in sales of these models. Unfortunately, this model has not yet been sufficiently developed and tested to be used in this study.

A study performed by Chase Econometrics Associates, Inc. addressed the question of what determines the share of sales of different size cars.[1] We have seen only a preliminary draft of their report under this contract, and the estimated equations may have been changed since this report. The study is quite ambitious, as it attempts to explain total new car sales, as well as the share of new cars in five different size classes. For our purposes, however, the estimated equations are not very satisfactory.[2] According to these equations, the absolute price of luxury cars affects the share of luxury car sales; the price of standard size cars relative to all cars affects the share of standard size car sales; and the price of intermediate cars relative to standard size cars affects the share of intermediate size sales. These are

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[1]Chase Econometric Associates, Inc., Report No. 2, submitted to the Council on Environmental Quality under Contract #EQ4AC004, January 1974.

[2]We do not evaluate the model here in the context of the purposes for which it was intended, bur rather for our own particular uses.

the only three size classes of cars for which the equations indicate that the share of sales depends on the price of that size class. Consequently, if we attempted to substitute the increase in price implied by the excise tax into these equations, the results would indicate that the share of new car sales in the compact and the subcompact car classes would not change. This result, while not formally impossible, strikes us as unlikely, as it indicates that there is no substitutability between, for example, compact cars and intermediate size cars. This result probably also violates the definitional constraint that the shares of sales must add up to unity.[1] It would be possible to tinker with the model by assuming that the loss in share of the larger size cars was captured by the combined shares of compact and subcompact cars, but any division between the latter two sizes would necessarily be arbitrary. Finally, because the equations are linear in untransformed variables, the size of the coefficients depends on the units of the variables. Consequently, this model would be difficult to apply without access to the raw data.

Instead of the above methods, we decided to use methods developed by Dewees.[2] These methods have several advantages for our purposes. First, they bear directly on the willingness of consumers to buy smaller and less powerful cars as the relative prices of large and more powerful cars increase. Second, the methods yield results that are internally consistent and plausible. Third, the equations are analytically

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[1]We say probably because, in principle, it is possible that the net change in the share of the three classes of cars which are affected by price would be zero.

[2]Donald N. Dewees, *Economics and Public Policy, The Automobile Pollution Case* (Cambridge, Ma.: MIT Press, 1974), pp. 168-178.

tractable. The equations and the methods used are undoubtedly not the last word on this difficult area of analysis, but, in our judgment, they are the best available at the present time.

As a full account of his methods can be found in his book, we only sketch his procedures here. This analysis builds on a relatively long tradition of hedonic analysis of automobile prices.[1] The basic notion is that when a consumer buys an automobile, he is in fact purchasing a bundle of attributes or characteristics of that automobile which can be adequately represented by the physical traits of that automobile. Such physical traits might include length, horsepower, engine displacement, gross vehicle carrying weight, and a number of less quantifiable attributes such as handling, power steering, braking ability, and so forth. The assumption is made that the price paid by consumers reflects the consumers' evaluation of these different attributes or characteristics. When the prices of automobiles are regressed on these physical characteristics, the coefficients of the characteristics can be interpreted as the marginal prices of the characteristics,

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[1]See, for example, Zvi Griliches, ed., *Price Indexes and Quality Change* (Cambridge, Ma.: Harvard University Press, 1971), pp. 55-87, 215-239, and the comprehensive bibliography, pp. 275-281. The first article was published by Andrew T. Court in *The Dynamics of Automobile Demand* (New York: General Motors Corporation, 1939), pp. 99-117.

such as the price a consumer is willing to pay for one additional horsepower, for example, or one additional inch of length.[1]

Dewees estimated a number of such equations from cross sections of data representing the models available in different periods over the post-war period. These equations gave him a number of observations on the implicit price of horsepower, which he then used as an independent variable to explain the average horsepower per car over the period. That is, he effectively constructed a demand curve, relating the amount of horsepower purchased to its price. As explained in the next sub-section, a tax on miles per gallon can be translated into a tax on horsepower, which,through the estimated equation, will lead to a decrease in the average horsepower demanded, and a corresponding increase in average fuel economy.

Methods Used to Analyze the Impact of Policies Affecting New Car Sales

In this section, we describe in detail the approach used to analyze the effects of excise taxes on new cars based on their fuel consumption and restrictions on the

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[1]This analysis assumes that the measurable dimensions adequately represent the characteristics of cars which consumers in fact value. Length and weight, for example, are frequently used because they represent sturdiness, head and leg room, carrying capacity, and so forth. Recent work by Ohta and Griliches suggests that these physical traits do, in fact, reasonably represent the quantifiable attributes valued by consumers. See, in this connection, M. Ohta and Zvi Griliches, "Automobile Prices Revisited: Extension of the Hedonic Hypothesis," (unpublished Harvard Institute of Economic Research Discussion Paper #235, October 1973).

fuel consumption of new cars.[1] A number of regression equations are used, but the discussion is non-technical. The technical details, along with additional mathematical tools and results, are presented in Appendix D.

The procedures involved a number of steps, so that a brief overview here may serve as a useful guide to what follows. One basic notion is that an auto's fuel economy depends on its weight and horsepower. Second, we assume for purposes of analysis that, of the different attributes of automobiles influencing fuel economy, consumers attach positive value only to weight and horsepower. Under these conditions, a tax on fuel economy can, for our purposes, be viewed as partly a tax on weight and partly a tax on horsepower. Because it is implicitly a tax on weight and horsepower, a tax on fuel consumption leads to a decrease in the average weight and horsepower of new cars sold, and hence an increase in their fuel economy.

A tax on fuel consumption thus has two effects: first, it leads people to shift their purchases of cars to cars achieving greater fuel economy. Second, the tax leads to an increase in the average price of new cars, which affects the stock of new cars. The stock is affected in two ways: first, the increase in the average price of new cars

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[1]The term "fuel consumption," as used here, refers to the number of gallons of gasoline consumed per mile. It is, therefore, the inverse of "fuel economy," which is measured in miles per gallon. For our measurement of fuel economy, we use the results obtained by the Environmental Protection Agency on its urban driving cycle. (See, for example, Environmental Protection Agency/Federal Energy Administration, *1975 Gas Mileage Guide for New Car Buyers*). This measure may not yield the same number as other tests of fuel economy because of differences in fuel consumption during different driving modes (cruising, acceleration, deceleration), the number of stops and starts, load factors, and other test conditions.

reduces new car sales; second, because of the increase in price of new cars and the decrease in new car sales, older cars will be maintained better and scrapped later in their service lives. Thus, the net effect on the stock of cars is to shift the distribution toward older cars.

The stock of cars and the average fuel economy of the stock affect the consumption of gasoline through the short-run demand equation for gasoline, discussed in Chapter 4. The emission factors change from their forecasted levels as well, because older cars have different emissions characteristics from new cars. The modified emission factors are applied to vehicle miles of travel (determined from gasoline consumption and fuel economy) to compute the emissions of the different pollutants and from this point on, the analysis is similar to that in Chapter 4.

The analysis of restrictions on fuel economy for each manufacturer differs in some respects from the analysis just sketched. As the proposed policies discussed here mandate a certain minimum level of fuel economy, the fuel economy characteristics of new cars are, in effect, known by assumption. It is not so easy to know, however, what the increase in new-car price implied by these restrictions will be. That is, it will almost certainly cost the manufacturers more to design cars that will achieve the new standards of fuel economy, without sacrificing other performance dimensions, and these costs will almost

certainly be passed along in the form of higher prices.[1,2] As we have been unable to find any data on the size of the cost increases implied by meeting these minimum standards, we make assumptions to bracket the range of these price increases. These assumptions will be discussed below. Once the average fuel economy and the average price increase are determined, the rest of the analysis follows similarly to the analysis for the excise taxes on new cars just discussed.

The rest of this section is organized as follows: First, we discuss in detail the methods used to analyze an excise tax on poor fuel economy. Then we discuss the changes in this approach needed to analyze restrictions on the fuel economy of new cars.

The methods used to analyze excise taxes on fuel economy can, for convenience, be broken down into five steps: First, we determine the change in fuel economy resulting from the excise tax. Second, we determine the change in new car sales resulting from the tax. Third, we calculate the change in scrappage of automobiles resulting from increased new car prices and the decreased sales. Fourth, these changes are

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[1]Manufacturers might choose to keep the price of cars constant, by sacrificing performance dimensions such as weight, interior space, engine performance, and so forth. These decreases in automotive quality can, however, be viewed symmetrically to an increase in price, as consumers are presumably interested in qualities per dollar. For the purposes of this discussion, therefore, we assume that performance and other attributes are maintained, and that the increase in fuel economy comes about because of design changes made by the manufacturers.

[2]As it is the sales-weighted *average* that is the standard set by the policy, manufacturers have an incentive to improve the fuel economy of *all* models, not just those below the average set by the standard.

translated into changes in gasoline consumption. Fifth, the change in gasoline consumption, coupled with the change in emission factors, leads to the change in emissions from the forecast levels.

The Response of Fuel Economy to an Excise Tax Based on Fuel Economy

We start by assuming that consumers' evaluation of all of the automotive characteristics that influence fuel economy can be summarized in their evaluation of weight and horsepower.[1] The equation relating miles per gallon to weight and horsepower is as follows:[2]

$$\textit{Miles per gallon} = 25.909 - 0.01022 * \textit{Horsepower} - 0.00270 * \textit{Weight (in pounds)}$$

This equation implies that, other things equal, increasing an engine's horsepower by ten leads to about a 0.1 mile per gallon decrease in fuel economy. Increasing a car's weight by 300 pounds, other things equal, leads to a reduction of about 0.8 miles per gallon. At the sample means, the elasticity of miles per gallon with respect to horsepower is -0.12 and with respect to weight is -0.85. Thus, although this equation implies that vehicle weight is the more important of the two determinants of fuel economy, differences in horsepower are also important. If *both* weight and horsepower increase by 1 percent, fuel economy declines by about 1 percent.

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[1]A discussion of this assumption can be found in Appendix D.

[2]This equation is discussed in detail in Appendix D.

This equation is used in the next step of the analysis, in which we determine the taxes on horsepower and weight implied by a tax on fuel consumption. The implied taxes on horsepower and on weight must satisfy two criteria. First, the total tax on a given car due to the fuel consumption tax must be equal to the sum of the tax on weight and the tax on horsepower. (In particular, the total tax must be zero when its horsepower and weight are such that they imply a fuel economy equal to 20 miles per gallon.) Second, this relationship must hold for all different combinations of weight and horsepower of cars. These criteria imply that a tax on fuel economy can be split into a unique marginal tax on weight and a unique marginal tax on horsepower, using the estimated linear relationship between fuel economy, weight, and horsepower. A fuller discussion of the derivation can be found in Appendix D. The tax rates per horsepower and per pound, corresponding to the different levels of tax on fuel economy, are shown in Table 5-1.

Taxes on weight and on horsepower imply, of course, increases in the prices of these characteristics. Since these characteristics are not, however, priced separately but are included implicitly in the price of the new automobile, we must also determine what these prices are. These prices were estimated by the technique of hedonic regression, discussed earlier. The regression coefficient of a characteristic (weight, horsepower, and so forth) can be interpreted as the price of an additional unit of that characteristic. Estimation of the implicit prices of weight and horsepower was beyond the scope of this study, and we relied on those estimated by Dewees.[1]

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[1]Dewees, *op. cit.*, pp. 168-178.

Table 5-1

EQUIVALENT TAXES ON WEIGHT AND HORSEPOWER IMPLIED BY A TAX ON EACH MILE PER GALLON LESS THAN 20

Dollars per MPG Less than 20[1]	Dollars Per 100 Pounds of Weight Above Threshold[2]	Dollars Per Horsepower Above Threshold[3]
$ 50	$13.50	$0.51
$100	$27	$1.02
$200	$54	$2.04

NOTES:

[1]The tax is designed so that the rate applies to each mile per gallon less than 20, tested in a city driving cycle according to the EPA test procedures.

[2]The "threshold" levels of weight and horsepower are such that, at these levels, miles per gallon (estimated according to the regression equation in the text) equal 20 (and hence the tax equals 0).

[3]See Note 2.

SOURCE:

For the derivation of these equivalences, see Appendix D.

The last year for which Dewees estimated the price of weight and horsepower was 1968. To determine the base prices of weight and horsepower, therefore, we needed to update these prices to 1975 levels. We assume that these prices have been rising at the same rate as new car prices. This assumption, besides being the simplest one, is corroborated for the period 1968 to 1971 by Ohta and Griliches in their recent study.[1] This assumption is also consistent with the relatively stable average weight of new cars over this period.[2,3]

A central feature of this approach is the estimate of the willingness of consumers to buy smaller cars as the price of larger, less fuel-economical cars increases. These behavioral relations are embodied in two equations. One equation

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[1]M. Ohta and Z. Griliches, "Automobile Prices Revisited: Extensions of the Hedonic Hypothesis," (unpublished paper, October 1973), pp. 34-35.

[2]Strict corroboration of this assumption would require not only weight but also all other characteristics to have remained constant over this period. In this case, quality, as measured for the purpose of the regressions, would also be constant and changes in new car prices would be reflected directly in the prices of the attributes characterizing cars. In fact, of course, other attributes have changed somewhat, but estimation of a relationship for 1975 model-year cars was beyond the scope of this study.

[3]A particular difficulty obscures comparison of 1975 horsepower with 1968 horsepower, as around 1971 there was a change in the way horsepower is reported. Whereas it had previously been measured with most of the engine components that draw power (such as alternators) receiving their power from other sources (gross horsepower), it has since been reported on the basis of the power generated net of the power used by these components (net horsepower). Consequently, a simple comparison of the 1975 horsepower figure with the 1968 ones is misleading, as this comparison seems to imply a decline in horsepower over this period.

estimates the demand for horsepower as a function of its price; the other estimates the demand for weight as a function of its price. The prices of weight and horsepower were derived from the hedonic regressions discussed above. The equations (discussed in detail in Appendix D), are as follows:

*LOG(Weight) = 7.350 - 0.0264*LOG(Weighted Average Price of Weight) + 0.103*LOG(Weighted Average Per Capita Income)*

and

*LOG(Horsepower) = -3.44 - 0.221*LOG(Weighted Average Price of Horsepower) + 1.258*LOG(Weighted Average Per Capita Income)*

In these equations, it appears that the demand for horsepower is considerably more elastic than the demand for weight, although both are quite inelastic. That is, the long-run elasticity of demand for horsepower is only -0.2, while the long-run elasticity of demand for weight is -0.026, even though both estimates are significantly different from zero.

Thus, suppose that the tax on weight implied by the tax on fuel economy doubles the effective price of weight. According to this equation, it will lead to a virtually imperceptible reduction in the average weight of cars purchased. Further, if the tax on fuel economy implies a doubling in the implicit price of horsepower, the decrease in the average horsepower of cars purchased will, after three years, be only about 22 percent. The inelasticity of these coefficients implies that consumers will not readily change their choice

of vehicle size and power in response to increased prices associated with these attributes.[1]

Given the reduction in horsepower and weight, we then compute what the average fuel economy of cars subject to the tax will be. A weighted average of this fuel economy and the average fuel economy of cars not subject to the tax results in the average fuel economy of new cars. We then use this average fuel economy, along with the sequence of fuel economy of cars sold in previous years, to estimate the average fuel economy of the stock of cars in each forecast year.

Given the estimate of average miles per gallon, we can also calculate the average tax. For example, if the average miles per gallon (after the tax has been imposed) is 18, the average price increase (assuming that the manufacturers pass along the full tax increase) will be 2 (20-18) times the tax per mile per gallon. I.e., if the tax per mile per gallon is $100, the average price increase will be $200. This increase in price plays an important part in determining how many new cars will be sold, as discussed next.

Change in New-Car Sales in Response to the Excise Tax

Given the sales-weighted average price of new cars before the imposition of the excise tax, we then calculate the percentage increase in the average price of new cars. The percentage decrease in sales in new cars in response to this tax depends on the elasticity of demand for new cars.

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[1]One problem with this procedure is that, over the period for which we have data, the prices of weight and horsepower were declining or stable. There is, therefore, no direct evidence on consumer reactions to sharply *increased* prices of weight and horsepower, as implied by the tax levels in Table 5-3. It is quite possible that, at very high prices of these characteristics, consumers would be much more willing to alter their choice of cars, but history has not run the experiment for us.

Estimation of an equation for new car demand was beyond the scope of this study. Demand for new cars is a very complex phenomenon, and the studies which have addressed this problem have frequently used quite complicated formulations in attempting to determine the structure of new car demand. Among the variables used, for example, have been variables to reflect credit conditions in the automobile industry, weighted average stocks of cars on the road, real disposable income (in various forms), and so forth. All of these studies, however, imply remarkably similar estimates of the elasticity of demand for new cars. As discussed in Appendix D, estimates of the elasticity range between -0.75 and -1.22. These estimates suggest that, if the excise tax on new cars causes their average price to rise by 10 percent, new car sales will fall by about 10 percent. As the main estimate in this study, we chose a value of -1.0 for the elasticity of new car demand. This value lies approximately midway between the high and low estimates. This elasticity estimate, along with the percentage increase in average price implied by the excise tax, allows us to estimate the percentage reduction in new car sales below the base case forecasts.

Change in Scrappage in Response to Tax

The decrease in new car sales does not, however, imply a corresponding decrease in the stock of cars. The increase in prices of new cars has two immediate effects: first, some people, instead of trading in their old car and buying a new car, will make repairs to their old car and postpone purchase of a new car (or simply drive the old one longer); second, some people who might have bought a new car will,

instead, buy a used car. This increase in the demand for used cars leads to an increase in used car prices. Consequently, dealers and other owners of used cars will repair them more frequently instead of scrapping them. The scrappage rate of all vintages of cars will decline, and used cars will account for a relatively larger proportion of the car population.[1]

The equation used to estimate the response of scrappage to changes in new car sales is as follows:[2]

$$LOG(S) = 1.70899 + 0.742378*LOG(R) - 0.912141*LOG(P)$$

where:

S = ratio of actual scrappage to scrappage expected on the basis of age alone;

R = ratio of new car sales during the year to stock of cars at beginning of year;

P = ratio of Consumer Price Index for used cars to Consumer Price Index for automotive repair and maintenance.

The equation implies that a 10 percent decrease in new car sales leads to about a 7 percent decrease in the scrappage rate, while a 10 percent increase in the price of used cars (relative to the price of maintenance) leads to about a 9 percent decrease in the scrappage rate. These parameters suggest, therefore, that scrappage is

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[1]A recent unpublished paper on scrappage rates by Richard Parks ("Automobile Scrappage Rates: the Choice Between Maintenance and Built-in Durability," University of Washington, October 1974) finds that, in recent years, scrappage rates have declined. It is quite possible that this decline has resulted from the installation of emission control devices that are not desired by buyers of new cars.

[2]Details on the specification and estimation of this equation are contained in Appendix D.

quite sensitive to new car sales directly, and also to new car prices indirectly, through their effect on used car prices.

As outlined above, one of the effects of an increase in new car prices is to bid up the prices of used cars. Thus, we need another equation to link used car prices to new car prices. Common sense suggests two properties that this relationship ought to have. First, it seems clear that an increase in new car prices ought to lead to an increase in used car prices, as used cars are a substitute for new cars.

Second, it seems plausible that, over the very long run (say 12 to 13 years), the prices of used cars must move proportionately to those of new cars. That is, suppose that the price of new cars rises by 10 percent in this year and stays constant for 13 years. Eventually, therefore, all cars on the road will, when new, have been sold at the increased prices. If the relative structure of vintage prices remains the same, all new and used car prices will have risen by 10 percent once all previously existing cars have been retired.

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[1]The relationship between new cars and used cars has been investigated by, among others, Gregory C. Chow, *Demand for Automobiles in the United States* (Amsterdam: North Holland Publishing Company, 1957), and Frank C. Wykoff, "A User Cost Approach to New Automobile Purchases," *Review of Economic Studies*, Vol. 40, No. 123 (July 1973), pp. 377-390. Both of these researchers found that used cars are imperfect substitutes for new cars. That is, their prices move together, but are not perfectly correlated.

The following equation reflects these constraints:[1]

$$LOG(CPIUC) = -0.1194 + 0.213*LOG(CPINC) + 0.787*LOG(CPIUC(-1))$$

where:

CPIUC = Consumer Price Index for used cars;

CPINC = Consumer Price Index for new cars; and

CPIUC(-1) = Consumer Price Index for used cars, lagged one year.

The estimated equation suggests that the impact of a change in the new car price index is only partially felt in the first year. That is, an increase in the new car price of 10 percent implies only a 2 percent increase in used car prices this year. After 12 years, the used car price index will have increased by 9.5 percent in response to a sustained 10 percent increase in new car prices.[2] This result is quite consistent with the average life of a car.

This equation translates a percentage change in the price of new cars into percentage changes in the used car price index in the years following the imposition of the excise tax. We then substitute these percentage changes, along with the changes in new car registrations, into the scrappage equation, to determine the change in the scrappage rate implied both directly and indirectly by the change in new car prices resulting from the excise tax. This procedure implies that scrappage rates for different vintages will all change in the

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[1]This equation is discussed in detail in Appendix D.

[2]For convenience, we assume that new car prices do not change (after the initial 10 percent increase) over this 12-year period. This assumption allows us to focus on the dynamic relationship between new and used car prices.

same proportion. That is, it implies that the relative scrappage rates of, say, one-year-old to two-year old cars do not change, even though the scrappage rates for both of these vintages have decreased.

Change in Gasoline Consumption

At this point, we have all the necessary elements to determine the change in gasoline consumption that will result from an excise tax on new cars. From earlier steps, we calculated the change in average fuel economy of the stock of cars in each of the years of the forecast period.[1] From the series of steps just described, we calculated the change in the stock of automobiles. These new values are then substituted into the short-run demand equation for gasoline. The short-run equation for gasoline, it will be recalled, predicts gasoline consumption as a function of, among other factors, the stock of registered automobiles and the average fuel economy of the stock of cars. When new values of these variables are substituted into this equation (holding other factors constant), new predictions of gasoline consumption result. These predictions are then compared

[1]An increase in fuel economy reduces the per-mile cost of operating an automobile. Gasoline costs per mile, that is, are equal to the price of gasoline (in dollars per gallon) times the number of gallons per mile (the inverse of miles per gallon). This effect was implicitly taken into account in the short-run demand equation for gasoline, since the coefficient on MPG (fuel economy of the stock of cars) reflects both the effect on operating costs and the direct effect on consumption. (Had the equation been specified to include per-mile operating costs -- i.e., price of gasoline divided by fuel economy -- then the new fuel economy would also have affected gasoline consumption through the coefficient of per-mile operating costs.)

with those of the corresponding baseline forecasts to estimate the percentage change in gasoline consumption due to a given policy.

Change in Emissions

It remains to calculate the change in emissions resulting from this set of policies. Emissions are affected in two ways. First, the change in gasoline consumption clearly affects emissions. Second, because these policies change the age distribution of the stock of automobiles, they also change the future emission factors for the stock of cars on the road in the forecast period. Consequently, using the emission factors of each individual model year, we recompute the emission factors corresponding to the stock of cars on the road in each year under the different policies. These emission factors, along with the new forecast of gasoline consumption, are then used to generate new forecasts of emissions under the different policies. Implicit in this calculation is the assumption that in spite of the changes in the number of cars, their average fuel economy, and the fewer vehicle miles of travel, the distribution of trips within different city sizes and between the different times of day is the same as in the base forecast. This assumption is not, probably, strictly accurate, as the change in the number of cars might be expected to alter somewhat the uses to which cars are put and, hence, trip lengths and frequencies. As we have no way to quantify these effects, however, we have chosen an assumption which simplifies interpretation of the results. As the percentage change in the size of the car stock is quite small (because of the substitution of used cars for new cars), the error we introduce by this assumption

is also likely to be quite small. The results of Chapter 4, in which we took explicit account of changes in trip length and frequencies, suggest that a more elaborate assumption would yield negligibly different results.

Restrictions on the Fuel Economy of New Cars

We have described in detail above the procedures used to analyze the effects of an imposition of an excise tax on new cars. Many of the same steps are also used in analyzing the effects of a policy restricting the fuel economy of new cars. There are, however, some important differences in the analysis of these latter policies.

First, the form of these policies implies directly what the fuel economy of new cars will be.[1] That is, since the policies we analyze require each manufacturer's sales-weighted average cars to achieve a certain number of miles per gallon (and assuming that manufacturers would not have chosen such a high standard in the absence of the policy), it follows directly that the fuel economy of new cars will be precisely that required by the policy. Given the age distribution

[1]We have assumed that imported cars are exempt from this set of policies (although not from the previous set of policies) and have taken them into account in the computation of the results. We have made this assumption because of difficulties in determining what jurisdiction U.S. statutes might have over foreign-based manufacturers and how the statutes might be applied. For example, would the regulations apply to the sales-weighted average of *all* sales by a foreign manufacturer, or only to U.S. imports? Many imports already meet these standards. For example, based on 1974 market shares, almost 90 percent of the top 10 imports achieved 20 miles per gallon or better, so that the costs of compliance for these manufacturers would be small. Thus, altering the assumption would not affect the results significantly.

of the car stock in each year of the forecast period, it is straightforward to use the fuel economy of new cars and the fuel economy of cars on the road for each year of the forecast period. It is, however, much more difficult to determine the age distribution and the total number of cars on the road in each year, and this is the second area in which the analysis differs substantially from that for the policies discussed above.

This second area is more difficult because the analysis depends critically not only on consumer demand but on the cost to the automobile manufacturers of improving fuel economy. There is a strong presumption that these costs will imply increases in prices that are greater than the value consumers attach to the improved fuel economy. This presumption follows from the view that, if the automobile manufacturers know how much it will cost to improve fuel economy, and if they also know that consumers will be willing to pay a price increase at least as great as that implied by the cost, then the automobile manufacturers would have already had an incentive to improve fuel economy up to this level. The response of the automobile makers to the recent increase in gasoline prices seems to bear out this line of reasoning. For example, if the share of sales in the first 7 months of 1974 are used to weight the fuel economy of U.S. cars, the sales-weighted average fuel economy of 1974 models was 13.1 miles per gallon. Partly because of the sharp increase in gasoline prices between the 1974 models and the introduction of the 1975 models, the sales-weighted average of 1975 model cars increased to 15.5 miles per gallon, an increase of 18 percent. Table 5-2 shows the sales and market share data for different periods of 1974, and it also shows the 1974 and 1975 fuel economy

TABLE 5-2

1974 Sales and Market Shares of U.S. Models and 1974 and 1975 Fuel Economy of These Models

Model	Sales in Thousands			% Share of Market			1974 M.P.G.	1975 M.P.G.
	Feb. 1974	July 1974	7 mos. 1974	Feb. 1974	July 1974	7 mos. 1974		
Gremlin	7.5	9.0	59.5	1.3	1.1	1.2	15.9	19
Hornet	5.7	5.5	41.7	.97	.6(	.85	14.7	18
Hornet Sportabout	3.1	5.1	28.7	.53	.61	.58	15.5	18
Matador	5.9	5.5	39.1	1.0	.66	.79	12.4	14
Matador Wagon	.6	.7	4.4	.10	.08	.09	12.3	13
Ambassador	1.2	1.3	9.8	.21	.15	.20	10.8	-
Javelin	1.7	1.7	13.5	.29	.20	.27	12.1	-
Chrysler Newport	2.3	4.0	20.3	.39	.48	.41	8.9	11[e]
New Yorker	.4	.6	3.3	.07	.07	.07	9.1	10[e]
Station Wagon	.7	.8	5.1	.12	.10	.10	8.9	10
Valiant	22.2	32.5	203.7	3.8	3.9	4.1	12.5	18
Satellite	8.0	11.6	70.0	1.4	1.4	1.4	12.5[e]	17[e]
Fury III	4.0	5.1	32.3	.68	.61	.65	8.7	11
Mercury Comet	5.2	7.8	46.8	.89	.93	.95	15.5	16
Montego Wagon	.6	.8	4.8	.10	.10	.10	11.4	11
Monterey	.7	.8	5.1	.11	.10	.10	10.0	-
Marquis	2.9	4.1	23.9	.50	.49	.48	8.1	-
Cougar	5.0	7.8	43.3	.86	.93	.88	9.3	11

Table continued on following page.

TABLE 5-2, CONTINUED

1974 Sales and Market Shares of U.S. Models and 1974 and 1975 Fuel Economy of These Models

Model	Sales in Thousands			% Share of Market			1974 M.P.G.	1975 M.P.G.*
	Feb. 1974	July 1974	7 mos. 1974	Feb. 1974	July 1974	7 mos. 1974		
Buick Century	7.9	15.2	80.6	1.4	1.8	1.6	10.4	16
Century Wagon	.6	1.1	6.1	.10	.13	.12	9.7	12
Le Sabre	3.6	4.4	28.0	.62	.52	.57	10.4	12
Electra	5.5	7.9	47.1	.94	.94	.95	8.3	11
Buick Wagon	.9	1.2	7.4	.15	.14	.15	9.6	11
Cadillac Calais	.3	.7	3.8	.05	.08	.08	8.9	-
De Ville	8.4	15.4	82.3	1.4	1.8	1.7	8.9	-
Fleetwood	1.0	.8	7.1	.17	.10	.14	8.7	11
Eldorado	2.3	2.5	18.2	.39	.30	.37	10.4	11
Chevy Vega	23.1	19.9	162.7	4.0	2.4	3.3	19.6	19
Vega Wagon	8.2	7.0	56.4	1.4	.83	1.2	20.0	-
Nova	18.0	30.9	168.9	3.1	3.7	3.4	15.2	16
Chevelle	16.4	30.8	155.4	2.8	3.7	3.1	9.9[e]	15[e]
Monte Carlo	14.9	32.4	158.8	2.5	3.9	3.2	9.9[e]	13
Impala	19.1	31.1	166.8	3.3	3.7	3.4	10.1	12[e]
Chevy Wagon	5.3	8.6	47.7	.91	1.0	.97	10	11
Camaro	7.1	14.9	75.9	1.2	1.8	1.5	9.9[e]	15[e]
Caprice	8.6	13.3	73.4	1.5	1.6	1.5	8.8	--

Table continued on following page.

TABLE 5-2, CONTINUED

1974 Sales and Market Shares of U.S. Models and 1974 and 1975 Fuel Economy of These Models

Model	Sales in Thousands			% Share of Market			1974 M.P.G.	1975 M.P.G.
	Feb. 1974	July 1974	7 mos. 1974	Feb. 1974	July 1974	7 mos. 1974		
Oldsmobile Omega	3.0	4.0	25.4	.51	.48	.51	10.4[e]	16[e]
Cutlass	13.6	26.7	137.5	2.3	3.2	2.8	9.5	15
Delta 88	2.4	4.0	20.6	.41	.48	.42	9	14
Delta Royale	3.6	6.8	34.0	.62	.81	.69	9	-
Ninety-Eight	3.7	5.2	32.4	.63	.62	.66	8.3[e]	11
Toronado	1.6	1.8	12.3	.27	.21	.25	8.3	11
Pontiac Ventura	4.4	5.9	36.6	.75	.70	.74	9.9	15
Le Mans	7.5	13.1	70.5	1.3	1.6	1.4	9.9	12
Catalina	6.5	9.1	54.5	1.1	1.1	1.1	8.8	-
Bonneville	1.3	1.9	11.2	.22	.23	.23	8.8	-
Grand Prix	4.3	7.8	42.6	.74	.93	.86	8.8	13
Pontiac Wagon	1.3	1.9	11.1	.22	.23	.22	8.5	11
Firebird	3.5	6.7	37.1	.60	.80	.75	9.9[e]	15[e]
Checker	.3	.2	3.0	.05	.02	.06	11	-
Dodge Dart	16.0	24.5	144.1	2.7	2.9	2.9	16.0	17.0
Sportsman Wagon	3.2	4.4	24.8	.55	.52	.50	11.5	11
Coronet/Charger	7.2	10.1	60.7	1.2	1.2	1.2	12.5[e]	17[e]
Dodge Wagon	.8	1.0	5.9	.14	.12	.12	8.2	10

Table continued on following page.

TABLE 5-2, CONTINUED

1974 Sales and Market Shares of U.S. Models and 1974 and 1975 Fuel Economy of These Models

Model	Sales in Thousands			% Share of Market			1974 M.P.G.	1975 M.P.G.
	Feb. 1974	July 1974	7 mos. 1974	Feb. 1974	July 1974	7 mos. 1974		
Ford Pinto	15.2	15.8	113.0	2.6	1.9	2.3	22.8	18
Pinto Wagon	13.6	15.9	102.2	2.3	1.9	2.1	19.6	18
Maverick	14.2	23.4	129.3	2.4	2.8	2.6	15.0	16
Torino	2.6	4.6	26.7	.44	.55	.54	11.8	11
Gran Torino	15.6	29.5	150.6	2.7	3.5	3.1	10.8	-
Torino Wagon	4.1	6.4	36.7	.70	.76	.74	11.4	11
Ford Wagon	7.1	9.6	54.1	1.2	1.1	1.1	10.4	9
Mustang II	20.2	24.9	165.4	3.5	3.0	3.4	16.9	18
Lincoln Continental	2.2	2.6	16.9	.38	.31	.34	7.9	10
Weighted Average, U.S. Cars[1]							13.05	15.50
Imports				18.0	15.0	15.0	21.1	22
Weighted Average, All Cars							14.44	16.62
Total % of Market				82.64	87.98	87.10		

e = estimates.

[1]Weighted by relative sales during the first 7 months of 1974.

SOURCE: Details on sources and methods of estimating miles per gallon (where the data were not available) are contained in Appendix E.

of U.S. cars for which data were available (Appendix D discusses the construction of this table in detail). Of the 48 models for which fuel economy figures were available in both years, 41 showed increases and only 7 showed decreases (all but 2 of the decreases were less than 1 mile per gallon).

Part of this improvement in fuel economy resulted from the use of radial tires as standard equipment on new models. Although their initial cost is higher, they also improve gasoline mileage, and higher gasoline prices enhance the value of better mileage. (Their safety and durability advantages also hastened the change-over to radial tires.)

To analyze the impacts of these policies fully and accurately, therefore, we would need to know two sets of relationships. First, what are the additional costs associated with producing cars with fuel economy improved sufficiently to meet the standard? Second, how much would consumers be willing to pay for the improvement in fuel economy? The difference between the increase in price and the amount consumers would be willing to pay can be analyzed as an excise tax on new cars, to which consumers will respond by purchasing fewer cars.

The value that consumers place on improved fuel economy can be approximated as follows. The only reason for consumers to value fuel economy is that better gasoline mileage reduces operating costs. Thus, the values of an improvement in fuel economy can be measured as the present discounted value of the savings in fuel, given the expected

pattern of future gasoline consumption.[1] For example, an average car travels about 16,000 miles in its first year of operation. At 16 miles a gallon, this implies a consumption of about 1,000 gallons. At 20 miles per gallon, only 800 gallons of gasoline will be consumed. At approximately $0.50 a gallon, this difference amoungs to a savings of $100 in the first year. In a similar fashion, the savings could be calculated for each successive year of the car's life, and these amounts discounted at an appropriate interest rate to calculate their present value to the consumer. Assuming that this calculation is implicitly performed (at least roughly) by consumers comparing the expected operating costs of cars, this present discounted value is the amount that consumers would be willing to pay for improved fuel economy. This amount depends not only on the current level of gasoline prices but also on their expected level. Thus, during the 1960's when gasoline prices were low by present standards and, having been declining in real terms, might be expected to continue to decline, consumers were presumably much less concerned with fuel economy, particularly as better gasoline mileage meant less weight, comfort, and horsepower. At current high gasoline prices, however, consumers ought to be

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[1]One car manufacturer, in a recent advertisement about the improved fuel economy of one of its models, followed this approach, estimating the number of gallons of gasoline saved over 50,000 miles. The advertisement did not, of course, take explicit account of the fact that $1 of future savings in gasoline costs is worth less than $1 of present savings, but it did note that the savings would be spread over a four-year period. Consumers probably at least implicitly discount future gasoline costs when considering purchase of an automobile.

willing to pay a much higher premium for improved fuel economy, especially if these prices are expected to last over the lifetime of the car. Gasoline currently costs, on average, about $0.55 per gallon. A realistic rate at which to discount future gasoline costs is 10 percent per year.[1] If these rates are expected to persist indefinitely, we can estimate the present discounted value to consumers of improvements in fuel economy.

The discounted savings differ, of course, for the different policies, which set different minimum standards on miles per gallon that a manufacturer's sales-weighted average fleet must attain. These average values are shown in Table 5-3. These values range between $365 (for an improvement in average fuel economy from 15.5 to 17.5 miles per gallon, on average) to $1,001 (for an improvement in average fuel economy from 15.5 to 22.5 miles per gallon, on average). These figures are used as the minimum cost estimates (for the respective policies) for each manufacturer to attain the average fuel economy required for his fleet. As discussed above, these figures are minimum figures because, if the cost were less than

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[1]The appropriate discount rate is not obvious in this case. If consumers finance the additional cost from savings, the after-tax income foregone may be about 5 percent per year. If they finance it by borrowing, the cost may be upwards of 10 percent per year. We have somewhat arbitrarily chosen 10 percent as the discount rate, implicitly including a premium for the risk that gasoline prices may fall.

TABLE 5-3

PRESENT DISCOUNTED VALUE OF GASOLINE SAVINGS
DUE TO IMPROVEMENTS IN AUTOMOTIVE FUEL ECONOMY

Age of Auto In Years	Average Annual Mileage (000s)	Average Annual Savings in Gallons of Gasoline at			Present Discounted Cost of One Gallon of Gasoline	Present Discounted Value of Savings at		
		17.5 MPG	20 MPG	22.5 MPG		17.5 MPG	20 MPG	22.5 MPG
1	15.9	116	231	318	.55	64	127	175
2	15.0	110	218	300	.50	55	109	150
3	14.0	102	203	280	.45	46	91	126
4	13.1	96	190	262	.41	39	78	107
5	12.2	89	177	244	.38	34	67	93
6	11.3	82	164	226	.34	28	56	77
7	10.3	75	149	206	.31	23	46	64
8	9.4	69	136	188	.28	19	38	53
9	8.5	62	123	170	.26	16	32	44
10	7.6	55	110	152	.23	13	25	35
11	6.7	49	97	134	.21	10	20	28
12	6.7	49	97	134	.19	9	18	25
13	6.7	49	97	134	.18	9	17	24
TOTAL	137.4	1003	1992	2748		$365	$724	$1001

Table continued on following page.

TABLE 5-3 (CONTINUED)

PRESENT DISCOUNTED VALUE OF GASOLINE SAVINGS DUE TO IMPROVEMENTS IN AUTOMOTIVE FUEL ECONOMY

Assumptions

(1) Base average miles per gallon = 15.5, the sales-weighted average fuel economy of 1975 model-year cars.

(2) Gasoline price = $0.55 per gallon, the "high" average price during the post-embargo period.

(3) The interest rate = 10 percent per year, compounded annually at the end of the year (i.e., the savings during the first year are not discounted at all, those during the second year are divided by 1.10, and so forth.)

SOURCES: Average annual mileage was taken from Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors*, Second Edition, (AP-42, April 1973), p. 3.1.2-8.

these figures, then manufacturers would have had an incentive to make the improvements already, given consumers' willingness to pay for them.[1]

Determining the *maximum* costs required for manufacturers to meet these standards is, however, much more difficult. We have been unable to locate any figures on these costs. Indeed, one study that examined the costs of different technological changes to improve fuel economy did not attempt to determine what the increase in price would have to be for manufacturers to cover their costs.[2] There are, of course, no estimates of such costs based on actual operating experience at commercial scales, as such improvements in fuel economy have not been implemented. Thus, in the absence of any data on these costs, we adopted another assumption to set a bound to the actual cost. This assumption leads to estimates that are undoubtedly too high, but we have no way to choose a tighter upper bound.

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[1]This argument is, strictly speaking, based on the assumption of equilibrium in the market for new cars. Because the increases in the price of gasoline have been quite sudden and quite recent, manufacturers have probably not had sufficient time to implement all the improvements in fuel economy that will be made if gasoline prices continue at their current levels (or higher) or if these prices are expected to remain high for the next several years.

[2]See Sorrell Wildhorn, Burke K. Burright, John H. Enns, and Thomas F. Kirkwood, *How to Save Gasoline: Public Policy Alternatives for the Automobile* (Santa Monica, California: RAND, October 1974). Although this study seems to suggest that cars with the improved technology can be made more cheaply than present cars, the study does not estimate the costs of research, development, retooling, and so forth that would be necessary to implement the technical changes. As these costs would, of course, ordinarily be reflected in the prices charged for the cars, their results are not useful for our purposes.

For the medium sensitivity case, we assumed that the costs of improving fuel economy up to the standard are double the minimum costs. For the high sensitivity case, we assumed that these costs are three times the minimum costs. These costs are undoubtedly too high. For one thing, they do not take into account that consumers would be *willing* to pay the amounts shown in Table 5-3 for the improvements in fuel economy.[1] Consequently, these assumptions tend to overstate the impact of these policies.

Summary of Parameters

Table 5-4 summarizes the coefficient and elasticity estimates used in determining gasoline consumption and the age distribution and size of the auto fleet as a result of the policies examined in this chapter.

Results

This section presents the results of the policies affecting gasoline consumption through new car sales. These results are, in some respects, different from the results presented in Chapter 4. That is, these policies affect not only gasoline consumption by automobiles, but also, through their impact on the age distribution of the

[1] In some sense, therefore, an appropriate lower bound is no increase in net cost at all. We decided not to analyze this assumption, because it would have still less effect than the low sensitivity assumption chosen. As the assumption used led to very small changes in fuel consumption, we decided to err on the side of overestimating the probable new-car price increases resulting from this set of policies, to give them the benefit of the uncertainty.

TABLE 5-4

SUMMARY OF COEFFICIENTS AND ELASTICITY ESTIMATES
USED IN ANALYZING EXCISE TAXES ON FUEL ECONOMY

Stage of Analysis		Coefficient Or Elasticity
Relationship between fuel economy and characteristics		
Weight		-.270
Horsepower		-.0102
Implied taxes on these characteristics		
Weight:	$50/mpg	13.50
	$100/mpg	27.00
	$200/mpg	54.00
Horsepower:	$50/mpg	0.51
	$100/mpg	1.02
	$200/mpg	2.04
Elasticity of demand for weight		
First year		-.0105
Second year		-.0211
Third year		-.0264
Elasticity of demand for horsepower		
First year		-.088
Second year		-.177
Third year		-.221
Elasticity of demand for new cars		-1.0
Change in scrappage in response to tax		
Elasticity with respect to change in new car sales		.742
Elasticity with respect to change in used car price		-.912
Elasticity of used car price index with respect to new car price index		
1975		.213
1976		.381
1977		.513

TABLE 5-4 (Continued)

SUMMARY OF COEFFICIENTS AND ELASTICITY ESTIMATES
USED IN ANALYZING EXCISE TAXES ON FUEL ECONOMY

Stage of Analysis	Coefficient or Elasticity
1978	.616
1979	.698
1980	.763
1981	.813
1982	.853
1983	.884
1984	.909
1985	.928
1986	.944
1987	.956
Average pre-tax price (all cars)	$4595
Average pre-tax miles per gallon	15.5
Pre-tax price of weight (per 100 pounds)	$ 62
Pre-tax price of horsepower (per rated HP)	$ 2.67
Pre-tax average weight (hundreds of pounds)	33.65
Pre-tax average horsepower	119.3
Share of cars subject to the tax	.858
Assumed price increase, 17.5 mpg restriction	$ 365
Assumed price increase, 20.0 mpg restriction	$ 724
Assumed price increase, 22.5 mpg restriction	$1001

stock of cars, the emission factors of the different pollutants. On the other hand, we assume that the reduction in gasoline consumption applied proportionately both to peak and to offpeak trips. Consequently, there is no difference in the percentage change between peak and offpeak gasoline consumption under these policies.

We discuss the percentage change in gasoline consumption, in the emissions of carbon monoxide, hydrocarbons, and nitrogen oxides in that order. We then discuss changes in the concentrations of these pollutants, as measured by the national index of concentrations, based on the 13 geographically dispersed cities.

Gasoline Consumption

Table 5-5 shows the best estimate of gasoline consumption under the policies affecting new car sales, for 1975, 1981, and 1987. Tables showing the detailed breakout of gasoline consumption in urban areas for these years, disaggregated into peak and offpeak gasoline consumption for 10 kilometer and 35 kilometer cities, appear in Appendix F.

It can be seen from Table 5-5 that the policies affecting new car sales have virtually no impact in the first year that they are in effect. Even the policy of requiring manufacturers to improve fuel economy to an average of 22.5 miles per gallon (which, it will be recalled, was assumed to imply an increase in the average price of new cars of $1001) leads to only a 6 percent decrease in gasoline consumption below the baseline forecast. Less drastic measures than this one imply negligible decreases in gasoline consumption, at least during the first year the policy is in effect. For example, the

Table 5-5

MEDIUM ESTIMATE OF GASOLINE CONSUMPTION
UNDER POLICIES AFFECTING NEW CAR SALES
(Billions of Gallons)

Year	Policy	10 Km Cities	35 Km Cities	Rural	Total	As Percentage of Baseline Forecast
1975	$50/MPG	18.12	38.20	48.71	105.03	100.2[1]
	$100/MPG	18.09	38.14	48.63	104.86	100.1[1]
	$200/MPG	18.04	38.03	48.49	104.55	99.8
	17.5 SWMPG	18.01	37.98	48.43	104.41	99.7
	20.0 SWMPG	17.54	36.99	47.17	101.71	97.1
	22.5 SWMPG	17.05	35.95	45.85	98.85	94.3
1981	$50/MPG	22.35	47.12	60.08	129.55	99.1
	$100/MPG	21.99	46.36	59.12	127.46	97.5
	$200/MPG	21.41	45.15	57.57	124.14	94.9
	17.5 SWMPG	21.64	45.63	58.19	125.46	96.0
	20.0 SWMPG	19.04	40.15	51.20	110.40	84.4
	22.5 SWMPG	16.87	35.57	45.36	97.79	74.8
1987	$50/MPG	26.89	56.70	72.31	155.91	97.3
	$100/MPG	26.26	55.37	70.61	152.25	95.0
	$200/MPG	25.24	53.22	67.86	146.32	91.3
	17.5 SWMPG	26.07	54.97	70.09	151.13	94.3
	20.0 SWMPG	21.52	45.37	57.86	124.75	77.8
	22.5 SWMPG	17.65	37.21	47.45	102.31	63.8

NOTES: Detail may not add to total because of independent rounding. Assumptions: medium elasticities, high prices.

[1]Consumption under the policy is estimated to be slightly less than baseline forecast, but rounding error causes the discrepancy.

policy requiring manufacturers to improve sales-weighted average fuel economy of their automobiles to 20.0 miles per gallon (which was assumed to cost, on average, $724 per auto) leads only to a 3 percent decrease in gasoline consumption in 1975. This decrease, in absolute terms, is about 3 billion gallons. In terms of barrels of crude oil, this amount corresponds to roughly 196,000 barrels per day, or only slightly more than 1 percent of current U.S. consumption of crude oil.[1]

The lack of effectiveness of these policies in the very short run is hardly surprising, as all their effect must come through a net reduction in the car stock from the reduction in new car sales, somewhat offset by a reduction in scrappage of old cars. Correspondingly, the change in the weighted average fuel economy of this stock of cars is also very slight. It is, therefore, only to be expected that the one year-impact of these policies should be negligible.

By 1981, however, the policies have had six years in which to take effect. It is interesting that, even for a length of time that will, under current conditions in the market, be sufficient to turn over about half of the car stock, most of these policies have little effect on gasoline consumption. For example, the effect of a $50 per mile per gallon tax, a $100 per mile per gallon tax, a $200 per mile per gallon tax, and a restriction of a sales-weighted miles per gallon to 17.5, lead only, at most, to a 5 percent reduction in gasoline consumption below the forecasted level.

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[1]This rough conversion was made by dividing the number of gallons by the number of gallons per barrel, and in turn dividing that by 365. Strictly speaking, a gallon of gasoline is not equivalent to a gallon of crude oil, as there are usually slight processing gains and losses in refining.

The other two policies requiring manufacturers to improve the average fuel economy to 20.0 and 22.5 miles per gallon are more effective. They are more effective both because the improvement in fuel economy is greater than for the other policy and because their increased costs (above the amount consumers would be willing to pay for these improvements in fuel economy) lead to a greater reduction in the stock of cars. After these effects have been operating for six years, the estimates show that these policies lead, respectively, to about a 15 percent decrease and a 25 percent decrease in gasoline consumption below the base forecast levels.

By 1987, when enough time has elapsed so that, under ordinary circumstances, complete turnover in the stock of cars would be expected, the results are quite similar to those of 1981. The three policies putting an excise tax on fuel economy and the least restrictive sales-weighted miles per gallon policy lead to decreases in fuel consumption of less than 10 percent below the forecasted level. The more restrictive fuel consumption policies -- requiring manufacturers to achieve 20.0 and 22.5 miles per gallon for their fleets on a sales-weighted basis -- lead, respectively, to about a 22 percent decrease and a 36 percent decrease in gasoline consumption below the base forecast levels.

In short, these policies seem very inefficient ways of reducing fuel consumption. As remarked elsewhere in this chapter, the uncertainties about the cost of improving fuel economy have been resolved by assumptions that will, if anything, greatly overstate the cost of improving fuel

economy.[1] If, as seems likely, the actual cost of improving fuel economy is much less than the amounts assumed, the long-run impact of these policies on gasoline consumption will be even less than that shown in the tables in Appendix F, because the stock of cars will increase at a faster rate than that implied by the policy analyzed under the assumptions here. When these tables are compared with Table 4-1, it is seen that an increase in the excise tax on gasoline of only $0.25 per gallon leads to a greater reduction in fuel consumption than the most extreme policy considered in this chapter for every year except 1987, when the tax on gasoline leads to a 30 percent reduction in gasoline consumption and the policy constraining sales-weighted miles per gallon of each manufacturer's fleet to be 22.5 leads to a 36 percent reduction in gasoline consumption. These estimates imply that the policies considered in this chapter are expensive, time consuming, and generally ineffective ways of reducing gasoline consumption. Moreover, to the extent that they are not as expensive as assumed here, they will be even less effective, because the stock of cars will increase at a faster rate than that implied by the policy analyzed under the assumptions here.

Moreover, these conclusions and results are not substantially changed if we examine the estimates of gasoline consumption under the assumptions leading to the lowest

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[1]These estimates, it will be recalled, are based solely on the amount consumers would be *willing* to pay for the improvement in fuel economy, and then increased by an arbitrary margin to increase the likelihood that the amounts are upper bounds on the costs.

plausible estimate of gasoline consumption.[1] Appendix F contains the estimates of gasoline consumption under the assumptions leading to the lowest and highest plausible gasoline consumptions.

The results are virtually the same in 1975 for all three sets of assumptions about price increases and behavioral parameters. Under the assumptions leading to least gasoline consumption, the more severe restrictions on sales-weighted fuel economy do lead to slightly greater decreases in gasoline consumption than under the medium estimates, but the difference is not substantial. The difference is greatest by 1987, but, again, both the medium and the low estimates lead to similar estimates of the percentage reduction in gasoline consumption, except for the two more restrictive policies on fuel economy of new cars. Even here, the differences do not appear to be substantial. For example, the medium estimate of the impact in 1987 of a 20.0 sales-weighted miles per gallon restriction implies a 22 percent decrease in gasoline consumption, while the low estimate of gasoline consumption implies a 32 percent decrease from the baseline forecast. Similarly, the 22.5 sales-weighted miles per gallon standard leads, under the central estimate, to a 36 percent decrease in gasoline consumption, while under the low estimate of gasoline consumption it leads to about a 50 percent decrease by 1987.

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[1]These conclusions are, of course, only strengthened if we examine the estimates leading to high gasoline consumption. These latter estimates, shown in Appendix F, are, for this reason, not discussed explicitly in the text.

Changes in Emission Factors

In the next subsection, we examine the changes in emissions, which are the product of the emission factors times the change in vehicle miles of travel. It is interesting, however, to separate out the influences due to these two factors. In the previous subsection, we considered the percentage change in vehicle miles of travel. In this subsection, we consider the changes in emission factors. Tables 5-6 to 5-8 show the emission factors for the baseline and for the different policies (assuming medium sensitivity and high gasoline prices) for carbon monoxide, hydrocarbons, and nitrogen oxides, respectively, for 1975, 1981, and 1987. It is clear that, for each pollutant type, the emissions factors in 1975 and 1987 are not very different from the baseline emission factors for all of the policies considered here. This similarity results in the case of 1974 because the stock cannot change very much in only one year, while it occurs for 1987 because it is a long enough time that, in spite of the delayed turnover in the stock of cars, the majority of the stock of cars has turned over under all of the policies. Consequently, by 1987, the emission factors of all vintages are very close to what is expected to be the eventual requirement for exhaust emissions. The increase in emission factors for 1981 is greatest for carbon monoxide and hydrocarbons. This occurs because these are pollutants for which the projected decline in the baseline emissions factors is greatest. As a result, by 1981, the shifts in the distribution of the car stock lead to an increase in the emissions factor for carbon monoxide of between 37 and 63 percent. In the case of hydrocarbons,

Table 5-6

LIGHT-DUTY VEHICLE CARBON MONOXIDE EMISSION FACTORS
FOR THE DIFFERENT POLICIES, 1975, 1981, AND 1987

Year	Policy	Running (g/mile)	Cold Start (g/start)	Average Factor (g/mile)
1975	Baseline	33.75	178.44	44.04
	$50/MPG	34.11	180.33	44.52
	$100/MPG	34.28	181.16	44.74
	$200/MPG	34.63	182.95	45.19
	17.5 SWMPG	34.25	181.02	44.78
	20.0 SWMPG	34.55	182.51	45.16
	22.5 SWMPG	34.81	183.83	45.42
1981	Baseline	6.28	65.34	10.05
	$50/MPG	9.52	72.05	13.68
	$100/MPG	9.92	73.55	14.17
	$200/MPG	10.95	77.76	15.44
	17.5 SWMPG	9.91	73.59	14.16
	20.0 SWMPG	10.71	76.64	15.13
	22.5 SWMPG	11.64	80.55	16.29
1987	Baseline	1.10	52.38	4.12
	$50/MPG	1.11	53.11	4.18
	$100/MPG	1.11	53.10	4.18
	$200/MPG	1.11	53.09	4.18
	17.5 SWMPG	1.11	53.12	4.18
	20.0 SWMPG	1.11	53.09	4.18
	22.5 SWMPG	1.11	53.06	4.18

SENSITIVITY: MEDIUM
PRICE ASSUMPTION: HIGH

Table 5-7

LIGHT-DUTY VEHICLE HYDROCARBON EMISSION FACTORS FOR THE DIFFERENT POLICIES, 1975, 1981, AND 1987

Year	Policy	Running (g/mile)	Cold Start (g/start)	Evaporative (g/day)	Hot Soak (g/trip)	Crankcase (g/mile)	Average (g/mile)[1]
1975	Baseline	3.71	8.30	20.30	12.37	0.38	6.23
	$50/MPG	3.75	8.39	20.29	12.57	0.42	6.34
	$100/MPG	3.77	8.42	20.30	12.58	0.39	6.33
	$200/MPG	3.81	8.50	20.34	12.59	0.39	6.38
	17.5 SWMPG	3.77	8.42	20.35	12.60	0.40	6.35
	20.0 SWMPG	3.80	8.48	20.45	12.64	0.40	6.39
	22.5 SWMPG	3.81	8.53	20.52	12.67	0.41	6.41
1981	Baseline	1.07	3.95	8.00	4.71	0.38	2.31
	$50/MPG	1.19	4.72	8.20	5.23	0.40	2.56
	$100/MPG	1.24	4.78	8.40	5.35	0.41	2.66
	$200/MPG	1.34	4.97	8.81	5.60	0.42	2.80
	17.5 SWMPG	1.23	4.78	8.75	5.58	0.42	2.67
	20.0 SWMPG	1.32	4.92	9.84	6.25	0.46	2.90
	22.5 SWMPG	1.41	5.10	10.85	6.88	0.49	3.12
1987	Baseline	0.37	3.95	1.66	1.06	0.36	1.10
	$50/MPG	0.37	4.06	2.42	1.50	0.41	1.22
	$100/MPG	0.37	4.06	2.52	1.58	0.42	1.24
	$200/MPG	0.37	4.05	2.75	1.73	0.43	1.27
	17.5 SWMPG	0.37	4.06	2.60	1.62	0.42	1.25
	20.0 SWMPG	0.37	4.05	3.11	1.98	0.45	1.32
	22.5 SWMPG	0.37	4.04	3.54	2.26	0.47	1.38

[1]Excluding evaporative emissions.

Table 5-8

LIGHT-DUTY VEHICLE NITROGEN OXIDES EMISSION FACTORS
FOR THE DIFFERENT POLICIES, 1975, 1981, AND 1987

Year	Policy	Running (g/mile)	Cold Start (g/start)	Average Factor (g/mile)
1975	Baseline	3.54	4.05	3.77
	$50/MPG	3.56	4.10	3.80
	$100/MPG	3.57	4.14	3.81
	$200/MPG	3.58	4.20	3.82
	17.5 SWMPG	3.56	4.13	3.80
	20.0 SWMPG	3.57	4.19	3.81
	22.5 SWMPG	3.58	4.23	3.82
1981	Baseline	1.54	0.98	1.60
	$50/MPG	1.52	1.44	1.60
	$100/MPG	1.55	1.49	1.64
	$200/MPG	1.63	1.61	1.72
	17.5 SWMPG	1.55	1.48	1.64
	20.0 SWMPG	1.61	1.58	1.70
	22.5 SWMPG	1.68	1.69	1.78
1987	Baseline	0.73	-0.81	0.68
	$50/MPG	0.78	-0.93	0.73
	$100/MPG	0.78	-0.83	0.73
	$200/MPG	0.79	-0.84	0.74
	17.5 SWMPG	0.78	-0.83	0.73
	20.0 SWMPG	0.78	-0.83	0.73
	22.5 SWMPG	0.80	-0.84	0.75

the emission factor increases by an amount between 11 and 35 percent. The increase is least for nitrogen oxides, for which the percentage increase in the 1981 emission factor ranges between 0 and 11 percent.

Changes in Emissions

Changes in urban emissions of the pollutants depend directly, as stated above, on the changes in emission factors and the changes in VMTs. Consequently, there are few surprises in Tables 5-9 to 5-11 (the medium estimate of urban carbon monoxide emissions for 1975, 1981, and 1987), Tables 5-12 to 5-14 (the corresponding tables for hydrocarbons), or Tables 5-15 to 5-17 (the corresponding tables for nitrogen oxides).

In the case of carbon monoxide, the forecast of urban emissions for 1975 shows, for most of the policies, a slight increase (on the order of 1 to 2 percent), but the reduction in vehicle miles traveled under the policy restricting sales-weighted average fuel economy to 22.5 miles per gallon leads to a very slight decrease in emissions. For 1987, most of the policies imply a very slight decrease in emissions, while the most restrictive fuel economy policy leads to about 13 percent decrease in emissions. This decrease is, of course, less than the nearly 40 percent decrease in gasoline consumption discussed above, because vehicle miles of travel do not fall by nearly as much as gasoline consumption, given the increase in average fuel economy of the stock of cars.

It is in 1981, however, that carbon monoxide emissions in urban areas increase relative to the baseline by between 35 to 48 percent. Although we have not calculated emissions for the years surrounding 1981, it seems quite likely that emissions

Table 5-9

URBAN CARBON MONOXIDE EMISSIONS IN 1975, MEDIUM SENSITIVITY

(Millions of Kilograms)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	4459.85	9536.49	13996.3	1.01316
OFF-P:	5352.5	11398.9	16751.4	1.01317
TOTAL	9812.35	20935.4	30747.7	1.01317
TAX: $100				
PEAK:	4474.44	9567.65	14042.1	1.01647
OFF-P:	5370.16	11436.5	16806.7	1.01651
TOTAL	9844.6	21004.2	30848.8	1.01649
TAX: $200				
PEAK:	4506.71	9636.62	14143.3	1.0238
OFF-P:	5409.03	11519.2	16928.2	1.02386
TOTAL	9915.74	21155.8	31071.6	1.02384
MPG: 17.5				
PEAK:	4476.13	9571.27	14047.4	1.01686
OFF-P:	5372.11	11440.7	16812.8	1.01688
TOTAL	9848.24	21012.	30860.2	1.01687
MPG: 20.0				
PEAK:	4441.43	9497.02	13938.5	1.00897
OFF-P:	5330.73	11352.5	16683.2	1.00905
TOTAL	9772.16	20849.5	30621.7	1.00901
MPG: 22.5				
PEAK:	4382.84	9371.73	13754.6	0.99566
OFF-P:	5260.45	11202.8	16463.3	0.99574
TOTAL	9643.29	20574.5	30217.8	0.995704

SENSITIVITY: MEDIUM
PRICE ASSUMPTION: HIGH

Table 5-10

URBAN CARBON MONOXIDE EMISSIONS IN 1981, MEDIUM SENSITIVITY

(Millions of Kilograms)

	10 KM	35 KM	TOTAL	FRACTION Or BASE
TAX: $50				
PEAK:	1771.17	3802.15	5573.32	1.32879
OFF-P:	2060.54	4402.3	6462.84	1.37172
TOTAL	3831.71	8204.45	12036.2	1.3515
TAX: $100				
PEAK:	1809.87	3884.3	5694.17	1.3576
OFF-P:	2109.64	4506.28	6615.92	1.40422
TOTAL	3919.51	8390.58	12310.1	1.38226
TAX: $200				
PEAK:	1929.15	4138.26	6067.41	1.44659
OFF-P:	2257.64	4820.43	7078.07	1.50231
TOTAL	4186.79	8958.69	13145.5	1.47606
MPG: 17.5				
PEAK:	1854.35	3979.87	5834.22	1.39099
OFF-P:	2161.1	4616.28	6777.38	1.43849
TOTAL	4015.45	8596.15	12611.6	1.41612
MPG: 20.0				
PEAK:	1897.45	4070.61	5968.06	1.4229
OFF-P:	2219.04	4738.35	6957.39	1.47669
TOTAL	4116.49	8808.96	12925.5	1.45136
MPG: 22.5				
PEAK:	1929.93	4138.73	6068.66	1.44689
OFF-P:	2263.85	4832.52	7096.37	1.50619
TOTAL	4193.78	8971.25	13165.	1.47826

SENSITIVITY: MEDIUM
PRICE ASSUMPTION: HIGH

Table 5-11

URBAN CARBON MONOXIDE EMISSIONS IN 1987, MEDIUM SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	719.649	1578.19	2297.84	0.992419
OFF-P:	691.355	1509.57	2200.93	0.992394
TOTAL	1411.	3087.76	4498.76	0.992407
TAX: $100				
PEAK:	706.783	1549.97	2256.75	0.974674
OFF-P:	678.994	1482.59	2161.58	0.974655
TOTAL	1385.78	3032.56	4418.34	0.974665
TAX: $200				
PEAK:	686.938	1506.45	2193.39	0.947307
OFF-P:	659.93	1440.96	2100.89	0.947289
TOTAL	1346.87	2947.41	4294.28	0.947298
MPG: 17.5				
PEAK:	744.763	1633.26	2378.02	1.02705
OFF-P:	715.482	1562.25	2277.73	1.02703
TOTAL	1460.25	3195.51	4655.76	1.02704
MPG: 20.0				
PEAK:	697.491	1529.6	2227.09	0.961863
OFF-P:	670.069	1463.1	2133.17	0.961843
TOTAL	1367.56	2992.7	4360.26	0.961854
MPG: 22.5				
PEAK:	632.414	1386.88	2019.29	0.872118
OFF-P:	607.55	1326.59	1934.14	0.872101
TOTAL	1239.96	2713.47	3953.43	0.87211

SENSITIVITY: MEDIUM
PRICE ASSUMPTION: HIGH

Table 5-12

URBAN HYDROCARBON EMISSIONS IN 1975, MEDIUM SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	593.043	1272.13	1865.17	1.01218
OFF-P:	775.828	1663.24	2439.07	1.01195
TOTAL	1368.87	2935.37	4304.24	1.01205
TAX: $100				
PEAK:	594.013	1274.16	1868.17	1.01381
OFF-P:	777.025	1665.74	2442.77	1.01348
TOTAL	1371.04	2939.9	4310.94	1.01363
TAX: $200				
PEAK:	596.411	1279.21	1875.62	1.01785
OFF-P:	780.021	1672.02	2452.04	1.01733
TOTAL	1376.43	2951.23	4327.66	1.01756
MPG: 17.5				
PEAK:	596.147	1278.76	1874.91	1.01747
OFF-P:	779.934	1672.01	2451.94	1.01729
TOTAL	1376.08	2950.77	4326.85	1.01737
MPG: 20.0				
PEAK:	588.637	1262.56	1851.2	1.0046
OFF-P:	769.914	1650.39	2420.3	1.00417
TOTAL	1358.55	2912.95	4271.5	1.00435
MPG: 22.5				
PEAK:	579.261	1242.38	1821.64	0.988561
OFF-P:	757.536	1623.75	2381.29	0.987978
TOTAL	1336.8	2866.13	4202.93	0.98823

SENSITIVITY: MEDIUM
PRICE ASSUMPTION: HIGH

Table 5-13

URBAN HYDROCARBON EMISSIONS IN 1981, MEDIUM SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	310.809	668.162	978.971	1.097005
OFF-P:	401.627	862.582	1264.21	1.098702
TOTAL	712.436	1530.74	2243.18	1.097958
TAX: $100				
PEAK:	312.32	671.24	983.56	1.102147
OFF-P:	403.498	866.367	1269.87	1.103618
TOTAL	715.818	1537.61	2253.43	1.102973
TAX: $200				
PEAK:	320.494	688.412	1008.91	1.130549
OFF-P:	413.898	888.161	1302.06	1.131597
TOTAL	734.392	1576.57	2310.97	1.131136
MPG: 17.5				
PEAK:	339.73	730.809	1070.54	1.199613
OFF-P:	440.94	947.78	1388.72	1.206913
TOTAL	780.67	1678.59	2459.26	1.203721
MPG: 20.0				
PEAK:	321.957	691.778	1013.74	1.135959
OFF-P:	416.246	893.528	1309.77	1.138302
TOTAL	738.203	1585.31	2323.51	1.137276
MPG: 22.5				
PEAK:	314.587	675.525	990.112	1.109489
OFF-P:	406.294	871.578	1277.87	1.110577
TOTAL	720.881	1547.1	2267.98	1.110099

SENSITIVITY: MEDIUM
PRICE ASSUMPTION: HIGH

Table 5-14

URBAN HYDROCARBON EMISSIONS IN 1987, MEDIUM SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	184.77	397.165	581.935	1.0813
OFF-P:	228.119	489.131	717.25	1.09161
TOTAL	412.889	886.296	1299.19	1.08697
TAX: $100				
PEAK:	181.588	390.328	571.916	1.06269
OFF-P:	224.223	480.784	705.007	1.07298
TOTAL	405.811	871.112	1276.92	1.06834
TAX: $200				
PEAK:	177.4	381.347	558.747	1.03822
OFF-P:	219.237	470.133	689.37	1.04918
TOTAL	396.637	851.48	1248.12	1.04424
MPG: 17.5				
PEAK:	204.81	440.556	645.366	1.19916
OFF-P:	254.949	547.233	802.182	1.22087
TOTAL	459.759	987.789	1447.55	1.2111
MPG: 20.0				
PEAK:	182.007	391.293	573.3	1.06526
OFF-P:	225.199	482.998	708.197	1.07783
TOTAL	407.206	874.291	1281.5	1.07217
MPG: 22.5				
PEAK:	164.402	353.429	517.831	0.962189
OFF-P:	203.368	436.152	639.52	0.973311
TOTAL	367.77	789.581	1157.35	0.968303

SENSITIVITY: MEDIUM
PRICE ASSUMPTION: HIGH

Table 5-15

URBAN NITROGEN OXIDES EMISSIONS IN 1975, MEDIUM SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	366.211	775.156	1141.37	1.00962
OFF-P:	474.145	1002.28	1476.43	1.00945
TOTAL	840.356	1777.44	2617.79	1.00953
TAX: $100				
PEAK:	366.356	775.479	1141.83	1.01003
OFF-P:	474.256	1002.53	1476.79	1.0097
TOTAL	840.612	1778.01	2618.62	1.00985
TAX: $200				
PEAK:	366.724	776.293	1143.02	1.01108
OFF-P:	474.583	1003.25	1477.83	1.01042
TOTAL	841.307	1779.54	2620.85	1.0107
MPG: 17.5				
PEAK:	366.655	776.11	1142.77	1.01086
OFF-P:	474.659	1003.38	1478.04	1.01056
TOTAL	841.314	1779.49	2620.8	1.01069
MPG: 20.0				
PEAK:	361.959	766.199	1128.16	0.997935
OFF-P:	468.445	990.268	1458.71	0.997343
TOTAL	830.404	1756.47	2586.87	0.997601
MPG: 22.5				
PEAK:	355.563	752.685	1108.25	0.980324
OFF-P:	460.066	972.575	1432.64	0.979517
TOTAL	815.629	1725.26	2540.89	0.979869

SENSITIVITY: MEDIUM
PRICE ASSUMPTION: HIGH

Table 5-16

URBAN NITROGEN OXIDES EMISSIONS IN 1981, MEDIUM SENSITIVITY

	(Millions of Kilograms) 10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	196.86	416.413	613.273	1.00609
OFF-P:	256.106	541.128	797.234	0.998647
TOTAL	452.966	957.541	1410.51	1.00187
TAX: $100				
PEAK:	198.41	419.71	618.12	1.01404
OFF-P:	258.038	545.226	803.264	1.0062
TOTAL	456.448	964.936	1421.38	1.0096
TAX: $200				
PEAK:	204.094	431.778	635.872	1.04316
OFF-P:	265.237	560.477	825.714	1.03432
TOTAL	469.331	992.255	1461.59	1.03815
MPG: 17.5				
PEAK:	203.253	429.952	633.205	1.03879
OFF-P:	264.348	558.558	822.906	1.0308
TOTAL	467.601	988.51	1456.11	1.03426
MPG: 20.0				
PEAK:	202.757	428.938	631.695	1.03631
OFF-P:	263.546	556.893	820.439	1.02771
TOTAL	466.303	985.831	1452.13	1.03144
MPG: 22.5				
PEAK:	200.188	423.536	623.724	1.02323
OFF-P:	260.063	549.563	809.626	1.01417
TOTAL	460.251	973.099	1433.35	1.01809

SENSITIVITY: MEDIUM
PRICE ASSUMPTION: HIGH

Table 5-17

URBAN NITROGEN OXIDES EMISSIONS IN 1987, MEDIUM SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	106.194	222.953	329.147	1.05303
OFF-P:	145.487	305.939	451.426	1.0513
TOTAL	251.681	528.892	780.573	1.05203
TAX: $100				
PEAK:	104.659	219.732	324.391	1.03781
OFF-P:	143.385	301.519	444.904	1.03612
TOTAL	248.044	521.251	769.295	1.03683
TAX: $200				
PEAK:	102.975	216.196	319.171	1.02111
OFF-P:	141.077	296.665	437.742	1.01944
TOTAL	244.052	512.861	756.913	1.02014
MPG: 17.5				
PEAK:	110.328	231.633	341.961	1.09402
OFF-P:	151.151	317.849	469	1.09223
TOTAL	261.479	549.482	810.961	1.09299
MPG: 20.0				
PEAK:	104.121	218.601	322.722	1.03247
OFF-P:	142.647	299.966	442.613	1.03078
TOTAL	246.768	518.567	765.335	1.03149
MPG: 22.5				
PEAK:	95.63	200.775	296.405	0.948278
OFF-P:	131.013	275.503	406.516	0.946716
TOTAL	226.643	476.278	702.921	0.947374

SENSITIVITY: MEDIUM
PRICE ASSUMPTION: HIGH

in 1980 and 1982, for example, will also increase by similar percentages. Carbon monoxide, therefore, is an example of the phenomenon discussed in the qualitative section above, where the policies designed to conserve gasoline lead to a large short-run increase in emissions of pollutants, although in the long run they do not increase emissions very much at all above the base level.

Urban emissions of hydrocarbons provide a similar example, with 1975 emissions being very close to the baseline forecasts and 1987 emissions being between 5 percent below the base case forecasts and about 20 precent above the base case forecasts, depending on the policy. In 1981, however, emissions of hydrocarbons ranged between 10 and 20 percent of the base case forecasts.

Urban emissions of nitrogen oxides, on the other hand, show only very slight increases above the base level forecasts in the different years. In 1975, for example, the policies implied levels of emissions that are within about 2 percent on either side of the base level forecasts. In 1981, the greatest increase is about 4 percent above the base case, while the least increase is virtually identical to the base case. Even by 1987, urban emissions of nitrogen oxides increased above their base level in five out of the six policies, by amounts ranging between 2 and 9 percent of the base case forecast level. Only the most severe restriction on fuel economy leads to a slight decrease in emissions of nitrogen oxides by 1987, through its impact on vehicle miles of travel.

Changes in Concentration

Tables 5-18 to 5-21 present the change in urban concentrations of these pollutants, according to the index of

Table 5-18

RELATIVE ONE-HOUR CARBON MONOXIDE CONCENTRATIONS FOR 13 CITY AVERAGES
(As Percentages of Baseline Concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$ 50/MPG	98.2	98.4
	$100/MPG	98.6	98.7
	$200/MPG	99.3	99.4
	17.5 SWMPG	98.6	98.8
	20.0 SWMPG	97.9	98.1
	22.5 SWMPG	96.7	97.0
1981	$ 50/MPG	129.0	119.9
	$100/MPG	132.1	122.0
	$200/MPG	141.4	128.3
	17.5 SWMPG	135.4	124.2
	20.0 SWMPG	139.5	127.0
	22.5 SWMPG	142.9	129.3
1987	$ 50/MPG	92.6	96.3
	$100/MPG	91.0	95.5
	$200/MPG	88.5	94.2
	17.5 SWMPG	95.9	97.9
	20.0 SWMPG	90.4	95.2
	22.5 SWMPG	82.7	91.3

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburg, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and medium sensitivity assumptions.

Table 5-19

RELATIVE EIGHT-HOUR CARBON MONOXIDE CONCENTRATIONS FOR 13 CITY AVERAGES
(As Percentages of Baseline Concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$ 50/MPG	95.2	96.1
	$100/MPG	95.5	96.3
	$200/MPG	96.2	96.9
	17.5 SWMPG	95.6	96.3
	20.0 SWMPG	94.9	95.8
	22.5 SWMPG	93.7	94.8
1981	$ 50/MPG	124.8	113.9
	$100/MPG	127.9	115.6
	$200/MPG	137.2	120.8
	17.5 SWMPG	131.1	117.4
	20.0 SWMPG	135.4	119.8
	22.5 SWMPG	138.9	121.7
1987	$ 50/MPG	82.1	93.4
	$100/MPG	80.7	92.8
	$200/MPG	78.5	92.0
	17.5 SWMPG	85.0	94.5
	20.0 SWMPG	80.2	92.7
	22.5 SWMPG	73.3	90.1

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburg, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and medium sensitivity assumptions.

Table 5-20

RELATIVE ANNUAL NITROGEN OXIDES CONCENTRATIONS FOR 13 CITY AVERAGES
(As Percentages of Baseline Concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$ 50/MPG	98.3	99.5
	$100/MPG	98.3	99.5
	$200/MPG	98.4	99.5
	17.5 SWMPG	98.4	99.5
	20.0 SWMPG	97.2	99.2
	22.5 SWMPG	95.5	98.7
1981	$ 50/MPG	97.4	99.6
	$100/MPG	98.1	99.7
	$200/MPG	100.8	100.1
	17.5 SWMPG	100.6	100.1
	20.0 SWMPG	100.6	100.1
	22.5 SWMPG	99.6	99.9
1987	$ 50/MPG	103.9	100.3
	$100/MPG	102.4	100.2
	$200/MPG	100.8	100.1
	17.5 SWMPG	108.0	100.6
	20.0 SWMPG	102.6	100.2
	22.5 SWMPG	95.0	99.6

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburg, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and medium sensitivity assumptions.

Table 5-21

RELATIVE ONE-HOUR OXIDANT CONCENTRATIONS FOR 13 CITY AVERAGES
(As Percentages of Baseline Concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$ 50/MPG	112.8	102.3
	$100/MPG	113.0	102.4
	$200/MPG	113.6	102.8
	17.5 SWMPG	113.8	102.8
	20.0 SWMPG	111.5	101.6
	22.5 SWMPG	108.8	100.1
1981	$ 50/MPG	351.4	0.635
	$100/MPG	351.0	0.637
	$200/MPG	358.8	0.647
	17.5 SWMPG	416.4	0.686
	20.0 SWMPG	370.4	0.653
	22.5 SWMPG	356.3	0.642
1987	$ 50/MPG	136.7	0.854
	$100/MPG	125.9	0.846
	$200/MPG	230.5	0.837
	17.5 SWMPG	161.4	0.831
	20.0 SWMPG	135.2	0.848
	22.5 SWMPG	210.9	0.812

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburg, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and medium sensitivity assumptions.

the 13 representative urban areas. Because of the simple diffusion model used, the changes in this index reflect very closely the changes in emissions of carbon monoxide and nitrogen oxides. Estimates of oxidant concentrations are somewhat unreliable, due to problems of nonlinearities in the oxidant-hydrocarbon relationship.

Fuel Consumption and Emissions by Alternative Modes

Fuel economy restrictions or excise taxes on the poor fuel economy of new vehicles will cause the autos added to the stock in each subsequent year to achieve better fuel economy than they would have without the policies. This reduces the automotive consumption of gasoline. Conserving fuel in this way -- by creating a more fuel-efficient auto stock -- should not by itself be expected to cause an increase in fuel use by other modes. But the new car policies have another, quite strong, effect. By imposing a tax or forcing manufacturers to incur greater costs, these policies increase the prices of new cars. Because new and used cars are substitutes, used car prices rise as well. As a result of cars becoming more expensive, fewer will be bought. Thus, the policies cause a reduction in the number of autos available to provide transportation services from what would have been available in their absence.. One may logically presume that such a reduction would lead to an increase in the use of other transport modes, and consequently an increase in the quantity of fuel consumed by these modes. Table 5-22 gives the percentage reduction from baseline in the size of the auto stock resulting from enacting the various policies. It may be seen that these effects are basically negligible in 1975, but (at least for the stronger policies) became significant in the years 1981 and 1987.

Table 5-22

PERCENTAGE REDUCTION IN SIZE OF AUTO STOCK
DUE TO ENACTMENT OF POLICIES

Policy	Year	Percentage Reduction
Tax = $50	1975	0.14
	1981	2.04
	1987	5.31
$100	1975	0.42
	1981	4.35
	1987	8.59
$200	1975	0.88
	1981	7.86
	1987	13.62
Fuel Economy Restrictions =		
17.5 mpg	1975	0.34
	1981	0.85
	1987	1.13
20.0 mpg	1975	2.72
	1981	7.96
	1987	10.32
22.5 mpg	1975	7.72
	1981	13.81
	1987	17.31

Based on parameters shown in Table 5-4.

Table 5-23 shows the associated conservation of fuel resulting from both the reduced size and the better fuel economy of the auto stock after the policies have been imposed. It may be determined from examination of Tables 5-22 and 5-23 that, for a given percentage reduction in the size of the auto stock, fuel economy restrictions reduce gasoline consumption by a substantially greater amount than do excise taxes on poor fuel economy. (This result arises from the relatively inelastic demand for weight and horsepower.) Thus, if two policies lead to the same reduction in the auto stock, and hence the same increase in transit fuel consumption, the fuel economy restriction policy leads to a greater reduction in automotive fuel consumption than the excise tax on poor fuel economy.

The increases in transit fuel consumption are, however, small relative to the decreases in gasoline consumption. These increases, shown in Table 5-24, imply an average increase in transit fuel consumption of less than 1 percent of the associated decrease in gasoline consumption.

To arrive at these estimates we employ a straightforward procedure. Since Table 5-22 gives the percentage reduction in auto stock resulting from alternative policies, we need only determine the sensitivity of transit ridership to changing auto ownership. But this has been

Table 5-23

REDUCTION IN FUEL CONSUMPTION BY AUTOMOBILES
DUE TO ENACTMENT OF POLICIES

Policy	Year	Reduction (Billions of Gallons)
Tax = $50	1975	0
	1981	1.50
	1987	4.99
$100	1975	0
	1981	3.59
	1987	8.65
$200	1975	0.26
	1981	6.91
	1987	14.58
Fuel Economy Restrictions =		
17.5 mpg	1975	0.40
	1981	5.59
	1987	9.77
20.0 mpg	1975	3.10
	1981	20.65
	1987	36.15
22.5 mpg	1975	5.96
	1981	33.26
	1987	58.49

SOURCE: Derived from Table 5-5 and baseline forecasts.

Table 5-24

INCREASE IN FUEL CONSUMPTION BY TRANSIT*
DUE TO ENACTMENT OF POLICIES

Policy	Year	Increase (Millions of Gallons)
Tax = $50	1975	9
	1981	26.8
	1987	69.9
$100	1975	0
	1981	57.2
	1987	113.0
$200	1975	11.58
	1981	103.4
	1987	179.2
Fuel Economy Restrictions =		
17.5 mpg	1975	4.5
	1981	11.2
	1987	14.9
20.0 mpg	1975	35.8
	1981	104.7
	1987	135.8
22.5 mpg	1975	101.6
	1981	181.7
	1987	227.8

*Base fuel consumption by transit in the years 1975, 1981, and 1987 is projected as constant at the level of 548.3 million gallons per year.

estimated by CRA in a concurrent project.[1] Given this elasticity we can determine the change in passenger miles of travel by transit and, assuming that the fuel economy of transit is constant,[2] the change in transit fuel consumption.

Increase in Emissions from Alternative Modes

The net reduction from diverting a passenger mile by automobile to a passenger mile by bus is the same for the

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[1]The estimated elasticity of work transit trips with respect to auto ownership is -3.33, while the estimated elasticity of transit trips with respect to auto ownership is -1.97 (both calculations based on 92.5 percent of trips being made by auto and on 0.95 autos per worker). See Charles River Associates, *Economic Analysis of Policies for Controlling Automotive Air Pollution in the Los Angeles Region* (March 1975), Appendix A. When weighted by their respective shares of total trips (68.1 percent for shopping, 31.9 percent for work; see Table 4-1), these elasticities yield an overall elasticity of transit trips with respect to auto ownership of -2.40. If we assume that average fuel consumption per passenger trip does not change, this figure becomes the elasticity of transit fuel consumption with respect to auto ownership. The underlying elasticities were estimated on Pittsburgh data. Other studies give conflicting estimates. We were not able to canvass all the studies that provide evidence on this question (a number of studies of modal split do not, moreover, report sufficient data to derive these elasticities), but one implied an elasticity of about -0.10 (Michael J. Demetsky, *Behavioral Approaches to Modal Demand Modeling* [Carnegie-Mellon University: May 1972], p. 164), while another implied an elasticity of about -1.30 (Antti Talvittie, "Comparison of Probabilistic Modal-Choice Models: Estimation Methods and System Inputs," *Highway Research Record*, No. 392, [1972], p. 117).

[2]This assumption is discussed above in some detail in the section on the modal shift effects of excise taxes on gasoline.

policies discussed in this chapter and the policies discussed in Chapter 4. There is, therefore, little to add here to the discussion found in the corresponding section of Chapter 4. However, these policies do tend to worsen the average emission factors of automobiles, particularly in the intermediate-run period.[1] As shown in Tables 5-6 to 5-8, the new emission factors are not large enough (relative to the emission factors for buses) to change qualitatively the discussion in Chapter 4.

Potential Changes in Structure and Secondary Impacts

In this section, we analyze qualitatively how these results would be changed by potential changes in the underlying structure. We also discuss, in qualitative terms, the probable secondary impacts of these policies.

Changes in Structure

In the preceding analysis of the impact on automotive gasoline consumption and ambient air quality of fuel economy restrictions and federal excise taxes on poor fuel economy, we have implicitly assumed that the underlying structure of the economy remains unchanged. That is, in estimating the implicit prices of automotive characteristics, (weight, horsepower), consumer demand for these characteristics, and total consumer demand for new cars, all variables *not* included

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[1] Increases in hydrocarbon diurnal evaporative emission factors are somewhat offset by reductions in the car stock. For 1981 and 1987, total diurnal evaporative emissions increase, while in 1975 they are nearly the same as in the base case.

in the equations are treated as constant for the duration of our analysis. Since these variables are likely to change and our estimates cannot reflect the impact of such changes, we investigate here in a qualitative fashion the direction in which our results are likely to be affected.

As defined above, structure represents the set of all factors not considered explicitly in the analysis. Since this is quite a large number of variables, we restrict ourselves to consideration of only the most important of these. Specifically we will analyze the impact of changes in the traffic regulations governing highway travel and the model mix of automobiles offered for sale by auto manufacturers. For reasons which will be specified below, the effects of these changes are extremely difficult to capture quantitatively. Thus we are able to speak only at a general level about their impact.

The Effects of Lowering National Speed Limits

There is every reason to believe that a vigorously enforced 55 m.p.h. national speed limit would change the fuel consuming characteristics of the vehicle stock. A lower speed limit reduces the value to drivers of additional vehicle weight and horsepower, because, on the one hand, the additional power cannot be used without the risk of a summons for speeding and, on the other hand, reduced highway speeds reduce the safety value of large, heavy cars.

In addition to the effect on demand for those vehicle characteristics associated with high speed driving, the lower national speed limit will also affect consumers' demand for long trips by automobile. Travel time by automobile will be significantly increased, while travel time

on most other modes will be unaffected. Since consumers value their time, the result is a reduction in the number of people choosing to make long trips by auto. But then this causes a softening of demand for those vehicles which provide comfort and safety on long highway excursions.

The net result of these effects is to diminish consumer demand for new vehicles with characteristics associated with high speed, high power,and comfort on long trips. Thus, in each year subsequent to the enforcement of lower national speed limits, the stock of vehicles on the road can be expected to have lower average values for these characteristics (horsepower, length, weight, engine displacement, etc.). Because fuel economy is inversely related to vehicle weight and horsepower, as shown earlier in this chapter, reduced speed limits will tend to cause an increase in the fuel economy of new cars.

Thus, if speed limits are effectively lowered after these policies have been in effect, average fuel economy of new cars will tend to increase and gasoline consumption will tend to fall, even aside from the direct impact on consumption from lower speeds. The net effect, however, may be small, because lower speed limits and a tax on fuel consumption tend to overlap in their impact. That is, both influence the demand for weight and horsepower, and these influences are not independent. We have not attempted to quantify the net impact.

Changes in the Mix of Vehicles Offered for Sale

The final structural change which we will investigate in this section is the introduction by auto manufacturers

of new, more fuel efficient models in response to the imposition of taxes by the federal government. As was indicated by our discussion of methods earlier in this chapter, it is completely reasonable to suggest that manufacturers will alter the fuel economy of the models which they offer for sale in response to a tax on fuel economy, or in response to fuel economy restrictions by the government. This earlier discussion also indicated the difficulty of quantifying this response, due to the lack of data on what it would cost auto manufacturers to implement these changes. While it is possible to infer a lower bound on these costs[1] from basic economic considerations, accurate characterization of manufacturers' behavior requires knowledge of the entire cost function for augmentation of vehicle fuel economy. In particular we would need to know the marginal cost of improving fuel economy by an additional mile per gallon as a function of the initial vehicle fuel economy and the amount of the improvement already undertaken. In the absence of this information, precise quantitative analysis is impossible.

It is possible to pursue a rigorous qualitative discussion of these issues, however. We will consider here how auto manufacturers would tend to respond to the introduction of taxes or restrictions on fuel economy, and then analyze how such behavior by auto manufacturers would modify

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[1]Recall that this lower bound was the present discounted value of the stream of reduced operating costs accruing to the consumer who drives the vehicle with average intensity over its life cycle, as a result of the improvement in fuel economy. If costs were less than this quantity, manufacturers could institute changes in fuel economy and make a profit. We assume that no such profit-making opportunities would go unexploited.

our derived results. We consider taxes on poor fuel efficiency and fuel economy restrictions in turn. We will assume throughout that the cost of improving a model's fuel economy depends only on the size of the improvement (i.e., is independent of the initial miles per gallon), and is the same for all models. We assume that, initially for each model, the cost of increasing the fuel economy of the vehicle by one mile per gallon is just equal to the present value of the savings in operating costs for the average driver which such an improvement would imply.[1] We denote this quantity by C_0. Furthermore, as the process of improving fuel economy is undertaken, we assume that the cost of increasing the fuel economy of a given model by another mile per gallon is greater, the greater has been the size of the improvement already made. That is, we assume increasing marginal cost of fuel economy improvement. Finally we let τ denote the tax rate in dollars/mile/gallon to be imposed on all new vehicles attaining less than 20 miles per gallon.

Let us now consider how an auto manufacturer would respond to such a tax policy. He will improve fuel economy so long as the marginal benefit of such improvement exceeds the costs. This is illustrated in Figure 5-1. Before the tax, the marginal benefit is shown as the curve C_0E.[2] After the tax is imposed, however, the gain to increased fuel

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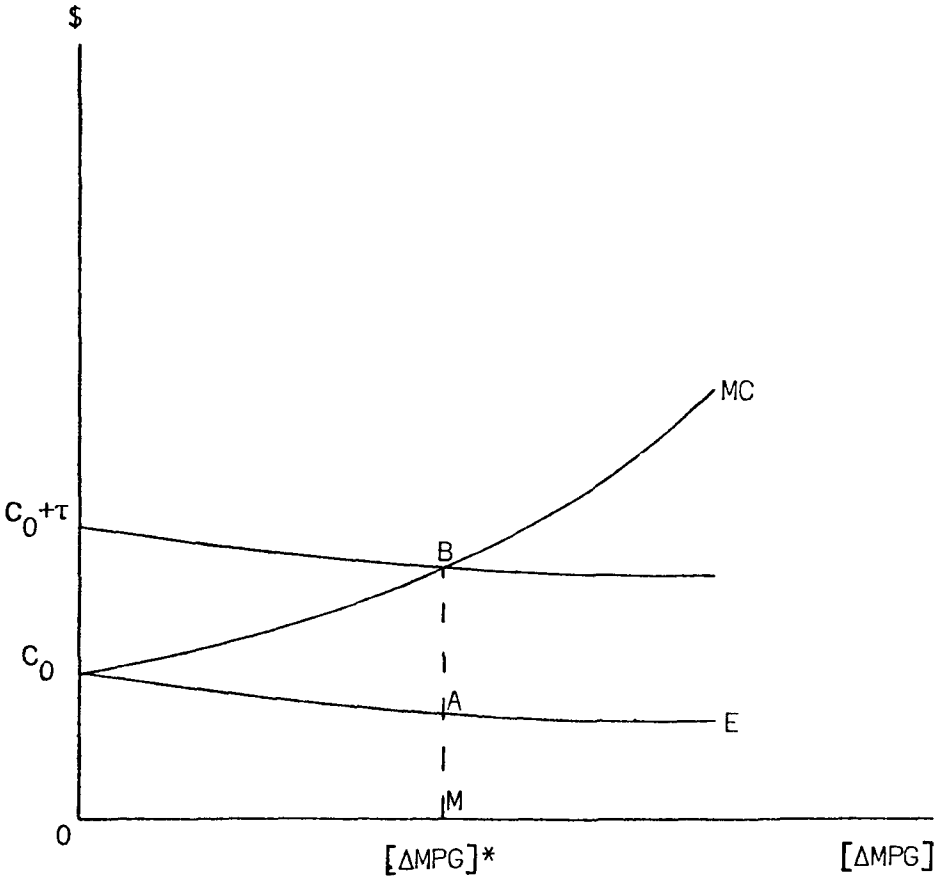
[1]This is the marginal cost of improved fuel economy at the initial point where no improvement has yet been undertaken.

[2]The downward slope of this curve reflects the decreasing dollar savings resulting from each additional mile per gallon. For example, the savings from increasing fuel economy from 24 to 25 m.p.g. are clearly much less than from increasing fuel economy from 1 to 2 m.p.g.

Figure 5-1

SCHEMATIC REPRESENTATION OF MANUFACTURERS' DETERMINATION OF OPTIMAL IMPROVEMENT IN MPG



economy by one mile per gallon is C_o plus the savings from lower federal taxes, τ. It will thus pay the manufacturer to continue to improve the vehicle's fuel economy until reaching the point where marginal cost equals $C_o + \tau$. This optimal improvement is denoted $[\Delta\ MPG]^*$ in Figure 5-1.

There is one important exception to the above discussion, however. This occurs when the vehicle's miles per gallon achieves the cut-off level of 20 m.p.g. before marginal cost has risen to the level $C_o + \tau$. Since there is no effective tax rate for vehicles over 20 m.p.g., there is no incentive for further improvement of fuel economy. This occurrence is technically known as a "corner solution", because the manufacturer's optimal choice lies on the boundary of the range of possible choices he could make. If fuel economy were subsidized (through a negative tax at the same rate) for vehicles with better than 20 m.p.g., then such solutions would not arise. In any event, this will happen only for models which were already close to the cut-off level in the first place.

We now examine the impact which such alterations of fuel economy by manufacturers is likely to have on our results. The first thing to observe is that under the above assumptions, every model with less than 20 m.p.g. will have its fuel economy improved by the same amount, except for those "corner solution" cases which were already close to the 20 m.p.g. cut-off. If these improvements are made, prices will increase by less than the full amount of the tax applied to the pre-tax fuel economies. Thus government revenues from taxation will be less. However, the cost to manufacturers of improving the fuel economy of the vehicles will be passed along to consumers in the form of higher pre-tax prices.

Thus, the overall price increase for a given model will be the sum of the tax rate (τ) times the difference in the m.p.g. of the model from 20 (this is zero if the model has a "corner solution") plus the additional costs incurred by the manufacturer in improving the fuel economy of the vehicle.[1]

An examination of Figure 5-1 reveals that the net price increases will be less than that which we have predicted in Appendix D. To support this assertion we first observe that the total increase in cost to the manufacturer for improving a vehicle's fuel economy by the optimal amount $[\Delta MPG]^*$ is the area $OMBC_0$, under the marginal cost curve between the vertical axis and the vertical dashed line at $[\Delta MPG]^*$. Recall that our price concept is that of price per unit quality. Since the improved fuel economy of the vehicle is shown by the curve C_0E, in terms of the present value of reduced operating costs, we may subtract the lower area, $OMAC_0$. This is because consumers are indifferent to such a price increase when accompanied by an equivalent reduction in operating costs over the life of the vehicle. Thus, the price increase due to costs incurred in improving fuel economy, after making allowance for the value placed by consumers on improved fuel economy, is the area of the "triangle" C_0AB in Figure 5-1. Had the change in fuel economy not been instituted however, the tax would have caused the price to rise by an additional amount equal to the area of the upper "triangle" $C_0B(C_0+\tau)$ (that is, there would be no quality correction factors).[2] It is equally

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[1]This assumes a competitive industry. In the real world of oligopoly there is no guarantee that the pre-tax price increase will not exceed the improvement costs.

[2]The amount of tax shown by the area $AEFB$ would have to be paid in either case (no improvement in fuel economy or improvement to $[\Delta MPG]^*$), and thus it does not affect the comparison here.

clear from Figure 5-2 that in the case of a corner solution, the price increase will be less than that implied by the tax. Therefore we may generally conclude that alteration of the fuel economy of autos by manufacturers in response to a federal tax policy will cause the ultimate increase in new car prices to be less than that which we have forecasted.

The immediate implication of this observation is that older car scrappage rates and new car demand will not be reduced by as much as we have assumed. Thus we will have overstated both the increase in average automobile age and the decrease in the size of the auto stock in future years attributable to these policies. This implies that, in the short run, emissions will increase less than estimated above; in the long run, emissions will be greater than forecasted.[1] Also, if the average fuel economy of the fleet was the same in both instances, this would imply more gasoline consumption than we have forecasted as well.

If manufacturers improve the fuel economy of their fleets in response to (or in anticipation of) the tax, this improvement operates in addition to the effect due to a shift in sales, especially if the shift in relative sales is not affected by the improvement in fuel economy of individual models. However, since the overall price increases for models subject to the tax will be less than if manufacturers' improvements occur, the shift in relative demands away from low mileage cars will not be as great. Thus, whether we have understated or overstated the average fuel economy of new vehicles added to the fleet in

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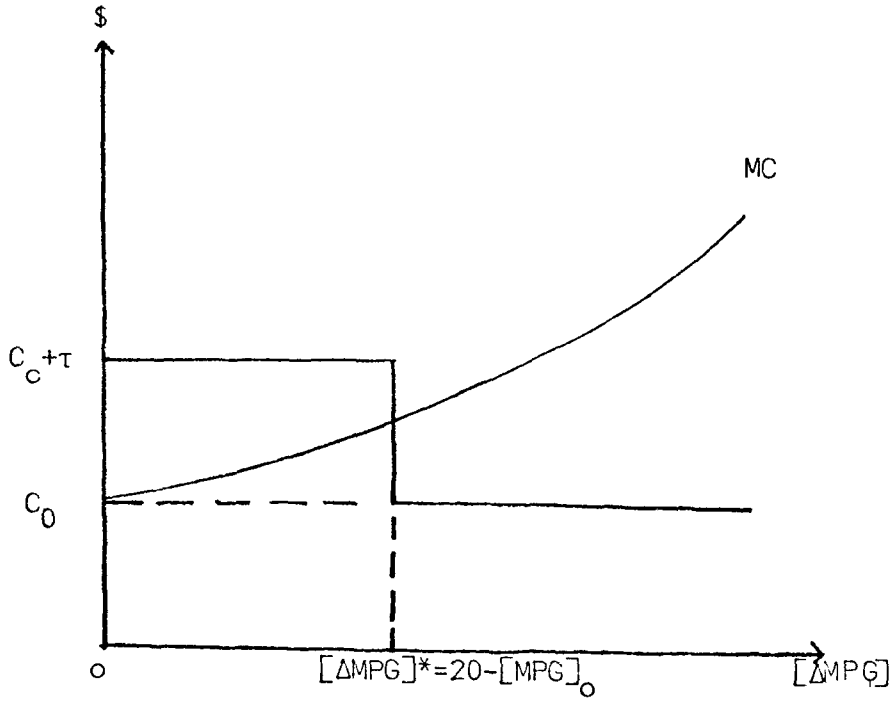
[1]The long-run result follows immediately from the increased car stock. The short-run result follows by a continuity argument from the results presented above.

Figure 5-2

SCHEMATIC REPRESENTATION OF MANUFACTURERS' DETERMINATION OF OPTIMAL IMPROVEMENT IN MPG: "CORNER SOLUTION."



years subsequent to the initiation of the tax policy depends on the shape and level of the cost function for fuel economy improvements and the structure of consumer demand for vehicles in different fuel economy classes. Two extreme examples may illustrate this point. If, on the one hand, fuel economy can be improved to 20 miles per gallon for each model at no cost, we will certainly have understated the improvement in the overall fuel economy of the fleet. If, on the other hand, such improvements cost more than the tax rate, our results are not affected. Further, the cross-elasticities of demand among different classes of autos clearly interact with the price increases in determining the eventual effects of these policies. Empirical investigation of these questions was beyond the scope of this study.

Secondary Impacts

We have so far in this chapter investigated the direct impacts on gasoline consumption and air quality of certain policies affecting the prices and fuel economy of new vehicles. There are, however, a number of secondary effects on the economy which occur as a result of the implementation of these policies. In this section we shall examine certain of these effects in a qualitative fashion. Precise measurement of the size of these effects would (aside from presenting numerous technical difficulties) take us too far afield from the main purpose of this study. Since the range of possible secondary impacts is quite large, we shall necessarily restrict ourselves to a consideration of three major impacts: changes in the distribution of income due to the policies; incentives for technical change and efficiency associated with the policies; and the impact on employment in the auto industry as a result of the policies.

Income Distribution

The imposition of a federal excise tax on poor fuel economy of new vehicles will constitute an increase in the prices which consumers must pay for such vehicles. If we assume that manufacturers react passively to the new tax regulations (i.e., they do not alter the fuel economy characteristics of their models), then the size of the price increase for any given model will be equal to the tax rate times the number of miles per gallon by which that model falls short of the cut-off level. This will imply that each purchaser of such a vehicle must transfer income in the amount of this price increase to the Treasury Department, and thus to the general taxpayer. Thus, in the case of passive behavior by auto makers, the tax policy leads to a transfer of income from the purchasers of low mileage vehicles to the general taxpayer.

We know from previous discussion however that it will generally benefit auto manufacturers to introduce more fuel-efficient autos to the market in the face of such a tax. In this instance the price increases which consumers of those autos subject to the tax must face will be due in part to the tax itself, but also to the increased costs which manufacturers incur in instituting the changes. In this case, the smaller transfer of income will be from the buyers of low mileage autos to the manufacturers of autos as well as to the federal government. Receipts by the auto manufacturers will not accrue entirely to profits, however, as improvements in fuel economy can be achieved only at higher costs.

With fuel economy restrictions, no collection of tax revenue by the government is involved. Consumers of all automobiles will have to pay higher prices for their new cars.

These higher prices will generate extra revenues for manufacturers, offsetting somewhat the costs of compliance with the federal restrictions. An important difference between the distributional effects of restriction policies and those of tax policies is that, in all probability, the restriction policies will lead to increases in all new-car prices, whereas excise tax policies imply that only those who wish to purchase less fuel-efficient vehicles must pay higher prices.

Incentives for Efficiency and Technical Change

A tax on poor fuel economy, by increasing prices and reducing sales for models subject to the tax, creates an incentive for auto manufacturers to find ways to produce more fuel-efficient vehicles at lower costs. The shift in incentives due to these policies is likely to cause special attention to be paid to finding and developing methods for producing automobiles with higher miles per gallon, without sacrificing other attributes of the vehicle which consumers find desirable (weight, horsepower, comfort, etc.). Similar incentives exist for manufacturers when fuel economy restrictions, as opposed to excise taxes, are the policy tools utilized.

Unlike increases in the excise tax on gasoline, these policies aimed at the auto stock will not provide incentives for the more fuel-efficient use of a car once it has been purchased. Thus, it is unlikely that these policies, by themselves, would lead to patterns of vehicle usage and driving techniques that are more fuel-economical.

Further, the incentives are aimed at fuel conservation, and not at lower automotive emissions. In general, these goals appear to be in conflict. It is possible, however, that research efforts directed toward improved fuel economy might

result in technologies that achieve both better fuel economy and lower emissions. The stratified charge engine might be an example of such a technology. Evaluation of different technological possibilities was beyond the scope of this study, however.

Impact on Automotive Employment

As shown by the current economic policy debate, employment in automotive-related industries is a volatile political issue. Both the excise tax on new cars and fuel economy restriction policies will lead to increases in new-car prices. These price increases will cause a reduction in new-car demand and a consequent fall in sales from what they otherwise would have been. The size of this reduction depends on the price elasticity of demand for new cars. If we assume that labor productivity in the automotive industry (as measured, say, by output per man-hour) is constant, then this fall in sales will imply a proportionate decline in employment in the automobile industry. We may also infer from this that reduction in demand by auto manufacturers for the products of related industries (steel, rubber, etc.) will also reduce employment there. All in all the policies under study in this report may be expected to have a depressing effect on employment in auto-related industries.

There are two points to make in this regard. First, the quantitative analysis suggests that the reduction in auto demand will not be sudden or drastic. For example, our analysis shows that an excise tax of $100.00 per mile per gallon less than 20 will cause average new car prices to rise eventually by 8.85 percent. If the price elasticity of demand for new cars is -1.0 (the medium estimate used in the quantitative analysis), this increase implies an ultimate reduction in

auto demand and auto industry employment of 8.85 percent. Furthermore, this reduction will be spread out over a number of years, because of the time required for demand for automobile characteristics to adjust to changes in their implicit prices.

Second, this reduction of automotive employment does not imply an equal loss of jobs to the economy as a whole. Demand for other transportation modes may be expected to increase. Similarly, consumers' spending power will be diverted toward the purchase of other kinds of goods and services in the economy. The loss in jobs is thus temporary -- a fractional loss due to shifts in consumer demand. The federal government can facilitate adjustment to such changes by providing relocation subsidies and job training programs for displaced workers, as well as by fiscal and monetary policies aimed at maintaining full employment.

6. CONCLUSIONS

In this chapter, we draw together the major conclusions from Chapters 4 and 5. While conclusions are subject to the qualifications and limitations discussed there and in the supporting appendices, we are confident that the thrust of these conclusions is correct. The estimates themselves are subject to varying degrees of uncertainty, as reflected by the sensitivity analysis. The conclusions stated here do not, for the most part, depend on the particular assumptions used.

Policies Affecting Gasoline Demand Directly

Table 6-1 summarizes reductions in gasoline consumption and pollutant emissions from these policies. Our estimates suggest that, in the short run, demand for gasoline is relatively *inelastic*. Consequently, for all the policies examined except rationing, the fuel conserved during the first year these policies are in effect is a small fraction of total gasoline consumption. Rationing achieves a large reduction in fuel consumption

Table 6-1

GASOLINE CONSUMPTION AND POLLUTANT EMISSIONS AS A PERCENTAGE OF BASE CASE LEVELS: POLICIES AFFECTING FUEL PRICE AND AVAILABILITY

	Gasoline	CO	HC	NO_x
1975				
$0.10/gal.	97.0	97.1	97.1	97.0
$0.25/gal.	92.6	92.3	92.7	92.6
$0.50/gal.	85.1	85.4	85.5	85.2
Coupon Rationing ($1.27/gal.)	62.2	63.0	63.1	62.5
1981				
$0.10/gal.	89.4	89.7	89.7	89.4
$0.25/gal.	73.4	74.3	73.3	73.5
$0.50/gal.	46.8	48.6	48.2	47.1
Coupon Rationing ($0.39/gal.)	58.5	59.9	59.6	58.7
1987				
$0.10/gal.	88.1	88.9	88.4	88.0
$0.25/gal.	70.4	72.1	71.0	70.1
$0.50/gal.	40.4	44.3	42.0	40.2
Coupon Rationing ($0.37/gal.)	55.9	58.8	57.1	55.8

ASSUMPTIONS:

(1): High gasoline prices;

(2): Central elasticity estimates.

in the short run only at the cost of a very high gasoline price (inclusive of the market value of the coupon needed to purchase a gallon of gasoline). If gasoline available is immediately rather than gradually reduced from its current consumption levels, to only 10 gallons per licensed driver per week, substantial income transfers are likely to result, as consumers bid for the limited supply. For example, we estimate that the implicit income transfer under rationing in 1974 could (according to the elasticity of demand used and the level of gasoline prices assumed) range between $56 and $172 billion.

Over a period of, say, four to five years, consumers can adjust to the new, higher prices of gasoline implied by the gasoline tax and rationing policies. For a given increase in the excise tax, these adjustments lead to greater percentage reductions in fuel consumption in later years than occur in the first year of the policy. Correspondingly, the implicit price of a ration coupon falls sharply during the first several years of the policy, because the additional time permits more adjustments to be made.

Our analysis implies that changes in emissions and concentrations of automotive pollutants reflect changes in gasoline consumption quite closely (after adjusting for the change in emission factors due to changing exhaust standards). Emissions do not change in exact proportion to changes in gasoline consumption, because of changes in average trip length, but the differences in percentage changes are very small.

Further, our results show that the reductions in emissions for peak and offpeak hours are very similar.[1] These results imply that the impact of these policies on emissions of carbon monoxide, measured during the worst hour of the day, can be determined quite accurately from the overall reduction in gasoline consumption, without resorting to the disaggregated models and methods of analysis used in this study.

The fuel conservation implied by these policies, as well as the reductions in emissions and concentration levels, are, to some extent, offset by increases in fuel consumption and emissions by alternative modes of transportation, primarily buses. The exact level of this offset is difficult to determine, as there are no reliable estimates of the cross-elasticity of demand between autos and other modes of transportation. Under the assumption putting an upper bound on this cross-elasticity, however, it turns out that the offsetting increase in emissions is quite substantial, particularly for the later years of the forecast period, when automobile emission factors are expected to have fallen sharply in response to standards imposed during the 1970's. Indeed, under some assumptions about relative occupancy rates of buses and automobiles, the emissions per passenger mile by bus are higher for some pollutants by 1981. This result implies that, if policies are put into effect that will greatly increase the demand

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[1]Different estimates of gasoline elasticity by trip type might modify this conclusion. However, the elasticity used for non-work trips was almost twice that used for work trips, so that different estimates would have to show a still greater relative difference before this conclusion would be affected.

for urban public transportation, some attention ought to be paid to stricter exhaust emission standards for buses, as they may well constitute a major source of mobile emissions of hydrocarbons, nitrogen oxides, and even carbon monoxide.

Policies Affecting the Stock of Cars

Policies designed to influence the fuel consumption characteristics of new cars, with the aim of eventually improving the fuel consumption characteristics of the entire stock of cars, take effect very slowly. In part, this slowness results from the small proportion of the total car stock accounted for by new cars. In addition, these policies tend to reduce new car sales, thereby reducing the scrappage of existing cars. Since the purpose of these policies is to reduce fuel consumption by increasing the fuel economy of new cars relative to that of used cars, this latter effect tends to work against the intention of the policy. Consequently, the short-run reduction in gasoline consumption from these policies is very small indeed. Moreover, even in the long run, the policies must require large increases in fuel economy to bring about substantial percentage reductions in fuel consumption. The estimates reported in Chapter 5 assumed (where existing data were not adequate) that the increases in prices of new cars due to these policies would be substantial. These increased prices, through their effect on the eventual size of the stock of cars, further tend to increase the effectiveness, such as it is, of these policies. They also imply, however, large percentage

increases in the prices of new cars. If the actual price increases are less than those assumed, the long-run fuel conservation effects of these policies will be even less than those estimated.[1]

The shift in the age distribution of the car stock resulting from these policies implies an increase in automotive emission factors above the base forecast level for a number of years. That is, because the newer cars have lower emission factors than older cars, policies which increase the share of older cars on the road will also tend to increase the average emission factors. This effect operates primarily in the middle years of the forecast period, after the policies have been in effect long enough to cause substantial shifts in the age distribution, but before they have been in effect so long that all of the older, pre-policy cars have been retired from the automobile stock. For some pollutants, these policies lead to substantial increases in emissions and concentrations during the middle years of the forecast period (say, roughly, 1979-1983). Moreover, because vehicle miles of travel are restricted much less than fuel consumption under these policies (because of the increase in average fuel economy of the car stock), total emissions do not increase in proportion to

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[1]In the first few years after the policy has been in effect, the fuel economy of the prior stock of cars dominates the fuel economy of the stock as a whole, so that the effect of the increase in the size of the stock outweighs the effect of improved new car fuel economy. In the long run, the speedier turnover has no effect so that the greater stock of cars implies more gasoline consumption. In the intermediate period, the impact cannot be determined without additional empirical investigation.

gasoline consumption. For example, for the medium sensitivity assumptions, emissions in 1987 (when the policies have been in effect long enough for the entire stock of cars to have been replaced once), the most severe policy leads to a reduction in urban emissions of carbon monoxide of only 13 percent below the base level. The corresponding reductions for hydrocarbons and nitrogen oxides are only 3 and 5 percent, respectively. Thus, the analysis implies that emissions and concentrations as a result of these policies are about the same in the early years and only slightly less in the later years of the forecast period. During the middle years, they increase substantially. From the point of view of air quality, then, it appears that policies designed to conserve fuel by improving the fuel economy of the auto stock have perverse effects.[1] Table 6-2 summarizes reductions in gasoline consumption and changes in pollutant emissions resulting from these policies.

Comparison of the Two Sets of Policies

It appears clear, then, that the policies affecting gasoline consumption directly are preferable to those

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[1]It should be stressed that this conclusion depends on current technology continuing to be used in automobiles. If there exists a different technology that leads both to improved fuel economy and to lower emission factors, policies which would hasten the introduction of this technology would, by the same token, lead to an improvement both in fuel economy and air quality. A rigorous policy of retrofitting older automobiles with high quality emission control devices would affect all parts of this analysis. Examination of this policy, however, was beyond the scope of this study.

Table 6-2

GASOLINE CONSUMPTION AND POLLUTANT EMISSIONS AS A PERCENTAGE OF BASE CASE LEVELS: POLICIES AFFECTING THE STOCK OF CARS

	Gasoline	CO	HC	NO_x
1975				
$50/MPG	100.2	101.3	101.2	101.0
$100/MPG	100.1	101.6	101.4	101.0
$200/MPG	99.8	102.4	101.8	101.1
17.5 SWMPG	99.7	101.7	101.7	101.1
20.0 SWMPG	97.1	100.9	100.4	99.8
22.5 SWMPG	94.3	99.6	98.8	98.0
1981				
$50/MPG	99.1	135.2	109.8	100.2
$100/MPG	97.5	138.2	110.3	101.0
$200/MPG	94.9	147.6	113.1	103.8
17.5 SWMPG	96.0	141.6	120.4	103.4
20.0 SWMPG	84.4	145.1	113.7	103.1
22.5 SWMPG	74.8	147.8	111.0	101.8
1987				
$50/MPG	97.3	99.2	108.7	105.2
$100/MPG	95.0	97.5	106.8	103.7
$200/MPG	91.3	94.7	104.4	102.2
17.5 SWMPG	94.3	102.7	121.1	109.3
20.0 SWMPG	77.8	96.2	107.2	103.1
22.5 SWMPG	63.8	87.2	96.8	94.7

ASSUMPTIONS:

(1): High gasoline prices;

(2): Central elasticity estimates.

Values actually slightly less than 100.0; difference is due to rounding error.

aimed at changes in the characteristics of the stock of automobiles, assuming that only one set of policies is put into effect. A $0.25 per gallon increase in the excise tax on gasoline, for example, has virtually the same impact on gasoline consumption as the most severe restriction on the fuel economy of new cars, but the real resource cost is much less.[1] Finally, policies designed to reduce gasoline consumption directly lead to reductions in emissions and improvements in air quality, while those aimed at the stock of cars lead to increases in emissions and deterioration of air quality, relative to the base forecast.

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[1]For example, the deadweight loss to consumers (as distinct from the income transfers) of a $0.25 per gallon excise tax is estimated at about $1 billion in 1975, while the resource cost of improving average fuel economy to 22.5 miles per gallon is estimated at over $8 billion in 1975.

APPENDIX A

In this appendix, we present the base case forecasts of gasoline consumption and emissions for the years 1973 to 1975, 1981, and 1987. The appendix presents an overview of the methods used to forecast consumption, disaggregate consumption by urban and rural use and by time of day, translate this consumption into emissions of the different pollutants, and determine ambient air concentrations.

The Demand for Gasoline

Two equations are presented and discussed in this section, one characterizing the short-run demand for gasoline, the other used to determine the long-run price elasticity.

Short-Run Demand for Gasoline

The technical discussion of the short-run demand for gasoline is divided into three parts: the estimating technique; the statistical properties of the equation, including goodness of fit; and a description of the variables and their sources.

Estimating Technique

The equation presented in Chapter 3 is reproduced here for convenience:

$$QGASLD = \underset{(5.359)}{1.14237} - \underset{(-2.108)}{41.8367}\ PGASD + \underset{(19.431)}{.38298}\ RVLD + \underset{(6.415)}{.151965}\ PCERVLD - \underset{(-2.881)}{.043262}\ MPG$$

Standard error of estimate = .0652 Number of observations = 1029

where

QGASLD = thousands of gallons of gasoline consumed in highway uses per licensed driver;

PGASD = price of gasoline at the pump, divided by the implicit price deflator for the Gross National Product;

RVLD = registered vehicles (a weighted sum of automobiles and trucks) per licensed driver;

PCERVLD = estimated registered vehicles per licensed driver that satisfy the 1968 exhaust emission standards;

MPG = estimated miles per gallon of the stock of automobiles.

Instruments:

KRU = an index of capacity utilization in the petroleum refining industry;

PCRUDED= the real average wholesale price of crude oil;

TAXD = real state and federal excise tax on gasoline;

WPETD = the real average hourly earnings in the petroleum refining industry.

This equation represents only the demand side of the market. The supply side, which reflects the behavior of gasoline refiners, distributors, and retailers, as well as the producers of crude oil, is not modeled here. The interaction of both demand and supply determines the equilibrium price, production, and consumption of gasoline. Because of this interaction, there is a mutual influence between the price of gasoline and gasoline consumption. That is, if the demand for gasoline should increase for some exogenous reason (for example, a change in the engine design of automobiles resulting in a reduction in fuel economy), this increase in demand would tend, in the short run at least, to bid up the price of gasoline. Conversely, if the supply of gasoline should suddenly contract for exogenous reasons, (for example, a production cutback by members of the Organization of Petroleum Exporting Countries), the resulting rise in price would tend to reduce consumption.

It is generally impossible to include in an equation all of the myriad influences on the demand for gasoline. Because of the omission of relatively unimportant variables, there is usually some unexplained variation, or residual error, in a statisticallly estimated equation. For the usual statistical properties of the estimates to hold, the error should be uncorrelated with the included influences of gasoline consumption, notably the price of gasoline.

Because of the interdependence of price and quantity, however, random disturbances will tend to affect both the error term and price. The error term and observed prices will thus tend to be correlated. Moreover, even as the sample size gets very large, this correlation will persist. Therefore, ordinary least squares, which is unbiased and consistent in a broad range of non-simultaneous contexts, results in biased and inconsistent coefficient estimates.

That is, even if the sample size becomes very large, the estimates will not converge to the true parameters. Although these undesirable properties of ordinary least squares do not mean it should never be used, consistent estimates are generally much to be preferred when the sample is large. For this reason, two-stage least squares was chosen as the estimating technique. This technique gives unbiased and consistent estimates of simultaneous equation coefficients. A full description of two-stage least squares can be found in any good econometrics textbook.[1] Simply described, the method uses the exogenous variables from the supply side and the exogenous variables from the demand side, to estimate the jointly dependent variable (prices, in this case). The estimated price is uncorrelated with the error term and is used in the demand equation.

The jointly dependent variable in this equation was PGASD, the real price of gasoline. The exogenous variables from the supply side, described in greater detail below, include real wages in petroleum refining, real state and federal gasoline excise taxes, the real price of crude oil, and an index of capacity utilization in the refining industry.

Goodness of Fit

Because of the two-stage estimating procedure, the test statistics associated with ordinary least squares either are not

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[1]See, for example, Henri Theil, *Principles of Econometrics* (New York: John Wiley and Sons, Inc., 1971), pp.451-460.

applicable or have different interpretations. For example, the multiple correlation coefficient, R- squared, no longer has the properties it has in ordinary least squares, and is not appropriate as a measure of goodness of fit. Accordingly, it is not reported here.

The numbers in parentheses under the coefficients are not precisely t-statistics. Instead, they might better be called quasi-t-statistics, inasmuch as each is the ratio of the coefficient to its asymptotic standard error. That is, as the sample size tends to infinity, the estimated asymptotic standard error of the coefficient converges to the true standard error of the coefficient, and the quasi t-statistic tends toward the true t-statistic. These quasi t-statistics are all quite respectable by conventional statistical standards, indicating a high degree of confidence in the coefficient estimates. The coefficient on the price of gasoline, however, is the least precisely estimated of the coefficients. A band of one asymptotic standard error around this coefficient implies that the estimated short-run price elasticity, evaluated at the sample mean, would lie between .09 and .27.

The standard error of estimate is a consistent estimate of the true standard error. In this equation it is about 65 gallons per licensed driver per year, less than 10 percent of the sample mean. This indicates a reasonably close fit to the data, although there remains considerable unexplained variation.

Description of the Variables and Their Sources

QGASLD

The dependent variable in this equation, *QGASLD*, is thousands of gallons of gasoline consumed in highway uses per licensed driver. Gasoline consumption was divided by the number of licensed drivers to reduce heteroscedasticity in the error term leading to more precise coefficient estimates.

A typical observation of the dependent variable is gasoline consumption per licensed driver in a given state in a given year. Pooling of states across time periods leads to a total of 1,029 observations (48 states plus the District of Columbia over 21 years of the post-war period). Highway use of gasoline per state was taken from the Federal Highway Administration, *Highway Statistics*, various issues. It was computed as highway use of motor fuels (Table MF-23) less highway use of special fuels (Table MF-25). This variable includes truck use of gasoline, but it does not include diesel fuel or non-highway uses of gasoline by automobiles. Consequently, this measure is the best available for the purposes of this study. The estimate of the number of licensed drivers per state was taken from Federal Highway Administration, *Highway Statistics*, various issues (Table DL-1A).

PGASD

The price of gasoline is in real terms. That is, it is the nominal price of gasoline relative to the overall price level. The nominal price used is the price of gasoline at the pump in dollars per gallon, including state and federal taxes, from Platt's *Oilgram Price Service and Oilmanac*, various issues. It was deflated by the implicit price deflator for the Gross National Product, taken from the 1974 *Economic Report of the President*.

RVLD

The variable representing the stock of motor vehicles, RVLD, is a weighted average of the number of registered autos and the number of registered trucks. The number of registered autos per state was taken from the Federal Highway Administration,

Highway Statistics, various issues (Table MV-1). The numbers used represent total registrations during the course of the year in each state, and are based on registration fees collected by the state. As a result, the figures overstate the actual number of registered vehicles, as they do not take account of vehicles registered during the year, but scrapped during the year. They also count twice those vehicles registered in more than one state during a year (if, for example, an owner moved to another state and registered his vehicle there).

In spite of these drawbacks, the data are the most readily available non-proprietary source of this information. Moreover, although the total tends to overestimate the total number of registered automobiles, if the number of double registrations and scrappage during the year is roughly a constant fraction of the total vehicle population, then this overestimate will not bias the estimated coefficients.

The number of registered trucks was taken from the same source (Table MV-1). One potential problem with trucks is that much of their use may occur outside of the the state in which they are registered. There is, however, no information on such use. To some extent, variations in fuel consumption by out-of-state trucks may cancel out among states.

The weighting scheme used to add up autos and trucks took into account two factors. First, some trucks consume diesel fuel rather than gasoline. As registration data on trucks by fuel use are not available, a rough estimate was made of the percentage of registered trucks using gasoline. It was assumed in every year that 96.7 percent of all registered trucks use gasoline. This estimate was derived from the *1967 Census of Transportation Truck Use Inventory Survey*, on the assumption that

all pick-up and panel trucks use only gasoline. This number also happens to be midway between the numbers for 1963 and 1972, taken from the *1972 Census of Transportation Truck Inventory and Use Survey*, U.S. Summary, p. 1. In 1963, 97.9 percent of those trucks reporting fuel use burned gasoline; in 1972, 95.4 percent of the trucks reporting fuel use burned gasoline. This very small range between 1963 and 1972 suggests that 96.7 percent may be a reasonable estimate for all years of the percentage of trucks using gasoline.

Second, annual gasoline consumption per vehicle is greater for trucks than for autos. Figures on annual gasoline consumption by passenger cars and by single unit trucks are available from 1963 to 1971 in *Highway Statistics*. On average over this period, single unit trucks consumed 1.395 times as much fuel as passenger cars. (We assumed for the purposes of this calculation that all single unit trucks use only gasoline.) The two adjustment factors, .967 and 1.395, were multiplied together and the resulting adjustment factor, 1.349, was multiplied by the number of registered trucks. That is, the number of car-equivalent automobiles has been estimated as the number of registered autos plus 1.349 times the number of registered trucks. This sum was then divided by the number of licensed drivers to obtain registered vehicles per licensed driver.

PCERVLD

It has been widely thought that the nationwide exhaust emission controls, effective with the 1968 models, were met by changes in engine design that increased gasoline consumption. To our knowledge, there does not exist a good measure of the increase in gasoline consumption due to these engine design changes.

Consequently, we used a dummy variable to account for increased fuel consumption from this source.

The dummy variable, *PCERVLD*, is the number of registered vehicles per licensed driver from the 1968 model year on. This variable is the product of *RVLD* and another variable, *PCEPROP*, the proportion of automobiles in the automobile stock accounted for by model years 1968 to the present. *PCEPROP* was computed from data published in the *Automotive News 1973 Almanac*, compiled by R.L. Polk and Company, on the distribution of automobiles by model year for each calendar year in the post-war period. These data, based on state registrations, are as of July 1 of each calendar year.

Registered trucks are included in this variable. This treatment seems proper, given that the standards were the same for all light-duty vehicles during this period and almost all gasoline trucks belong to this category. The standards will be different for trucks and automobiles starting in 1975, however.

Two remarks should be made about the interpretation of this variable. First, as a dummy variable it may not precisely capture the effects of the engine design changes associated with the pollution control regulations. That is, to interpret the coefficient of this variable as showing the effect of these design changes, one must assume that any systematic increase in gasoline consumption with 1968 and later model year cars must be associated with the pollution control regulations.

Second, the standards have been evolving steadily since that time. No attempt has been made to take the impact of the changes in standards into account. The main reason for this neglect is that most of them come into effect after 1971, the last year of the sample used to estimate the equation. Further,

it is not clear that, in the future, fuel economy will be worsened by the pollution control requirements. For example, one car manufacturer is claiming that the catalytic converters, installed to meet EPA restrictions, will increase fuel economy. In any event, we have no way to estimate these future changes.

MPG

Another variable influencing fuel consumption has been the change in fuel consumption characteristics of new cars over this period. It is important to draw the distinction between fuel consumption characteristics and measured fuel consumption per mile by the stock of cars. This distinction is important because the actual fuel consumption achieved, (that is, the total gallons of gasoline per mile driven), depends on other things besides the fuel consumption characteristics. For example, in two-car families, higher gasoline prices may cause the car that gets better gas mileage to be driven more intensively. This effect ought properly to be included in the measurement of price elasticity, rather than included in the fuel consumption characteristics of the stock of cars. The most readily available measure of fuel consumption, in *Highway Statistics*, is a measure of average fuel economy achieved. For this reason, we constructed a variable to measure the actual fuel consumption characteristics of the stock of cars on the road in each year.

This construction, the most complex of any of the variables used in this equation, consisted of four steps. First, we obtained an equation relating miles per gallon of a given automobile to its engine displacement and weight. Second, for each year, we estimated the average weight and the average displacement of new cars sold in that year. Third, using the figures on the age distribution of the stock of automobiles referred to above,

we estimated for each year the average weight and engine displacement of new cars registered. Finally, we applied the equation mentioned above to the average weight and displacement of the cars to obtain an average miles per gallon of the stock of cars in the years 1950 to 1971, the sample used in this estimation.

The equation used to relate miles per gallon to vehicle weight displacement was as follows:

$$MPG = 23.0 - .0006 \times WGT - .0166 \times DIS$$

where

MPG = miles per gallon;

WGT = weight in pounds; and

DIS = engine displacement in cubic inches.

This equation was estimated by Dewees using actual miles per gallon obtained in the Mobilgas test economy runs from 1966 to 1968.[1] All of the cars in the sample had automatic transmissions. Dewees adjusted the actual coefficients obtained in the regression to those reported here, so that the average miles per gallon would be 14 to 15.

The second step was the calculation of average curb weight and engine displacement for new cars sold in each of the years 1941 to 1971. These calculations required the share of sales for different size cars, their weights, and their engine displacements in each year over this period. In any given year, the number of models is so large, that to calculate the actual

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[1]Donald N. Dewees, *Economics and Public Policy, the Automobile Pollution Case* (Cambridge, Mass.: M.I.T. Press, 1974), p.152. A fuller description of the different equations estimated, their test statistics, and the samples used to estimate them can be found in this source.

sales-weighted average vehicle weight displacement for each of the years would have been beyond the scope of this study. Instead, we grouped the sales into three classes: imports, including subcompacts in the years 1970 and 1971; compacts; and the remainder, which were assumed to have weight and engine displacement characteristics similar to the intermediate-sized three. Thus, the share of sales of imported cars was taken from the *Automotive News Almanac*, various issues. In 1970-71, the shares of Gremlin, Pinto, and Vega were included in the imported car category. The models in the compact car class changed somewhat over the period 1959 to 1971. The models whose sales were included in this category for each year are shown in Table A-1 The share of the intermediate-sized three was computed as a residual; that is, one minus the shares of imports and compacts.

Curb weight figures for the different models were taken from *Consumer Reports*. The figures for 1950 to 1960 in *Consumer Reports* are only for shipping weight; that is, curb weight less heater, fuel, oil, and water. Using the estimate given in *Consumer Reports*, we added 150 pounds to the shipping weight to get the approximate curb weight. The average weight of the intermediate-sized three was taken as the sales-weighted average weight of the standard Fords, Chevrolets, and Plymouths. The average weight of compacts was taken to be the simple average of Corvair, Falcon, and Valiant, except in 1970 and 1971 when the Chevrolet Nova was used instead of the Corvair, and in 1971 when the Maverick was used instead of the Falcon. The average weight of Volkswagens was used to represent the average weight of imports.

These same models were also used in calculating average engine displacement. Engine displacement figures were also taken from *Consumer Reports*. The average weight and displacement for

Table A-1

Models Used to Calculate Market Share of Compacts

	59	60	61	62	63	64	65	66	67	68	69	70	71
Valiant		x	x	x	x	x	x	x	x	x	x	x	x
Dart	x	x	x	x	x	x	x	x	x	x	x	x	x
Falcon	x	x	x	x	x						x	x	
Corvair	x	x	x	x	x	x	x	x	x	x			
Nova										x	x	x	x
Chevy II			x	x	x	x	x	x	x				
American	x	x	x	x	x	x	x	x	x				
Comet		x	x	x	x	x	x					x	x
Tempest		x	x	x	x	x	x						
Hornet											x	x	x
Maverick											x	x	x
Ventura													x
Club Wagon													x

each of these size classes of cars -- the intermediate three, compacts, and imports -- were then used along with the share of sales as described above to calculate the sales-weighted average weight and displacement for new car sales in each of these years.

The average displacement of new cars calculated this way was compared with that shown in Dewees.[1] For the years in which both sets of figures exist -- 1950, 1952, 1954, 1956, 1958, 1960, and 1968 -- the figures calculated this way were considerably below those estimated by Dewees. In order to achieve comparability with Dewees' figures, therefore, these figures were adjusted according to a ratio procedure, shown in Table A-2, so that they would be the same as Dewees' figures where Dewees' figures exist, but would elsewhere keep the same ratio as shown by this calculation procedure.

The third step was then to compute the average weight and displacement for cars on the road in each of the years 1950 to 1971. This was done using the figures for registration by vintage mentioned above, taken from the *Automotive News Almanac*. The Dewees equation was then applied to these average figures to obtain the average miles per gallon characteristic of the stock of cars in each of these years.

Although the miles per gallon estimated this way are probably considerably above the actual miles per gallon experienced, this discrepancy is not a source of concern, as long as the miles per gallon accurately reflects the trend in miles per gallon observed over this period. From this point of view, the trend as shown in Table A-3 appear reasonable. In general, miles per

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[1]D. N. Dewees, *op. cit.*

Table A-2

Adjustment of Estimated Average Displacement of New Car Sales to Link With Dewees' Data

	Unadjusted	Adjusted	Dewees' Estimate
1941	205.51	219	--
1942	205.51	219	--
1943	205.51	219	--
1944	205.51	219	--
1945	205.51	219	--
1946	225.51	240	--
1947	225.02	239	--
1948	224.12	238	--
1949	224.58	239	--
1950	223.04	237	--
1951	224.81	239	--
1952	222.85	237	237
1953	233.36	247	--
1954	236.40	250	250
1955	249.74	273	--
1956	251.36	275	275
1957	244.3	293	--
1958	244.13	293	293
1959	234.77	282	--
1960	204.97	268	268
1961	204.13	230	--
1962	207.05	233	--
1963	204.94	231	--
1964	220.09	248	--
1965	253.36	285	--
1966	258.61	291	--
1967	262.14	295	--
1968	270.17	304	304
1969	277.32	312	--
1970	262.82	296	--
1971	361.25	295	--

Table A-3

Average Curb Weight, Engine Displacement

and Estimated Miles Per gallon of the Stock of Automobiles, 1950-1971

	Curb Weight	Engine Displacement	Estimated Miles per Gallon
1950	3238.3	227.7	17.08292
1951	3284.0	228.6	17.03780
1952	3288.5	231.8	16.98171
1953	3289.5	234.5	16.93620
1954	3290.6	236.5	16.90230
1955	3306.8	243.7	16.77207
1956	3329.1	247.9	16.68763
1957	3357.3	252.7	16.58934
1958	3371.1	257.8	16.49557
1959	3400.1	261.2	16.42003
1960	3426.3	264.2	16.35291
1961	3443.5	263.3	16.35650
1962	3431.5	262.9	16.37107
1963	3437.6	260.2	16.41186
1964	3449.5	261.7	16.37914
1965	3449.8	262.7	16.36234
1966	3477.0	267.5	16.26465
1967	3472.8	269.0	16.24253
1968	3480.2	270.3	16.21611
1969	3502.1	273.3	16.15181
1970	3488.7	273.3	16.16068
1971	3487.7	278.3	16.07832

Table A-3 (cont.)

Average weight is curb weight in pounds; engine displacement is in cubic inches.

Average weight was calculated from the estimated average weight of new cars sold according to the following equation:

$$Average\ weight\ (t) = \sum_{\tau=1}^{T} \alpha_{\tau}(t) WGT_{\tau}$$

where t represents a calendar year

$\alpha_{\tau}(t)$ is the proportion of τ-model year cars on the road in year t.

WGT_{τ} is the average weight of τ-model year cars

τ is an index from 1 to T of the model years on the road in year t.

Average displacement was calculated analogously.

Miles per gallon were computed according to the following formula:

$$MPG = 23.0 - .00066\ WGT - .0166\ DIS$$

where: MPG = miles per gallon
WGT = average weight
DIS = average engine displacement

gallon has been declining over the period 1950 to 1971, with a slight increase in the period 1960 to 1963 when the influence of the sales of compact cars made itself felt. The size of the stock of cars is so large relative to new car sales, however, that the influence of any one model year is slight, so that the sharp changes in year-to-year miles per gallon are smoothed out when averaged in with all of the cars on the road.

Variables from the Supply Side

Four variables from the supply side were also included in the equation, as excluded predetermined variables. These variables, although they do not affect the demand curve, affect the supply price and are used in the first stage of the regression to estimate the real price of gasoline. These variables are used to obtain unbiased and consistent estimates of the coefficients, but they do not need to be forecast in order to forecast gasoline consumption. The four variables are the real price of crude oil, real state and federal excise taxes, real wages in the petroleum refining industry, and an index of capacity utilization in the refining industry. The first three of these variables were converted from current dollars to 1958 dollars by dividing the current dollars by the implicit price deflator for Gross National Product, taken from the *Economic Report of the President*.

The average wholesale price of crude petroleum, PCRUDED, an average of eight producing areas in dollars per barrel, was taken from Platt's *Oilgram Price Service and Oilmanac*. This variable measures the input cost of crude oil to the gasoline refineries.

The state and federal excise tax on gasoline, TAXD, was taken from the Federal Highway Administration, *Highway Statistics*, various issues (Table FE-101 and MF-1). These taxes are an important

part of the difference in the price paid by consumers and the prices received by refiners.

Average hourly earnings in the petroleum refining industry, WPETD, are in dollars per hour. They were taken from the Bureau of Labor Statistics, *Employment and Earnings 1909-1968*, p. 682 (for the years 1950 to 1967) and *Employment and Earnings*, various issues, 1968 to 1971. These wages are also a cost faced by refiners, and may be expected therefore to influence supply price of gasoline.

The index of capacity utilization in the petroleum refining industry, with 1967 = 100, was taken as the quotient of two independent indexes. The numerator was the Federal Reserve Board index of durable manufacturing production, taken from the *Economic Report of the President, 1973*, Table C-34, p. 232. This index was taken as an activity variable influencing refinery capacity utilization. It should be pointed out that actual crude runs distilled, or some other such measure of refinery throughput, would not be truly exogenous, but would instead depend on the price of gasoline and other factors within the petroleum refining industry. The denominator was an index constructed from annual data on oil refining capacity, including both operating and operable shutdown capacity. The figures on capacity were taken from the U.S. Bureau of Mines, *Mineral Industry Surveys*, "Petroleum Refineries in the United States." The series on refining capacity was then divided by the 1967 value of refining capacity, and the resulting series was then multiplied by 100 to obtain the index used as the denominator of the overall index of refinery capacity utilization.

The Long-Run Adjustment Coefficient

The equation just discussed is a short-run equation, in that other factors, such as the number of cars on the road and their average fuel consumption, which can respond to price changes over a period of time, are held constant. Therefore, the only influence that price has on gasoline consumption is through the current price.

However, it seems reasonable that the price of gasoline will influence the number of cars per licensed driver as well as the average fuel economy they achieve. Estimation of the complete structural model, that is, one which would in turn explain the number of cars on the road and their average fuel consumption in terms of the price of gasoline and other variables, was beyond the scope of this report. The approach used, therefore, assumes instead that, as prices and incomes change, people adjust their gasoline consumption in response to these changes. The adjustment takes time, however, as it is assumed to occur through the stock of cars and through the average fuel economy of these cars. Other changes and habits, such as residential location or place of work, take even longer to adjust. The model may be formalized as follows:[1]

$$LOG(QGASLD_t) - LOG(QGASLD_{t-1}) = \lambda[LOG(QGASLD^*_t) - LOG(QGASLD_{t-1})] \quad (1)$$

where

$QGASLD_t$ = highway consumption of gasoline per licensed driver at time t;

$QGASLD^*_t$ = desired highway consumption of gasoline per driver;

λ = adjustment parameter, $0<\lambda<1$.

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[1]This relationship is modeled after the stock adjustment model set out by Nerlove. [Marc Nerlove, *The Dynamics of Supply: Estimation of Farmers' Response to Price* (Baltimore, Md.: Johns Hopkins University Press, 1958).] The advantage of it for our purposes is its simplicity -- the lagged dependent variable implicitly takes account of the past history of responses to price change.

Desired highway gasoline consumption, $QGASLD^*_t$, depends on real price and income in the contemporaneous time period:

$$LOG(QGASLD^*_t) = \alpha+\beta LOG(PCPYD_t) + \lambda LOG(PGASD_t) \quad (2)$$

where

$PCPYD$ = real per capital disposable income;

$PGASD$ = real price of gasoline.

Substituting (2) into (1) and rearranging terms we get the equation in a form suitable for estimation:

$$LOG(QGASLD_t) = (\alpha\lambda) + (\beta\lambda)LOG(PCPYD_t) + (\gamma\lambda)LOG(PGASD_t) + (1-\lambda)LOG(QGASLD_{t-1}) \quad (3)$$

A change in $LOG(PGASD_t)$ has the impact $\gamma\lambda$ in the current period, $\gamma\lambda(1-\gamma)$ in the next period, $\gamma\lambda(1-\gamma)^2$ in the following period, and so forth. The eventual long-run effect is the sum of the infinite series

$$\gamma\lambda[1+(1-\lambda)+(1-\lambda)^2+(1-\lambda)^3\ldots] \quad (4)$$

Since λ is constrained to be between 0 and 1, the term in brackets has a finite sum, and expression (4) can be written in closed form as

$$\frac{\gamma\lambda}{1-(1-\lambda)} = \frac{\gamma\lambda}{\lambda} = \gamma \quad (5)$$

The parameter λ is estimated from an equation of the form (3), and this parameter is then used to translate the short-run elasticities (estimated as described in the previous section) into long-run elasticity estimates.

The equation used to estimate λ is as follows.

$$
\begin{aligned}
LOG(QGASLD) = {} & -1.84801 - .0059467*DTN1 + .0376118*DTN2 \\
& \quad (-3.290) \quad (-0.466) \quad (2.010) \\
& + .0552728*DTN3 + .0161467*DTN4 + .0824185*DTN5 \\
& \quad (2.260) \quad (1.061) \quad (2.252) \\
& - .290442*LOG(PGASD) + .787675*LOG(QGASLDL) \\
& \quad (-3.400)\# \quad (9.782)\# \\
& + .0128903*LOG(PCPYD) \\
& \quad (1.076)
\end{aligned}
$$

\# indicates jointly dependent variable

Number of observations = 1029 Standard error of estimate = .0496

Where

QGASLD = thousands of gallons of gasoline consumed in highway uses per licensed driver;

QGASLDL = *QGASLD*, lagged one year;

PCPYD = real per capita disposable income (in 1958 dollars);

PGASD = price of gasoline at the pump, divided by the implicit price deflator for the Gross National Product

DTN1, ..., *DTN5* = regional constant terms for groupings of states, 1 through 5 (the states in each group are shown in the Descriptive Summary of this appendix). *DTN1*, for example, takes the value 1.0 if the observation belongs to a state in group 1 and 0 otherwise.

Instruments:

LOG(PCPYDL), where *PCPYDL* = *PCPYD*, lagged one year,

LOG(KRU), where *KRU* is an index of capacity utilization in the petroleum refining industry;

LOG(PCRUDED), where *PCRUDED* is the real average wholesale price of crude oil;

LOG(TAXD), where *TAXD* is the real state and federal excise tax on gasoline;

LOG(WPETD), where *WPETD* is the real average hourly earnings in the petroleum refining industry.

The coefficient on $LOG(QGASLDL)_2$ is $1-\lambda$, so that the estimate of λ is 0.212325. That is, only about one-fifth of the desired change in consumption is carried out in the first period. That is, using the short-run elasticity of 0.18 from the short-run equation, the eventual responses to a 10 percent increase in the price of gasoline will be about an 8.5 percent decrease in consumption.

This response takes a number of years to be felt substantially, however. After 12 years, for example, the estimate implies that about 96 percent of the total response will have occurred. This estimate accords reasonably well with the length of time required to replace the stock of cars implied by the age distribution.

This model was used to estimate the lagged adjustment coefficient. The quasi-t-statistic on this estimate, 9.782, is quite large, indicating a fair degree of precision on this estimate. The equation as a whole, moreover, appears quite reasonable. The quasi t-statistics on the price of gasoline and on the lagged dependent variable are significant at conventional statistical levels. The standard error of estimate of the equation is about 5 percent. The coefficient of per capita disposable income suggests that gasoline consumption is quite insensitive to this variable, given the price of gasoline and the previous year's consumption. The income elasticity, .01, implies that 10 percent increase in

real per capital disposable income, other things being equal, would lead to only a one-tenth of a percent increase in gasoline consumption. This elasticity is quite consistent with the failure to find any income effect in the short-run demand equation, where the stock of cars was explicitly taken into account. The short-run price elasticity in this equation, -.29, is quite close to the elasticity implied by the short-run demand equation, -.18. In fact, when the sampling error of the coefficients is taken into account, these two estimates are not very different.

This equation also was estimated by two-stage least squares. The price of gasoline, for the reasons discussed in the section on short-run demand, was taken as a jointly dependent variable. The lagged gasoline consumption was also taken to be jointly determined, because of possible auto correlation in the error term. That is, suppose that this year's disturbance is related to last year's disturbance, perhaps because of the same excluded influences varying consistently over time. Then, since last year's disturbance is related to last year's gasoline consumption, it follows that last year's gasoline consumption and this year's disturbance are also related. Consequently, last year's gasoline consumption, QGASODL, was taken to be jointly determined and was also purged of the part associated with the error by the use of instrumental variables.[1]

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[1]A fuller discussion of the problems associated with distributed lag models can be found in any good econometrics textbook, for example, Arthur Goldberger, *Econometric Theory* (New York: John Wiley and Sons, Inc., 1964), pp.274-278.

Forecasting Methods

The methods of forecasting the independent variables can be divided into two groups. First, several variables were fitted to time trends of historical data, and these trends were then projected for the forecast years. Second, the forecasts of other independent variables were derived either by assumption or by a combination of assumption and time trend equations.

Variables Forecasted by Time Trends

Three variables -- LD, the number of licensed drivers; *REGAUTO*, the number of registered automobiles; and *REGTRK*, the number of registered trucks -- were forecasted using time trend equations. As these variables were forecasted on a state-by-state basis, the observations for the different states were grouped according to the regional groupings of states reported in the equation used for long-run adjustment cofficient. The six groupings of states into regions are shown in Table A-4. Each state was allowed to have its own constant term, or base level, in the forecasting equation. States in each group were constrained to have the same growth rate over time, but at different levels.

Table A-5 summarizes the equations used to forecast licensed drivers, registered trucks, and registered autos. Growth rates implied by these equations are shown in Table A-6. Table A-5 shows coefficient estimates for the individual state constant terms and for the time trend. The dependent variable on each equation was in logarithmic form. Therefore, the coefficient on the time variable can be interpreted as the annual rate of growth, continuously compounded. Over the period for which these equations were estimated, 1950 to 1972, this

Table A-4

GROUPING OF OBSERVATIONS BY STATES FOR FORECASTING EQUATIONS

Group 1

Connecticut
Massachusetts
New Jersey
Rhode Island

Group 2

Arizona
California
Colorado
Iowa
Kansas
Nebraska
Oregon
Washington

Group 3

Alabama
District of Columbia
Delaware
Florida
Georgia
Idaho
Indiana
Kentucky
Louisiana
Maryland
Maine
Michigan
Minnesota

Group 3 (cont.)

Missouri
Montana
North Carolina
North Dakota
New Hampshire
New Mexico
Nevada
Oklahoma
South Carolina
South Dakota
Tennessee
Texas
Utah
Virginia
Vermont
Wisconsin
West Virginia
Wyoming

Group 4

Illinois
Ohio
Pennsylvania

Group 5

Arkansas
Mississippi

Group 6

New York

Table A-5

SUMMARY OF EQUATIONS USED TO FORECAST
LICENSED DRIVERS, REGISTERED TRUCKS, AND REGISTERED AUTOS

		Licensed Drivers		Registered Trucks		Registered Autos	
Group	State	K	T	K	T	K	T
1	CT	13.7738 (740.9)	.03065 (29.49)	11.4754 (759.1)	.02494 (29.51)	13.3864 (1350.381)	.03895 (70.281)
	MA	14.3189 (770.3)		11.9168 (788.3)		13.8555 (1397.7)	
	NJ	14.5074 (780.4)		12.2606 (811.0)		14.1503 (1427.4)	
	RI	12.5725 (676.3)		10.3247 (683.0)		12.2038 (1231.1)	
	R-Sq.	.9933		.9951		.9981	
	Std. Err.	.0661		.05377		.03526	
	# of Obs.	92		92		92	
2	AZ	13.1569 (462.3)	.02673 (20.92)	11.2637 (415.8)	.04889 (40.186)	12.6244 (511.8)	.03799 (34.302)
	CA	15.6724 (549.1)		13.4266 (495.6)		15.2781 (619.3)	
	CO	13.5652 (476.6)		11.7177 (432.5)		13.0554 (529.2)	
	IA	13.8916 (488.1)		11.9258 (440.2)		13.4655 (545.9)	
	KS	13.7914 (484.6)		12.0407 (444.4)		13.2547 (537.3)	
	NB	13.3371 (468.6)		11.5618 (426.8)		12.8041 (519.0)	
	OR	13.4847 (473.8)		11.3961 (420.6)		13.1413 (532.7)	
	WA	13.8807 (487.7)		11.9692 (441.8)		13.5027 (547.4)	
	R-Sq.	.9775		.9777		.9857	
	Std. Err.	.1150		.1095		.09966	
	# of Obs.	184		184		184	

Table A-5 (Continued)

SUMMARY OF EQUATIONS USED TO FORECAST
LICENSED DRIVERS, REGISTERED TRUCKS, AND REGISTERED AUTOS

		Licensed Drivers		Registered Trucks		Registered Autos	
Group	State	K	T	K	T	K	T
3	AL	13.8233 (625.9)	.02615 (45.98)	11.9838 (503.1)	.03935 (64.15)	13.3986 (527.3)	.03781 (57.78)
	DC	12.4176 (562.2)		9.4278 (395.8)		11.7313 (461.7)	
	DE	12.0583 (546.0)		9.8134 (412.0)		11.5849 (455.9)	
	FL	14.4457 (654.0)		12.2223 (513.1)		14.0567 (553.2)	
	GA	14.1349 (640.0)		12.1904 (511.8)		13.6196 (536.0)	
	ID	12.5995 (570.5)		11.1782 (469.3)		12.0438 (474.0)	
	IN	14.3710 (650.7)		12.3707 (519.4)		13.9097 (547.4)	
	KY	13.7510 (622.6)		12.0035 (503.9)		13.3531 (525.5)	
	LA	13.7717 (623.5)		11.9350 (501.1)		13.3149 (524.0)	
	MD	13.8811 (628.5)		11.4961 (482.6)		13.4104 (527.8)	
	ME	12.6819 (574.2)		10.7875 (452.9)		12.1753 (479.2)	
	MI	14.8789 (673.7)		12.5174 (525.6)		14.4703 (569.5)	
	MN	14.1329 (639.9)		12.1317 (509.3)		13.6545 (537.4)	
	MO	14.2887 (646.9)		12.3345 (517.8)		13.7226 (540.1)	
	MT	12.4756 (564.8)		11.2456 (472.1)		12.0071 (472.5)	
	NC	14.2225 (643.9)		12.3232 (517.4)		13.7328 (540.5)	
	ND	12.4208 (562.4)		11.2059 (470.5)		11.9119 (468.8)	

Table A-5 (Continued)

SUMMARY OF EQUATIONS USED TO FORECAST

LICENSED DRIVERS, REGISTERED TRUCKS, AND REGISTERED AUTOS

Group	State	Licensed Drivers		Registered Trucks		Registered Autos	
		K	T	K	T	K	T
3 (cont.)	NH	12.3535 (559.3)		10.2807 (431.6)		11.8679 (467.1)	
	NM	12.7413 (576.9)		11.1663 (468.8)		12.2130 (480.6)	
	NV	11.8669 (537.3)		10.2495 (430.3)		11.4152 (449.3)	
	OK	13.7215 (621.3)		12.2190 (513.0)		13.2668 (522.1)	
	SC	13.6197 (616.7)		11.5635 (485.5)		13.0975 (515.5)	
	SD	12.5728 (569.2)		11.0671 (464.6)		12.0103 (472.7)	
	TN	13.9937 (633.6)		12.0134 (504.4)		13.4783 (530.4)	
	TX	15.0300 (680.5)		13.3451 (560.3)		14.6620 (577.0)	
	UT.	12.7502 (577.3)		10.9661 (460.4)		12.2771 (483.2)	
	VA	14.1125 (639.0)		11.9543 (501.9)		13.6870 (538.7)	
	VT	11.8395 (536.0)		9.7313 (408.5)		11.3593 (447.1)	
	WI	14.1871 (642.3)		12.0641 (506.5)		13.6727 (538.1)	
	WV	13.3154 (602.9)		11.3384 (476.0)		12.6707 (498.7)	
	WY	11.9512 (541.1)		10.6076 (445.3)		11.3568 (447.0)	
	R-Sq.	.9893		.9875		.9872	
	Std. Err.	.1007		.1086		.1159	
	# of Obs.	713		713		713	

Table A-5 (Continued)

SUMMARY OF EQUATIONS USED TO FORECAST
LICENSED DRIVERS, REGISTERED TRUCKS, AND REGISTERED AUTOS

		Licensed Drivers		Registered Trucks		Registered Autos	
Group	State	K	T	K	T	K	T
4	IL	15.1221 (1219.0)	.02327 (31.16)	12.7458 (859.3)	.02816 (31.55)	14.6270 (2268.0)	.03471 (89.42)
	OH	15.1094 (1218.0)		12.7330 (858.4)		14.7228 (2282.9)	
	PA	15.2117 (1226.3)		12.9397 (872.4)		14.7334 (2285.1)	
	R-Sq.	.9420		.9506		.9923	
	Std. Err.	.04114		.04919		.02139	
	# of Obs.	69		69		69	
5	AR	13.2488 (552.1)	.03307 (20.99)	11.9050 (758.8)	.03426 (33.27)	12.6217 (961.3)	.043809 (50.819)
	MS	13.2146 (550.7)		11.8379 (754.6)		12.7059 (967.7)	
	R-Sq.	.9116		.9634		.9840	
	Std. Err.	.07088		.04634		.03878	
	# of Obs.	46		46		46	
6	NY	15.5091 (1447.0)	.0202 (22.76)	12.9766 (877.5)	.0203 (16.59)	15.0216 (341.1)	.02968 (9.242)
	R-Sq.	.9610		.9291		.8026	
	Std. Err.	.02822		.03893		.1022	
	# of Obs.	23		23		23	

NOTES:

[1]State Zip Codes identify the states in each group.

[2]K refers to state constant terms, T to time (time trend coefficients constrained to be the same for all states within a group), 1950 = 1.

[3]Numbers in parentheses beneath the coefficients are *t*-statistics.

[4]R-Sq. is the coefficient of multiple determination.

[5]Std. Err. is the standard error of the regression.

[6]# of Obs. is the number of observations in the regression.

Table A-6

GROWTH RATES FOR INDEPENDENT VARIABLES IN GASOLINE DEMAND EQUATION

	1	2	3	4	5	6
REGAUTO	103895	.03799	.03781	.03471	.043809	.02968
REGTRK	.02494	.04889	.03935	.02816	.03426	.0203
DRIV	.03065	.02673	.02615	.02327	.03307	.0202

where:

REGAUTO = number of registered automobiles (Federal Highway Administration, *Highway Statistics*, Table MV-1, various issues);

REGTRK = number of registered trucks (*ibid.*, Table MV-9, various issues); and

DRIV = estimated number of licensed drivers (*ibid.*, Table DL-1A, various issues).

The form of the forecasting equation for each group was

$$log_e(dependent\ variable) = \sum_j \alpha_{ij} + \beta_i T$$

where α_{ij} is a constant term for state j in group i (0 for states $\neq j$) and β_i is the estimated group-specific growth rate. The β_i can be interpreted as the annual compound growth rate (continuous compounding).

semi-logarithmic time trend explains most of the change in licensed drivers, registered trucks, and registered automobiles. For example, all except one of the coefficients of multiple determination are greater than .90, and most of them are on the order of .98 or .99. The standard errors of the regressions range between about 3 percent and 12 percent. That is, on the assumption that the errors are normally distributed, a standard error of 3 percent implies that the predicted value will lie within 3 percent on either side of the actual value about two-thirds of the time. This amount of variation, while large, is to be expected in equations that are going to be used only for forecasting purposes. These equations do not purport to explain all the variation in such variables as licensed drivers, registered trucks and registered automobiles. The coefficients of determination and the t-statistics on the individual estimated coefficients suggest, however, that the equations are quite adequate for forecasting purposes. The t-statistics, in particular, indicate that the coefficients have been estimated with a high degree of precision. Although autocorrelation in these equations tends to bias the t-statistics upward, the size of the t-statistics suggests that the coefficient estimates are quite accurate.

Variables Forecasted by Other Methods

For three variables, *PGASD*, *PCERVLD*, and *MPG*, extrapolations on the basis of historical time series were considered to be unreliable. For these variables, then, other methods of forecasting were used.

PGASD

A major influence on the price of gasoline is the price of crude oil. For the last several years, this price has reflected primarily not competitive forces of supply and demand, but rather the decisions on taxes and prices made

by the Organization of Petroleum Exporting Countries (OPEC). In the United States, moreover, the price of gasoline has, in the last several years, been affected by price controls and by the rules set up by the Federal Energy Office and most recently by the Federal Energy Administration.

Because of the uncertainty associated with future actions of OPEC and of the United States government, two assumptions have been chosen to bracket the price of gasoline expected to be observed during the forecast period. The forecasts are in constant 1958 dollars.[1] They assume, therefore, that any changes in the price of gasoline relative to the overall price level will occur within the levels of the real price assumed.

Table A-7 shows, on a state-by-state basis, the assumed low and high prices of gasoline, expressed in nominal (1974) dollars per gallon. The low prices shown were those taken from September 1973, before the Yom Kippur War led to the Arab oil embargo, production cutbacks, and subsequent price increases. The high prices shown are for July 1974, when the high world prices of oil had begun to affect U.S. gasoline prices strongly, but before U.S. gasoline prices started to fall in response to developing excess supply. Although the nominal price of gasoline increased by about 43 percent between September 1973 and April 1974, the increase in the real price was about 33 percent, because of the increase in the overall price of goods and services.

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[1]Gasoline consumption is influenced by a number of factors, including the real price of gasoline (that is, the price of gasoline relative to the prices of all other goods and services). Thus, if all prices and income increase by the same proportion (as a result of pure price inflation, for example), the equation specifies that gasoline consumption would not be affected.

Table A-7

LOW AND HIGH PRICES FOR GASOLINE ASSUMED IN THE FORECASTS

State	Cities Used to Estimate State Prices	Pre-Embargo Price: Price of Gasoline in Current Dollars as of September 11, 1973	Post-Embargo Price: Price of Gasoline in Dollars Per Gallon as of July 16, 1974
CT	Boston, MA	0.389	0.557
MA	Boston	0.389	0.557
NJ	Newark	0.399	0.567
RI	Boston, MA	0.389	0.557
AZ	Phoenix	0.389	0.539
CA	Los Angeles, San Diego, San Francisco	0.386	0.532
CO	Denver	0.389	0.589
IA	Des Moines	0.379	0.539
KS	Kansas City, Wichita	0.379	0.564
NB	Omaha	0.399	0.569
OR	Portland	0.389	0.547
WA	Seattle, Spokane	0.399	0.549
AL	Birmingham	0.379	0.549
DC	Baltimore, MD	0.399	0.559
DE	Baltimore, MD	0.399	0.559
FL	Jacksonville, Miami, Tampa	0.386	0.554
GA	Atlanta	0.389	0.557
ID	Cheyenne, WY	0.399	0.589
IN	Indianapolis	0.399	0.569
KY	Louisville	0.379	0.569
LA	New Orleans	0.369	0.539
MD	Baltimore	0.389	0.559
ME	Boston, MA	0.389	0.557
MI	Detroit	0.399	0.555

Table A-7 (continued)

LOW AND HIGH PRICES FOR GASOLINE ASSUMED IN THE FORECASTS

State	Cities Used to Estimate State Prices	Pre-Embargo Price: Price of Gasoline in Current Dollars as of September 11, 1973	Post-Embargo Price: Price of Gasoline in Dollars Per Gallon as of July 16, 1974
MN	Minneapolis - St. Paul	0.389	0.549
MO	St. Louis	0.389	0.559
MT	Cheyenne, WY	0.399	0.589
NC	Charlotte	0.389	0.559
ND	Wichita Falls	0.339	0.491
NH	Boston, MA	0.389	0.557
NM	Albuquerque	0.379	0.579
NV	Albuquerque, NM	0.379	0.579
OK	Oklahoma City, Tulsa	0.369	0.549
SC	Charlotte, NC	0.389	0.559
SD	Wichita Falls, ND	0.339	0.491
TN	Memphis	0.379	0.539
TX	Amarillo, Corpus Christi, Fort Worth, Houston, San Antonio, Texarkana	0.339	0.494
UT	Salt Lake City	0.369	0.569
VA	Norfolk	0.379	0.547
VT	Boston, MA	0.389	0.557
WI	Milwaukee	0.389	0.559
WV	Norfolk, VA	0.379	0.547
WY	Cheyenne	0.399	0.589
IL	Chicago, Springfield	0.409	0.578
OH	Cleveland	0.379	0.549
PA	Philadelphia, Pittsburgh	0.379	0.549
AR	Little Rock	0.369	0.529
MS	Little Rock, AR	0.369	0.529
NY	Albany, Buffalo, New York	0.406	0.586
	Weighted Average	0.385	0.551

Table A-7 (continued)

LOW AND HIGH PRICES FOR GASOLINE ASSUMED IN THE FORECASTS

Notes to Table A-7

1. Prices were taken from the *Oil and Gas Journal*, September 17, 1973 and July 22, 1974 issues. They represent the suggested retail price of major brand regular gasoline at the pump, including state and federal taxes. The cities used as representative of the state prices are shown in Column 2. Where more than one city appears, the simple average of the prices was used.

2. The weighted average uses forecasted 1973 consumption as weights. Use of any other forecasted year as weights changes the weighted average current prices only in the fourth decimal place.

PCERVLD

Forecasting this variable required forecasts of *RVLD* and of the proportion of cars on the road accounted for by model years from 1968 on. The forecast of *RVLD* has already been discussed. Forecasting the proportion of automobiles accounted for by model years from 1968 on requires a forecast of the age distribution of automobiles in each year to 1987. There are two alternative ways to make this forecast. First, one could predict new car sales and use these predictions, along with predicted scrappage and the existing stock of cars, to generate the future stock of cars and the age distribution. Second, one could use forecasts of the total stock and of scrappage to derive forecasts of new car sales and the age distribution. The second method was followed here, primarily for reasons of simplicity. On the one hand, we already had the forecasts of registered autos, discussed above. On the other hand, we did not have the time or resources to develop a model of new car demand to forecast new car sales.

The procedure used to forecast the age distribution of the stock of cars was essentially recursive. That is, the age distribution in 1973 was constructed from the age distribution in 1972 and forecasts of the total stock of cars in 1973. The age distribution in 1974 was forecasted from the age distribution in 1973 and total cars in 1974, and so forth. For ease of exposition, we will describe in detail how the 1973 forecast was made. Because the 1973 actual figures are available, they can be used to check the reasonableness of the forecasting procedure.

First, the 1973 state-by-state forecast of registered autos was added up across states to obtain a national forecast of registered autos.

Second, because this figure represents year-end registrations as reported in *Highway Statistics*, it was adjusted for comparability with the figure from the *Automotive News Almanac*. The age distribution shown in the *Automotive News Almanac*

is as of July 1 of each year, adjusted for duplicate registrations. That is, vehicles which are registered in more than one state during the year ought not to be counted twice. The figure in *Highway Statistics*, however, is based on registration fees from the different states. Consequently, it applies to the entire calendar year, not just July 1, and does not subtract duplicate registrations. The adjustment made to the forecast total was straightforward: the forecasts of registered automobiles were divided by 1.0949, the average ratio of the *Highway Statistics* total to the *Automotive News* total over the 1959-1972 period. The annual ratio of these two numbers ranged between 1.0728 and 1.1217, showing considerable stability. We selected the years 1959 to 1972 to ensure comparable treatment of the Hawaii and Alaska data in the figures. However, if the average was taken over 1950 to 1972, it would have led to an adjustment figure of 1.0955, quite close to the one used.

At this point, then, we have a forecast of the total U.S. stock of cars on the road as of July 1, roughly comparable to the data in the *Automotive News Almanac*.

Third, we applied Walker's estimated age-specific scrappage rates to the automobiles of each vintage as of July 1, 1972.[1] We then had estimates of the 1971 cars surviving in 1973, the 1970 cars surviving in 1973, and so forth.

Fourth, we added up the forecasts of surviving automobiles of each vintage 1971 through all previous years

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[1] The description of the scrappage rates is found in Appendix D. The basic source is Franklin V. Walker, "Determinants of Auto Scrappage," *Review of Economics and Statistics*, (November 1968): 503-506.

and subtracted this sum from the 1973 total forecast to obtain the number of 1972 and 1973 model-year cars. Splitting out the 1972 from the 1973 model-year cars required another assumption.[1] (This assumption cannot influence the forecast of PCERVLD, as all of these model years are later than 1968.) This assumption was that the ratio of one-year-old cars to current-year cars would be the same as the average ratio over the period 1957 to 1972. Thus, the sum of 1972 and 1973 model year cars was multiplied by .5819 to obtain forecast of 1972 model year cars on the road as of July 1, 1973.[2]

The forecasted age distributions are shown in Table A-8. For purposes of comparison, the actual age distribution in 1973 is shown alongside that of the forecasted one. There is reasonable agreement between these two distributions, and the forecasted total differs from the actual total by less than 1 percent.

MPG

The forecasts of *MPG* depend on the forecasted average weight and average displacement of new car sales in each year. The assumptions for these variables for the weight and displacement that lead to the low forecast of gasoline consumption are explained in the descriptive summary of this appendix. The forecasts of these variables that lead to the high forecast of gasoline consumption were based on time trend regressions of the average weight and displacement of new cars. These forecasting equations are shown in Table A-9.

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[1] The number of 1972 cars on the road in 1973 cannot be found by applying the appropriate scrappage rate to the number of 1972 cars on the road in 1972, because 1972 cars continue to be sold and registered after July 1, 1972. As a result, the figures on 1972 model-year registrations in 1972 are necessarily less than the total number that will eventually be registered.

[2] Over the 1957 to 1972 period, this ratio ranged between .5300 and .6799.

Table A-8

FORECASTS OF AGE DISTRIBUTION OF AUTOMOBILE STOCK, 1973-1975, 1981, 1987
(Thousands of Autos)

Model Year	(1) Forecasted Cars in Use	(2) Share of Cars in Use	(3) Actual Cars in Use	(4) Share of Cars in Use	(3)-(1) / (3)
1973	7239.46	.0799	7988	.0889	.0937
1972	10075.7	.1112	10158	.1131	.0080
1971	8899.84	.0982	8715	.0970	-.0212
1970	8819.14	.0973	8612	.0959	-.0240
1969	9053.58	.0999	8881	.0989	-.0194
1968	8461.9	.0934	8291	.0923	-.0206
1967	7263.53	.0802	7120	.0793	-.0199
1966	7460.54	.0823	7333	.0816	-.0174
1965	6818.63	.0753	6715	.0747	-.0154
1964	5030.82	.0555	4963	.0552	-.0137
1963	3795.38	.0419	3698	.0411	-.0262
1962	2587.48	.0285	2470	.0275	-.0473
1961	1378.4	.0152	1268	.0141	-.0867
1960	1054.24	.0116	967	.0107	-.0899
1959	596.827	.0065	548	.0061	-.0894
1958	287.51	.0031	274	.0030	-.0510
1957	1726.01[1]	.0190	1781[1]	.0198	.0308
TOTAL	90549.	0.9990[2]	89782	0.9992[2]	

SOURCE: *Automotive News 1974 Almanac.*

[1] Includes all earlier year models.

[2] Detail may not add to total because of rounding.

Table A-8 (continued)

FORECASTS OF AGE DISTRIBUTION OF AUTOMOBILE STOCK, 1973-1975, 1981, 1987

(Thousands of Autos)

YEAR: 1974	
MODEL YEAR	CARS IN USE
1974	7172.58
1973	9982.6
1972	10058.6
1971	8867.81
1970	8752.99
1969	8912.35
1968	8196.2
1967	6833.53
1966	6708.52
1965	5794.47
1964	4051.32
1963	2937.62
1962	1955.36
1961	1028.42
1960	781.613
1959	441.115
1958	1485.12
TOTAL=	93960.2

YEAR: 1975	
MODEL YEAR	CARS IN USE
1975	7385.14
1974	10278.4
1973	9965.63
1972	10022.3
1971	8801.3
1970	8616.45
1969	8632.5
1968	7710.98
1967	6144.71
1966	5700.9
1965	4666.29
1964	3135.72
1963	2219.96
1962	1458.89
1961	762.472
1960	577.69
1959	1420.82
TOTAL=	97500.2

YEAR: 1981	
MODEL YEAR	CARS IN USE
1981	9366.98
1980	13036.7
1979	12545.4
1978	12040.7
1977	11493.1
1976	10858.4
1975	10079.3
1974	9102.6
1973	7949.48
1972	6818.46
1971	4858.37
1970	3739.74
1969	2923.18
1968	2070.75
1967	1360.55
1966	1097.85
1965	2396.46
TOTAL=	121738.

YEAR: 1987	
MODEL YEAR	CARS IN USE
1987	11666.8
1986	16237.5
1985	15618.1
1984	14997.2
1983	14350.4
1982	13623.3
1981	12726.5
1980	11545.3
1979	10007.4
1978	8191.6
1977	6344.26
1976	4712.82
1975	3413.09
1974	2444.46
1973	1760.16
1972	1313.07
1971	3083.84
TOTAL=	152036.

Table A-9

Equations Used to Forecast Average New-Car Weight and Displacement for "High" Gasoline Consumption Forecasts

1. Weight

$$WGT = 3329.81 + 10.7126 \times time$$
$$(96.561) \quad (3.596)$$

$R\text{-}SQ$ = .3927 — Sample Years = 1950-1971

Standard Error = 88,646 — $\frac{\text{Standard Error}}{\text{Mean WGT}}$ = .0257

2. Displacement

$$DSP = 239.636 + 2.53755 \times time$$
$$(27.448) \quad (3.367)$$

$R\text{-}SQ$ = .3617 — Sample Years = 1950-1971

Standard Error = 22.43 — $\frac{\text{Standard Error}}{\text{Mean DSP}}$ = .0834

where: WGT= average curb weight (pounds) of new cars;

DSP= average engine displacement (cubic inches) of new car

$Time$= a dummy variable for years 1950 = 1, 1951 = 2, and so forth

$R\text{-}SQ$= coefficient of multiple determination

Numbers in parentheses under the coefficients are t-statistics

These equations imply a slow but steady increase in average weight and displacement of new car sales over the period. The coefficients of multiple determination are quite low, indicating that the trend alone does not explain much of the variation in these variables. The standard errors, on the other hand, are also quite low, less than 3 percent in the case of weight and less than 10 percent in the case of displacement. The forecasts show the average weight of new cars increasing by about 11 pounds per year and the average displacement of new cars increasing by about 2.5 cubic inches per year. Table A-10 shows the forecasts of average weight and horsepower of new cars.

The Dewees equation reported above was then used to link MPG to these variables each year. Given the forecasts of average MPT in each year, the age distribution forecasts described in the preceding section were then used to calculate the weighted average miles per gallon of the total stock of cars on the road in each year.

Table A-10

ASSUMED VALUES FOR AVERAGE WEIGHT AND ENGINE DISPLACEMENT OF NEW CARS, 1973-1978

		Weight (Pounds)	Engine Displacement (Cubic Inches)
Low		3431	230
High	1973	3587	301
	1974	3598	303
	1975	3608	306
	1981	3673	321
	1987	3737	336

NOTES:

1. Low values were average values for 1961, the year in the post-war period when average engine displacement was estimated to be smallest.

2. High values were projected on the basis of equations described in the text of this appendix. The equations were time trends fitted to average weight and displacement for new cars in each year 1950-1971.

Disaggregation of Gasoline Consumption By City Size and Rural Area

The basis for the method to disaggregate gasoline consumption by city size is to employ independent estimates of the variation in VMT per household by city size, and population by geographical area to derive the percent of a state's total VMT driven in each geographical area. Assuming that automobile fuel economy does not vary by geographical area, the fraction of a geographical area's VMT to the state total also describes the fractional amount of gasoline consumption.

Consider the method as it applies to any given state. Let

pop_i = population in geographical area i, $i=1, 4$ where i = 1 for unincorporated areas

$$\begin{cases} 2 \text{ for cities with 2.5-5K residents} \\ 3 \text{ for cities with 5-25K residents} \\ 4 \text{ for cities with 25-50K residents} \end{cases}$$

$upop_j$ = population in urbanized area j, $j=1,\ldots J$ where J is the number of urbanized areas in the state

$udist_{j\,i}$ = fraction of urbanized area j's population place size i where i = 1 to 4 is defined as above and i = 5 is for places with greater than 50,000 residents

h_i = average number of persons per household in place size i where i = 1 to 5 is defined above.

These data were obtained for each geographical area category and urbanized area in the U.S. from the 1970 Census of Population.

We define:

vh_i = VMT per household in place size

where

i = 1 to 5 as defined above.

This data was obtained from the *National Personal Transportation Survey*, Report No. 7. By definition, estimated state total VMT is simply the sum of estimated VMT in each geographical area within the state:

$$VMT = \sum_{i=1}^{4} \frac{pop_i}{h_i} vh_i + \sum_{j=1}^{J} \sum_{i=1}^{5} \frac{upop_j \; udist_{ji}}{h_i} vh_i \qquad (6)$$

The fraction of VMT (and hence of gasoline consumption) in each geographical area and urbanized area is simply the computed ratio of area-specific vehicles miles of travel to total state VMT as defined in Equation (6).

Emission Production Functions

Introduction

As discussed in Chapter 3, the production of pollutants from automobiles (light duty-vehicles, LDV) depends critically on the relative intensity of auto use in different vehicle-operating regimes. The importance of separating out the individual components of pollutant emissions -- vehicle running exhausts, cold start exhausts, crankcase and evaporative sources -- stems from the fact that the policies under consideration in this report have a differential impact on the size and vintage distribution of the auto stock, vehicle miles of travel, and average trip lengths and thus differentially affect LDV pollution production. In this section, we will trace out in detail the assumptions and methodologies underlying the determination of emission levels for three pollutant types: carbon monoxide (CO), the oxides of nitrogen (NO_x), and hydrocarbons (HC). We begin with a discussion of the sources and uses of data describing pollutant emission rates for light-duty vehicles.

Sources of LDV Emission Rates

It is convenient to separate the sources of LDV emissions into three basic categories: exhaust (comprising running and cold start) emissions, crankcase losses, and evaporative (comprising hot soak and diurnal) losses. The oxides of nitrogen have no evaporative or crankcase sources and are relatively insensitive to cold starts and small variations in speed. Like NO_x, LDV carbon monoxide production derives only from exhaust emissions. LDV hydrocarbon emissions are

produced from all three vehicle source components -- cold start and running *exhausts*, *crankcase* losses and hot soak and diurnal *evaporative* losses.

Several different test procedures have been employed in recent years to determine the production *rates* for the three basic sources of LDV emissions.[1] The emission rates determined from the various test procedures differ -- in some cases substantially -- partly as a result of differing assumptions concerning what constitutes a "representative" urban trip driving cycle as well as the sample-specific nature of the test procedures. For the purposes of this report, we have chosen to make use of the exhaust emission rates obtained from the 1975 CVS-CH Federal Test Procedure. This EPA cycle consists of a 7.45 mile, 23-minute nonrepetitive driving sequence. The cycle, performed on a chassis dynamometer, is primarily made up of stop-and-go driving and includes some operation at speeds up to 57 mph. The average vehicle speed is approximately 20 mph. The test includes a cold start cycle[2] followed by a hot engine start[3] and a repeat of the simulated 7.45 mile driving pattern. The cold start and hot start portions of the test are then weighted by values representative of the percent of urban trips starting with a cold (43 percent) or hot start (57 percent).

Exhaust Emission Rates

EPA has published LDV exhaust emission rate test results for a range of automobile model years in its *Compilation of Air Pollutant Emission Factors*[4] (see Table A-11). Unfortunately,

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[1]For a good summary of commonly used pollutant emission test procedures see J.B. Heywood, and M. K. Martin, "Aggregate Emissions from the Automobile Population," paper presented at the Combined Commercial Vehicle and Fuels and Lubricants Meetings, Chicago, Illinois, June 17-21, 1974.

[2]Twelve-hour soak at 68°F to 86°F before start-up.

[3]Ten minute shutdown following the cold start cycle.

[4]U. S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors*, Second Edition, April 1973.

Table A-11

CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDE EMISSION FACTORS FOR LIGHT-DUTY VEHICLES AT LOW AND HIGH ALTITUDE

Location and Pollutant	Exhaust Emission Factors at Low Mileage Per Model-Year								
	Pre 1968	1968	1969	1970	1971	1972	1973 through 1974	1975	Post 1975
Low Altitude									
Carbon Monoxide g/mi	87	46	39	36	34	19	19	1.8	1.8
Exhaust Hydrocarbons g/mi	8.8	4.5	4.4	3.6	2.9	2.7	2.7	0.23	0.23
Nitrogen Oxides g/mi	3.6	4.3	5.5	5.1	4.8	4.8	2.3	2.3	0.31
High Altitude									
Carbon Monoxide g/mi	130	74	48	72	75	42	42	1.8	1.8
Exhaust Hydrocarbons g/mi	10	6.0	5.4	6.1	5.3	4.9	4.9	0.23	0.23
Nitrogen Oxides g/mi	1.9	2.2	2.6	2.8	3.1	3.1	1.4	1.4	0.31

Source: U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors.* Second Edition, April 1973.

the EPA data do not separate out the individual contributions of cold starts and running exhaust emissions and thus are not immediately useful for our purposes. In order to perform the disaggregation of exhaust emissions into cold start and running components, we made use of test data presented in an article by Martinez *et al.*[1] These emission rates were obtained from recent test data using the DHEW driving cycle.[2] In order to assure consistency between the estimates derived from the DHEW and CVS-CH test procedures, the Martinez cold start and vehicle running emission rates were scaled to conform to the EPA exhaust emission rates shown in Table A-11.

This scaling procedure was performed as follows. Let:

e^{m}_{jnt} = emission rate in vehicle model year j, pollutant type n (1=CO, 2=NO_x, 3=HC) by type t (1 = running for which the units of e^{m}_{jn1} are g/mile; 2 = cold start for which the units of e^{m}_{jn2} are g/start) from Martinez estimates.

e^{E}_{jna} = EPA's published emission rates (CVS-CH test procedure) in g/mile for vehicle model year j, pollutant type n and altitude class a (1 = low altitude, 2 = high altitude).

e^{*}_{jnta} = scaled Martinez emission rates.

Assuming that the running exhaust emission rate is identical for both cold and hot start vehicle operation and remembering

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[1]J. Martinez, R. A. Nordsieck, and A. Q. Eschenroeder, "Morning Vehicle-Start Effects on Photochemical Smog," *Environmental Science and Technology*, 7, No. 10 (October 1973).

[2]"DHEW Urban Dynamometer Driving Schedule," *Federal Register* 35(129), Part II, Appendix A, 17311 (1970).

that the CVS-CH test procedure forms a weighted average of cold and hot start emissions over a 7.45 mile trip cycle with weights of 0.43 and 0.57 respectively, we have by definition the condition that:[1]

$$0.43\left[e^{*}_{jp1a} + \frac{e^{*}_{jp2a}}{7.45}\right] + 0.57\left[e^{*}_{jp1a}\right] = e^{E}_{jpa} \qquad (7)$$

Using this formulation, we may define the scaling factor for adjusting the Martinez cold start and running emission rates as:

$$f_{jpa} = \frac{e^{E}_{jpa}}{e^{m}_{jp1a} + \frac{0.43}{7.45}\, e^{m}_{jp2a}} \qquad (8)$$

where:

f_{jpa} = scaling factor for model year j, pollutant type p and altitude class a.

The scaled emission rates are then defined as

$$e^{*}_{jpta} = f_{jpa} * e^{m}_{jpt} \qquad (9)$$

Table A-12 presents the scaled running and cold start exhaust emission rates by pollutant type, vehicle model year, and altitude class used in this study.

Evaporative Sources

In addition to vehicle *exhausts*, HC emissions are produced from two evaporative sources: diurnal and hot soak losses. Diurnal losses derive from the evaporation of fuel from vehicle gas tanks and as such are independent of vehicle *use*. Hot soak hydrocarbon emissions are formed by the evaporation of residual fuel in vehicle carburetors after engine shutdown, and thus are dependent only on the *frequency* of auto travel.

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[1]Note also that we assume zero cold start emissions during a hot engine startup.

Table A-12

SCALED EXHAUST EMISSION RATES

CO	Pre-1968	1968	1969	1970	1971	1972	1973	1974	1975	Post-1975
Running g/mile[1]										
High Altitude	91.91	53.09	37.29	52.75	63.56	36.38	36.38	36.38	.48	.48
Low Altitude	61.51	33.0	30.3	26.38	28.81	16.46	16.46	16.48	.48	.48
Cold Start g/cold start[2]										
High Altitude	659.92	362.33	185.5	333.46	198.27	97.29	97.29	97.29	22.9	22.9
Low Altitude	441.64	225.23	150.72	166.73	89.88	44.01	44.01	44.01	22.9	22.9
NO_x										
Running g/mile[1]										
High Altitude	1.80	2.07	2.39	2.63	2.86	2.85	1.29	1.29	1.49	.33
Low Altitude	3.40	4.05	5.06	4.80	4.43	4.41	2.11	2.11	2.45	.33
Cold Start g/cold start[2]										
High Altitude	1.80	2.19	3.57	2.88	4.13	4.31	1.95	1.95	-1.57	-0.35
Low Altitude	3.41	4.29	7.55	5.24	6.40	6.67	3.21	3.21	-2.57	-0.35
HC										
Running g/mile[1]										
High Altitude	8.918	5.067	4.668	4.932	4.701	4.482	4.482	4.482	.142	.142
Low Altitude	7.954	3.8	3.801	2.910	2.573	2.470	2.470	2.470	.142	.142
Cold Start g/cold start[2]										
High Altitude	16.471	16.181	12.688	20.248	10.376	7.242	7.242	7.242	1.522	1.522
Low Altitude	14.689	12.136	10.332	11.946	5.679	3.991	3.991	3.991	1.522	1.522

[1]Running emissions are divided into low and high altitude categories. They are measured in grams/mile.

[2]Cold start emissions are divided into low and high altitude categories. They are measured in grams/cold start.

This study employed data reported in Heywood[1] on evaporative source emission rates. These emission rates are shown below in Table A-13 by vehicle model year and altitude class. Hydrocarbon evaporative emission controls were introduced in 1971, resulting in a reduction in hot soak and diurnal emission rates of 27.5 percent and 37.3 percent respectively. As in the Heywood study,[2] we assumed that post-1977 vehicle control devices would effect a 95 percent reduction in precontrolled vehicle hot soak and diurnal evaporative emissions.

For both HC hot soak and diurnal losses, high altitude emission rates are approximately three times higher than the low altitude levels presumably due to the differences in atmospheric pressure and gasoline composition between the two topographical areas.

Crankcase Emissions

The final source of HC emissions is from automobile *crankcase*. Crankcase emission controls were introduced in the early 1960s. The "positive control ventilation" (PCV) system, when maintained effectively, eliminates HC crankcase losses. However, field studies have shown[3] that deterioration in crankcase emission controls due to inadequate maintenance leads to significant increases in HC emissions. Cross-sectional data analyzed by Voelz *et al.* has shown that the percent of vehicles of a particular model year with clogged PCV systems rises approximately linearly with vehicle age, at the rate of 1.8 percent per year. Assuming that crankcase HC emissions from a vehicle with a clogged PCV system are the same as those from a vehicle with no crankcase controls (estimated to be

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[1] Heywood, *op. cit.*

[2] *Ibid.*

[3] F.L. Voelz, *et al.*, "Survey of Nationwide Automotive Exhaust Emissions and PCV System Conditions - Summer 1970," Paper 710834 presented at SAE Combined National Truck, Powerplant, and Fuels and Lubricants Meetings, St. Louis, October 1971, cited in Heywood, *op. cit.*

Table A-13

HC EVAPORATIVE EMISSION RATES

Model Year	Hot Soak Emissions[1] (g/Trip)		Diurnal Emissions[1] (g/Veh/Day)	
	Low Altitude	High Altitude	Low Altitude	High Altitude
Pre-1971	15	48	26	75.288
1971-1976	10.875	34.8	16.3	47.200
Post-1977[2]	0.75	2.4	1.3	3.764

[1]Values represent low-mileage emissions.

[2]Assumed 95 percent reduction from pre-1971 rates.

4.08 g/mile by Voelz), we get the following relationship for predicting HC crankcase emission rates:

$$c_{mj} = 4.08 \; min \left[1.0, \; 0.018(j-m)\right] \qquad (10)$$

where:

c_{mj} = crankcase emission rate in year j for vehicle of model year m in g/mile.

The minimum bound restricts the model from predicting more than 100 percent of a given model year's vehicles from having clogged PCV systems. Note that current year automobiles have zero crankcase emissions.

Required Inputs for the Determination of Selected Urban and National Average Emission Levels

The preceding paragraphs have traced out the derivation and sources of light duty vehicle *emission rates* for a range of automobile *model years*. In order to apply this data to the prediction of pollutant *emission levels* in specific analysis *years* for selected urban areas and the national aggregate, several additional input data items are required.

The disaggregation of national gas consumption by city size has already been discussed. Our first task here will be to describe the methods for predicting *vehicle miles of travel* (VMT) in selected areas. These data will be applied to those emission rates -- running exhausts and crankcase losses -- that depend on miles of vehicle travel. Hot soak losses and cold start exhausts are related to the number of vehicle trips. Our next task therefore will be to develop a method for predicting the *frequency of vehicle travel.*

In order to develop estimates of emission levels in selected analysis years, we will need to determine the *distribution*

of VMT and auto stock by model year. Moreover, the emission rates presented in the preceding paragraphs (assumed to be "low-mileage" values) will have to be adjusted by emission control device *deterioration factors* that vary with vehicle age. Finally, since one of the emission rates discussed earlier pertains to vehicle cold starts, our analysis will require a method for determining the percentage of all trips which involve vehicle cold starts. Each of these data items is discussed in the following paragraphs.

Analysis Years

The analysis of LDV emission levels in this report was performed for three analysis years: 1975, 1981, and 1987.

Analysis Areas

Emission levels of carbon monoxide, the oxides of nitrogen, and hydrocarbons were predicted for a selected sample of urban areas in the United States, as well as for national aggregate level in two city-size classes. Analysis areas were chosen from the list of cities[1] having Environmental Reporting Stations to facilitate a comparison of predicted and reported emission levels and pollutant source strengths. Our sample was comprised of 13 cities representative of different city sizes and topographical and meteorological conditions (see Table A-14).

For the analysis of national aggregate emission levels, two city-size classes were chosen, namely cities with an average diameter of 10 and 35 kilometers, respectively. In this classification scheme, cities whose average diameter was closer to 10 kilometers than to 35 kilometers were assigned

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[1]For our analysis, we have employed the Bureau of the Census' 1970 definitions of *urbanized areas.* Throughout this report we will use the terms "city" and "urbanized area" interchangeably.

Table A-14

SAMPLE CITIES

Region	City	Population in Millions (1970)	Diameter (Km)	Area (Sq. Miles)	Fraction of State's Gas Consumption (Percent)
Northeast	Portland, ME	.106	13.55	55.7	8.83
	New York, NY	16.2	89.43	2425.1	54.97
Appalachian	Nashville, TN	.448	33.66	343.5	8.66
	Pittsburgh, PA	1.85	44.35	596.4	14.78
Great Plains	Little Rock, AR	.226	17.73	95.3	8.45
	Oklahoma City, OK	.579	33.44	339.1	18.67
Southern Florida	Tampa, FL	.368	20.74	130.5	4.36
	Miami, FL	1.22	29.21	258.7	15.83
Rocky Mountain	Spokane, WA	.23	16.02	77.8	5.55
	Denver, CO	1.05	31.07	292.8	42.02
Washington Coastal	Seattle, WA	1.24	36.91	413.1	32.12
California Coastal	San Francisco-Oakland, CA	2.98	47.39	681.0	13.96
	Los Angeles, CA (Santa Monica)	8.35	72.0	1571.9	37.97

Source: Bureau of the Census, Census of Population, 1970, State Report.

to the "small" city category and vice versa. Roughly half of the 247 urbanized areas fell into each city size category. However the 35 kilometer cities consumed approximately 79 percent of the total urbanized area gasoline usage.

Prediction of Vehicle Miles of Travel by Analysis Year and Area

Vehicle miles of travel (VMT) estimates are derived from baseline and policy analysis gasoline consumption forecasts. These forecasts, discussed in the body of the report, were developed for each state and analysis year under two assumed price scenarios. Thus to convert these fuel forecasts to VMT for our purposes here, we need to account for:

- the fraction of state (national) consumption occurring in each sample city (city size category), and
- the vehicle gasoline consumption rate (in units of miles per gallon).

The former factor was derived from data published in the *Nationwide Personal Transportation Survey*[1] describing vehicle use by city size, as discussed elsewhere in this Appendix.

Average gasoline consumption rates in a given analysis year clearly depend on the vintage distribution of the auto stock since these rates have changed from one *model* year to another. For the baseline analysis, we derived a fuel consumption rate for each analysis year and price scenario, using as inputs the sales-weighted average of vehicle gas consumption by model year, and the distribution of VMT in a given analysis year by vehicle age.[2] Data on fuel consumption rates for our baseline analysis are presented in Table A-15. Due to the lack of appropriate data, we have assumed gas consumption rates to be constant across cities.

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[1] *Op. cit.*

[2] Derivation of sales-weighted average vehicle gas consumption by model year is discussed in this appendix. Distribution of VMTs by vehicle age is shown in Chapter 5, Table 5-3.

Table A-15

BASELINE GASOLINE CONSUMPTION RATES (NATIONAL AVERAGE)
BY ANALYSIS YEAR AND PRICE SCENARIO

(Miles Per Gallon)

Analysis Year	Low Price Scenario	High Price Scenario
1975	11.8564	12.2319
1981	11.6486	12.5835
1987	11.4413	12.7017

As discussed in the report, the policies dealing with automobile excise taxes and fuel economy restrictions affect both the fuel economy of new-car sales and the vintage distribution of the auto stock. For each of these policies, the change in average gas consumption rates was derived using revised estimates of the age distribution of the auto stock and model-year fuel economy rates. Table A-16 presents the change from baseline gas consumption rates associated with each of the policies dealing with new car sales.

Using these data, VMT in a given city (or city size category) was derived as

$$VMT_{ijpsr} = G_{kjpsr} * c_{i/k} * mpg_{js} * mfac_{jpr} \quad (11)$$

where:

VMT_{ijpsr} = vehicle miles of travel in city i=1,...,13 (or city size category i=1,2) in analysis year j (1975, 1981, 1987) for policy p (baseline, fuel excise taxes, rationing, new car excise taxes, or new car fuel economy restrictions), price scenario s (low or high) and sensitivity range r[1] (low, medium, or high) in units of miles per year.

G_{kjpsr} = gas consumption in state k where k is the state containing city i (or k is the nation) in analysis year j, for policy p, price scenario and sensitivity range r[1], in units of gallons per year.

$C_{i/k}$ = fraction of state k's (or national total) gas consumption occurring in city i (city size category i).

mpg_{js} = fuel consumption rate for baseline analysis in year j and price scenario s in units of miles per gallon (see Table A-15).

$mfac_{jpr}$ = fractional change from baseline fuel consumption rate for policy p dealing with new car sales[2] in year j for sensitivity range r (see Table A-16).

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[1]Sensitivity ranges do not apply to baseline analysis.

[2]The policies dealing with gasoline excise taxes are assumed not to alter the age distribution of the auto stock, and thus do not change gasoline consumption rates.

Table A-16

FRACTIONAL CHANGE FROM BASELINE GASOLINE CONSUMPTION RATES
ASSOCIATED WITH NEW CAR EXCISE TAXES AND FUEL ECONOMY RESTRICTIONS

Sensitivity Range	Excise Tax Policies								
	$50			$100			$200		
	1975	1981	1987	1975	1981	1987	1975	1981	1987
Low	1.0003	1.0084	1.0129	1.0005	1.0162	1.0253	1.0008	1.0312	1.0502
Medium	1.0000	1.0036	1.0060	1.0001	1.0072	1.0119	1.0002	1.0134	1.0235
High	1.0003	1.0011	1.0020	1.0001	1.0024	1.0039	.9983	1.0047	1.0074

	Fuel Restriction Policies								
	17.5 mpg			20.0 mpg			22.5 mpg		
	1975	1981	1987	1975	1981	1987	1975	1981	1987
Low	1.0029	1.0456	1.0726	1.0091	1.1186	1.2063	1.0116	1.1658	1.3187
Medium	1.0056	1.0492	1.0738	1.0156	1.1428	1.2191	1.0237	1.2212	1.3485
High	1.0058	1.0507	1.0753	1.0166	1.1472	1.2218	1.0261	1.2331	1.3560

NOTE: Rates are measured in miles per gallon. Hence values greater than unity in this table imply an improvement in fuel economy.

Prediction of Trip Frequency

As mentioned earlier, two of the pollutant emission sources -- cold start exhausts and hot soak evaporative losses -- depend on the number of auto trips undertaken. In this study, we derived frequency of auto travel in terms of total vehicle miles of travel and average trip length:

$$nt_{ijpsr} = \frac{VMT_{ijpsr}}{atl_i} \qquad (12)$$

where:

nt_{ijpsr} = number of trips in city i, year j, policy p, price scenario s and sensitivity range r.

atl_i = average trip length in city i.

Average trip lengths vary from one city to another. Everything else equal, one would expect that a larger city is characterized by longer trips than smaller cities. However, another important consideration is the degree of "urban sprawl" within the boundaries of the urbanized area. In this regard, we would expect that the greater the decentralization of a city's population (i.e., the lower the population density), the greater will be the average trip length of urban travel. In order to capture the influence of city form on urban driving patterns, we obtained data on the distribution of average trip lengths by size of place from the *Nationwide Personal Transportation Survey*[1] (NPTS). The trip length distribution is shown in Table A-17.

Using 1970 census data on the distribution *within* each of our sample urbanized areas by size of place, we then computed

[1] *Op. cit.*

Table A-17

VARIATION IN AVERAGE TRIP LENGTH BY SIZE OF PLACE

Size of Place (Population in Thousands)	Average Trip Length (Across All Purposes)
Unincorporated	9.8
<5	10.4
5-25	7.9
25-50	7.8
50-100	8.1
100-1000	7.7
>1000	11.7

SOURCE:

Nationwide Personal Transportation Survey, #10, May 1974; *Purposes of Automobile Trips and Travel*, p. 16, Table 4.

average trip length for each city[1] according to:

$$atl_i = \sum_s p_{is} l_s \qquad (13)$$

where:

atl_i = average trip length in city i.

p_{iz} = percent of city i's population residing in place size s.

l_s = average trip length for population place size s.

Note that average trip length calculations are performed only for baseline analysis. The effect of the various policies considered in this report on average trip length and ultimately on auto travel frequency is determined by the use of the trip frequency elasticities. Average trip lengths for baseline analysis in the 13 sample cities and two national aggregate city-size categories are shown in Table A-18.

Exhaust Emission Deterioration Factors

The scaled exhaust emission rates presented in Table A-12 represent "low-mileage" values for each model year. The deterioration of the effectiveness of emission control devices as vehicles age leads to a significant increase in low-mileage emission rates, particularly for exhaust hydrocarbon emissions. We have used EPA's data[2] on deterioration factors (see Table A-21) to adjust the nominal model-year emission rates for aging and deterioration of pollution control devices.

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[1] Average trip lengths for national aggregate analysis was derived as the weighted average trip length across all cities in the 10 km and 35 km city size categories.

[2] U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors, op. cit.*

Table A-18

AVERAGE TRIP LENGTHS (ACROSS ALL PURPOSES) IN SAMPLE CITIES
(Baseline)

City	Average Trip Length
Portland, ME	8.1097
New York, NY	10.2184
Nashville, TN	7.7728
Pittsburgh, PA	8.5262
Little Rock, AR	8.0645
Oklahoma City, OK	7.7669
Tampa, FL	8.1052
Miami, FL	8.5005
Spokane, WA	8.3938
Denver, CO	7.8811
Seattle, WA	8.5811
San Francisco, CA	9.4695
Los Angeles, CA	9.0245
10 Km Cities (Average)	8.1
35 KM Cities (Average)	7.7

Table A-19

CARBON MONOXIDE, EXHAUST HYDROCARBON, AND NITROGEN OXIDES DETERIORATION FACTORS FOR LIGHT-DUTY, GASOLINE-POWERED VEHICLES IN ALL AREAS EXCEPT CALIFORNIA

Pollutant and Model Year	Vehicle Age, Years									
	0	1	2	3	4	5	6	7	8	≥9
Carbon Monoxide										
Pre-1968	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1968	1.00	1.24	1.35	1.41	1.47	1.53	1.58	1.63	1.67	1.72
1969	1.00	1.42	1.53	1.59	1.63	1.68	1.71	1.75	1.79	1.82
1970 through 1974	1.00	1.18	1.32	1.38	1.40	1.44	1.47	1.50	1.51	1.56
1975	1.00	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48	3.77
Post-1975	1.00	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48	3.77
Exhaust Hydrocarbon										
Pre-1968	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1968	1.00	1.12	1.18	1.21	1.23	1.26	1.28	1.30	1.32	1.35
1969	1.00	1.10	1.16	1.18	1.21	1.23	1.25	1.28	1.29	1.31
1970 through 1974	1.00	1.05	1.10	1.13	1.15	1.17	1.20	1.22	1.24	1.26
1975	1.00	1.45	1.95	2.40	2.76	3.14	3.46	3.79	4.07	4.42
Post-1975	1.00	1.45	1.95	2.40	2.76	3.14	3.46	3.79	4.07	4.42
Nitrogen Oxides										
Pre-1968	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1973 through 1975	1.00	1.11	1.18	1.20	1.21	1.22	1.23	1.24	1.25	1.26
Post-1975	1.00	1.34	1.77	2.14	2.42	2.73	2.99	3.26	3.48	3.77

SOURCE: U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors.*

As discussed in a preceding section of this appendix, the definition of crankcase emission rates explicitly incorporates PCV system deterioration factors. Following Heywood,[1] we have assumed no deterioration in the evaporative rates of hydrocarbon emissions.

Averaging Period for the Prediction of Pollutant Emissions

In promulgating its national primary and secondary ambient air quality standards, the EPA specified specific pollution concentration *averaging periods* for each pollutant type. In order to facilitate a comparison of predicted pollutant concentration levels to the national standards, we have derived emissions of each pollutant in the sample cities over the relevant averaging periods. These averaging periods are as follows:

Pollutant	Averaging Period
CO	One-hour and eight-hour annual maximum
HC	Three-hour (6-9 a.m.) annual maximum
NO_x	One-year arithmetic mean

For carbon monoxide emissions, we chose the periods 7-8 a.m. and 6 a.m. to 2 p.m. to represent the one-hour and eight-hour periods, respectively, since these periods are characterized by the highest one- and eight-hour ambient concentrations of CO. Similarly, for the three-hour HC standard, we predicted emission levels for 6-9 a.m. morning peak period in conformance with EPA's ambient air quality standards for hydrocarbons.

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[1] *Op. cit.*

In order to predict period-specific emission levels of the three pollutant types, it was necessary to revise our previously described estimates of vehicle miles of travel, average trip length, and percent of all trips with cold starts since each of these data items is characterized by a *diurnal* distribution. Data reported in the NPTS pertaining to the variation in VMT and average trip length by hour of the day is presented in Table A-20. To convert yearly VMT figures (see equation 11) to VMT during the relevant pollutant averaging period we employed the relation

$$vmt^{P}_{ijpsr} = \left[\frac{VMT_{ijpsr}}{52}\right] * wfac * vfac^{P} \qquad (14)$$

where

vmt^{P}_{ijpsr} = vehicle miles of travel during pollutant averaging period P(1 hour CO, 8 hour CO, or 3 hour NO_x) in city i, analysis year j, policy p, price scenario s and sensitivity range r, in miles per duration of the averaging period

$\left[\frac{VMT_{ijpsr}}{52}\right]$ = *VMT per week*, with indices as defined above.

$wfac$ = fraction of weekly travel occurring on most heavily traveled weekday.[1]

$vfac^{P}$ = fraction of daily *VMT* occurring during pollutant P's averaging period (see Table A-20).

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[1] As reported in the NPTS #10, Friday is the most heavily traveled weekday, accounting for 14.9 percent of weekly travel.

Table A-20

DIURNAL DISTRIBUTION OF VMT AND ATL

Hour of the Day Trip Began	Percent of Daily VMT	Average Trip Length (Miles)
4 a.m.	1.1	32.4
5 a.m.	1.4	18.4
6 a.m.	4.7	12.8
7 a.m.	7.5	10.4
8 a.m.	5.8	9.0
9 a.m.	5.0	9.5
10 a.m.	4.9	9.4
11 a.m.	4.6	8.3
12 noon	4.4	6.7
1 p.m.	4.7	8.8
2 p.m.	4.9	7.8
3 p.m.	8.4	9.2
4 p.m.	9.4	10.0
5 p.m.	8.3	8.4
6 p.m.	6.2	8.0
7 p.m.	4.8	7.3
8 p.m.	4.4	7.8
9 p.m.	3.0	7.9
10 p.m.	2.3	8.1
11 p.m.	1.9	9.7
12 Midnight	1.2	8.5
1 a.m.	0.6	11.0
2 a.m.	0.3	10.6
3 a.m.	0.2	7.5
All	100.0	8.9

SOURCE: *Nationwide Personal Transportation Survey*, #8, August 1973, Table A-28.

Average trip lengths for our sample cities as shown in Table A-18 were adjusted to conform to the appropriate pollutant averaging period by multiplying the given values by the ratio of the weighted average trip length during a particular averaging period to the average daily trip length (8.9 miles) shown in Table A-19. These adjustment factors assumed the following values:

Time Period	Factor Change in City-Specific Average Trip Length
7-8 a.m. (1 hour CO)	1.12
6 a.m. - 2 p.m. (8 hours CO)	0.93
6-9 a.m. (3 hours HC)	1.20
24 hour period (NO_X)	1.00

Finally some account had to be taken of the change in the fraction of cold starts across different pollutant averaging periods. We would expect, for example, that the percentage of cold starts during the three-hour morning peak HC averaging period (where a large proportion of travel consists of work trips following a long soak period) would be higher than the percentage of cold starts during CO eight-hour averaging period (where many journeys involve multistop shopping trips with short duration vehicle soaks).

Our method for accounting for these considerations runs as follows:

let

F_n = fraction of non-work trips that begin with a cold start

F_w = fraction of work trips that begin with a cold start

T_{np} = fraction of total trips that are non-work related during averaging period P

T_{wp} = fraction of total trips that are work related during averaging period P

By definition, $T_{np} + T_{wp} = 1$. Assuming that all work trips initiate with a cold start,[1] (i.e., $F_n = 1$), and the weights used in the CVS-CH test procedure (43 percent for cold starts and 57 percent for hot starts; see equation [1]) are representative of 24-hour urban driving patterns, we get the definitional relationship:

$$0.43 = F_n T_{nP} + F_w T_{wP} = F_n(1-T_w) + T_w \qquad (15)$$

where in this case the index P represents a 24-hour period. Values for T_w and T_n were derived from NPTS Number 8. In particular, NPTS data indicate that over a representative 24-hour period, 68.1 percent of all trips are non-work related (T_n) and 31.9 percent of all trips are work-related (T_w).

Using these values in equation (9) we may solve for F_n, the fraction of non-work trips that are cold started:

$$F_n = \frac{0.43 - T_{wp}}{1 - T_{wp}} = 0.163 \qquad (16)$$

Finally, going back to equation (9), employing data from the NPTS on the fraction of work and non-work trips in each appropriate pollutant averaging period (T_{np} and T_{wp}), we get the following results:

[1]This assumption is somewhat unrealistic. However, since we have more unknowns than equations, it was required to fix the value of one of our variables.

Time Period P	α^P Fraction of Trips Cold Started During Period P
7-8 a.m. (1 hour CO)	0.50617
6 a.m.-2 p.m. (8 hours CO)	0.3708
6-9 a.m. (3 hours HC)	0.7595
24 hour period (NO_x)	0.4300

The Emission Production Functions

Using the input data discussed in the preceding sections, the calculation of LDV emissions for hydrocarbons, the oxides of nitrogen, and carbon monoxide is straightforward. The following six equations describe the emissions model used in this report.

Total Emissions

$$E^{T_n P}_{ijpsr} = \sum_{k=1}^{5} E^{k_n P}_{ijpsr} \qquad (17)$$

where

$E^{T_n P}_{ijpsr}$ = total emissions of pollutant n ($n=1$: CO, $n=2$: NO_x, $n=3$: HC) in city i, year j, policy p, price scenario s and sensitivity range r in averaging period P

E^{kP}_{ijpsr} = emissions by source k (where $k=1$: running, $k=2$: cold starts, $k=3$: hot soaks, $k=4$: evaporative diurnal, $k=5$: crankcase).

In equation (11), it should be noted that

$$E^{k}_{ijpsr} = 0 \text{ for all } k \geq 3 \text{ and } n \neq 3.$$

Running Exhausts

$$E^{1_n P}_{ijpsr} = vmt^{P}_{ijpsr} \sum_{h=j-17}^{j} e^{*}_{hn1a}\, d^{n}_{j}(h)\, v_{jpsr}(h)$$

where

$E^{1_n P}_{ijpsr}$ = running emissions of pollutant n during averaging period P in city i, year j, policy p, price scenario s, and sensitivity range r

vmt^{P}_{ijpsr} = vehicle miles of travel during averaging period P in city i, year j, for policy p, price scenario s, and sensitivity range r

h = vehicle age $(h = 1,\ldots 17)$

e^{*}_{hn1a} = scaled low mileage running exhaust emission rate for year j-h, pollutant type n, and altitude class a[1]

$d^{h}_{j}(h)$ = deterioration factor in year j and pollutant type n for vehicles that are h years old

$v_{jpsr}(h)$ = percent of vehicle miles of travel in year j driven by vehicles that are h years old for policy p, price scenario s, and sensitivity range r

[1] Denver was the only city in our sample considered to be in the high altitude category.

Cold Start Exhausts

$$E^{2_n P}_{ijpsr} = \alpha^P \left[\frac{vmt^P_{ijpsr}}{atl^P_{ijpsr}} \right] \sum_{h=j-17}^{j} e^*_{hn2a} \, d^n_j(h) v_{jpsr}(h)$$

where

$E^{2_n P}_{ijpsr}$ = cold start emissions of pollutant n during averaging period P in city i, year j, policy p, price scenario s, and sensitivity range r

α^P = fraction of all trips which are cold started during averaging period P

atl^P_{ijpsr} = average trip length for averaging period P

e^*_{hn2a} = scaled low mileage cold start emission rate for year j-h, pollutant type n, and altitude class a.

Hot Soak Emissions (HC only)

$$E^{3_n P}_{ijpsr} = \left[\frac{vmt^P_{ijpsr}}{atl^P_{ijpsr}} \right] \sum_{h=j-17}^{j} e_{h3a} \, v_{jpsr}(h)$$

where

$E^{3_n P}_{ijpsr}$ = hot soak HC emissions during averaging period P in city i, year j, policy p, price scenario s, and sensitivity range r

e^*_{h3a} = hot soak HC emission rate for year j-h and altitude class a

Diurnal Evaporative Emissions (HC only)

$$E^{4_nP}_{ijpsr} = \beta^P A_{ijpsr} \sum_{h=j-17}^{j} e_{h4a}\, v_{jpsr}(h)$$

where

$E^{4_nP}_{ijpsr}$ = diurnal evaporative HC emissions during averaging period P in city i, year j, policy p, price scenario s, and sensitivity range r

β^P = fraction of a day represented by averaging period P

A_{ijpsr} = number of autos in city i, year j, policy p, price scenario s, and sensitivity range r

e_{h4a} = evaporative HC emission rate for year j-h and altitude class a

Crankcase Emissions (HC only)

$$E^{5_nP}_{ijpsr} = vmt^P_{ijpsr} \sum_{h=j-17}^{j} e_{h5a}\, v_{JPsr}(h)$$

where

$E^{5_nP}_{ijpsr}$ = crankcase HC emissions during averaging period P in city i, year j, policy p, price scenario s, and sensitivity range r

e_{h5a} = crankcase HC emissions rate for year j-h

Air Quality Calculations and Validation of the Model

The model used to determine concentrations of carbon monoxide, nitrogen oxides and oxidants were discussed in Chapter 3. This section presents the methods used to calculate concentrations of pollutants for the 13 sample cities and compares the estimates with the observed values for 1973.

Modeling Calculation Procedure

Modeling calculations were performed for 13 urban areas selected to be representative of a range of socioeconomic, demographic, and meteorological factors. These areas and the corresponding diameter size parameters (S) are listed in Table A-21. The diameter in each case was calculated on the basis of the equivalent area circle.

Values of $\overline{\chi}/\overline{Q}$ have been calculated by the Miller-Holzworth Model as a function of season, time of day (morning and afternoon), and frequency of occurrence (median, upper quartile, upper decile). Figure A-1 gives an example of these data for the case of upper decile autumn morning for 10- and 100-kilometer diameter urban areas. In the current study, these parameters were selected to correspond to the periods of peak concentration levels. Consequently, the upper decile fall morning model values were applied to calculations of carbon monoxide concentrations; the median annual values were applied to calculation of nitrogen oxide concentrations, and the upper decile summer morning values were applied to calculation of hydrocarbon-oxidant concentrations. The resultant $\chi/\overline{Q}$ values, interpolated for each of the 13 urban area diameters, are presented in Table A-21.

TABLE A-21

URBAN AREA DIAMETER AND INTERPOLATED χ/Q

City	Diameter (km)	χ/Q (sec/m) CO*	NO_x**	HC†
Portland, Maine	13.6	70	10.2	57
New York, New York	89.4	152	16.2	86
Nashville, Tennessee	33.7	275	16.1	235
Pittsburgh, Pennsylvania	44.3	365	15.7	328
Little Rock, Arkansas	17.7	103	12.8	88
Oklahoma City, Oklahoma	33.4	58	13.1	53
Tampa, Florida	20.7	38	12.1	25
Miami, Florida	29.2	32	11.8	21
Spokane, Washington	16.0	70	14.5	59
Denver, Colorado	31.1	178	33.9	155
Seattle, Washington	36.9	103	13.7	112
San Francisco, California	47.4	344	20.7	92
Los Angeles, California	72.0	310	34.3	170

* CO - Upper decile fall morning

** NO_x - Median annual

† HC - Upper decile summer morning

Figure A-1

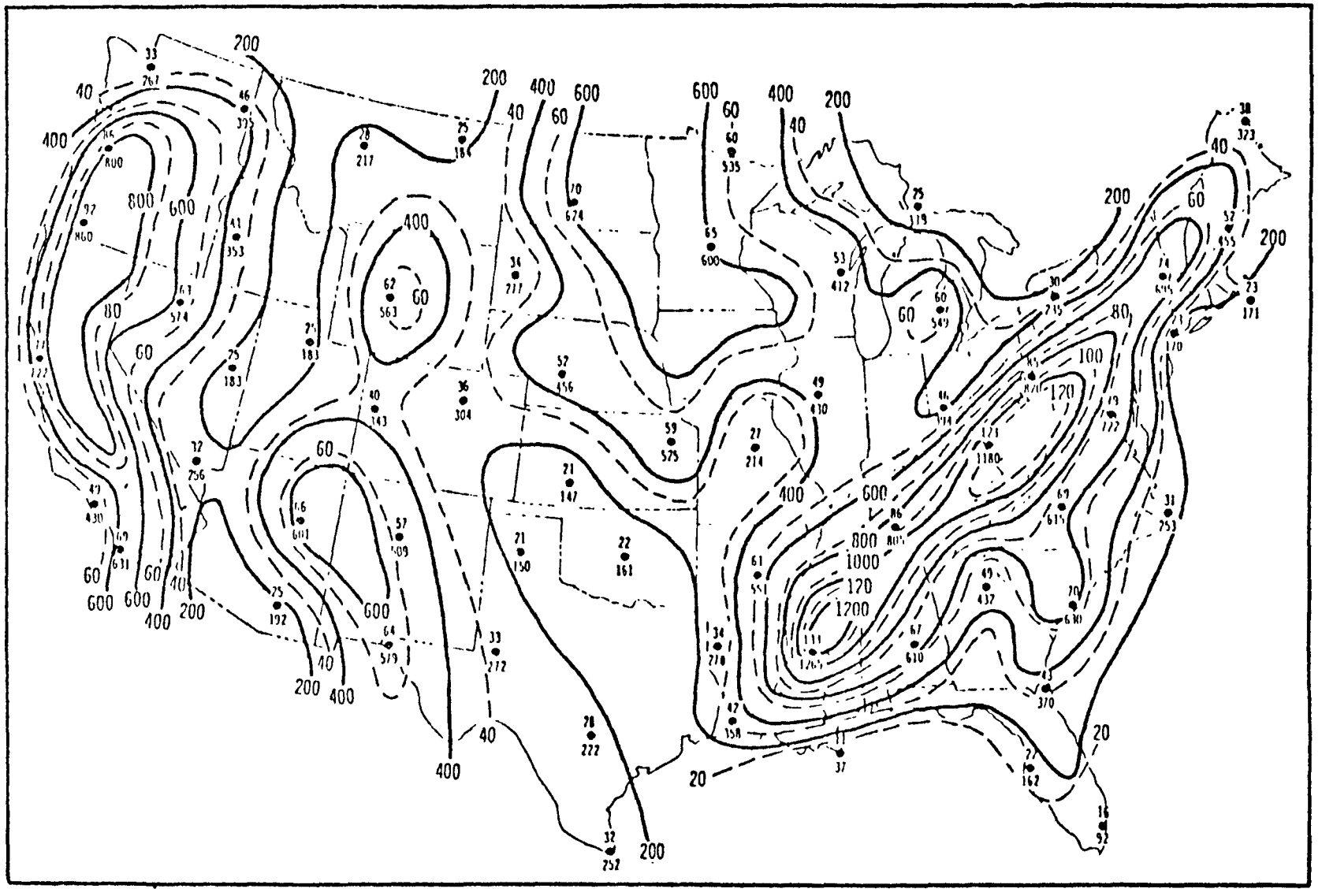

Figure A-1. Data and isopleths (sec m^{-1}) of upper decile autumn morning $\bar{\chi}/\bar{Q}$ values (see text) for 10- (upper numerals and dashed isopleths) and 100-km (lower numerals and solid isopleths) city sizes.

The effect on ambient air quality resulting from changes in LDV emissions was analyzed both in terms of total urban area emissions and in terms of only the LDV component. The procedures used in each case are described briefly below.

1. LDV Component

The changes in pollutant concentration resulting from LDV source emissions were calculated by the equation

$$\overline{X}_{LDV} = \left(\frac{\overline{X}}{\overline{Q}}\right) \overline{Q}_{LDV}$$

where

$\overline{Q}_{LDV}$ is the LDV emission rate ($\mu g/m^2/sec$)

$\overline{X}_{LDV}$ is the component of the ambient concentration ($\mu g/m^3$)

The averaging period of the concentration prediction is determined by the averaging period of the source emission.

2. Total Urban Emissions

To calculate pollutant concentrations resulting from total urban area emissions, an estimate was made of the emissions from all sources other than LDV sources. The total emission rate for a given averaging period $\overline{Q}_{TOT}$ is defined as

$$\overline{Q}_{TOT} + \{\overline{Q}_{OS}\} + \overline{Q}_{LDV}$$

where $\{\overline{Q}_{OS}\}$ is the average annual emission rate for all other sources in the urban area ($\mu g/m^2/sec$).

In this model, short period variations in emission rates for all other urban sources are not considered. The quantity $\{\overline{Q}_{OS}\}$ can be estimated from the equations

$$\{\bar{Q}_{OS}\} = \bar{Q}_{LDV} \cdot T \cdot \left[\frac{1}{R} - 1\right]$$

$$R = \{\bar{Q}_{LDV}\}/\{\bar{Q}_{TOT}\}$$

$$T = \{\bar{Q}_{LDV}\}/\bar{Q}_{LDV}$$

where

$\{\bar{Q}_{LDV}\}$ is the average annual emission rate for LDV sources $(\mu g/m^2/sec)$

$\{\bar{Q}_{TOT}\}$ is the total urban area average annual emission rate for all sources $(\mu g/m^2/sec)$

Under the assumption that R is approximately constant for all urban areas, this parameter can be determined from the national emission trends developed in Chapter 2. Values of R were calculated from these data for each pollutant and each year of the study (see Table 2-12).

The parameter T represents the ratio of annual average LDV emission rate to peak averaging period LDV emission rates. This ratio is also assumed to be constant for all urban areas and to possess the values shown in Table A-22. The peak emission rates are considered to occur during 1-, 3-, and 8-hour periods of an average Friday during the year.

Thus, the pollutant concentration resulting from total urban area emissions is given by

$$\bar{X}_{TOT} = \left[\frac{\bar{X}}{\bar{Q}}\right] \bar{Q}_{TOT}$$

where

$\bar{X}_{TOT}$ is the total ambient pollutant concentration $(\mu g/m^3)$

TABLE A-22

RATIO OF ANNUAL AVERAGE TO PEAK LDV EMISSION RATES (T)

Pollutant	T Values 1-Hour	3-Hour	8-Hour	Annual Average
CO	0.45		0.77	
NO_x				1.0
HC		0.72		

The averaging period of the concentration prediction is determined by the averaging period of the LDV source emissions.

Model Validation

To test the performance of the modeling procedures described above, a set of predicted ambient concentrations was compared to observed values recorded at monitoring stations. The most recent monitoring data reported in the EPA *Monitoring and Air Quality Trends Report, 1973* were used for this purpose.[1] The data extracted from this report for the urban areas analyzed in this study are shown in Table A-23. Several aspects of these data should be noted, namely,

- Observations of carbon monoxide, nitrogen oxides, and oxidants were available for seven, two, and six of the urban areas considered, respectively. Observations of hydrocarbon concentrations were not reported for any of these urban areas.
- The tabulated values represent maximum site location data rather than regional averages of all monitoring stations.
- The upper decile carbon monoxide levels shown are interpolated from observed frequency distributions by application of the methods suggested by Larsen.[2]

Predicted pollutant concentrations calculated from estimated total urban area emissions for 1973 are listed in Table A-24. A graphical comparison of these predicted concentrations and

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[1] *Monitoring and Air Quality Trends Report*, 1973, U.S. EPA -450/1-74-007, October 1974.

[2] *A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards*, U.S. EPA Pub. No. AP-89, Research Triangle Park, N.C., November 1971.

TABLE A-23

AIR QUALITY MONITORING DATA FOR 1973

City	Pollutant CO* (mg/m^3)	NO_x** ($\mu g/m^3$)	O_x† ($\mu g/m^3$)
Portland, Maine	—	—	—
New York, New York	—	—	260
Nashville, Tennessee	—	—	205
Pittsburgh, Pennsylvania	14.5	—	—
Little Rock, Arkansas	—	—	—
Oklahoma City, Oklahoma	4.6	—	—
Tampa, Florida	—	—	—
Miami, Florida	—	—	—
Spokane, Washington	5.2	—	—
Denver, Colorado	7.4	—	403
Seattle, Washington	6.6	—	110
San Francisco, California	4.7	64	235
Los Angeles, California	8.5	128.5	892

* Upper decile 1-hour average

** Annual average

† Peak 1-hour average

TABLE A-24

PREDICTED AIR QUALITY CONCENTRATIONS FOR 1973

City	Pollutant CO* (mg/m^3)	NO_x** ($\mu g/m^3$)	O_x† ($\mu g/m^3$)
Portland, Maine	—	—	—
New York, New York	—	—	184
Nashville, Tennessee	—	—	102
Pittsburgh, Pennsylvania	18.2	—	—
Little Rock, Arkansas	—	—	—
Oklahoma City, Oklahoma	1.1	—	—
Tampa, Florida	—	—	—
Miami, Florida	—	—	—
Spokane, Washington	1.9	—	—
Denver, Colorado	12.0	—	490
Seattle, Washington	3.1	—	249
San Francisco, California	14.9	86.2	248
Los Angeles, California	16.0	168.4	442

* Upper decile 1-hour average

** Annual average

† Peak 1-hour average

the observed pollutant concentrations is presented in Figures A-2 through A-4. Departures from the line of perfect fit on each graph are indicative of the performance of the model. Examination of these graphs indicates that the model tends to underpredict peak carbon monoxide concentrations at low concentration levels and to overpredict at high concentration levels. The number of cases available for comparison for nitrogen oxides, however, is too small to yield any trend indications. Similarly, for the case of photochemical oxidants, no trend is evident from the scatter of data about the line of perfect fit.

Any one of a number of factors can contribute to differences between the observed and the predicted levels. Among these are:

- The $\overline{X}/\overline{Q}$ values are non-representative for the year 1973
- The Miller-Holzworth assumption of steady-state conditions over the averaging period is not satisfied
- The air quality monitoring data are not representative of the area-wide concentration levels
- The assumption of circular regions is not valid
- The estimated total urban area emission levels are in error.

Overall, the model and the observed values are within a factor of two for approximately two-thirds of the cases. This may be compared to more detailed and sophisticated models, used for control strategy evaluation, whose performance generally yields correspondence within a factor of two for 90% of the cases. The performance of the simple model, however, is considered adequate for the purpose of the current study objectives.

Figure A-2

COMPARISON OF PREDICTED VS. OBSERVED CARBON MONOXIDE CONCENTRATIONS FOR 1973

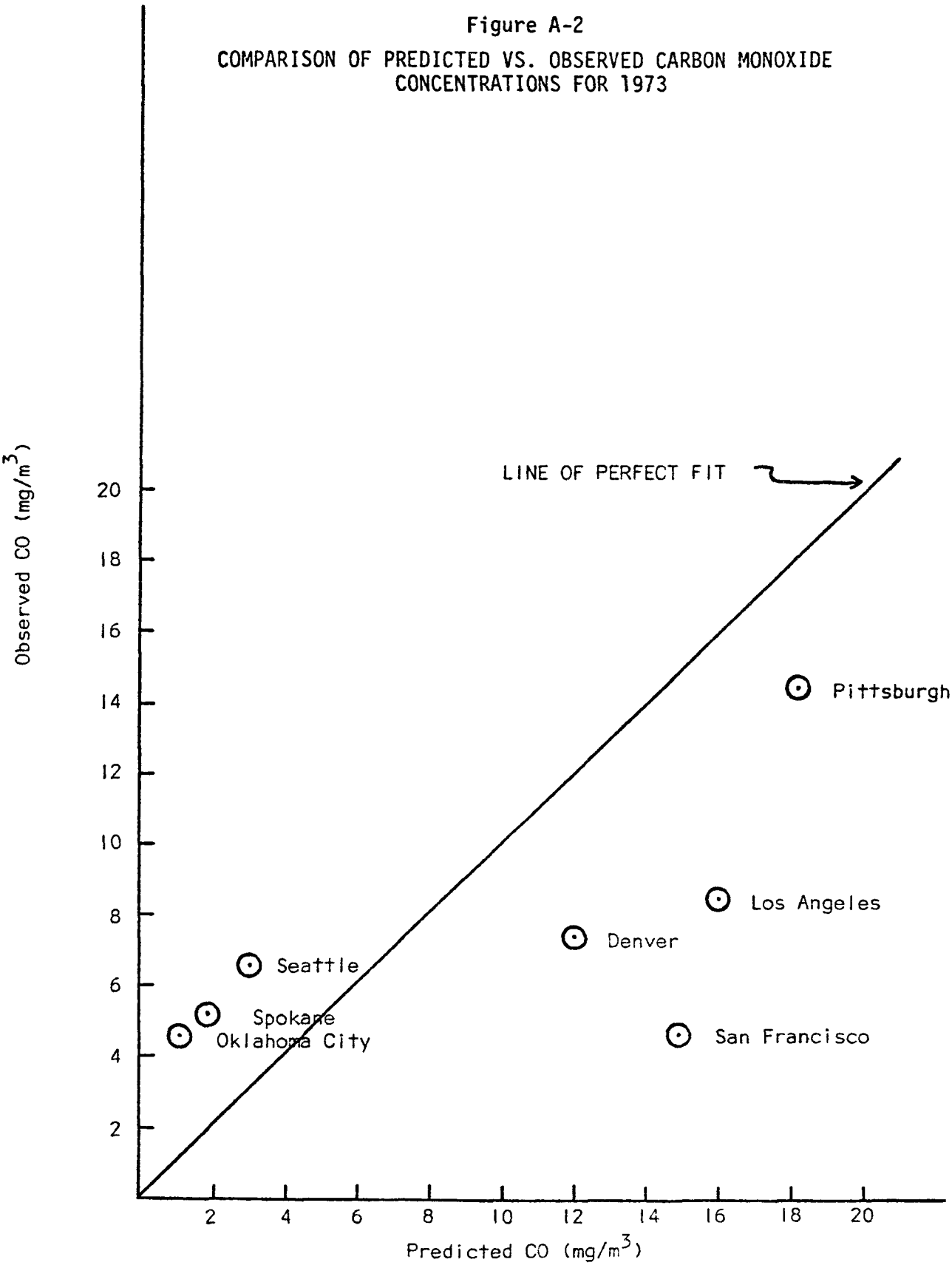


Figure A-3

COMPARISON OF PREDICTED VS. OBSERVED NITROGEN OXIDE CONCENTRATIONS FOR 1973

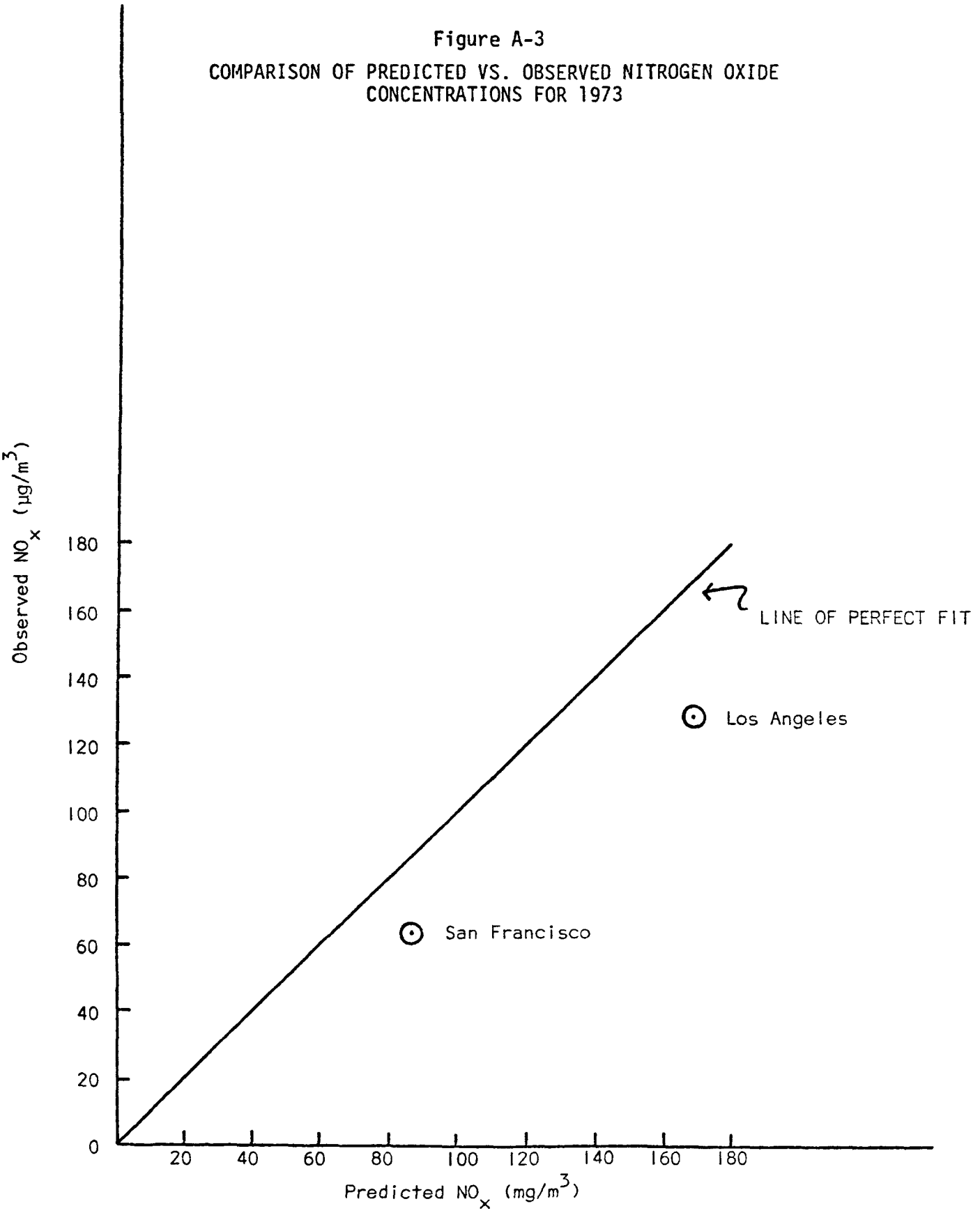
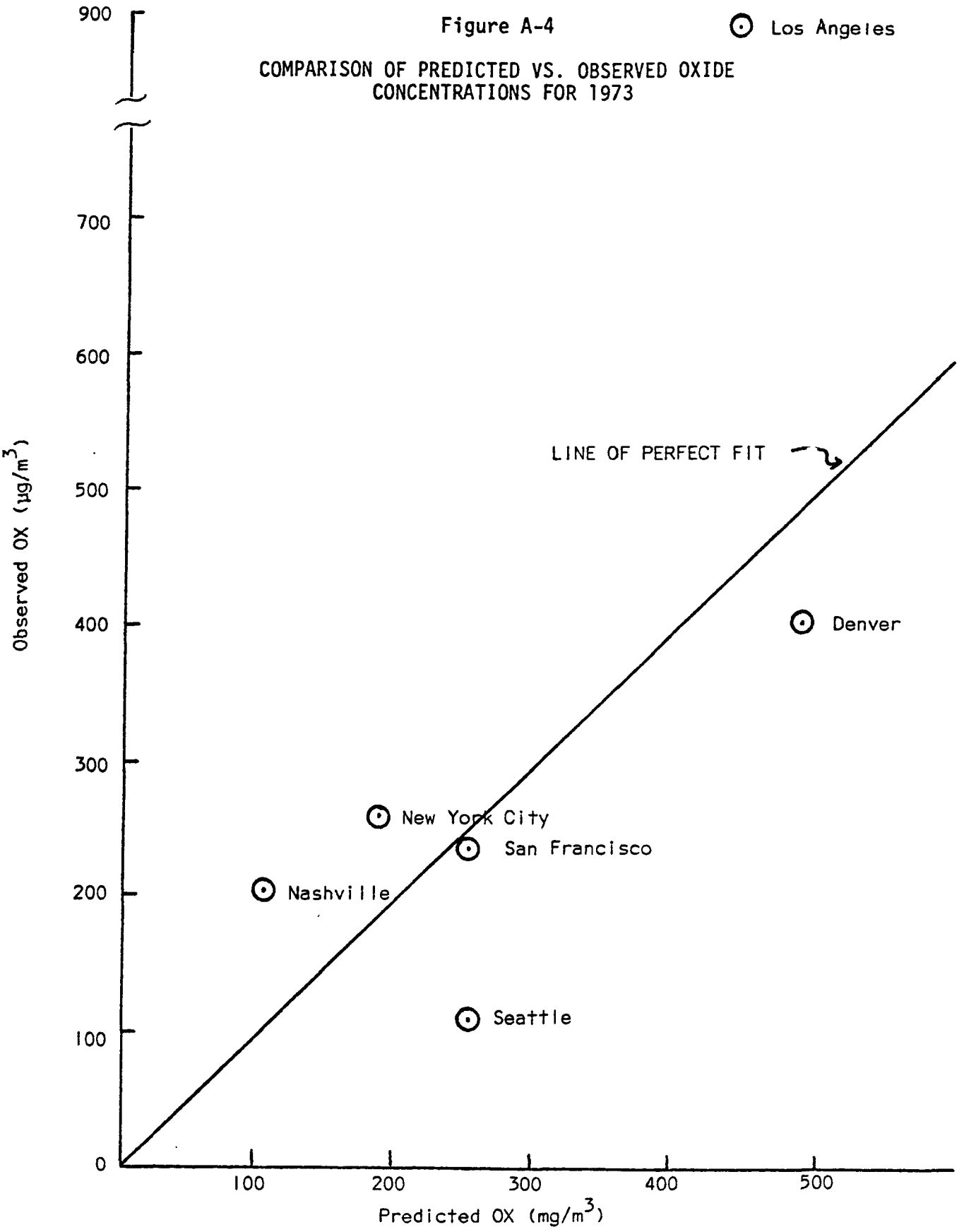


Figure A-4

COMPARISON OF PREDICTED VS. OBSERVED OXIDE CONCENTRATIONS FOR 1973



APPENDIX B

This appendix presents in greater detail the trends in emissions of carbon monoxide, hydrocarbons, nitrogen oxides,and oxidants.

Carbon Monoxide

The trend in nationwide emissions of carbon monoxide (CO) from 1940 to 1970 is shown in

Table B-1. This table shows an annual average CO emissions of slightly less than 3 percent over this time period. Table B-2 shows that transportation sources account for almost three-fourths of CO emissions and that gasoline-powered motor vehicles account for almost two-thirds of total CO emissions. Between 1940 and 1969, the annual increase in CO emissions from all transportation sources was 4 percent. CO emissions have been expected to decline after 1969 as a result of the introduction of automobile emission controls. The estimated change in recent CO emissions in selected states and cities is shown in Figure B-1.

Ambient CO trends in urban areas can be expected to reflect trends in motor vehicle exhaust emission, which depend on (among other factors) changing exhaust emission standards and vehicle miles of travel (over a certain time period). In spite of the long-term increase in CO emissions through 1969, CAMP data for five major metropolitan areas (Chicago, Cincinnati, Denver, Philadelphia, and St. Louis) report that average CO levels generally declined during the period 1962 to 1972. The average percentage decrease for the five stations from 1962 to 1971 was 31 percent.[1] Carbon monoxide concentrations also show a nationwide decline from 1970 to 1973, as indicated by a downward trend in the percentage of annual values above the eight-hour standard of 10 mg/m^3, as shown in Figure B-2. However, CEQ reports that CO annual average trends have not been uniform, with some urban areas recently showing increases.[2]

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[1] *The National Air Monitoring Program: Air Quality and Emissions Trends, Annual Report, op. cit.*

[2] *The Fifth Annual Report of the Council on Environmental Quality, op. cit.*

Table B-1[1]

NATIONWIDE ESTIMATES OF CARBON MONOXIDE EMISSIONS, 1940-1970
(10^6 tons/year)

Source Category	1940	1950	1960	1968	1969	1970
Fuel combustion in stationary sources	6.2	5.6	2.6	2.0	1.8	0.8
Transportation	34.9	55.4	83.5	113.0	112.0	111.0
Solid waste disposal	1.8	2.6	5.1	8.0	7.9	7.2
Industrial process losses	14.4	18.9	17.7	8.5	12.0	11.4
Agricultural burning	9.1	10.4	12.4	13.9	13.8	13.8
Miscellaneous	19.0	10.0	6.4	5.0	6.3	3.0
TOTAL	85.4	103.0	128.0	150.0	154.0	147.0
Total controllable[2]	66.4	92.9	121.0	145.0	148.0	144.0
Percent of controllable emissions from transportation sources	52.6	59.6	69.0	77.9	75.7	77.1

[1]Environmental Protection Agency, *Monitoring and Air Quality Trends Report*, various years. In this and in Tables B-2 through B-6 and B-8, and Figures B-1 and B-4, the data are drawn from sources reported in footnote 1, page 2-5.

[2]Miscellaneous sources not included.

Table B-2

NATIONWIDE ESTIMATES OF CARBON MONOXIDE EMISSIONS, 1970

Source Category	Emissions 10^6 tons/year	Percent total
Transportation	111.0	74.5
Motor Vehicles	96.6	64.8
Gasoline	95.8	64.3
Diesel	0.8	0.5
Aircraft	3.0	2.0
Railroads	0.1	0.1
Vessels	1.7	1.2
Other nonhighway use of motor fuels	9.5	6.4
Fuel combustion in stationary sources	0.8	0.6
Coal	0.5	0.3
Fuel Oil	0.1	0.1
Natural Gas	0.1	0.1
Wood	0.1	0.1
Industrial process losses	11.4	7.7
Solid waste disposal	7.2	4.9
Agricultural burning	13.8	9.3
Miscellaneous	4.5	3.0
Forest fires	4.0	2.7
Structural fires	0.2	0.1
Coal refuse burning	0.3	0.2
TOTAL	149.0	

Figure B-1

NORMALIZED CARBON MONOXIDE EMISSION CURVES FOR SELECTED AREAS

1970-1973

(These curves are based on the Federal Motor Vehicle Control Curve and appropriate Transportation Control Plans.)

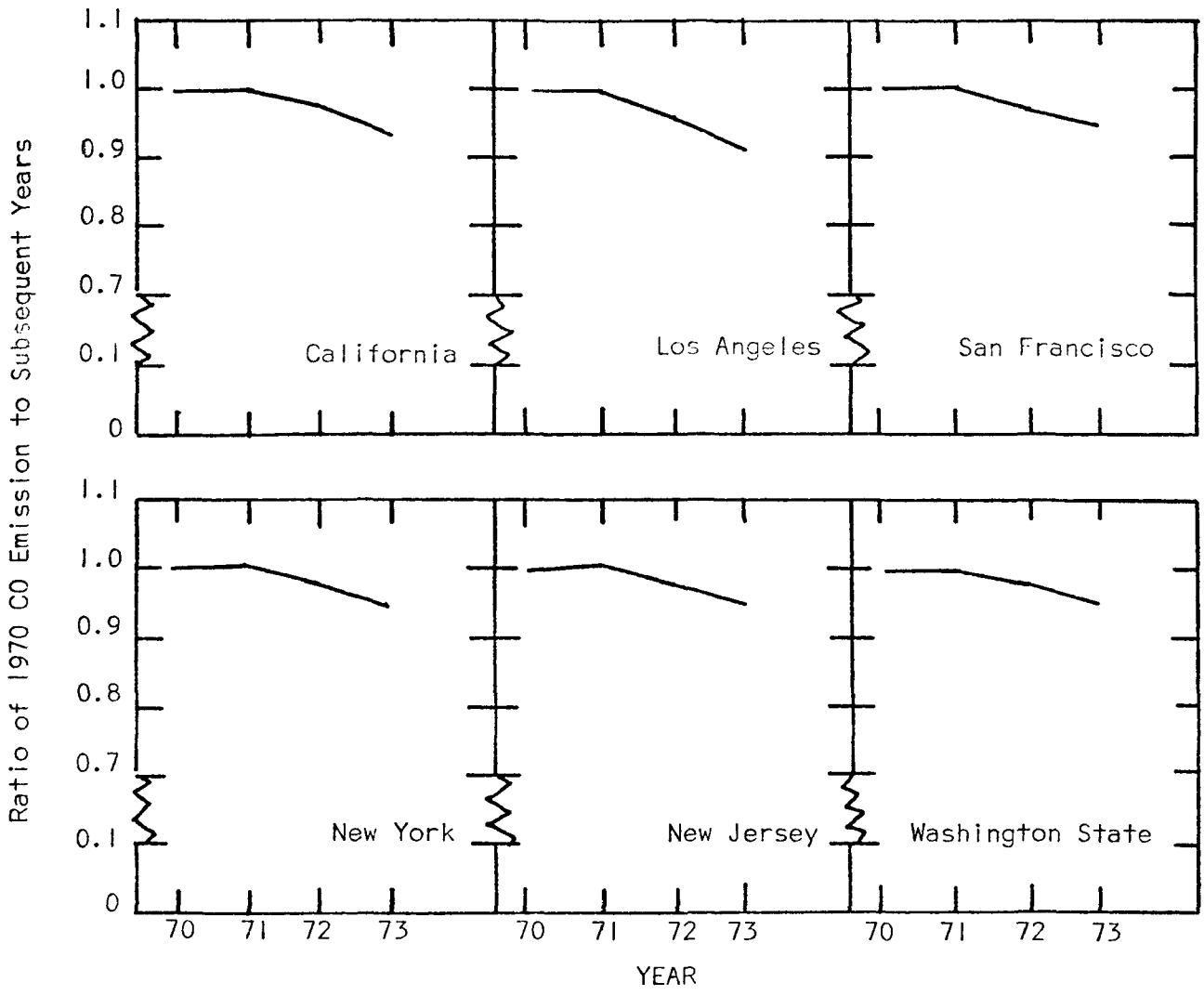
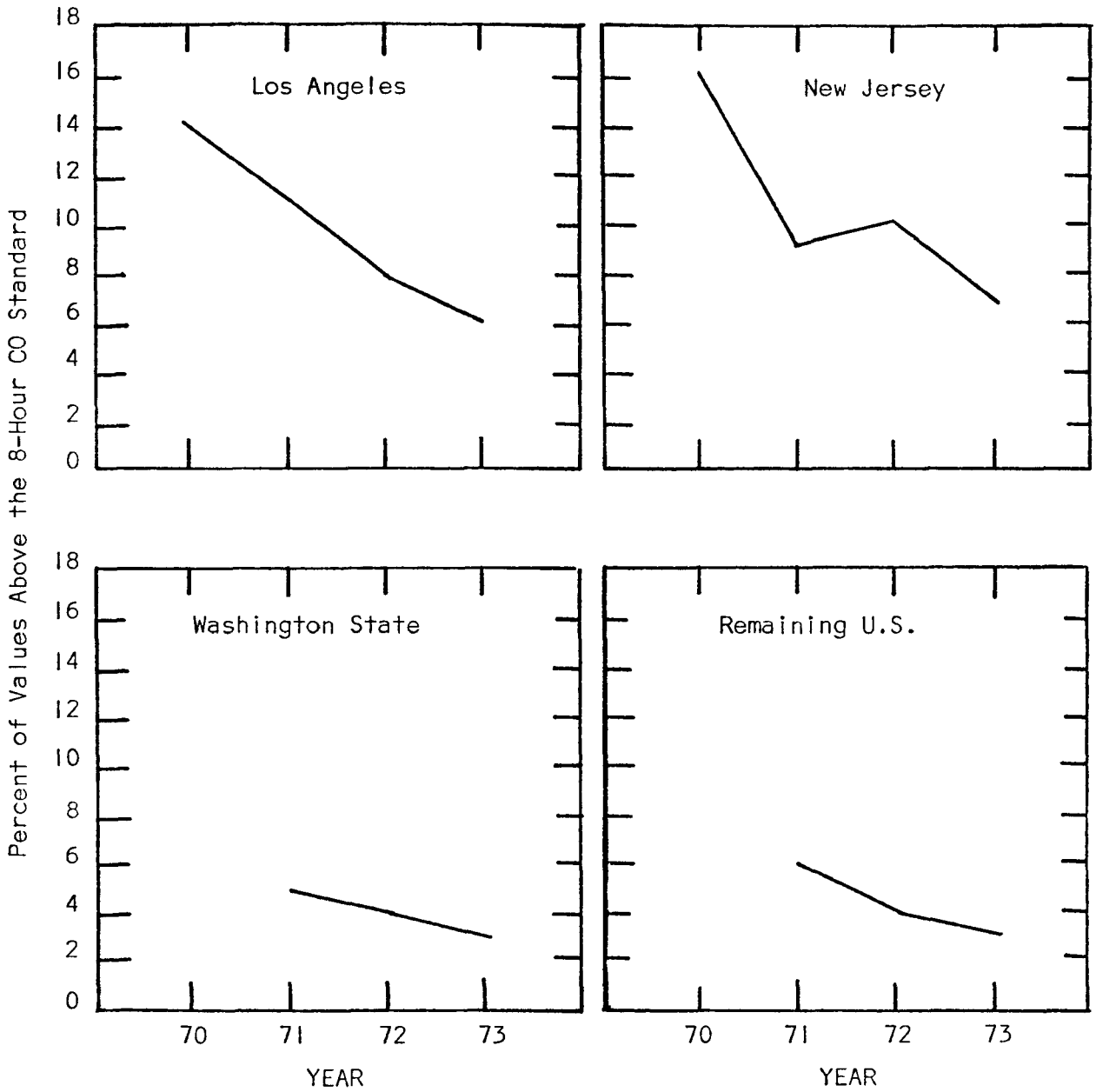


Figure B-2

ANNUAL AVERAGE PERCENT OF VALUES ABOVE THE 8-HOUR C. MONOXIDE STANDARD FOR SELECTED AREAS, 1970-1973



Hydrocarbons

Emissions trends for hydrocarbons (HC) from 1940 to 1970 are shown in Table B-3. These data show that overall hydrocarbon emissions have increased at an annual rate of about 1.7 percent during this period. In 1968-1969, the emission rate stabilized, and has decreased since 1969. Table B-4 shows that transportation sources accounted for 55.9 percent of the total hydrocarbon emission in 1970. EPA reports that, for 1940 to 1970, "automotive sources alone represent a rate increase for HC emissions of nearly 3.3 percent. The control of hydrocarbons from the crankcase (or blowby) reduced average per-vehicle emissions by one-third in the early 1960's. This has resulted in an HC emission growth rate from vehicles that is lower than the CO growth rate."[1]

Nationwide air quality trends for hydrocarbons have not been reported.

Nitrogen Oxides

"Emissions of nitrogen oxides have continued to increase due to increasing fuel combustion (particularly from rural power plants) combined with the introduction of new combustion systems for both stationary and transportation sources which, while designed to control hydrocarbon and CO emissions, in some cases lead to increased emissions of nitrogen oxides."[2]

Nationwide estimates of nitrogen oxide (NO_x) emission trends for 1940 to 1970 are shown in Table B-5. NO_x emissions

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[1] *The National Air Monitoring Program, op. cit.*

[2] National Academy of Sciences and National Academy of Engineering, *Air Quality and Automobile Emission Control*, Vol. 3, *The Relationship of Emissions to Ambient Air Quality*, prepared for the Committee on Public Works, U.S. Senate, No. 93-24, September 1974, p. 62.

Table B-3

NATIONWIDE ESTIMATES OF HYDROCARBON EMISSIONS, 1940-1970
(10^6 tons/year)

Source Category	1940	1950	1960	1968	1969	1970
Fuel combustion in stationary sources	1.4	1.3	1.0	1.0	0.9	0.6
Transportation	7.5	11.8	18.0	20.2	19.8	19.5
Solid waste disposal	0.7	0.9	1.3	2.0	2.0	2.0
Industrial process losses	3.3	5.2	4.3	4.4	4.7	5.5
Agricultural burning	1.9	2.1	2.5	2.8	2.8	2.8
Miscellaneous	4.5	4.2	4.4	4.9	5.0	4.4
TOTAL	19.1	25.6	31.6	35.2	35.2	34.7
TOTAL CONTROLLABLE[1]	14.7	21.4	27.2	30.3	30.2	30.3

[1]Miscellaneous sources not included.

Table B-4

NATIONWIDE ESTIMATES OF HYDROCARBON EMISSIONS, 1970

Source Category	Emissions 10^6 tons/year	Percent total
Transportation	19.5	55.9
Motor Vehicles	16.7	47.9
Gasoline	16.6	47.6
Diesel	0.1	0.3
Aircraft	0.4	1.1
Railroads	0.1	0.3
Vessels	0.3	0.9
Nonhighway use of motor fuels	2.0	5.7
Fuel combustion in stationary sources	0.6	1.7
Coal	0.2	0.6
Fuel oil	0.1	0.3
Natural gas	0.3	0.8
Wood	Neg.[1]	---
Industrial process losses	5.5	15.8
Solid waste disposal	2.0	5.7
Agricultural burning	2.8	8.0
Miscellaneous	4.5	12.9
Forest fires[2]	0.3	0.9
Structural fires	0.1	0.3
Coal refuse burning	0.1	0.3
Gasoline and solvent evaporation	4.0	11.4
TOTAL	34.9	

[1]Negligible (less than 0.05 x 10^6 tons/year).

[2]Includes prescribed burning.

Table B-5

NATIONWIDE ESTIMATES OF NITROGEN OXIDE EMISSIONS, 1940-1970
(10^6 tons/year)

Source Category	1940	1950	1960	1968	1969	1970
Fuel combustion in stationary sources	3.5	4.3	5.2	9.7	10.2	10.0
Transportation	3.2	5.2	8.0	10.6	11.2	11.7
Solid waste disposal	0.1	0.2	0.2	0.4	0.4	0.4
Industrial process losses	Neg.[1]	0.1	0.1	0.2	0.2	0.2
Agricultural burning	0.2	0.2	0.3	0.3	0.3	0.3
Miscellaneous	0.8	0.4	0.2	0.2	0.2	0.1
TOTAL	7.9	10.4	14.0	21.3	22.5	22.7
TOTAL CONTROLLABLE[2]	7.1	10.0	13.8	21.1	22.3	22.6

[1]Negligible (less than 0.05×10^6 tons/year).

[2]Miscellaneous sources not included.

increased steadily from 1940 to 1968; since 1968 NO_x emissions have increased, but at a slower rate. Table B-6 indicates that transportation sources contributed just over half the total NO_x emissions in 1970. EPA has reported that automotive pollution control devices which reduce CO and HC emissions are ineffective in reducting NO_x emissions, and have resulted in increased NO_x emissions.[1]

Figure B-3 presents CAMP data on NO_x for five major urban areas from 1962 to 1971. Linear regression analysis lines plotted through the data show, on the average, an increase in NO_x concentrations in all five urban areas. These data must be used with caution, because the monitoring method, the Jacobs-Hochheiser technique, has been shown to overestimate ambient NO_x levels at low concentrations. Other NO_x measurements reported in the first National Air Monitoring Program report indicate that NO_x concentrations at twelve sites near Los Angeles from 1963 to 1971 have shown a general upward trend, and three sites in New Jersey have shown a slight downward trend for the period 1966 to 1970, and a stabilized trend for the period 1971 to 1972.[2]

Oxidants

Oxidants (O_x) are not directly emitted by any man-made source in significant quantities. They are a class of atmospheric pollutants which arise from a complex series of atmospheric photochemical reactions between hydrocarbons and oxides of nitrogen in the presence of sunlight. The two most important reaction products are ozone and the peroxyacyl nitrates (PAN). In addition, large numbers of deleterious by-products are formed during the reactions,

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[1]*Nationwide Air Pollutant Emission Trends 1940-1970, op. cit.*

[2]*The National Air Monitoring Program: Air Quality and Emissions Trends, Annual Report*, EPA-450/1-73-001a and EPA-450/1-73-001b, Research Triangle Park, North Carolina, December 1973.

Table B-6

NATIONWIDE ESTIMATES OF NITROGEN OXIDE EMISSIONS, 1970

Source Category	Emissions 10^6 tons/year	Percent of Total
Transportation	11.7	51.3
Motor vehicles	9.1	39.9
Gasoline	7.8	34.2
Diesel	1.3	5.7
Aircraft	0.4	1.8
Railroads	0.1	0.4
Vessels	0.2	0.9
Nonhighway use of motor fuels	1.9	8.3
Fuel combustion in stationary sources	10.0	43.8
Coal	3.9	17.1
Fuel oil	1.3	5.7
Natural gas	4.7	20.6
Wood	0.1	0.4
Industrial process losses	0.2	0.9
Solid waste disposal	0.4	1.8
Agricultural burning	0.3	1.3
Miscellaneous	0.2	0.9
Forest fires[1]	0.2	0.9
Structural fires	Neg.[2]	---
Coal refuse burning	Neg.	---

[1]Includes prescribed burning.

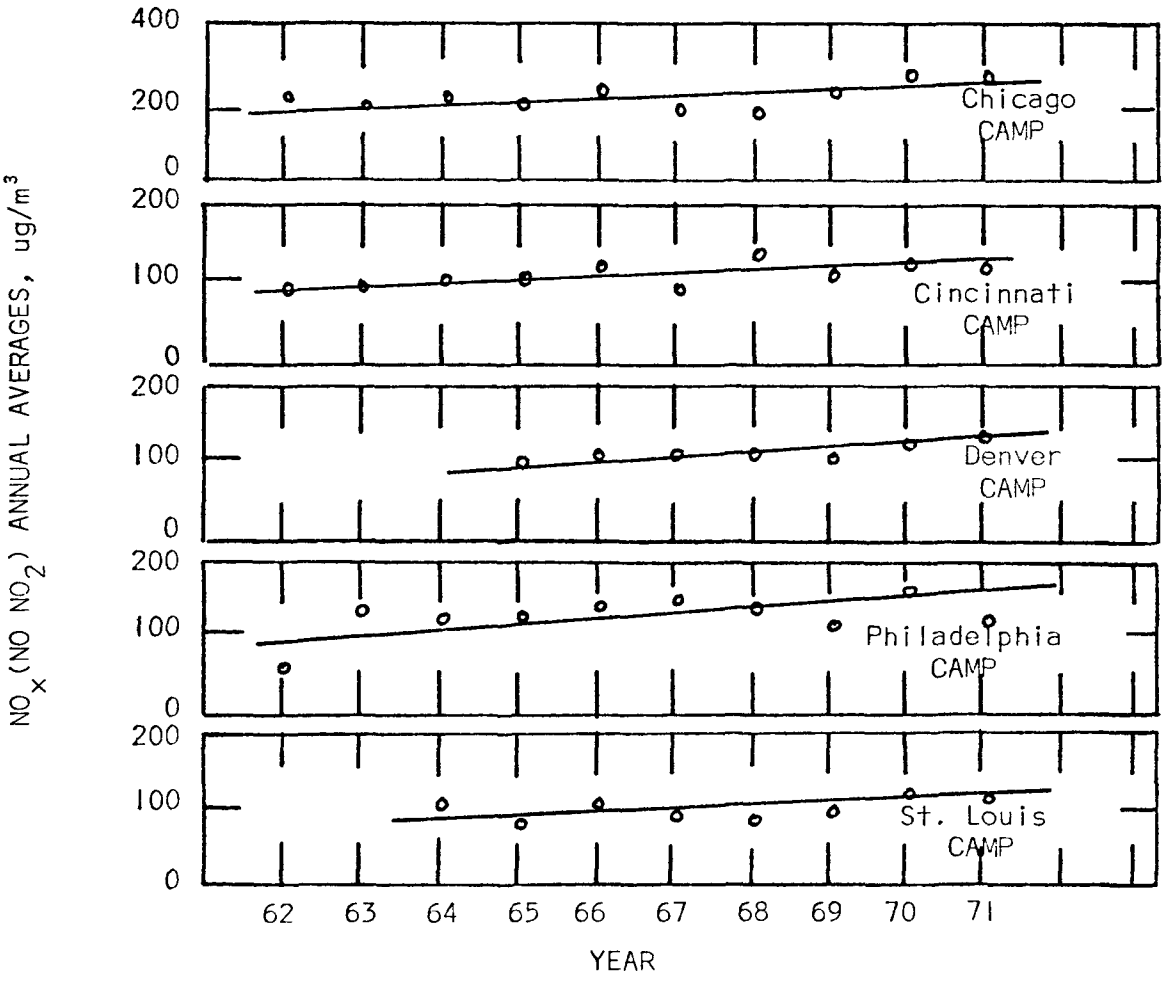
[2]Negligible (less than 0.05×10^6 tons/year).

Figure B-3

TREND LINES FOR NO_x ANNUAL AVERAGES IN FIVE CAMP CITIES

•Indicates invalid average (average based on incomplete data)

•Note change in ordinate scale for these data



including nitrate aerosols. Oxidant levels depend significantly on climatology and on levels (and on ratios as well) of NO_x and HC.

CAMP air quality data for oxidants have been reported intermittently for the time period 1962 to 1971 for five major urban areas. These data are not sufficiently continuous or complete to allow trend analysis of urban oxidant levels. California began monitoring for oxidants in 1963. In the Los Angeles area, oxidant levels have shown a slight decrease; however, it is possible that meteorological influences, as well as reductions in HC emissions, have played a significant role in the declining trend. Figure B-4 presents oxidant trend values for the second highest annual one-hour level for three groups of California sites. The high 1973 Coastal Los Angeles measurement is thought to result from a meteorological anomaly. Monitoring has also been conducted in New Jersey at three sites from 1966 to 1972. At these sites, oxidant levels have generally declined.[1] Meeting the Federal standard for oxidants will be the most difficult task in attaining the National Ambient Air Quality Standards in a number of cities throughout the country. A recent detailed description of urban and non-urban ozone trends can be found in *Air Quality and Automobile Emission Control.*[2] Altshuller has recently evaluated oxidant trends at CAMP sites. He has reported that "with the exception of Chicago, a large downward trend in oxidant concentrations has been occurring at CAMP sites."[3]

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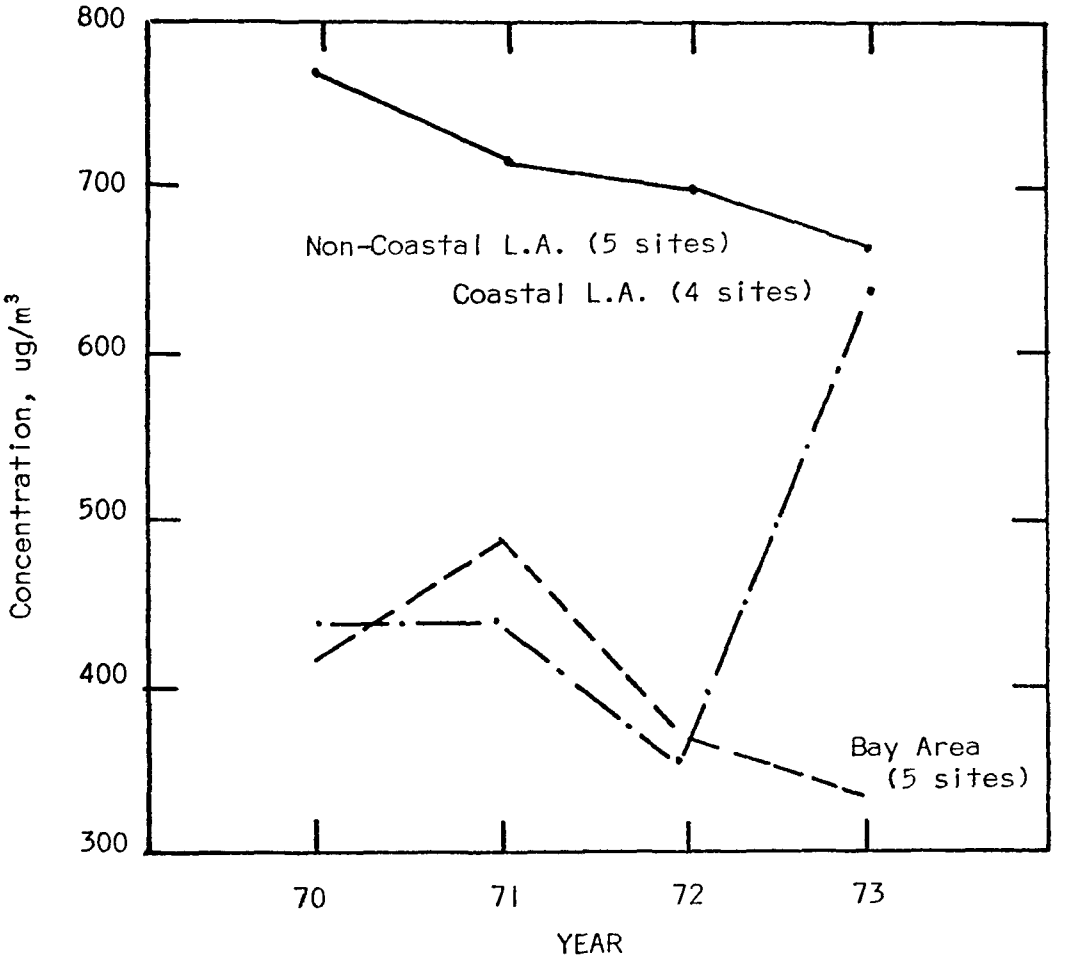
[1]*Monitoring and Air Quality Trends Report 1972, op. cit.*

[2]National Academy of Sciences and National Academy of Engineering.

[3]A. P. Altshuller, "Evaluation of Oxidant Results at CAMP Sites in the United States," *Journal of the Air Pollution Control Association,* Vol. 25, No. 1, January 1975.

Figure B-4

COMPOSITE AVERAGES OF SECOND HIGH ANNUAL 1-HOUR OXIDANT VALUES FOR VARIOUS AREAS WITHIN CALIFORNIA



Emissions Data for 1971 and 1972

Table B-7 presents emissions data for 1971. The 1971 values cannot, however, be compared with the 1970 values, because of changed methods of calculations. (See the notes to Table B-7 for details.) Table B-8 presents National Emissions Data System (NEDS) emission estimates for 1972. Data for gasoline land vehicles are given along with total emission estimates. Again, these estimates are calculated on a new basis (NEDS) and are only roughly comparable to previously published data. The proportion of each pollutant accounted for by gasoline land vehicles is (with the exception of nitrogen oxides) reasonably close to the 1970 proportion reported in Tables B-2, B-4,and B-6.

Table B-7

ESTIMATED EMISSIONS OF AIR POLLUTANTS
BY WEIGHT NATIONWIDE 1971[1,2]

(In Million Tons Per Year)

Source	CO	Particulates	SO_2	HC	NO_x
Transportation	77.5	1.0	1.0	14.7	11.2
Fuel combustion in stationary sources	1.0	6.5	26.3	.3	10.2
Industrial processes	11.4	13.6	5.1	5.6	.2
Solid waste disposal	3.8	.7	.1	1.0	.2
Miscellaneous	6.5	5.2	.1	5.0	.2
TOTAL	100.2	27.0	32.6	26.6	22.0
Percent change 1970 to 1971[1]	-.5	+5.9	-2.4	-2.6	0

[1]Figures for 1971 are not comparable to those for 1970 published in last year's report because of changed methods of calculation. Percent change 1970 to 1971 was calculated using 1970 figures computed on the 1971 basis. The most significant difference from the calculations used last year was the use of automobile emission factors based on the 1975 federal test procedures, as opposed to the previously used 1972 test procedures. The new method results in much lower estimates of automobile emissions.

[2]The table does not include data on photochemical oxidants because they are secondary pollutants formed by the action of sunlight on nitrogen oxides and hydrocarbons and thus are not emitted from sources on the ground.

SOURCE: *The Fourth Annual Report of the Council on Environmental Quality.*

Table B-8

NATIONAL EMISSIONS DATA SYSTEM EMISSION ESTIMATES

for 1972

(Millions of Tons)

Pollutant	Gasoline Land Vehicles	Total	Gasoline Land as Percent of Total
Hydrocarbons	10.98	27.82	39.5
Nitrogen Oxides	5.16	24.64	20.9
Carbon Monoxide	59.53	107.3	55.5

APPENDIX C

This appendix has three parts. The first part derives the relationship between a tax increase and the equilibrium price of gasoline. In the second part we derive disaggregated elasticities of demand for gasoline. The third section describes the long-run adjustment process and the derivation of long-run elasticities of demand.

A. Relationship Between a Tax Increase and the Equilibrium Price of Gasoline

A. We derive here a relationship between a tax increase and the market clearing price of gasoline, in terms of the elasticities of demand and supply at the initial equilibrium. Toward this end, define

p = price of gasoline;
$D(p)$ = quantity of gasoline demanded at price p;
$S(p)$ = quantity of gasoline supplied at price p;
Δt = increase in the federal excise tax on gasoline;
$\bar{p}(\Delta t)$ = market-clearing price after the tax increase, Δt.

Assume the market is initially in equilibrium at p^*. Then

(1) $D(p^*) - S(p^*) = 0.$

Furthermore, from Figure 2 in the text of Chapter 4 it is apparent that $\bar{p}(\Delta t)$ must satisfy

(2) $D(\bar{p}(\Delta t)) = S(\bar{p}(\Delta t) - \Delta t)$

(3) $\bar{p}(0) = p^*.$

Total differentiation of (2) then implies for "small" Δt,

$$(4) \quad \frac{d\bar{p}}{d(\Delta t)} = \frac{-\frac{dS}{dp}(p^*)}{\frac{dD}{dp}(p^*) - \frac{dS}{dp}(p^*)}.$$

If we assume that demand and supply have the usual slopes,

$$\frac{dD}{dp} \leq 0, \quad \frac{dS}{dp} \geq 0$$

We get from (4) that

$$(5)\quad 0 \leq \frac{d\tilde{p}}{d(\Delta t)} = \frac{1}{1 - \left[\frac{\frac{dD}{dp}(p^*)}{\frac{dS}{dp}(p^*)}\right]} \leq 1.$$

Let $\eta_S = \frac{P^*}{S(P^*)} \frac{dS}{dP}(P^*)$, the elasticity of supply.

Let $\eta_D = \frac{P^*}{D(P^*)} \frac{dD}{dP}(P^*)$, the elasticity of demand.

Then

$$\frac{\eta_D}{\eta_S} = \frac{\frac{P^*}{D(P^*)} \frac{dD}{dP}(P^*)}{\frac{P^*}{S(P^*)} \frac{dS}{dP}(P^*)}$$

Since, at equilibrium, $D(P^*) = S(P^*)$, this expression simplifies to

$$(6)\quad \frac{\eta_D}{\eta_S} = \frac{\frac{dD}{dP}(P^*)}{\frac{dS}{dP}(P^*)}$$

Substituting this expression into equation (5), we have

$$(7)\quad \frac{d\tilde{p}}{d(\Delta t)} = \frac{1}{1 + \left|\frac{\eta_D}{\eta_S}\right|}.$$

Now, in the short run η_D is close to zero, while in the long run η_S becomes very large.

For example, if in the short run $\eta_D = -.18$ and $\eta_S = 1.0$, then $\frac{d\bar{p}}{d(\Delta t)} = .85$. If, in the long run, $\eta_D = -.54$ and $\eta_S = 4.0$, $\frac{d\bar{p}}{d(\Delta t)} = .88$.

We conclude then that

$$\frac{d\bar{p}}{d(\Delta t)} \approx 1.$$

In the absence of reliable estimates of the elasticity of supply, we have used this assumption throughout.

B. Disaggregation of Gasoline Demand Elasticities

Herein we describe the procedure used in performing the disaggregation of the elasticity of demand for gasoline discussed in the text, and present the results of this disaggregation. We first deduce the general result that the overall elasticity is equal to the weighted sum of the individual elasticities, disaggregated by categories relevant to this study. We then use the existing estimates for some of the desired parameters along with natural assumptions to isolate the

parameters for which more heroic assumptions must be made. This enables us finally to express the disaggregate elasticities in question as functions of known parameters.

Precise Relations

The following well-known result will prove invaluable:

WKR

Let $f(x) = f(g^1(x), g^2(x), \ldots, g^n(x))$ be a composite function of the scalar variable x. Let

η_f = elasticity of f with respect to x;

η_i = elasticity of g^i with respect to x; $(i = 1, n)$

f_i = $\frac{\partial f}{\partial g^i}$; $f_x = \frac{df}{dx}$; and $g^i_x = \frac{dg^i}{dx}$

Then

$$\eta_f = \sum_{i=1}^{n} \beta_i \eta_i \quad \text{where} \quad \beta_i \equiv \frac{f_i g^i}{f}$$

Proof:

$$\eta_f = \frac{x}{f} f_x = \frac{x}{f} \sum_{i=1}^{n} f_i g^i_x = \sum_{i=1}^{n} \left[\left(\frac{f_i g^i}{f}\right) \left(\frac{x g^i_x}{g^i}\right)\right]$$

$$= \sum_{i=1}^{n} \beta_i \eta_i. \qquad QED.$$

Note that this general result yields familiar formulae for the elasticities of sums, products, etc. The following notation will be used:

i = index for location: $i = 1$ => urban,
$i = 2$ => rural;

j = index for time: $j = 1$ => peak hours,
$j = 2$ => off-peak hours;

g = flow consumption of gasoline (thus, g_{12} = gas consumed in urban off-peak travel);

η = elasticity with respect to gas price of indicated variable;

M = average miles traveled;

T = number of trips;

d = average miles per trip;

f = fuel economy ([avg. mile/gal]$^{-1}$); and

$\alpha_{ij} = \frac{g_{ij}}{g}$ = share of total consumption done at location i, time j. $(i = 1, 2; j = 1, 2)$.[1]

We have immediately that

(1) $g = \sum_i \sum_j g_{ij}$

(2) $g_{ij} = f_{ij} M_{ij}$

A1: Assume $f_{ij} = f$, for all i, j.

That is, average fuel economy is constant over space and time. This is relatively harmless. Using (A1) and substituting (2) into (1) we get

(3) $g = f \sum_i \Sigma_j M_{ij}$.

Using *WKR* and the constancy of fuel economy we observe

(4) $\eta_{g_{ij}} = \eta_{M_{ij}} + \eta_f \equiv \eta_{ij}$ (since $\eta_f = 0$)

Therefore, from (3), (4), and *WKR* we have

(5) $\eta_g = \sum_i \Sigma_j \alpha_{ij} \eta_{ij}$.

This says that the aggregate elasticity is the weighted sum of the time/place specific elasticities, where the weights are time/place specific shares of total gas consumption.

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[1] g, η, M, T, d, and f are all specific, in principle, to location and time of day. In this listing, we omit for convenience the subscripts i and j.

It is also clear that

(6) $M_{ij} = T_{ij} d_{ij}$,

whence (by *WKR* and (4))

(7) $\eta_{ij} = \eta_{T_{ij}} + \eta_{d_{ij}}$

combining (5) and (7) leads to the fundamental relation

(8) $\eta_g = \sum_i \sum_j a_{ij} [\eta_{T_{ij}} + \eta_{d_{ij}}]$.

Determining the Individual Elasticities

This section contains a further analysis of the disaggregation problem, detailing assumptions necessary to go from the general relation (8) above to the computation of the urban peak and off-peak elasticities necessary for policy analysis. We concern ourselves in this report with urban air quality, making the rural consumption elasticities of interest only insofar as they affect the determination of urban elasticities. Thus we may neglect the peak/off-peak distinction for rural travel, and rewrite (8) as

(8') $\eta_g = \alpha_1 [\eta_{T_1} + \eta_{d_1}] + \alpha_2 [\eta_{T_2} + \eta_{d_2}] + \alpha_r \eta_r$

where variables subscripted with *1*, *2*, or *r* refer to urban peak travel, urban off-peak travel or rural travel, respectively.

Now α_1, α_2, α_r are known parameters. η_{d_1} and η_{d_2} (gasoline price elasticities of the average length of an urban trip -- peak and off-peak) are unknown, however.

Independent estimates of the gasoline price elasticity of average trip length have been undertaken by CRA for work trips and shopping trips in the Los Angeles area. These estimates may be used to deduce η_{d_1} and η_{d_2} with the aid of the assumptions below. Similarly, though η_{T_1} and η_{T_2} (gasoline price elasticities of peak and off-peak trip frequencies) are unknown, previous CRA work has derived estimates of work and shopping trip frequency elasticities in the San Francisco area which, with the aid of further assumptions, may be used to deduce η_{T_1} and η_{T_2}. Since to our knowledge no reliable estimates of rural gasoline demand exist, we will assume throughout this report that the rural elasticity and the aggregate elasticity are identical. We need the following assumptions:

A2: All urban trips are either work trips or shopping trips.

As a first approximation, this assumption seems reasonable. Work trips, more than any other kind of trip, are highly constrained as to trip frequency and trip length. Although some kinds of non-work trips -- such as visits to doctors or dentists -- may be considered essential, even these trips are usually more flexible than work trips as to trip length and, to some extent, trip frequency and travel arrangements. Among the several broad classes of non-work trips (shopping, social and recreational, medical and dental, and educational, civic and religious), it is quite probable that there are different elasticities of trip length and trip frequency. Given that estimated elasticities exist only for work and shopping trips, however, it is reasonable to assume that trip-making behavior in all of the non-work categories resembles shopping trip behavior more closely than work trip behavior.

A3: The temporal distribution of work and shopping trips is independent of changes in gasoline price.

This assumption is necessary if we are to use work/shopping trip behavior to deduce peak/off-peak trip behavior. It is certainly reasonable in the short run, but unfortunately we find it necessary to adopt (A3) throughout the duration of our analysis.

As mentioned above, we desire to use CRA estimates of work and shopping trip elasticities to deduce peak/off-peak trip elasticities. The estimates we will use are specific to particular cities, however, and cannot be expected to accurately reflect trip making behavior in all regions of the country. While this may appear to be an insurmountable problem, it can be solved by using the information about regional differences in the responsiveness of gasoline consumption to changes in gasoline price contained in our estimate of the overall demand elasticity η_g, which does vary across states. A procedure of this sort (described in more detail below) will be valid, so long as the relative responsiveness of work and shopping trip frequency to changes in gasoline price is invariant across states, even though the absolute level of these elasticities may vary significantly between different regions. Specifically we assume:

A4: The ratio of the percentage reduction in the number of work trips in response to a 1 percent increase in the price of gasoline to the percentage reduction in the number of shopping trips resulting from the same price change is constant across all urban areas. This enables us to use our locally estimated trip frequency elasticities on a national basis.

We also need to assume constancy in the break-down of reduced gasoline consumption into portions attributable to shorter trips and to fewer trips. The assumption which follows, in conjunction with (A4), enables the local trip length elasticities which we have estimated to be applied at the national level:

A5: For both work and shopping trips, the ratio of the elasticity of average trip length with respect to gasoline price to the corresponding trip frequency elasticity is constant across all urban areas.

Now, let

T_S = number of urban shopping trips;

T_W = number of urban work trips;

α_S = fraction of shopping trips occurring during peak hours;

α_W = fraction of work trips during peak hours;

η_{d_s}, η_{d_w} = Shopping and work trip length elasticities with respect to gasoline price

η_S, η_W = shopping and work trip frequency elasticities with respect to gasoline price; and

d_S, d_W = average length of a shopping trip or work trip, respectively.

All of the above parameters, with the exception of the elasticities, may be determined from sources listed below in the section on computations. Their values are shown in Table C-1 (page C-16). Definitional consistency requires

(9) $T_1 = \alpha_S T_S + \alpha_W T_W$

(10) $T_2 = (1 - \alpha_S) T_S + (1 - \alpha_W) T_W$.

Equations (9), (10), and *WKR* then imply

(11) $\eta_{T_1} = [\frac{\alpha_S T_S}{T_1}] \eta_S + [\frac{\alpha_W T_W}{T_1}] \eta_W$

(12) $\eta_{T_2} = [\frac{(1 - \alpha_S) T_S}{T_2}] \eta_S + [\frac{(1 - \alpha_W) T_W}{T_2}] \eta_W$.

Since each number on the RHS of (11) and (12) can be determined (see below), η_{T_1} and η_{T_2} are identified.

Turning now to urban trip length elasticities, consider the following:

(13) $d_1 = \frac{\alpha_S T_S}{T_1} d_S + \frac{\alpha_W T_W}{T_1} d_W$

$$(14)\quad d_2 = \frac{(1-\alpha_S)\,T_S}{T_2}\,d_S + \frac{(1-\alpha_W)\,T_W}{T_2}\,d_W$$

We further require

A6: Average trip length by purpose is independent of the time of day of the trip.

This assumption is both *a priori* reasonable, and supported by a cursory examination of the data (*Nationwide Personal Transportation Survey*, 1969).

Now, using (A6) and *WKR*, (13) and (14) imply

$$(15)\quad \eta_{d_1} = \frac{\alpha_s T_s}{T_1}\,\eta_{d_s} + \frac{\alpha_w T_w}{T_1}\,\eta_{d_w}$$

$$(16)\quad \eta_{d_2} = \frac{(1-\alpha_s)T_s}{T_2}\,\eta_{d_s} + \frac{(1-\alpha_w)T_w}{T_2}\,\eta_{d_w}$$

Again, each number on the RHS of (15) and (16) can be determined. Thus η_{d_1} and η_{d_2} are identified.

This leaves undetermined only the rural elasticity, for which we adopt the following assumptions:

A7: $\eta_r = \eta_g$

That is, we assume that rural gasoline demand is precisely as price-elastic as the aggregate demand for gasoline.

$$(8'') \quad \eta_g = \alpha_r \eta_r + (1-\alpha_r)\left\{\left[\alpha_1 \frac{\alpha_s T_s}{T_1} + \alpha_2 \frac{(1-\alpha_s)T_s}{T_2}\right] \times \left[\eta_s + \eta_{d_s}\right] + \left[\alpha_1 \frac{\alpha_w T_w}{T_1} + \alpha_2 \frac{(1-\alpha_w)T_w}{T_2}\right]\left[\eta_w + \eta_{d_w}\right]\right\}$$

where α_1 and α_2 now stand for the fraction of urban VMT occurring during peak and off-peak hours respectively. Note that assumption (A7) implies that the rural share of gasoline consumption is irrelevant to our analysis. Now, define

$$\gamma \equiv \left[\alpha_1 \frac{\alpha_s T_s}{T_1} + \alpha_2 \frac{(1-\alpha_s)T_s}{T_2}\right] ,$$

and observe that definitional consistency requires

$$1-\gamma = \left[\alpha_1 \frac{\alpha_w T_w}{T_1} + \alpha_2 \frac{(1-\alpha_w)T_w}{T_2}\right] .$$

γ is the share of all urban VMT due to shopping trips. From (8") and (A7) it then follows that

$$(17) \quad \eta_g = \gamma\left[\eta_s + \eta_{d_s}\right] + (1-\gamma)\left[\eta_w + \eta_{d_w}\right] .$$

Now equation (17) must hold everywhere, even though η_g will vary across states. This of course means that η_s, η_{d_s}, η_w and η_{d_w} must also be made state-specific. However, as will be seen below, our assumptions about the invariance of certain ratios of these elasticities will enable us to express them as proportional to the aggregate elasticity η_g, where the constants of proportionality are state-invariant. Toward this end, observe that

$$(A4) \Rightarrow \frac{\eta_w}{\eta_s} = \text{constant} \equiv K_1, \text{ for all states, and}$$

$$(A5) \Rightarrow \frac{\eta_{d_w}}{\eta_w} = \text{constant} \equiv K_2,$$

$$\frac{\eta_{d_s}}{\eta_s} = \text{constant} \equiv K_3, \text{ for all states.}$$

It then follows immediately that

$$(18) \quad \eta_w = K_1 \eta_s$$

$$(19) \quad \eta_{d_w} = K_1 K_2 \eta_s$$

$$(20) \quad \eta_{d_s} = K_3 \eta_s,$$

enabling us (by 17) to write

$$(21) \quad \eta_s = K_4 \eta_g$$

where $K_4 \equiv [K_1(1+K_2) + (1+K_3-K_1(1+K_2))]^{-1}$. Equations (18)-(21) give us η_s, η_{d_s}, η_w, η_{d_w} as constant fractions of η_g in each state. We may then use equations (7') to determine the desired peak and off-peak consumption elasticities. It is apparent from the linearity of these equations that these too will be proportional to the aggregate elasticity in each state. Combining equations (18)-(21) with (7') enables to express the disaggregate elasticities as follows:

$$(7'') \quad \eta_1 = [K_4(1+K_3)\ (\frac{\alpha_s T_s}{T_1}) + K_1 K_4(1+K_2)\ (\frac{\alpha_w T_w}{T_1})]\ \eta_g$$

$$\eta_2 = [K_4(1+K_3)\ [\frac{(1-\alpha_s)\ T_s}{T_2}] + K_1 K_4(1+K_2)\ [\frac{(1-\alpha_w) T_w}{T_2}]]\ \eta_g$$

In Appendix A, statistical estimation of η_g for each state is described. In previous work, CRA has already estimated work trip and shopping trip gasoline consumption elasticities with respect to line-haul cost.[1] We adopt this estimate in determining η_s and η_w, making appropriate adjustment for the share of line-haul cost which gasoline expenditures represent.[2] We also borrow from CRA estimates of work and shopping trip length elasticities for the Los Angeles area.[3] These elasticity estimates, and the implied values of the constants in equations (7") are given in Table C-1. With these estimates, urban elasticities specific to cities in a given state may be determined from (7"). Data from the Nationwide Personal Transportation Survey (1969) are used to determine the values of α_1, α_2, α_s, T_s, α_w, T_w, T_1, and T_2 in (7"). Table C-1 shows the values of these parameters.[4] They are assumed constant across states. Incorporating these numbers into our equations yields the final formulae used in subsequent calculation:

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[1]See Thomas A. Domencich, Gerald Kraft and Jean-Paul Valette, "Estimation of Urban Passenger Travel Behavior: An Economic Demand Model," Highway Research Record (No. 238, 1968). While reported as trip frequency elasticities, these numbers are properly interepreted as consumption elasticities for our purposes.

[2]This share is estimated to be 0.55 from data on motor vehicle operating costs given in *Cost of Operating an Automobile*, Federal Highway Administration, April 1972.

[3]See Charles River Associates Inc., "Study of Alternatives to Gas Rationing in the Los Angeles Area." This work is currently in preparation for the Environmental Protection Agency under Contract No. 68-01-2235.

[4]The parameter estimates shown in this table are the most consistent and complete set of these estimates known to us. Other estimates from disaggregated travel demand studies are frequently intractable for our purposes.

Table C-1

ESTIMATES OF PARAMETERS USED IN ELASTICITY DISAGGREGATION[1] [2]

$\alpha_1 = .42$	Source: NPTS,[3] Volume 8, Table A-27, page 78.
$\alpha_2 = .58$	Source: NPTS, Volume 8, Table A-27, page 78.
$\alpha_s = .30$	Source: NPTS, Volume 8, Table A-27, page 78.
$\alpha_w = .625$	Source: NPTS, Volume 8, Table A-27, page 78.
$T_s = 1.138 \times 10^9$	Source: NPTS, Volume 8, Table A-25, page 76.
$T_w = .532 \times 10^9$	Source: NPTS, Volume 8, Table A-25, page 76.
$T_1 = .674 \times 10^9$	Source: NPTS, Volume 8, Table A-26 pages 76-78. & A-27.
$T_2 = .996 \times 10^9$	Source: NPTS, Volume 8, Table A-26 pages 76-78. & A-27.
$\gamma = .68$	Source: Definition and parametric values given above.
$\eta_s = -.48$	Source: CRA[4]
$\eta_w = -.19$	Source: CRA[4]
$\eta_{d_s} = 0$	Source: CRA[5]
$\eta_{d_w} = -.08$	Source: CRA[5]
$K_1 = .40$	
$K_2 = .42$	Source: Definitions and elasticity values given above.
$K_3 = 0$	
$K_4 = 1.16$	

Table C-1 (Continued)
ESTIMATES OF PARAMETERS USED IN
ELASTICITY DISAGGREGATION[1,2]

[1] For definition of symbols, see the text.

[2] Peak hours are defined as 6AM - 9AM and 4PM - 7PM.

[3] Nationwide Personal Transportation Study, U.S. Department of Transportation, August, 1973.

[4] See Domencich, Kraft,and Valette, *op. cit.* Study uses San Francisco area data.

[5] See Charles River Associates, Inc., "Study of Alternatives to Gas Rationing in the Los Angeles Area."

(22) $\eta_1 = .911\eta_g$ $\eta_2 = 1.058\eta_g$

Formulae may also be derived for disaggregated trip frequency elasticities using equations (11) and (12):

(23) $\eta_{T_1} = .817\eta_g$ $\eta_{T_2} = 1.020\eta_g$

Table C-2 summarizes our estimates of the short-run (as well as long-run) urban peak and off-peak elasticities under the alternative assumptions that gasoline prices remain at their pre-embargo (post-embargo) levels. Since these estimates vary by state, we report in Table C-2 the highest and lowest state estimates of each elasticity, as well as the national average.

As noted earlier, the estimates of η_g used in computing the disaggregate elasticities from equations (22) are subject to error. Since our estimates of the effects of policies depend on the calculated disaggregated elasticities, we should like to know how sensitive are these calculations to error of the kind mentioned.

The way in which we have chosen to approach this problem is to suppose that the true values of the estimated aggregate elasticities for each state may diverge from our estimates in either direction by as much as one standard error.[1] Taking this divergence as a possibility, we then ask by how much can the disaggregated elasticities diverge from the values determined when our estimates of aggregate elasticities are assumed correct.

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[1] Estimates of the standard error are obtained by dividing the estimated coefficient by its quasi-t-statistic. See Appendix A for coefficient estimates and corresponding t-statistics.

Table C-2

SUMMARY OF ESTIMATES OF DISAGGREGATE
URBAN GASOLINE DEMAND ELASTICITIES:
Short-Run and Long-Run

1975	High-Price Scenario[1] Peak	High-Price Scenario[1] Off-Peak	Low-Price Scenario Peak	Low-Price Scenario Off-Peak
Highest[2]	- .182	- .211	-.126	- .146
Lowest [2]	- .112	- .130	-.079	- .092
National Avg.[3]	- .149	- .173	-.106	- .123

1981	High Price Scenario Peak	High Price Scenario Off-Peak	Low Price Scenario Peak	Low Price Scenario Off-Peak
Highest	- .663	- .749	- .442	- .513
Lowest	- .395	- .459	- .272	- .316
National Avg.	- .539	- .626	- .364	- .432

1987	High Price Scenario Peak	High Price Scenario Off-Peak	Low Price Scenario Peak	Low Price Scenario Off-Peak
Highest	- .757	- .879	- .496	- .576
Lowest	- .440	- .511	- .300	- .348
National Avg.	- .600	- .697	- .405	- .470

[1]High- (low-) price scenario assumes prices at their post- (pre-) embargo levels.

[2]Our estimates indicate that New York is the state in which gasoline demand is most elastic, while North Dakota has the least elastic demand.

[3]Computation of national averages uses the national average η_g derived from our estimate of the demand for gasoline described in Chapter 4.

Since equations (22) are linear in the estimated aggregate elasticities, the greatest divergence of our disaggregated elasticities from their "true" values will occur when the true aggregate elasticities diverge most from our estimates of their values. Thus, one generates "high" and "low" values for the disaggregate elasticities in a straightforward manner from the corresponding values of the aggregate elasticities. These values determine what may be considered confidence intervals around the point estimates, and are used in the sensitivity analysis reported in Appendix E.[1]

Determination of the Long-Run Demand Elasticities

It was observed in the text of this chapter that analysis of the impact of conservation policies over an extended horizon requires measurement of the speed with which consumers of gasoline respond to a change in its price. The fact that the total adjustment of the consuming habits of individuals and of the fuel economy characteristics of the stock of automobiles to a change in the price of gasoline do not occur immediately, implies that the effect of a price change on gasoline consumption in a given year will be greater the longer the price change has been in effect. In order to say how much greater, we must estimate the speed of adjustment.

Toward this end, let us assume that desired gasoline consumption in any year is a function of the price of gasoline, consumer income, and a set of "other factors," satisfying the following specifications:[2]

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[1] These are not "true" confidence intervals, since the use of the quasi-t-statistic does not reflect the (unknown) small sample distribution of the estimated parameters.

[2] The discussion here is illustrative. The actual equation estimated is discussed in detail in Appendix A.

(1) $Log(g^*)_t = a_1 + a_2\ Log(p)_t + a_3\ Log(y)_t + a_4 x_t$

where

g^*_t = desired per capita gas consumption in year t.
p_t = real price of gasoline in year t.
y_t = real per capita disposable income in year t.
x_t = vector of other factors influencing consumption in year t.
a_1, a_2, a_3 = scalar coefficients; a_4 = vector of coefficients.

Let g_t represent actual gasoline consumption in year t. Assume that in any year, actual consumption needn't equal desired consumption, but that consumption is partially adjusted toward the desired level from its level in the previous year, in the following manner:

(2) $\left(\frac{g_t}{g_{t-1}}\right) = \left(\frac{g^*_t}{g_{t-1}}\right)^{\lambda}$ $(0<\lambda<1)$, or

(3) $LOG(g_t) = \lambda LOG(g_t^*) + (1-\lambda)\ LOG(g_{t-1})$

combining (1) and (3) yields

(4) $LOG(g_t)=(\lambda a_1)+(\lambda a_2)LOG(P_t)+(\lambda a_3)LOG(y_t)+(\lambda a_4)X_t+(1-\lambda)LOG(g_{t-1})$

Our statistical estimation of this equation from time series data has two significant outputs. First, one obtains an estimate of the short-run (one-year) price elasticity which is the estimated coefficient (λa_2) of $LOG(P_t)$ in (4). In addition, the coefficient of $LOG(g_{t-1})$ in (4) provides an estimate of the speed of adjustment λ. These estimates are discussed in Appendix A.

Let ${}_t\eta_\tau$ represent the percentage increase in gasoline consumption in year τ from a once and for all, one percent increase in the price of gasoline in some earlier year t. Then it is apparent that

$$(5) \quad {}_t\eta_\tau = \lambda a_2 \quad ,$$

the short-run elasticity, while

$$(6) \quad \lim_{\tau \to \infty} {}_t\eta_\tau = a_2 .$$

That is, the ultimate effect of a price change on actual consumption equals the effect of that price change on desired consumption. For the analysis of the effects of policies over periods of intermediate duration we merely take the sum of the partial adjustments made each period between the time the policy was instituted and the year in which we desire to examine its effect. Now

$$(7) \quad {}_t\eta_\tau = \frac{\partial LOG(g_t)}{\partial LOG(p_\tau)} = \frac{\partial LOG(g_t)}{\partial LOG(p_t)} \cdot \frac{\partial LOG(p_t)}{\partial LOG(p_\tau)} + \frac{\partial LOG(g_t)}{\partial LOG(g_{t-1})} \cdot \frac{\partial LOG(g_{t-1})}{\partial LOG(p_\tau)}$$

and

$$(8) \quad \frac{\partial LOG(g_{t-1})}{\partial LOG(p_\tau)} = \frac{\partial LOG(g_{t-1})}{\partial LOG(p_{t-1})} \cdot \frac{\partial LOG(p_{t-1})}{\partial LOG(p_\tau)} + \frac{\partial LOG(g_{t-1})}{\partial LOG(g_{t-2})} \cdot \frac{\partial LOG(g_{t-2})}{\partial LOG(p_\tau)}$$

Now if the price increase in year τ is once and for all, it must be that

$$(9) \quad \frac{\partial LOG(p_t)}{\partial LOG(p_\tau)} = 1 \qquad \text{for } \tau \leq t.$$

Using this fact, the recursive relations (7) and (8), and the observations from (4) that $\frac{\partial LOG(g_t)}{\partial LOG(p_t)} = \lambda a_2$ and $\frac{\partial LOG(g_t)}{\partial LOG(g_{t-1})} = (1-\lambda)$, we deduce the following expression for ${}_t\eta_\tau$:

$$(10)\quad {}_t\eta_\tau = [\lambda a_2 + (\lambda a_2)(1-\lambda) + (\lambda a_2)(1-\lambda)^2 + \ldots + (\lambda a_2)(1-\lambda)^{t-\tau}]$$

$$= (\lambda a_2) \sum_{j=0}^{t-\tau} (1-\lambda)^j = \lambda a_2 \left[\frac{1-(1-\lambda)^{t-\tau+1}}{\lambda}\right].$$

Thus, to find the long-run elasticity appropriate to a period of length $(t-\tau)$, we multiply the short-run elasticity by the scaling factor

$$\left[\frac{1-(1-\lambda)^{t-\tau+1}}{\lambda}\right].$$

This factor is determined from our estimate of λ in equation (4). The estimated value of λ is 0.788. This implies that for an excise tax increase occurring at the beginning of 1975, the effect on consumption by year's end will be 26.2% of the effect which the policy will have by 1981, and 22.2% of the impact which will have occurred by 1987. Hence the major impact on consumption of an excise tax increase occurs several years after the initiation of the policy. A lag of this magnitude would seem to militate against the use of excise tax policies for purely short-term objectives.

Let us now combine this analysis with the disaggregation procedure described in the preceding section of this appendix. If (as is the case) the aggregate demand elasticities specific to each state vary with the period of analysis, then so will the urban peak and off-peak elasticities. However, if we assume that over time people adjust their trip making behavior to changed line-haul cost at the same rate that they adjust their gasoline consumption behavior, then the linearity of the equations of Section B of this appendix enables us to determine disaggregated elasticities for 1981 and 1987 immediately from our 1975 estimates. These elasticities are found by multiplying the 1975 estimates by the same scaling factor discussed above.[1] The results are summarized in Table C-2.

In computing these disaggregate long-run elasticities, we must again face the reality that our aggregate estimates may be in error. Here, however, the parameter λ may also be incorrectly estimated. The procedure described at the end of Section B of this appendix must therefore be modified to account for this additional possible pitfall before analysis of the sensitivity of our long-run projections to estimation error may proceed.

To do this, we assume that the true value of the parameter λ lies within one standard error of our point estimate.[2]

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[1]Actually one must first adjust the base elasticities to account for shifts in demand due to changes in exogenous variables (such as income) over time. Since we use a linear rather than logarithmic specification in estimating the aggregate demand elasticities, this shifting will, in general, cause the relevant elasticities to change. The methods used to forecast changes in exogenous variables are described in some detail in Appendix A.

[2]As before, the standard error is determined from the quasi-t-statistic associated with the estimate of the coefficient $(1-\lambda)$.

We again consider the worst possible case that λ exceeds (falls short of) its estimated value by the full amount of the standard error. This then gives us an upper (lower) bound on the possible values of λ. To get the upper (lower) bound on the disaggregate elasticities for 1981 and 1987, we use the upper (lower) bound on our 1975 estimates and the upper (lower) bound on appropriate scaling factor implied by the bound on λ. Thus, in the sensitivity analysis, we acknowledge the possible effect that concatenation of errors in the independent estimates of parameters entering successively into our computational procedure may have on the final long-run predictions.

APPENDIX D: POLICIES AFFECTING NEW CAR SALES

Qualitative Analysis of Policies Affecting Gasoline Consumption and Air Quality

A. Gasoline Consumption

1) Effect of a Tax on Fuel Economy of New Vehicles

Here we present the technical analysis underlying our discussion of the impact of a tax on the fuel economy of new vehicles on gasoline consumption. This analysis requires the development of a dynamic model of the auto stock. We will also use this model in Section B, where the policy impact on air quality is studied. The following notation will be used:

j index of fuel economy class of auto; $j = 1,2\ldots,m$.

i age of auto; $i = 0,1,\ldots,n$.

P_j^t average price[1] of new auto in class j in year t;

$p^t \equiv (p_1^t, p_2^t,\ldots,p_m^t)$.

P_A^t average price of new auto in year t.

Π_j^t relative demand for new auto in class j in year t;

$\sum_{j=1}^{m} \Pi_j^t = 1$, for all t. $\Pi^t \equiv (\Pi_1^t,\ldots,\Pi_m^t)'$

h^t total demand for new autos in year t.

λ_{ij}^t fraction of class j autos of age i retired in year t.

---

[1]Price in this context should be interpreted as price per unit quality. See discussion of assumption A4 below for a further elaboration of this point.

f_{ij}^t average fuel consumption (gallons/mile) of class j autos of age i in year t.

M_{ij}^t average VMT for age i autos in class j in year t.

g^t aggregate consumption of gasoline in year t (gallons).

X_{ij}^t number of autos of age i, class j in year t.

By the way the variables are defined,

$$g^t = \sum_{i=0}^{n} \sum_{j=i}^{m} M_{ij}^t \, f_{ij}^t \, X_{ij}^t \qquad (1)$$

That is, the consumption of gasoline of a given age vehicle in a given fuel economy class is the product of its mileage and its gallons per mile. Total gas consumption is then the sum of these numbers over all age-fuel economy categories, weighted by the number of vehicles in each category.

The following assumptions are useful for our purposes and innocuous:

A1: $f_{ij}^t = f_{ij} = f_j$ for all i, j, t.

That is, fuel consumption does not increase with age.[1] f_j is then the average fuel consumption of a new vehicle in class j.

A2: $M_{ij}^t = M^t$ for all i, j.

---

[1]We have found no evidence to suggest any significant increase in the fuel consumption of a well maintained vehicle with age. One may readily incorporate a "mileage decay" factor here, in which case the analysis would proceed as in Section B of this Appendix, where emissions of pollutants per mile are assumed to vary exponentially with vehicle age.

The use of a vehicle in year t is independent of its age and its fuel economy.[1] This assumption is made for convenience only, and does not affect our result. Use of the auto depends on factors such as the price of gasoline, income, and the price of alternative modes of transportation. All of these factors are unaffected by the proposed policy and therefore are suppressed here.

A3: $\lambda_{nj}^{t} = 1$ for all j, t.

All vehicles are automatically retired at age n. This involves no loss of generality, since n may be chosen to be as large as we desire. Of course, this does not preclude $\lambda_{rj}^{t} = 1$, $r<n$, for some j and t.

In addition to the above assumptions aimed at simplifying the mechanics of our model, three assumptions embody the model's economic content. The first of these assumptions concern the demands for different classes of automobiles.

A4:
(a) $\pi_j^t = \pi_j(p_1^t, p_2^t, \ldots, p_m^t) \equiv \pi_j(p^t)$,

(b) $\pi_j(p^t)$ is homogeneous of degree zero, for all j; and

(c) $\frac{\partial \pi_i}{\partial p_j} > 0 \quad i \neq j, \quad \frac{\partial \pi_j}{\partial p_j} < 0$, for all j.

In nontechnical language, assumptions A4(a) and A4(b) state that the share of new cars demanded in class j in any year depends only on the *relative* prices of new cars in the various classes for that year.

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[1] This assumption, clearly at variance with reality, is made only for convenience. Use of the full distribution of mileage by vintage would not change our results. See footnote 1, p. 5-12 for further discussion of this assumption.

Assumption A4(c) implies that the market share of a given model declines as its own relative price increases, whether because its own price has increased (all other prices constant) or the price of another model has decreased (its own price constant).[1] These assumptions are not, in all probability, completely correct, but they seem like reasonable approximations to behavior in this market. We also assume no shifting of the relative demand functions over time. Shifting relative demand functions would unnecessarily complicate the theoretical analysis and add little to it, as little is known about the direction of changes in consumers' tastes.

Define $\pi(p) \equiv col\ (\pi_1(p), \ldots, \pi_m(p))$

Then if by average auto price we mean sales-weighted average price, we can write this price as

$$p_A^t = p^t \cdot \pi(p^t).$$

It will simplify matters considerably if we rule out the kind of pathology which permits an *increase* in the price of one auto to lead to a *decrease* in average automobile price. Thus we also assume under (A4) that

$$\text{(d)}\quad \frac{\partial P_A^t}{\partial P_i} = \pi_i(p^t) + P^t \cdot \left[\frac{\partial \pi}{\partial P_i}(p^t)\right] > 0$$

for all $i = 1, m$ and for all price vectors P.

As noted in the footnote on page D-1, we interpret the price variable here as price per unit quality. So far, the only distinction we have drawn between automobiles is their differences in fuel economy. Of course there are many other

[1]Goods satisfying this assumption are said to be gross substitutes. C.f. Kenneth Arrow and Frank Hahn, *General Competitive Analysis* (San Francisco: Holden-Day, 1971).

characteristics of automobiles which affect consumers' choices among them, such as horsepower, length, weight, and accessories. Since we will study policies which change an auto's price by an amount which depends on its fuel economy only, we wish to control for price variability stemming from other sources. Thus one may consider the price per unit quality of a vehicle as a normalized price concept accounting for variability in vehicle characteristics other than fuel economy.

This convention has an important implication for our analysis. Since the quality-corrected price of an auto controls for differences in vehicle characteristics, these prices must be nearly equal across all automobile models. This ensures that the tax scheme discussed here imposes a relatively more heavy burden on less fuel-efficient vehicles, since the percentage increase in the quality-corrected price of a vehicle will be greater for the less fuel-efficient vehicle. Note that this need not be the case if one employs the nominal cost of a new automobile as the appropriate price concept.

The second assumption concerns scrappage rates:

$$\underline{\text{A5}}: \begin{cases} \text{(a)} \ \lambda_{ij}^{t} = \lambda_i(P_A^t) \ \text{for all } i, j, t \text{ and} \\ \text{(b)} \ \frac{\partial \lambda}{\partial P_A} \leq 0, \quad \lambda_i^t \leq \lambda_k^t \ \text{for } 1 \leq i < k \leq n \end{cases}$$

Here the retirement rate for a vehicle in any class in year t is assumed to depend on the age of the vehicle and the average price of new vehicles in year t. It seems reasonable to posit that older vehicles have higher retirement rates, other things being equal, and that an increase in the average price of new vehicles causes a fall in the scrappage rate of older vehicles of all vintages.[1] While the first part of this assumption needs no support, we can justify this last statement by an argument similar to that given in the text. Essentially one need only observe that the scrappage rates of older vehicles vary inversely with used-car prices, while used-car prices vary directly with new-car prices. This yields the assumed inverse relationship between scrappage rates and average new-car price.

The assumption that scrappage rates are independent of fuel economy class is adopted here for convenience in manipulating the rather involved expressions deduced in the sequel. It appears not to affect the derived qualitative results.[2] Note that while scrappage rates will depend on other factors such as maintenance costs, gasoline prices, disposable income, scrap metal prices, etc., these are unaffected by the policy under consideration and thus are not explicitly considered here.

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[1]Of course, $\frac{\partial \lambda_n}{\partial P_A} \equiv 0$ by (A3).

[2]We have not formally proved the qualitative results when this assumption is relaxed. As these results depend only on the sign of the partial derivative in assumption A5(b), allowing differences by fuel economy class ought not to affect the proofs. The *quantitative* results would, however, be affected, but there are no published data on scrappage rates by fuel economy class, so that this assumption is maintained in the quantitative analysis.

The third assumption concerns aggregate demand for automobiles:

$$\underline{A6}: \quad h^t = h(P_A^t), \text{ and } \frac{\partial h}{\partial P_A} < 0$$

Total new car demand varies inversely with the average price of new autos. The other important determinants of new car demand are implicitly assumed constant, being irrelevant for the purposes of this analysis.

Now suppose at the initial date ($t=0$) the following policy is put into effect: If the fuel economy of a new automobile is below $\bar{m}$ (in miles per gallon) then a tax will be levied on that auto in an amount proportional to the difference between $\bar{m}$ and the automobile's actual miles per gallon. Rearrange the f_j so that $f_1 < f_2 < \ldots < f_m$. We may interpret this policy as saying that if j^* satisfies

$$\frac{1}{f_{j^*}} < \bar{m} \leq \frac{1}{f_{j^*-1}}, \text{ then}$$

$$P_i^t = \overline{P}_i^t + \xi\left[\bar{m} - \frac{1}{f_i}\right] \text{ for } i \geq j^*, \text{ while}$$

$$P_t^i = \overline{P}_i^t \text{ for } i < j^*.^2$$

---

[1]Recall our convention that f_j measures the average fuel economy of the class j vehicle in units of gallons per mile. This is convenient for determining total gasoline consumption from the fuel economy characteristics and average mileage of the stock of vehicles. The policy proposals investigated in this report specify tax rates in units of "dollars per mile per gallon," however. Since in general there does not exist a constant tax rate in units of "dollars per gallon per mile" (i.e., a tax rate based on fuel *consumption*) that is equivalent

(footnotes continued on following page)

Here we take $\bar{P}_i^t$ to be the price of an auto in class i, year t, absent the policy. The ξ is the constant tax rate in units of \$/mile/gallon. It is then clear that

$$P_i^t > \bar{P}_i^t \quad \text{for all } t,\ i \geq j^* \quad \text{and by } A4\text{-}(d), \tag{2}$$

$$P_A^t > \bar{P}_A^t \quad \text{for all } t.$$

Now by (A1) and (A2) we can rewrite (1) as

$$g^t = m^t \sum_{i=0}^{n} \sum_{j=1}^{m} f_j X_{ij}^t \tag{1'}$$

(Footnotes 1 and 2 continued)

to a given tax rate in "dollars per mile per gallon" (i.e., a tax rate based on fuel *economy*). Consequently, we will describe a class j auto's fuel economy by $\frac{1}{f_j}$ for purposes of computing tax charges, and f_j for purposes of determining gasoline consumption.

[2]We implicitly assume that such a j^* exists. If not then either every model is taxed ($\bar{m} > \frac{1}{f_1}$), or no models are taxed ($\bar{m} < \frac{1}{f_m}$). We dismiss this latter possibility since it implies that no effective policy is in force. In the former instance, all of our propositions remain valid, so long as the proviso of footnote 1, p. D-11 holds.

Since in year t, the number of cars of class j, age i is the number of cars of class j age $i-1$ surviving from the previous year we also have that

$$X_{ij}^{t} = (1 - \lambda_{i-1}^{t-1}) X_{i-1,j}^{t-1} \qquad \begin{array}{l} 1 \leq i \leq n \\ 1 \leq j \leq m \\ t \geq 1 \end{array} \tag{3}$$

Now if we treat x_{ij}^{0} as given historical data for $i=1,\ldots,n$ and iterate in (3) we get

$$X_{ij}^{t} = \left[\prod_{k=0}^{min(i,t)} \left(1 - \lambda_{i-k,\,j}^{t-k} \right) \right] X_{i-min(i,t),\,j}^{t-min(i,t)} \tag{4}$$

where $min\ (x,y) = x$ for $x \leq y$

$= y$ otherwise[1]

Therefore,

$$g^{t} = m^{t} \sum_{i=0}^{n} \sum_{j=1}^{m} \left\{ f_j X_{0,j}^{t} + \prod_{k=0}^{min(i,t)} \left(1 - \lambda_{i-k,j}^{t-k} \right) X_{i-min(i,t),j}^{t-min(i,t)} \right\} \tag{5}$$

We may interpret this apparently complicated expression as follows:

for $t < i \leq n$,

$$X_{ij}^{t} = \left[\prod_{k=0}^{t} \left(1 - \lambda_{i-k,j}^{t-k} \right) \right] X_{i-t,j}^{0} \ ; \tag{6}$$

while for $i \leq t$,

---

[1] Throughout we shall use the symbol $\prod_{r=1} (dr)$ to represent the product of a sequence of terms indexed by r. This symbol differs from that used for the relative demand functions $\pi_j(P_1,\ldots,P_m)$ already defined.

$$X_{ij}^{t} = \left[\prod_{k=0}^{i}\left(1-\lambda_{i-k,j}^{t-k}\right)\right] X_{0,j}^{t-i} \tag{7}$$

Notice that the $X_{i-t,j}^{0}$ are constants $(i>t)$ given to us at $t=0$, while the $X_{0,j}^{t-i}$ are known functions of auto prices in the years $t-i$ $(i\leq t)$.

That is

$$X_{0,j}^{t-i} = h(P_A^{t-i})\ \pi_j(P^{t-i}) \tag{8}$$

Using (6) - (8), (5) may be rewritten as $(0<t<n)$

$$g^t = m^t\ h(P_A^t) \sum_{j=1}^{m} f_j \pi_j(P^t) \tag{9}$$

$$+ \sum_{i=1}^{t} h(P_A^{t-i}) \prod_{k=0}^{i}\left(1-\lambda_{i-k}(P_A^{t-k})\right) \sum_{j=1}^{m} f_j \pi_j(P^{t-i})$$

$$+ \sum_{i=t+1}^{n} \prod_{k=0}^{t}\left(1-\lambda_{i-k}(P_A^{t-k})\right) \sum_{j=1}^{m} f_j X_{i-t,j}^{0}$$

Now the first term in the brackets is the total gallons of gasoline consumed in year t when all new autos purchased in year t are driven one mile. The second term represents the same consumption equivalent for the surviving stock of automobiles which have been purchased prior to time t, but subsequent to the initiation of the tax policy. The last term gives total gallons consumed if all cars purchased prior to date zero but surviving until date t are driven one mile. Though equation (9) seems more complicated than ever, it is convenient for deriving the desired results.

Beginning at the end, it is apparent that enacting the policy under consideration can only increase the last expression

$$\sum_{i=t+1}^{n} \prod_{k=0}^{t} \left[1-\lambda_{i-k}(P_A^{t-k})\right] \sum_{j=1}^{m} f_j X_{i-t,j}^{0}$$

This is so because the post-tax average auto price exceeds the pre-tax average price (from (2)), meaning that the λ_{i-k} are decreased ex-post (by A5(b)), hence $[1-\lambda_{i-k}]$ is increased, leading to the product of these terms being increased. Since $\sum_{j=1}^{m} f_j X_{i-t,j}^{0}$ is invariant with respect to the imposition of the tax, we have the desired result:

Proposition 1: Under (A1)-(A6), at any date subsequent to the enactment of the policy, the policy will lead to an increase in gallons of gasoline consumed by surviving automobiles that were already on the road when the policy was enacted.

Consider now the first expression in the brackets in (9). As mentioned above, this represents the contribution to total gasoline consumption of new vehicles purchased in period t. That this is decreased by implementing the tax policy in question is readily demonstrable. Taking p^t, $\bar{p}^t$ as before, we assume that there exists a $j^{**} \geq j^{*}$ for which

$$\pi_j(\bar{P}^t) > \pi_j(P^t) \qquad j<j^{**}$$

and

$$\pi_j(\bar{P}^t) < \pi_j(P^t) \qquad j \geq j^{**}.$$ [1]

---

[1] Recall, many prices are changing at once. The net effect could increase the share of some borderline models just below the minimum miles/gallon. We assume, however, that if relative demand for a given model falls, then demand for any less fuel-efficient model must also fall.

Now we want to show that

$$h(\bar{P}^t) \sum_{j=1}^{n} f_j \pi_j(\bar{P}^t) > h(P^t) \sum_{j=1}^{n} f_j \pi_j(P^t)$$

It is clear from (2) and (A6) that $h(\bar{P}^t) > h(P^t)$. Also,

$$\sum_{j=1}^{n} f_j \left[\pi_j(\bar{P}^t) - \pi_j(P^t) \right]$$

$$= \sum_{j=1}^{j^{**}-1} f_j \left[\pi_j(\bar{P}^t) - \pi_j(P^t) \right] + \sum_{j=j^{**}}^{n} f_j \left[\pi_j(\bar{P}^t) - \pi_j(P^t) \right]$$

$$< f_{j^{**}-1} \sum_{j=1}^{j^{**}-1} \left[\pi_j(\bar{P}^t) - \pi_j(P^t) \right] + f_{j^{**}-1} \sum_{j=j^{**}}^{n} \left[\pi_j(\bar{P}^t) - \pi_j(P^t) \right]$$

$$= f_{j^{**}-1} \sum_{j=1}^{n} \left[\pi_j(\bar{P}^t) - \pi_j(P^t) \right] = 0,$$

using the facts that $\{f_j\}$ is an increasing sequence, and that $\sum_{j=1}^{m} \pi_j(P) = 1$ for all P. We have thus proven

Proposition 2: Under (A1)-(A6), introducing the tax policy will decrease gasoline consumption by the new cars added to the auto stock.

Let us now consider the intermediate expression on the right hand side at equation (9), which represents gasoline consumption per mile by automobiles purchased after the policy was imposed and surviving until date t. This expression is

$$\sum_{i=1}^{t} h(P_A^{t-i}) \prod_{k=0}^{i} \left(1 - \lambda_{i-k}(P_A^{t-k}) \right) \sum_{j=1}^{m} f_j \pi_j(P^{t-i}).$$

Now we have already observed above that imposing the tax on poor fuel economy increases P_A^{t-i} and P^{t-i} in each subsequent year. The proof of Proposition 2 shows that the factor

$\sum_{j=1}^{m} f_j \pi_j (P^{t-i})$ is thereby diminished for each $i = 1, \ldots, t$. This factor is the average gallons per mile of a new auto sold in year $t-i$. Thus, as we would expect, automobiles manufactured after the policy is imposed will on average achieve better mileage as long as they survive. However the increase of p^{t-i} tends to decrease new car sales in year $t-i$, and to slow the retirement of all autos manufactured after the imposition of the policy. If the policy-induced reduction in the retirement of these autos is greater than the cumulative reduction in new car sales then in a given year the policy, while increasing auto prices (new and used) could cause the number of autos on the road manufactured after the initiation of the policy to increase. This means that the aggregate demand for automobiles manufactured after the policy would be an increasing function of the average price of these autos. The following assumption eliminates this perverse possibility:

$$\underline{A7}: \quad \frac{\left|\frac{\partial h(P_A)}{\partial P_A}\right|}{h(P_A)} > \left\{(n-1) \max_{0 \leq i \leq n-1}\right\} \left\{\frac{\left|\frac{\partial \lambda_i(P_A)}{\partial P_A}\right|}{\left(1 - \lambda_i(P_A)\right)}\right\}$$

In words, (A7) states that the percentage decrease in new car sales in a given year resulting from a one percent increase in new-car prices always exceeds the corresponding percentage increase in the fraction of those new cars surviving in any subsequent year. That fraction is $\prod_{k=0}^{i} \left[1-\lambda_{i-k}(P_A)\right]$. Its elasticity with respect to P_A is

$\sum_{k=0}^{i} \frac{\left|\frac{\partial \lambda_{i-k}(P_A)}{\partial P_A}\right|}{\left(1-\lambda_{i-k}(P_A)\right)}$. Thus, (A7) insures that for any $i \leq n$,[1] the number of cars manufactured after the policy is imposed but remaining on the road in year i will decrease. This enables us to state

---

[1] Recall that assumption A3 implies $\frac{\partial \lambda_n}{\partial P_A} \equiv 0$.

Proposition 3: Under (A1)-(A7), gasoline consumption by post-tax manufactured automobiles will be less than in the absence of a tax, in every year subsequent to the imposition of the tax.

Our long-run qualitative result on gasoline consumption follows immediately from this observation. When $t > n$, that is when the policy has been in force long enough for all autos on the road at the time of its initiation to be retired, then the only vehicles on the road are post-tax manufactured automobiles. It then follows:

Proposition 4: Under (A1)-(A7), an excise tax on poor fuel economy of new autos eventually *reduces the size of the auto stock, improves the average fuel economy of the auto stock, and thus reduces the automotive consumption of gasoline.*

2) Effect of Restrictions on the Fuel Economy of New Vehicles

We may use the framework of definitions and assumptions established above for a formal analysis of this class of policies. As discussed in the text of Chapter 5, this type of policy operates by imposing restrictions on $\{f_j\}$ $(j = 1, m)$, the fuel consumption of new autos. Specifically if the minimum sales-weighted average miles per gallon is set at $\bar{m}$, then manufacturers must choose $\{\bar{f}_j\}$ $(j = 1, m)$ so that

$$\sum_{j=1}^{m} \frac{1}{\bar{f}_j^t} \pi_j (p^t) = \bar{m} \qquad (1)$$

in each subsequent year t.[1]

[1] Henceforth, we take f_j as ex ante fuel consumption, $\bar{f}_j$ as ex post fuel consumption in class j.

We assume that this is done in the least-cost fashion. The increase in costs to auto producers from having to meet this requirement is assumed to result in the price of autos in each fuel economy class rising by the same proportion. Thus, if P represents the price vector for autos prior to the imposition of the policy, and if we assume all other influences on prices are stationary we have that

$$p^t = \delta p \text{ for all } t, \ \delta > 1 \qquad (2)$$

Hence, by (A4-b) of the previous section

$$\pi(p^t) = \pi(p) \text{ for all } t \qquad (3)$$

That is, relative auto demand by fuel economy class is invariant with respect to the initiation of the proposed policy. If we assume the imposed minimum level of average fuel economy exceeds the current average (as it must if the policy is to have any effect), then we are assured that the policy will improve the average fuel economy of the new autos being added to the stock in each year subsequent to the imposition of the restrictions. This result is analogous to Proposition 2 of the preceding section.

It is also true that the increased costs induced by the fuel economy restrictions will push up auto prices,causing a slowing of the retirement rate of older autos as well as a reduction in the overall size of the auto stock. As we know, these two effects will work in opposite directions and one cannot determine a priori what the resultant effect will be. Under (A7) of the previous sub-section however, the policy will ultimately reduce gasoline consumption for reasons

identical to those given in that section.[1] In the long run federal restrictions on the average fuel economy of new cars will cause the size of the auto stock and the automotive consumption of gas-line to diminish.

B. Ambient Air Quality

1. Effect of a Tax on Fuel Economy of New Vehicles

We continue our analysis of the qualitative impact of policies affecting the stock of vehicles by examining the impact of a tax on poor fuel economy of new vehicles on the quantity of pollutant emissions (and thus, ambient air quality) in years subsequent to the policy enactment. We will use the following notation:

e_{it} = emissions of pollutant per mile by age i vehicle manufactured in vear t.[2]

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[1] If auto prices are stationary and the policy has been in effec for a "long time" then gas savings is proportional to

$$\left[-h(\delta P_a)\left[\sum_{j=1}^{m} f_j \pi(P)\right]\sum_{i=o}^{n}\prod_{k=0}^{i}(1-\lambda_{i-k}(\delta P_a))\right.$$

$$\left.+\ h(P_a)\left[\sum_{j=1}^{m}\Pi_j(P)f_j\right]\sum_{i=0}^{n}\prod_{k=0}^{i}(1-\lambda_{i-k}(P_a))\right]$$

since $\delta > 1$ and $\left[\sum_{j=1}^{m}\Pi_j(P)f_j\right] < \left[\sum_{j=1}^{m}\Pi_j(P)f_j\right]$ this is a positive number.

[2] There are actually three different pollutants whose impact on air quality is studied in this report: hydrocarbons, carbon monoxide and oxides of nitrogen. We will procede (in this qualitative analysis) as though there were only one. However, if one reinterprets e_{it} as an ordered triple of numbers, each one corresponding to emissions per mile of a particular pollutant by an age i vehicle manufactured in year t, we can carry through the same analysis for all three pollutant types simultaneously. Thus no loss of generality is incurred when we speak as though there were but one pollutant type.

M_{it}^{τ} = annual vehicle miles travelled in year τ by vehicle of age i manufactured in year t.

X_{it}^{τ} = number of vehicles on the road in year τ of age i manufactured in year t.

P_j^{τ} = price of new vehicle of fuel economy class j manufactured in year τ.

P_a^{τ} = average price of new vehicles manufactured in year τ.

Π_j^{τ} = relative demand for new vehicles of fuel economy class i in year τ.

h^{τ} = total demand for new autos in year τ.

λ_i^{τ} = fraction of vehicles of age i retired in year τ.

β_{τ} = annual rate of increase of emissions per mile of vehicles manufactured in year τ.

Now emissions in year τ is the sum of emissions by each individual auto on the road in year τ. For an auto of age i manufactured in year t this quantity is

$$E_{it}^{\tau} \equiv M_{it}^{\tau} e_{it} \qquad (1)$$

where E_{it}^{τ} is the total quantity of emissions in year τ by a vehicle of age i manufactured in year t $(t=\tau-i)$. Since there are X_{it}^{τ} such vehicles, total emissions in year τ must then be

$$E^{\tau} = \sum_i \sum_t M_{it}^{\tau} e_{it} X_{it}^{\tau} = \sum_i M_{i,\tau-i}^{\tau} e_{i,\tau-i} X_{i,\tau-i}^{\tau} \qquad (2)$$

It is the behavior of E^{τ} in response to the alternative policy measures which we wish to examine. Toward this end, let us make the following assumptions:

B1: $M^{\tau}_{it} = M^{\tau}$, for every i, t.

B2: $\beta_{\tau} = \beta$, for all τ, $\beta > 1$

B3: $e_{it} = \beta^{i} e_{o,t-i} \equiv \beta^{i} e_{t-i}$

(where e_{τ} is the emissions per mile of a new vehicle in year τ.)

In (B1), we have assumed, for convenience only, that the number of vehicle miles travelled by an arbitrary auto in a given year is independent of the vehicle's age and year of manufacture. Furthermore, we assume in (B2) and (B3) that emissions per mile by a vehicle increases at a constant exponential rate with the vehicle's age, this rate being independent of the year of the vehicle's manufacture.[1] In addition to the above assumptions, we adopt intact assumptions (A3)-(A6) of the previous section of this appendix. These assumptions are discussed in some detail there.

We shall take the date on which the proposed policies are enacted as year zero. Thus, an auto of age i at the initial date was manufactured in year $-i$ $(i=0,1,2,\ldots,n)$. We assume that the number of autos of age i on the road in year zero is given by the historical datum X^{0}_{i}. Further, we take the initial emissions factor for a new vehicle manufactured in year t as known, exogenous constants e_{t}, $(t=-(n-1), -(n-2), \ldots, 0, 1, 2, \ldots)$. That is, we assume that the quantity of pollutant per mile emitted by a new

---

[1] We allow for different initial emissions rates for vehicles manufactured in different years (see discussion below). This assumes the technology of emissions control to be advancing over time. It may well be that the rate of decay or incidence of malfunction of the control devices will be slowed with advancing technology, though EPA projections indicate the opposite tendency (see U.S. Environmental Protection Agency, "Compilation of Air Pollutant Emission Factors," 2nd edition, April 1973, Table 3.1.2-5). In the absence of reliable estimates, however, it seems best to assume this rate constant over time.

vehicle manufactured in any year subsequent to policy enactment is precisely known. In the quantitative calculations of this chapter we will use the projected EPA emission standards for these years, assuming that these standards will in fact be met. However, recent policy debate[1] has introduced some degree of uncertainty as to whether or not these standards will remain in force. Thus, for the purposes of qualitative analysis, we will take these emissions factors as arbitrary, though it seems reasonable to presume that, at a minimum, the sequence $\{e_t\}$ is non-increasing.

As we observed in the text of this chapter, the assumptions that the emission of pollutant by a given vehicle is proportional to vehicle miles travelled, and that vehicle miles travelled is the same for all autos imply that it is the effect of the proposed policies on the size and age distribution of the auto stock, not its average fuel efficiency, which is of interest in determining the policy impact on air quality. For this reason, our analysis needn't take explicit account of the shift of the distribution of vehicles across fuel economy classes resulting from the policy imposition. However, we must be concerned about the policy impact on new car sales and the rate of retirement of older vehicles. We may employ the methodology of the preceding section of this appendix to study these effects.

The first step is to determine the number of vehicles of a given age surviving until a given future year. That is, we wish to express $X^{\tau}_{i,\tau-i}$ in terms of known parameters. Employing the logic of the previous section, we have (for $i \geq 1$)

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[1] For example, see President Gerald Ford's address to the American people, January 13, 1975, where he suggests that scheduled EPA standards be postponed for five years.

$$X^{\tau}_{i,\tau-i} = h(P_a^{\tau-i}) \prod_{k=0}^{i} (1-\lambda_k(P_a^{\tau-i+k})) \qquad (\tau \leq i)$$

$$= X^{0}_{i-\tau} \prod_{k=0}^{\tau} (1-\lambda_{i-\tau+k}(P^k)) \qquad (\tau \leq i) \qquad (3)$$

Combining (3) with (2), and using (B1)-(B3) we can express aggregate emissions in year τ as follows:

$$E^{\tau} = M^{\tau}\{ \sum_{i=0}^{\tau} h(P_a^{\tau-i}) \prod_{k=0}^{i} (1-\lambda_k(P_a^{\tau-i+k})) \beta^i e_{t-i}$$

$$+ \sum_{i=\tau+1}^{n} X^{0}_{i-\tau} \prod_{k=0}^{\tau} (1-\lambda_{i-\tau+k}(P_a^k)) \beta^i e_{\tau-i}\} \quad (0<\tau \leq n) \quad (4)$$

When $\tau>n$, the last term above, disappears and the sum in the first term is extended through n.

We are now in a position to examine the impact of a tax on poor fuel economy. Notice that the factor $e_{\tau-i}$ appears in each term of the sums in (4) above. This indicates that the direction of change in emission of pollutants as a result of the policy is likely to be sensitive to how these factors e_t change over time. Using the notation of Section A, the imposition of the tax will increase P_j^{τ} for each $j \geq j^{**}$, leading (by (A4)) to an increase in P_a^{τ}, in each year τ subsequent to enactment of the policy. This means that $h(P_a^{\tau})$ will decrease (by (A6)), as will $\lambda_k(P_a^{\tau})$ (by (A5)). That is, fewer new cars will be purchased in each year subsequent to the imposition of the tax, but once on the road a car will tend to stay there longer. If the emissions standards of the Environmental Protection Agency require a rather rapid reduction in the factors e_t at some point shortly after the tax has been imposed, then this tendency to keep older vehicles

(manufactured before the advent of stricter standards) in the auto stock for a longer period of time will almost certainly have a detrimental effect on air quality.

We conclude then that in the short run the effect of the tax policy on emissions cannot be *unambiguously* determined. Should the emissions factors e_t show a sharp decrease in the early years after the policy is initiated however (due to the imposition of significantly more strict EPA standards), then air quality will likely suffer in the short run.[1]

For the long run, more concrete results are obtainable. Let us suppose that the tax on poor fuel economy has been in effect long enough for all autos on the road when the tax was imposed to be retired. Suppose further that the average price of autos has stabilized at P_a, that each auto is driven $\bar{m}$ miles per year, every year, and that enough time has elapsed for all autos (when new) to meet the irreducible EPA minimum standard, which we take to be $\bar{e}$.[2] When an economy satisfies these qualifications we say it is in a "stationary state", meaning that it is in long-run equilibrium with all exogenously fluctuating factors assumed constant.

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[1] This, indeed, appears to be the case in 1975. For example, average grams per mile of carbon monoxide emitted by 1974 manufactured vehicles was 39.0 (i.e., $e_{1974} = 39.0$), while the EPA standard currently due to go into effect in 1977 is 3.4 g/mi. Thus e_t will have dropped by a factor greater than 10 in three years. (For this and other emissions data, see Federal Register, 2/27/74, No. 39FR7545.)

[2] $\bar{e}$ is the idealized "best" we can hope to do in terms of emissions control. It, therefore, is constant over time.

We are then able to state the following result:

Proposition 5: Under (A3)-(A7) and (B1)-(B3), the imposition of a tax on poor fuel economy will lead to less automotive emissions and better ambient air quality, in the stationary state, than would have been the case in the absence of the policy.

This proposition rests strongly on assumption (A7). This assumption insures that when the price of new cars rises, the reduction in new car sales will outweigh the increased average lifetime of autos to such an extent that the number of autos of any age on the road in the stationary state will be less by virtue of the initial price increase.

Proof of Proposition 5

From (4) above we can write stationary state emissions as

$$E = \bar{M}\,\bar{e}\,h(P_a)\sum_{i=0}^{n}\beta^i\prod_{k=0}^{i}(1-\lambda_k(P_a)). \tag{5}$$

The only variable above is P_a. Imposing the tax causes P_a to rise. Thus, Proposition 5 is equivalent to

$$\frac{\partial E}{\partial P_a} < 0. \tag{6}$$

Performing the differentiation we find

$$\frac{1}{\bar{M}\,\bar{e}}\frac{\partial E}{\partial P_a} = \frac{\partial h}{\partial P_a}\sum_{i=0}^{n}\beta^i\prod_{k=0}^{i}(1-\lambda_k(P_a)) + h(P_a)\frac{\partial}{\partial P_a}\left\{\sum_{i=0}^{n}\beta^i\prod_{k=0}^{i}(1-\lambda_k(P_a))\right\}. \tag{7}$$

Expanding the derivative on the RHS of (7) gives

$$\frac{\partial}{\partial P_a}\left\{\sum_{i=0}^{n}\beta^i\prod_{k=0}^{i}(1-\lambda_k(P_a))\right\}=\sum_{i=0}^{n}\beta^i\frac{\partial}{\partial P_a}\prod_{k=0}^{i}(1-\lambda_k(P_a))$$

$$=\sum_{i=0}^{n}\beta^i\left[\sum_{k=0}^{i}\left(-\frac{\partial\lambda k}{\partial P_a}\prod_{\substack{j=0\\ j\neq k}}^{i}(1-\lambda_j(P_a))\right)\right]$$

$$=\sum_{i=0}^{n}\beta^i\left[\sum_{k=0}^{i}\frac{\left|\frac{\partial\lambda k}{\partial P_a}\right|}{(1-\lambda_k(P_a))}\prod_{j=0}^{i}(1-\lambda_j(P_a))\right]$$

$$=\sum_{i=0}^{n}\left[\beta^i\prod_{j=0}^{i}(1-\lambda_j(P_a))\sum_{k=0}^{i}\frac{\left|\frac{\partial\lambda k}{\partial P_a}\right|}{(1-\lambda_k(P_a))}\right]. \quad (8)$$

Combining (7) and (8) we get

$$(\bar{M}\,\bar{e}h(P_a))^{-1}\frac{\partial E}{\partial P_a}$$

$$=\frac{\frac{\partial h}{\partial P_a}}{h}\sum_{i=0}^{n}\beta^i\prod_{k=0}^{i}(1-\lambda_k)+\sum_{i=0}^{n}\left[\beta^i\prod_{k=0}^{i}(1-\lambda_k)\sum_{k=0}^{i}\frac{\left|\frac{\partial\lambda k}{\partial P_a}\right|}{(1-\lambda_k)}\right]$$

$$\leq\left[\sum_{i=0}^{n}\beta^i\prod_{k=0}^{i}(1-\lambda_k)\right]\left[\frac{\frac{\partial h}{\partial P_a}}{h}+n\max_{0\leq k\leq n-1}\left(\frac{\left|\frac{\partial\lambda k}{\partial P_a}\right|}{(1-\lambda_k)}\right)\right]. \quad (9)$$

Now since $\frac{\partial h}{\partial P_a}$ is negative (A6), we have by (A7) that inequality (6) must hold. Q.E.D.

2. Effect of Restrictions on the Fuel Economy of New Vehicles

No additional technical analysis is needed in this case. As described in the text of this chapter, we may rely totally on propositions developed above.

Derivation of Change in Miles Per Gallon Resulting From Excise Taxes

Excise taxes on poor fuel economy lead to a change in the mix of automobiles purchased, resulting in higher average miles per gallon of new cars. Prices also increase, assuming that the tax is passed along to the consumer. This section discusses, without (in general) using numbers, how the increases in fuel economy and price were derived.

We start with the technical relationship between fuel economy and vehicle characteristics:

$$M = 25.909 - .270(\Sigma\gamma_j W_j) - .0122(\Sigma\gamma_j H_j) \qquad (1)$$

where

M = average fuel economy;
W_j = weight of car j;
H_j = horsepower of car j;
γ_j = share of sales of car j, $\Sigma\gamma_j = 1$.

Average weight and horsepower demanded are, in turn, explained by two behavioral equations, as follows:

$$\Sigma\gamma_j W_j = \alpha_o P_W^{\alpha_1} Y^{\alpha_2} \qquad (2)$$

and

$$\Sigma\gamma_j H_j = \alpha_o P_H^{\beta_1} Y^{\beta_2} \qquad (3)$$

where

P_W = price of weight;
P_H = price of horsepower;
Y = real per capita disposable income

A tax on fuel economy increases the implicit prices of weight and horsepower. With the tax, therefore, the prices of weight and horsepower are different for models subject to the tax from those not subject to the tax, and the average price and weight can be written as follows:

$$P_W^* = \gamma^O(P_W + T_W) + (1 - \gamma^O)P_W = P_W + \gamma^O T_W \quad (4)$$

$$P_H^* = \gamma^O(P_H + T_H) + (1 - \gamma^O)P_H = P_H + \gamma^O T_H \quad (5)$$

where

T_W = implied tax on weight;
T_H = implied tax on horsepower;
γ^O = market share of cars subject to the tax (before the tax is put into effect);
$*$ = index for post-tax values.

Hence, after the policy,

$$\Sigma\gamma_j W_j = \alpha_o Y^2 [P_W + \gamma^O T_W]^{\alpha_1} = \alpha_o Y^2 \left[P_W^*\right]^{\alpha_1} \quad (6)$$

and

$$\Sigma\gamma_j H_j = \beta_o Y^2 [P_H + \gamma^O T_H]^{\beta_1} = \beta_o Y^2 \left[P_H^*\right]^{\beta_1} \quad (7)$$

We can then substitute these values into equation (1) to derive average miles per gallon after the tax.

Since the estimated miles per gallon differs slightly from the actual miles per gallon for the 1975 sample, we adjust the estimated figures by the ratio of the sales-weighted average actual miles per gallon to the sales-weighted average estimated miles per gallon.[1] In symbols,

$$\hat{M} = \gamma^1 M_1 \left(\frac{M(a,75)}{M(e,75)}\right) + (1 - \gamma^1) M_2 \qquad (8)$$

where

$\hat{M}$ = adjusted estimate of average miles per gallon, all new cars (for a given year);

$M(a,75)$ = sales-weighted average actual miles per gallon, cars subject to the tax in 1975;

$M(e,75)$ = sales-weighted average miles per gallon of cars subject to the tax in 1975, estimated by equation (1);

γ^1 = post-tax share of new-car sales accounted for by cars subject to the tax;

M_1 = post-tax sales-weighted average miles per gallon, new cars subject to the tax (estimated from substituting into equation (1) estimates of weight and horsepower; the derivation of these estimates is discussed below);

M_2 = post-tax sales-weighted average miles per gallon, new cars not subject to the tax (this estimate is based on actual fuel economy data, as described below).

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[1] The difference is very slight indeed (less than 1 percent), but the adjustment is made for the sake of comparability.

Derivation of the Average Price Increase

Equations (6), (7), and (8) allow us, therefore, to determine the average fuel economy, vehicle weight,and horsepower that will be bought after the tax is in effect. The average price increase, however, cannot be as readily determined. Assuming that the tax is fully passed along to consumers, the average price increase can be written as

$$\Delta P = \gamma^1 S(20 - M_1) \tag{9}$$

where

ΔP = change in price of new cars;

S = tax rate (dollars per mile-per-gallon less than 20);

γ^1, M_1 = as defined above.

The percentage increase in price is $\frac{\Delta P}{P_o}$, where P_o = 1975 sales-weighted average price of automobiles.

We are, however, unable to identify γ^*, M_1 or M_2 independently or uniquely. The problem may be sketched as follows. In addition to the symbols already defined, let

W_1^o be average weight of cars with miles per gallon < 20 (before tax);

H_1^o be average horsepower of cars with miles per gallon < 20 (before tax);

W_1^1 be average weight of cars with miles per gallon < 20 (after tax);

H_1^1 be average horsepower of cars with miles per gallon < 20 (after tax);

W_2^o be average weight of cars with miles per gallon ≥ 20 (before tax);

H_2^o be average horsepower of cars with miles per gallon ≥ 20 (before tax);

W_2^1 be average weight of cars with miles per gallon ≥ 20 (after tax);

H_2^1 be average horsepower of cars with miles per gallon ≥ 20 (after tax).

The pre-tax average weight and horsepower can be expressed as

$$W_o = \gamma^o W_1^o + (1 - \gamma^o) W_2^o \tag{10}$$

$$H_o = \gamma^o H_1^o + (1 - \gamma^o) H_2^o \tag{11}$$

The post-tax average weight and horsepower can be written as

$$W_1 = \gamma^1 W_1^1 + (1 - \gamma^1) W_2^1 =$$

$$[\gamma^o W_1^o + (1 - \gamma^o) W_2^o] \left(\frac{P_{W^*}}{P_W}\right)^{\alpha_1} \tag{10A}$$

$$H = \gamma^1 H_1^1 + (1 - \gamma^1) H_2^1 =$$

$$[\gamma^o H_1^o + (1 - \gamma^o) H_2^o] \left(\frac{P_{H^*}}{P_H}\right)^{\beta_1}, \tag{11A}$$

using equations (2), (3) and (4) and simplifying.

Where

W = average weight (all cars) after the tax;

H = average horsepower (all cars) after the tax;

Write $\rho_W = (P_W^*/P_W)^{\alpha_1}$,

$\rho_H = (P_H^*/P_H)^{\beta_1}$,

$W_o = \gamma^o W_1^o + (1 - \gamma^o) W_2^o$,

and $H_o = \gamma^o H_1^o + (1 - \gamma^o) H_2^o$.

Then, rewriting equations (10) and (11), we get

$$\rho_W W_o = \gamma^1 W_1^1 + (1 - \gamma^1) W_2^1 \tag{10B}$$

and

$$\rho_H H_o = \gamma^1 H_1^1 + (1 - \gamma^1) H_2^1 \tag{11B}$$

Equations (10), (11), (10B), and (11B) give us a system of four equations in five unknowns (γ^*, W_1^1, W_2^1, H_1^1, and H_2^1). Note that W_2^1 and H_2^1 (the post-tax average weight and horsepower of cars exempt from the tax) are also unknown, because it is reasonable to expect the average weight and horsepower of cars not subject to the tax to increase, as the larger cars not subject to the tax are better substitutes for the cars whose prices have increased than are the smaller cars.

The following constraints enable us to put bounds on the possible values of the unknown variables.

(1) $\gamma^1 \leq \gamma$

(2) $W_1^1 \leq W_1^0$ (2') $H_1^1 \leq H_1^0$

(3) $W_2^1 \geq W_2^0$ (3') $H_2^1 \geq H_2^0$

(4) $W_2^1 \leq \left(\dfrac{W_2^0 + (\gamma^0 - \gamma^1) W_{2_b}^0}{1 + \gamma^0 - \gamma^1} \right)$ (4') $H_2^1 \leq \left(\dfrac{H_2^0 + (\gamma^0 - \gamma^1) H_{2_b}^0}{1 + \gamma^0 - \gamma^1} \right)$

Where

$W_{2_b}^0$ = maximum weight of any car getting 20 or more miles per gallon; and

$H_{2_b}^0$ = maximum horsepower of any car getting 20 or more miles per gallon.

The constraints have natural interpretations. Constraint (1) says that the share of sales of cars subject to tax cannot increase with the imposition of a tax. Constraints (2) and (2') state that the average weight and horsepower of cars subject to the tax cannot increase in response to the tax, while constraints (3) and (3') state that the average weight and horsepower of cars exempt from the tax cannot be less after the tax than before. Constraints (4) and (4') state the maximum possible increase in average weight and horsepower of cars exempt from the tax occurs when the entire change in market share (of cars subject to the tax) is transferred to the model having the greatest weight and horsepower in the exempt group.

To find the maximum and minimum price increases consistent with the above constraints, we differentiate equation (9) with respect to γ^1:

$$\frac{\partial \Delta P}{\partial \gamma^1} = S(20 - M_1) > 0$$

Thus, to find the greatest tax increase consistent with the M implied by a given policy, we maximize γ^1 subject to constraint (1). Substituting this constraint into constraints (4) and (4'), we find that $W_2^1 = W_2^o$ and $H_2^1 = H_2^o$. That is, the average weight of cars not subject to the tax remains constant; hence all the decrease in average weight and horsepower implied by equations (5) and (6) comes through a change in average weight and horsepower within the class of cars subject to the tax. This also implies that H_2^1 and W_2^1 are minimized subject to constraints (3) and (3'). The maximum tax increases implied for the different levels of the excise tax were used in the "low" and "medium" sensitivity analyses (to find the maximum decrease in new car sales).

To find the minimum tax increase, we minimize γ^1, subject to the constraints above. It turns out that min γ^1 occurs when $W_1^1 = W_1^o$ and $W_2^1 = (W_2^o + (\gamma^o - \gamma^1)W_{2_b}^o)/(1 + \gamma^o - \gamma^1)$.[1] We find min γ^1 by solving, for each value of W_1 implied by a tax policy, the following pair of equations:

$$\gamma^1 = \frac{W_1 - W_2^1}{W_1^1 - W_2^1} \left(= \frac{W_1 - W_2^1}{W_1^o - W_2^1} \right)$$

and $W_2^1 = (W_2^o + (\gamma^o - \gamma^1)W_{2_b}^o)/(1 + \gamma^o - \gamma^1)$

---

[1]Since γ^1 must satisfy constraints (2), (2'), (3), (3'), (4), and (4'), it follows that the *admissible* min γ^1 = max (min γ^1 from constraints (2), (3) and (4), min γ^1 from constraints (2'), (3') and (4')). Because $W_{2_b}^o$ is much closer to W_2^o than $H_{2_b}^o$ is to H_2^o, the max min γ^1 is determined by constraints (2), (3), and (4).

These values were then used in the corresponding "high" sensitivity analysis (to find the minimum decrease in new car sales).

Derivation of the Average Fuel Economy of the Car Stock

The average fuel economy measure used in the structural demand equation for gasoline is defined as follows:

$$\mu = \Sigma \alpha_j \mu_j \tag{18}$$

where

μ = average fuel economy of stock of registered automobiles;

α_j = proportion of stock composed of automobiles of age j $(j = 1,\ldots,n)$.

μ_j = sales-weighted average fuel economy of automobiles of age j.

It is convenient here to rewrite this expression as

$$\mu = \alpha_1 \mu_1 + \sum_{j=2}^{n} \alpha_j \mu_j \tag{19}$$

where μ_1 is sales-weighted average fuel economy of new cars.

Then we can adjust μ_1 to take into account the effect of these policies as follows:

$$\mu_1^* = \mu_1 \left(\frac{M^*}{Me,75}\right) \tag{'20}$$

That is, we assume that the sales-weighted average fuel economy of new cars used in the equation changes by the same percentage as that estimated according to equation (1) above. Note, however, two features of equation (19). First, μ depends on the α_j, which also change in response to these policies (see the derivation of these changes below). Second, equation (19) describes the impact only in the first year of the policy. In later years, of course, $\mu_2, \mu_3,\ldots,\mu_n$ are all affected by the policy.

Expressing this equation as of a particular time, t,

$$\mu(t) = \sum_{j=1}^{n} \alpha(t,j)\mu(t,j) \qquad (18')$$

where $\alpha(t,j)$ is the share of automobiles of age j in year t; $\mu(t,j)$ is the average miles per gallon of autos of age j in year t, prior to the introduction of the policy.

Let $t = t^*$ be the year of the policy change (assumed to be 1975). Then, for all years and model years after the policy change, we write

$$\mu^*(t) = \sum_{j=1}^{n} \alpha(t,j)\mu^*(t,j) \qquad (21)$$

where

$$\mu^*(t,j) = \begin{cases} \mu(t,j), & \text{if } (t - j + 1) < t^* \\ \mu(t,j)\left(\frac{M^*}{Me,75}\right), & \text{if } (t - j + 1) \geq t^* \end{cases}$$

As described in Appendix A, two assumptions were made about $\mu(t,j)$, for $(t-j+1) \geq 1973$. The assumption used in the low gasoline consumption base forecasts was that $\mu(t,j) = \mu_o$, a constant derived from the smallest average engine displacement and weight observed during the postwar period. The assumption used in the high gasoline consumption base forecasts was

$$\mu(t,j) = \beta_o - \beta_1(W_o exp(gt)) - \beta_2(D_o exp(ht)),$$

i.e., an extrapolation of miles per gallon based on extrapolations of weight and displacement (the β's are the coefficients used to estimate miles per gallon from weight and displacement data).

Derivation of the Change in New Car Sales

From equation (9), we have the average increase in price resulting from the tax ΔP. Letting η be the elasticity of demand for new cars, and $X(t)$ be the forecast of new car sales in year t, the percentage change in new car sales, $\Delta X(t)/X(t)$, can be written as

$$\Delta X(t)/X(t) = \eta \Delta P/P \tag{22}$$

and the resulting new car sales forecast as

$$X^1(t) = X(t) + \Delta X(t) = X(t)(1 + \eta \Delta P/P) \tag{23}$$

Derivation of the Change in Scrappage

We can write the equation for scrappage as

$$LOG(S) = A + B \cdot LOG(R) + C \cdot LOG(P) \tag{24}$$

where

S = the ratio of actual scrappage to scrappage expected on the basis of age alone;

R = the ratio of new car sales to the stock of cars at the beginning of the year; and

P = the ratio of the used-car price index to an index of the price of automotive repair and maintenance.

Two of the independent variables, R and P, are affected by the policies considered here. Letting R^1 be the value of R after the policy has taken effect, we write

$$R^1 = \frac{X^1(t)}{\sum_v X(t,v)} = \frac{X(t)(1+\eta \Delta P)}{\sum_v X(t,v)} = (1+\eta \Delta P)R \tag{25}$$

where $X(t,v)$ is the number of automobiles of vintage v surviving as of the beginning of year t.

The new value of P is somewhat more complicated to derive because of the dependences on past as well as current values. From the linking equation, we have

$$LOG(CPIUC) = A1+B1\ LOB(CPINC) + C1\ LOG(CPIUC(-1)) \quad (26)$$

where $CPIUC$ = price index of used cars;
$CPINC$ = price index of new cars; and
$CPIUC(-1)$ = $CPIUC$, lagged one year.

If we write the after-tax new-car price index as $CPINC^1$,

$$CPINC^1 = CPINC\ (1 + \Delta P/P) \quad (27)$$

Substitution of (27) into (26) yields a sequence of $CPIUC$ over time, which, on the assumption that the relative price index for automotive repair and maintenance does not change, leads to a new sequence of $P^1(t)$.

Substituting R^1 and the sequence $P^1(t)$ into equation (24), we arrive at a sequence of new values, $S^1(t)$. Letting $s^1(t) = S^1(t)/S$, and r_v = the scrappage rate for the v-th vintage on the basis of age alone, we write

$$r_v{}^1 = r_v s^1(t) \quad (28)$$

for the new scrappage rates.

Derivation of the Change in the Car Stock

Letting $A(t)$ be the stock of automobiles in year t, it follows by definition that

$$A(t) = \sum_{v} X(t,v) + X^1(t) - \sum_{v} r_v X(t,v) \qquad (29)$$

This equation can be written as

$$A(t) = \sum_{v} X(t,v)(1-r_v) + X^1(t) \qquad (29')$$

Starting with the values of $X(t,v)$ in 1974, and given the forecasted sales $X^1(t)$ from equation (23) and the new scrappage rates $r_v{}^1$ from equation (28), we then derive the new sequence $A^1(t)$ by substitution and iteration.

Derivation of the Change in the Proportion of Cars Produced After 1968

The structural demand equation for gasoline includes a dummy variable based on the proportion of autos on the road of 1968 model year and later. This proportion is found directly from equation (29') as

$$PCEPROP = \frac{X^1(t) + \sum_{v^*} X(t,v)\ (1-r_v)}{A(t)} \qquad (30)$$

where the summation index, v^*, refers only to $v \geq 1968$.

Derivation of the Change in Gasoline Consumption

The results of equations (21), (29'), and (30) can then be substituted into the structural demand equation for gasoline to obtain the gasoline consumption under the excise taxes on new cars based on fuel economy.

Restrictions on Fuel Economy of New Cars

The analysis of this set of policies is much simpler. The value of $\mu^*(t)$ in equation (21) is assumed to be that mandated by the policy, while the percentage change in price,

$\Delta P/P$, follows directly from the assumptions about the cost of the fuel economy improvements. (These assumptions are discussed in the text of Chapter 5. From equation (22) onward, then, the analysis is the same as that for excise taxes.

Parameters and Sensitivity Analysis

To determine the maximum and minimum probable impacts of these policies, we used one standard error above and below the coefficient point estimates. The low estimate, for example, used *all* of the permissible values that will minimize gasoline consumption, while the high estimate is based on all the parameter values to maximize gasoline consumption.

Table D-1 shows the parameter values assumed for each sensitivity. Table D-2 shows the 1974 age distribution of the auto stock (the initial distribution used in equation (29')), while Table D-3 shows the forecasted base case new car sales ($X(t)$ in equation (23)).

Table D-1

SUMMARY OF COEFFICIENTS AND ELASTICITY ESTIMATES

USED IN ANALYZING EXCISE TAXES ON FUEL ECONOMY

Stage of Analysis		Low Gasoline Consumption	Medium Gasoline Consumption	High Gasoline Consumption
Relationship between fuel economy and characteristics				
Weight		-.316	-.270	-.244
Horsepower		-.0201	-.0102	0
Implied taxes on these characteristics				
Weight:	$50/mpg	15.80	13.50	11.20
	$100/mpg	31.60	27.00	22.40
	$200/mpg	63.20	54.00	44.80
Horse-power	$50/mpg	1.01	0.51	0
	$100/mpg	2.01	1.02	0
	$200/mpg	4.02	2.04	0
Elasticity of demand for weight				
First year		-.0142	-.0105	-.0069
Second year		-.0285	-.0211	-.0138
Third year		-.0356	-.0264	-.0172
Elasticity of demand for horsepower				
First year		-.124	-.088	-.053
Second year		-.248	-.177	-.106
Third year		-.311	-.221	-.132
Elasticity of demand for new cars		-1.22	-1.0	-0.75

Table D-1, Continued

SUMMARY OF COEFFICIENTS AND ELASTICITY ESTIMATES USED IN ANALYZING EXCISE TAXES ON FUEL ECONOMY

Stage of Analysis	Low Gasoline Consumption	Medium Gasoline Consumption	High Gasoline Consumption
Change in scrappage in response to tax			
Elasticity with respect to change in new-car sales	.5720	.742	.9128
Elasticity with respect to change in used-car price	-.744	-.912	-1.079
Elasticity of used car price index with respect to new-car price index			
1975	.091	.213	.345
1976	.175	.381	.571
1977	.251	.513	.719
1978	.322	.616	.816
1979	.387	.698	.879
1980	.447	.763	.921
1981	.501	.813	.948
1982	.552	.853	.966
1983	.598	.884	.978
1984	.641	.909	.985
1985	680	.928	.990
1986	716	.944	.994
1987	.749	.956	.996
Average pre-tax price (all cars)	4595	4595	4595

Table D-1 , Continued

SUMMARY OF COEFFICIENTS AND ELASTICITY ESTIMATES

USED IN ANALYZING EXCISE TAXES ON FUEL ECONOMY

Stage of Analysis	Low Gasoline Consumption	Medium Gasoline Consumption	High Gasoline Consumption
Average pre-tax miles per gallon	15.5	15.5	15.5
Pre-tax price of weight (per 100 pounds)	$62	$62	$62
Pre-tax price of horsepower (per rated HP)	$2.67	$2.67	$2.67
Pre-tax average weight (hundreds of pounds)	33.65	33.65	33.65
Pre-tax average horsepower	119.3	119.3	119.3
Share of cars subject to the tax (γ^{o})	.858	.858	.858
Assumed price increase, 17.5 mpg restriction	$730	$365	$265
Assumed price increase, 20.0 mpg restriction	$1448	$724	$526
Assumed price increase, 22.5 mpg restriction	$2002	$1001	$728

TABLE D-2

1974 AGE DISTRIBUTION OF THE AUTOMOBILE STOCK

Model Year	Thousands of Autos
1974	7172.6
1973	9982.6
1972	10058.6
1971	8867.8
1970	8753.0
1969	8912.4
1968	8196.2
1967	6833.5
1966	6708.5
1965	5794.5
1964	4051.3
1963	2937.6
1962	1955.4
1961	1028.4
1960	781.6
1959	441.1
1958[1]	1485.1

[1] Includes all previous year models.

SOURCE: Base case forecast, discussed in Appendix A.

TABLE D-3

BASE FORECASTS OF NEW-CAR SALES

Year	Thousands of Autos
1974	10278.4
1975	10708
1976	11173
1977	11642
1978	12105
1979	12567
1980	13037
1981	13520
1982	15081
1983	13918
1984	14820
1985	15541
1986	16200
1987[1]	11640

[1] Sales as of July 1, 1987 only.

SOURCE: Derived by the methods described in Appendix A.

Sources of Data and Estimation Details

In this appendix, we present the sources for the data used in the different equations and the analysis. Where technical discussion of an equation is warranted, this discussion also appears here rather than in the text.

Equation Relating Fuel Economy to Weight and Horsepower

We start by assuming that consumers' evaluation of all of the automotive characteristics that influence fuel economy can be summarized in their evaluation of weight and horsepower. There are, of course, a great many characteristics valued by consumers that influence fuel economy, such as length, interior room, trunk space, number of passengers a car can comfortably carry, acceleration, top speed, and so forth.[1] We assume that these characteristics are sufficiently related either to weight or to horsepower (or to a combination of them) that, by considering only weight and horsepower, we in effect consider all of them.[2] This assumption is supported by hedonic regressions done by a number of investigators. These regressions, which include a number of different attributes of automobiles, explain automobile prices quite well. Of the attributes generally included in these

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[1] As discussed elsewhere, fuel economy is given positive value in consumers' valuation of automobiles, so there are presumably other attributes, inversely related to fuel economy, valued by consumers.

[2] We assume that miles per gallon are measured on the models tested by EPA for compliance with emissions standards. These tests are made "on vehicles equipped with frequently purchased equipment" (*1975 Gas Mileage Guide for New Car Buyers*, p. 2). There are bound to be differences in fuel economy that cannot be explained completely by weight and horsepower, but the relative size of this variation does not appear to be large.

equations, weight and horsepower, on the basis of technological evidence, are the ones most closely related to fuel economy. When other variables, such as vehicle length or engine displacement, have been tried, they are so closely correlated to weight and horsepower that it is very difficult to choose, on statistical grounds, among the different measures of automobile size and engine capacity.

Technologically, weight and horsepower appear to be important determinants of fuel economy. This relationship is subject to change over time, as different technologies are used, but it appears to be reasonably stable for a given technology and the model year.[1] Vehicle weight is generally accepted as an important determinant of fuel economy.[2] "Higher weight usually means poorer fuel economy because more work is required to move the vehicle."[3] Horsepower or other measures of engine size are not as widely accepted as determinants of fuel economy. A number of studies have shown, however, that there is a statistical relationship between

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[1]Different kinds of engines, transmissions, carburation techniques, body styling, and so forth all may change the relationship between weight and horsepower on the one hand and fuel economy on the other. The impacts of different technologies and different designs are important, but they lie beyond the scope of this study. For our purposes, therefore, we will assume that the technology can be represented by that embodied in 1975 model-year cars.

[2]See, for example, Environmental Protection Agency, *Fuel Economy and Emission Control* (November 1972), NTIS, #PB 228 384.

[3]*Ibid.*, p. 3.

horsepower (or engine displacement) and fuel economy, even holding weight constant.[1] This effect occurs "because a higher powered car operates in normal driving at a smaller fraction of maximum power, so that friction, pumping, and other losses loom larger."[2] Our own statistical investigation, reported below, suggests that both weight and horsepower influence fuel economy (for a given technology). A simple linear specification, chosen for its convenience in the rest of this analysis, was estimated as follows:[3]

$$MPG = 25.909 - .01022*HP - .270*WGT$$
$$(27.58)\quad (-1.03)\quad (-5.91)$$

64 observations R-SQ = .758

Standard error of estimate = 1.433

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[1]See, for example, Franklin M. Fisher, Zvi Griliches and Carl Kaysen, "The Costs of Automobile Model Changes Since 1949," *Journal of Political Economy*, Vol. 70, No. 5, pp. 441-445. See also Donald N. Dewees, *Economics and Public Policy: The Automobile Pollution Case* (Cambridge, Mass.: MIT Press, 1974), pp. 147-156. Clayton LaPointe, in "Factors Affecting Vehicle Fuel Economy," Society of Automotive Engineers paper 730791, pp. 6-8, uses weight and displacement to explain fuel economy. He uses displacement rather than horsepower "because the method of reporting horsepower was changed during the 1967-1973 period." (p. 6) This reason does not apply to our method, as we use a cross-section of 1975 model-year cars. Moreover, for any given model year, displacement and horsepower are so closely correlated that it makes little difference which is used.

[2]Charles E. Cohn, "Improved Fuel Economy for Automobiles," *Technology Review* (February 1975), p. 51.

[3]LaPointe, *op. cit.*, used a log-linear specification, which he justified on the basis of a theoretical consideration of the factors influencing fuel economy. For our purposes, however, a log-linear specification would complicate the translation of a tax on fuel consumption into a tax on weight and horsepower. We also estimated a log-linear equation, but the results -- both in terms of the size of the coefficients and the fit to the data -- were virtually identical to those of the linear specification. At least for the range of data represented by 1975 model-year cars, therefore, the linear approximation is very close to the log-linear one. Dewees, *op. cit.*, found similar results (pp. 151-153).

where

MPG = miles per gallon, according to the EPA city driving cycle test;

HP = maximum net horsepower; and

WGT = vehicle weight, in hundreds of pounds.

This equation implies that, other things equal, increasing an engine's horsepower by ten leads to about a 0.1 mile per gallon decrease in fuel economy. Increasing a car's weight by 300 pounds, other things equal, leads to a reduction of about 0.8 miles per gallon. These estimates agree quite closely with those cited by Cohn. He implies that increasing horsepower by 10 leads to a reduction in fuel economy of about 0.083 miles per gallon, while increasing car weight by 300 pounds reduces fuel economy by 0.3 miles per gallon for large cars and 1.2 miles per gallon for small cars.[1] The t-statistic of the coefficient of weight suggests that the weight-miles per gallon relationship has been quite precisely estimated.[2] At the sample means, the elasticity of miles per gallon with respect to horsepower is -0.12 and with respect to weight is -0.85. Thus, although this equation implies that vehicle weight is the more important of the two determinants of fuel economy, differences in horsepower are also important. If *both* weight and horsepower increase by 1 percent, fuel economy declines by about 1 percent.

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[1]Cohn, *op. cit.*, pp. 51-52.

[2]The t-statistic of the cofficient of horsepower is statistically significantly different from 0 only at about the 30 percent level. We have chosen to include it all the same, because the coefficient is reasonable and because, on theoretical grounds, it ought to be included (see LaPointe, *op. cit.*). This result may also be an anomaly of the 1975 model-year cars, as a similar equation for the 1974 model-year cars showed horsepower to be as important as weight in determining fuel economy.

The data for this equation consist of 64 observations on 1975 model-year U.S. cars. These observations included all models for which data on fuel economy, weight, and horsepower were available. The measure of fuel economy was city fuel economy (in miles per gallon), published in the Environmental Protection Agency *1975 Gas Mileage Guide for New Car Buyers* (Washington: 1974). Fuel economy measurements differ with driving conditions. In this study, we have used the city fuel economy measure as the basis for the taxes on poor fuel economy and for the relationship of fuel economy to weight and horsepower.

Corresponding data on engine horsepower and vehicle weight were taken from *Automotive News*, November 4, 1974, pages 24-25. These are specifications as represented by the manufacturers, and they should be reasonably accurate for these dimensions. As mentioned in the text, the way horsepower is measured was changed around 1971, but that change did not affect our results, as all cars in the sample were 1975 models. Although it might be argued that engine displacement is a more consistent measure of engine size, it tends (particularly for any model year) to be highly correlated with horsepower. The overriding reason for the choice of horsepower, however, was that the implicit prices of horsepower were available in Dewees, *op. cit.* but comparable implicit prices of displacement were not available.

The equation was estimated by ordinary least squares. This method seems appropriate, in that there is no simultaneity between miles per gallon and vehicle characteristics. In this case, ordinary least squares is a best linear unbiased estimator.

Demand for Weight and Horsepower

The equations reported here are patterned on the equation used by Dewees. Because it takes time for consumers to adjust their patterns of automobile purchases in response to changes in the implicit prices of weight and horsepower or to disposable income, we postulated a fixed distributed lag on both price and income terms. This lag imposes a constraint that 40 percent of the impact of the change in prices is felt in the current year, 40 percent in the following year, and 20 percent in the third year. In other words, an increase in the price of horsepower requires about three years before its full impact is felt.

The equations estimating the demand for weight and for horsepower are as follows:

$$LOG(WGT) = \underset{(36.95)}{7.350} - \underset{(-2.862)}{0.0264}*LOG(PWGTWAV) + \underset{(3.93)}{0.103}*LOG(YWAV)$$

YEARS = 1954-1968 R-SQ = .659

SEE = .011

where

WGT = average weight of cars sold, in pounds;

PWGTWAV = weighted average of the contemporaneous price of weight, the price of weight lagged one year, and the price of weight lagged two years.

$$LOG(HP) = \underset{(-1.98)}{-3.44} - \underset{(-2.47)}{.221}*LOG(PHPWAV) + \underset{(5.00)}{1.258}*LOG(YMAV)$$

YEARS = 1954-1968 R-SQ = .677

SEE = .078

where

HP = average horsepower bought;

PHPWAV = weighted average of the contemporaneous price of horsepower, the price of horsepower lagged one year, and the price lagged two years; and

YMAV = weighted average of real per capita disposable income in the contemporaneous and previous years.

These equations fit the data reasonably well, and the estimates on the price of horsepower and the price of weight are reasonably precise by conventional statistical standards. The standard errors of the regressions are about 8 percent for the quantity of horsepower demanded and 1 percent for the quantity of weight demanded.

Data on average weight and horsepower of cars bought in the United States were taken from Dewees, *op. cit.*, Table B-4, page 172. Dewees estimated hedonic equations for 1952, 1954, 1956, 1958, 1960, and 1968. For these years, the sales-weighted average weight and horsepower are estimated from his sample. For these years, also, there are actual measurements of the implicit prices of weight and horsepower. Following Dewees, we interpolated linearly between different years to provide observations on average weight and horsepower (as well as on the prices of weight and horsepower) for the missing years. Linear interpolation is far from satisfactory, but Dewees considered the job of collecting and analyzing data for each year from 1952 to 1968 to exceed the resources of his study. This task was also beyond the scope of this study.

Because the assumptions underlying ordinary least squares are not appropriate to this equation, the estimated "standard errors" are almost certainly too small and the reported

"t-statistics" are too large. The reported "standard errors" do provide a lower bound on the size of the true errors.

Change in New Car Sales in Response to the Excise Tax

The percentage decrease in new car sales in response to this tax depends on the elasticity of demand for new cars. As shown in Table D-4, which summarizes a number of post-war studies, estimates of the elasticity range between -0.75 and -1.22. These estimates suggest that, if the excise tax on new cars causes their average price to rise by 10 percent, new car sales will fall by about 10 percent.

As the main estimate in this study, we chose a value of -1.0 for the elasticity of new car demand. This value lies approximately midway between the high and low estimates reported in Table D-4. To test the sensitivity of our results to differing estimates, however, we also performed the calculations for elasticities of -0.75 and -1.22.

Scrappage of Used Cars

The equation used to estimate the response of scrappage to changes in new car sales is as follows:[1]

*LOG(S) = 1.70899 + 0.742378*LOG(R) - 0.912142*LOG(P)*
(4.860) (4.356) (-5.436)

YEARS = 1949-1971 R-SQ = .6346

SEE = .111

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[1]This equation is modeled after one developed by Franklin V. Walker, "Determinants of Auto Scrappage," *Review of Economics and Statistics* (November 1968), pp. 503-506. The equation used here updates his equation, but both its specification and the coefficient estimates are quite similar to those in Walker.

Table D-4

Survey of Models of New-Car Demand

Author	Years In Sample	Dependent Variable	Price Elasticity
Chow	1921-1953	New car sales per capita	-1.2
Suits	1929-1956	New car sales	-1.22
Nerlove	1922-1953	New car sales per capita	-0.9 (short run)
			-1.2 (long run)
Dyckman	1929-1962	New car sales per capita	-0.75[a]
			-1.2[b]
	1948-1962		-0.98[a]

NOTES:

[a]Newspaper price series used as price variable.

[b]Bureau of Labor Statistics new car price index used as price variable.

FULL REFERENCE:

Gregory C. Chow, *Demand for Automobiles in the United States* (Amsterdam: North-Holland Publishing Company, 1957); Daniel B. Suits, Senate Antitrust Subcommittee Staff, *Hearings on Administered Prices in the Automobile Industry* (Washington: GPO, 1958), pp. 3195-3220; Marc Nerlove, "A Note on Long-run Automobile Demand," *Journal of Marketing*, Vol. 22 (July 1957); Thomas R. Dyckman, "An Aggregate Demand Model for Automobiles," *Journal of Business*, Vol. 38, (July 1965).

SOURCE:

Adapted from Lawrence J. White, *The Automobile Industry Since 1945* (Cambridge, Mass.: Harvard University Press, 1971), pp. 94-95.

where

S = ratio of actual scrappage to scrappage expected on the basis of age alone;

R = ratio of new-car sales during the year to stock of cars at beginning of year; and

P = ratio of Consumer Price Index for used cars to Consumer Price Index for automotive repair and maintenance.

This equation fits the data quite well, and the coefficients appear to be sensible in size, as well as being quite precisely estimated, by conventional statistical criteria.[1] The equation implies that a 10 percent decrease in new-car sales leads to about a 7 percent decrease in the scrappage rate, while a 10 percent increase in the price of used cars (relative to the price of maintenance) leads to about a 9 percent decrease in the scrappage rate.

The dependent variable in this equation is the ratio of actual scrappage to scrappage expected on the basis of age alone. Actual scrappage was taken from the *Automotive News 1973 Almanac*, page 78. Scrappage expected on the basis of age alone is a more complicated construct, which is explained in detail in Walker's article. Scrappage expected on the basis of age alone can be written as

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[1]Note that the dependent variable in this equation is the ratio of actual scrappage to scrappage expected on the basis of age alone. Consequently, the standard error of about 11 percent refers not to actual scrappage but to deviations of actual scrappage from expected scrappage. When the predictions of scrappage are compared with actual scrappage, the fit is much closer. The coefficient of multiple determination computed between actual scrappage and predicted scrappage, for example, is .894.

$$M(T) = \sum_{V} A(V)X(V,T)$$

where

$M(T)$ = scrappage expected on the basis of age alone (in thousands of vehicles);

$A(V)$ = the expected scrappage rate for vehicles of vintage V; and

$X(V,T)$ = thousands of automobiles of vintage V in year T.

Walker estimated the $A(V)$ from a logistic function. Different scrappage rates were estimated for pre-war vintages and post-war vintages. The distribution of the auto stock by vintage was taken from the *Automotive News Almanac*, annual issues, 1940-1973.

The prices of weight and horsepower were also taken from Dewees, *op. cit.*, Table B-6, Equation D, page 175. As the most recent equation in this set was 1960, however, the 1968 prices of weight and horsepower were taken from Equation F, in the same table.

The income variable used was per capita disposable personal income, in 1958 dollars, taken from the *Economic Report of the President*, February 1974, Table C-18, page 269.

The specification reported in the text assumed that average weight and horsepower bought depend on previous prices of weight and horsepower and previous levels of income, as well as on current prices and income. The particular distributed lag chosen had fixed weights, with the current observation receiving 40 percent of the total weight, the previous year's observation also receiving 40 percent, and the observation lagged two years receiving 20 percent of the weight. This formulation implies that, for a given sustained change in the price of weight, the total impact is felt after three years. The same weighting scheme was used for the price of weight, the price of horsepower, and income.

Both equations were estimated by ordinary least squares. Given the probable simultaneity between the price of weight and the quantity of weight bought, coupled with the fact that the price of weight is measured subject to error, ordinary least squares is not a consistent estimator. In spite of this drawback, it was chosen for two reasons. First, since it is a very small sample, the desirable asymptotic properties of other estimators are relatively less important. Second, two-stage least square equations (following Dewees' specification) led to implausible results.

The new-car sales variable, R, is the ratio of new-car sales during the year to the stock of cars at the beginning of the year. This ratio was computed from the *Automotive News 1973 Almanac*, page 78.

The price variable, P, was the ratio of the used car price index to the automotive repair and maintenance price index. The index of automotive repair and maintenance is the Bureau of Labor Statistics Consumer Price Index for Automotive Repair and Maintenance, with 1967 = 100. For the years 1949 to 1970, it was taken from the Bureau of Labor Statistics, *Handbook of Labor Statistics*, 1971, Table 117, page 268. The 1971 value was taken from the Bureau of Labor Statistics, *Monthly Labor Review*, December 1972, Table 25, page 102. The index for used-car prices was the Bureau of Labor Statistics *Consumer Price Index for Used Cars*, with 1967 = 100. The sources are the same as those for the index of automotive repair and maintenance for 1953 to 1971. To extend this index to 1949, we linked it with the price index for used cars calculated by Gregory Chow, *Demand for Automobiles in the United States*, Table 5, page 106. (This procedure follows that outlined by Walker in his article.)

The equation was estimated by ordinary least squares. Given the simultaneity between scrappage and used car prices, this estimating technique is probably inconsistent. Given the small size of the sample, however, the asymptotic properties of two-stage least squares are less critical. This link in the research did not seem crucial enough to warrant a large expenditure of resources, so that estimating a simultaneous equation for scrappage did not seem appropriate in this study. As the estimated equation appears reasonable, we decided simply to follow Walker's methods.

The Relationship Between the Price Indexes for Used Cars and New Cars

The source of the new car consumer price index was the same as that for the consumer price index for automotive repair and maintenance.

The specification was a distributed lag of the type developed by Koyck.[1] The specification constrains the long-run elasticity of used cars with respect to new-car prices to be unity.[2] The following shows how this constraint was used in the estimation: We write, in general terms,

LOG (CPIUC) + A + B.LOG(CPINC) + C.LOG(CPIUC(-1))

---

[1]See L.M. Koyck, *Distributed Lags and Investment Analysis* (Amsterdam: North-Holland Publishing Company, 1954). The same kind of distributed lag was specified for the long-run adjustment coefficient in the demand for gasoline. The theoretical approach is discussed in Appendix C, pp. C-20 to C-25. There is, however, a difference in interpretation, as gasoline demand is assumed to adjust over time in response to the gap between desired and actual consumption, while we have not found a behavioral basis for the specification used to link new-car and used-car prices.

[2]The justification for this constraint is discussed in the text of Chapter 5.

where

CPIUC = Consumer Price Index for used cars;

CPINC = Consumer Price Index for new cars; and

CPIUC(-1) = *CPIUC*, lagged one year.

when the one-year elasticity is *B*, while the long-run elasticity is *B/(1-C)*

$$B = 1-C.$$

Using the specification that

LOG(CPIUC/CPIUC(-1)) = A + B* LOG(CPINC/CPIUC(-1))*

implies, in retransformed form, that

LOG(CPIUC) = A + B* LOG(CPINC) + (1-B*)LOG(CPIUC(-1))*,

which is the required relationship between the coefficients of *LOG(CPINC)* and *LOG(CPIUC(-1))*.

The equation (in the form estimated), along with its test statistics, is as follows:

*LOG(CPIUC/CPINC) = -0.01994 + 0.787*LOG(CPIUC(-1)/CPINC)*
(-0.789) (5.974)

YEARS = 1951-1971 R-SQ = .6526

SEE = .0656

where

CPIUC = Consumer Price Index for used cars;

CPINC = Consumer Price Index for new cars; and

CPIUC(-1) = Consumer Price Index for used cars, lagged one year.

The equation in this form is not easy to interpret, however. Therefore, we have rearranged terms to write the equation in a more readily interpretable form, as follows:

*LOG(CPIUC) = -0.1194 + 0.213*LOG(CPINC) + 0.787*LOG(CPIUC(-1))*.

As discussed elsewhere in this appendix, this formulation requires used-car prices, in the long run, to increase in lock step with new-car prices.

For purposes of comparison, we also estimated this equation in a distributed lag form that did not impose this requirement. Although the coefficients were somewhat different, the unconstrained equation fit the data only slightly better than the constrained equation. For example, the coefficient of multiple determination in the unconstrained equation was .78, while the implied coefficient of determination in the constrained equation (in the retransformed formulation) was .76. Similarly, the standard error in the unconstrained form was about 6.4 percent, while in the constrained form it was 7 percent. Hence the requirement appears consistent with the data, at least for this sample period.

The estimated equation suggests that the impact of a change in the new-car price index is only partially felt in the first year. That is, an increase in the new-car price of 10 percent implies only a 2 percent increase in used-car prices this year. Although this result may, at first, appear surprising, it should be remembered that this is an average price index for all used cars, including all vintages. Even though the prices of one-year-old cars, which are quite close substitutes for new cars, may rise by close to the full 10 percent, it is not to be expected that the prices of older cars, which are less good substitutes, will rise by that amount. In fact, the equation implies that, after 12 years, the used-car price index will have increased by 9.5 percent in response to a sustained 10 percent increase in new-car prices.[1] This result is quite consistent with the average life of a car.

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[1]For convenience, we assume that new-car prices do not change (after the initial 10 percent increase) over this 12 year period. This assumption allows us to focus on the dynamic relationship between new and used-car prices.

The estimating technique used was ordinary least squares which reflects that new-car prices directly affect used-car prices, but used-car prices affect new-car list prices (on which the CPI is based) with about a year's lag.

Sources of Other Data Used in the Analysis

Sales-Weighted Average Miles per Gallon, Weight, and Horsepower

In computing the sales-weighted averages used in the analysis, the sale shares applied to the 1975 model-year were the sale shares of the corresponding models during the first seven months of 1974. These shares were the most recent available at the time of the computations. Gross sale figures appeared in *Automotive News*, September 22, 1974, page 8.

For the computation of sales-weighted average miles per gallon, the miles per gallon used were taken from the source cited earlier. Where miles per gallon figures were not available, we substituted the miles per gallon of other cars for which weight, engine size, and axle ratio were similar. Table D-5 lists the models for which fuel economy was estimated. These models account for less than 20 percent of the total weight in the sample.

Weight and horsepower of 1975 model-year U.S. cars were taken from the source cited above. Similar specifications for 1975 model-year foreign cars were not available. Because, however, specifications of foreign cars change very little from year to year, we used the specifications corresponding to the 1974 model-year cars, taken from the *Automotive News 1974 Almanac*, page 38.

TABLE D-5

1975 MODELS FOR WHICH FUEL ECONOMY WAS ESTIMATED

Model	Curb Weight (pounds)	Displacement (cubic inches)	Axle Ratio	Model Used to Estimate Fuel Economy
Satellite V-8 4 doors	3690 (4000)	318 (318)	2.94 (2.94)	Plymouth Compact
Chevelle V-8 4 doors	3683 (4000)	350 (350)	3.08 (3.08)	Pontiac Ventura
Monte Carlo	4036 (4000)	350 (350)	3.08 (3.08)	Pontiac Ventura
Camaro	3554 (4000)	350 (350)	3.08 (3.08)	Pontiac Ventura
Coronet Charger V-8 4 doors	3685 (4000)	318 (318)	2.94 (2.94)	Plymouth Compact
Oldsmobile Omega V-8 2 doors	3524 (4500)	350 (350)	2.73 (2.73)	Buick Century 350
Oldsmobile 98 V-8	4778 (5500)	455 (455)	2.73 (2.73)	Toronado
Firebird V-8	3611 (4000)	350 (350)	3.08 (3.08)	Pontiac Ventura

NOTE: Numbers in parentheses are the corresponding specifications of the models used to estimate fuel economy for the models in the left-hand column.

TABLE D-5 (Continued)

1975 MODELS FOR WHICH FUEL ECONOMY WAS ESTIMATED

SOURCES: 1) Specifications of cars for which fuel economy data were not available were taken from *Automotive News*, November 4, 1974, pp. 24-25. Curb weight for all models was taken from this source.

2) Specifications (except curb weight) of the models used to estimate fuel economy were taken from EPA, *1975 Gas Mileage Guide for New Car Buyers*, pp. 5-8.

Sales-Weighted Average Price

Prices of 1975 model U.S. cars were taken from *Automotive News*, November 4, 1974, pages 28-29. The prices used included the prices of optional equipment installed in more than 50 percent of the cars produced, where these options were priced separately. Table D-6 lists the options whose prices were included, along with the percentage of 1974 models on which these options were installed. Prices of foreign cars were taken as of the 1974 model-year (the latest available) from the *Automotive News 1974 Almanac*, pages 66-68. In general, these prices did not include the dealer preparation fee.

1975 Pre-Tax Price of Weight and Horsepower

The last year for which Dewees estimated the implicit prices of weight and horsepower was 1968. To estimate this price for 1975 model-year cars, we multiplied the 1968 price by the ratio of the price index for new cars corresponding to the 1975 model year to the price index for new cars corresponding to 1968 model year. The index corresponding to the 1975 model year was taken as the average consumer price index for new cars for October and November of 1974. The index corresponding to the 1968 model year was taken as the average of the October and November 1967 values of the consumer price index for new cars. The 1967 values were taken from the *Survey of Current Business*, January 1968, pages 5-7. The 1974 values were taken from the same source, December 1974, page S-8.

Share of Cars Subject to the Tax

This share was estimated from the data on sales referred to above.

TABLE D-6

OPTIONS WHOSE PRICES WERE INCLUDED IN PRICES OF NEW CARS[1]

Option	Percent of Output
Power Steering	88.7
Radio	91.2
Automatic Transmission	95.4
V-8 Engines	84.5
Disk Brakes	87.3
Air Conditioners	73.8
Power Brakes	76.5

SOURCE: *Automotive News Almanac 1974*, pp. 54-60.

[1] Prices were included for all options installed in over 50 percent of U.S. cars in 1974.

APPENDIX E

This appendix presents the results of the scenarios analyzed in Chapter 4 under alternative assumptions about elasticities and gasoline prices. The high estimate of gasoline consumption assumes pre-embargo gasoline prices and relatively inelastic demand; the low estimate assumes post-embargo gasoline prices and relatively elastic demand. These two estimates bracket the range of likely outcomes. Percentage changes are compared with the corresponding base case forecast -- e.g., high consumption estimates are compared with the base forecast using pre-embargo prices.

Table E-1 shows the peak, offpeak, and total national elasticities used to derive the low gasoline consumption forecasts, while Table E-2 shows the corresponding elasticities for the high gasoline consumption forecasts. As described in Appendix C, these elasticities depend on both the elasticity from the short-run demand equation and the long-run adjustment coefficient.

The rest of this appendix presents the estimates of gasoline consumption, emissions and concentrations for these assumptions under the policies analyzed in Chapter 4.

Table E-1

NATIONAL AVERAGE DISAGGREGATED URBAN GASOLINE ELASTICITIES, LOW GASOLINE CONSUMPTION FORECASTS

Year	Peak	Offpeak	Total
1975	-0.221	-0.257	-0.243
1981	-0.808	-0.938	-0.887
1987[1]	-0.915	-1.062	-1.004

[1]All elasticities assume that the price change occurs at the beginning of 1975 and remains in effect throughout the period of analysis.

Table E-2

NATIONAL AVERAGE DISAGGREGATED URBAN GASOLINE ELASTICITIES, HIGH GASOLINE CONSUMPTION FORECASTS

Year	Peak	Offpeak	Total
1975	-0.056	-0.065	-0.061
1981	-0.157	-0.182	-0.192
1987[1]	-0.167	-0.194	-0.183

[1]All elasticities assume that the price change occurs at the beginning of 1974 and remains in effect throughout the period of analysis.

Gasoline Consumption

To determine the sensitivity of our results to the parameter estimates and the price assumptions used, we also performed the analysis under the most extreme cases leading to low gasoline consumption and under the most extreme assumptions leading to high gasoline consumption. The corresponding tables for the estimates leading to low gasoline consumption are Tables E-3, E-4, E-5, and E-6. For the analogous results leading to high gasoline consumption, the results are shown in Tables E-7 through E-10. It can be seen by a comparison of these tables that the results for 1975 are relatively insensitive to the permissible parameter estimates and to the assumption about the price of gasoline. For example, the greatest divergence occurs for a tax of 50 cents per gallon. Practically doubling the price of gasoline leads to reductions, according to these estimates, of between 8 and 22 percent in gasoline consumption. Although this range may seem rather wide, it has in fact been conservatively estimated to cover most possibilities of plausible behavior. By 1981, however, the range is much broader, due to the multiplicative differences in the long-run adjustment coefficient. For example, the plausible range in gasoline consumption in response to a 50 cent per gallon tax ranges from between 112 billion gallons to 30 billion gallons, with the best estimate being about 60 billion gallons. These estimates represent a range of 22 percent reduction to a 70 percent reduction from their respective base forecast levels.

Given the way the peak and offpeak elasticities were constructed, there is not a great deal of difference between elasticities even for the low gasoline consumption estimates. For example, as can be seen in Table E-10, the gap between them in 1987 for a 25 cent per gallon tax is only the difference

Table E-3

LOW ESTIMATE OF GASOLINE CONSUMPTION
UNDER POLICIES AFFECTING GASOLINE DEMAND DIRECTLY
(Billions of Gallons)

Year	Policy	10 Km Cities	35 Km Cities	Rural	Total	As Percentage of Base Line Forecast
1975	$0.10/gal.	17.29	36.43	46.49	100.21	95.6
	$0.25/gal.	16.10	33.93	43.27	93.30	89.0
	$0.50/gal.	14.12	29.76	37.93	81.81	78.1
	Rationing ($0.86/gal.)	11.27	23.75	30.21	65.23	62.2
1981	$0.10/gal.	19.02	39.87	51.14	110.03	84.0
	$0.25/gal.	13.59	28.47	36.44	74.50	56.9
	$0.50/gal.	4.53	9.49	11.94	29.96	22.9
	Rationing ($0.26/gal.)	13.23	27.71	35.45	63.16	48.2
1987	$0.10/gal.	22.81	47.56	61.32	131.69	81.9
	$0.25/gal.	15.24	31.79	40.85	87.88	54.6
	$0.50/gal.	2.63	5.49	6.73	14.86	9.2
	Rationing ($0.25/gal.)	15.24	31.79	40.85	87.88	54.6

Assumes (1) high gasoline prices and (2) high sensitivity.

Table E-4

URBAN GASOLINE CONSUMPTION IN 1975, HIGH SENSITIVITY
(Billions of Gallons)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:$0.10				
PEAK:	7.44435	15.6907	23.135	0.959885
OFF-P:	9.84163	20.7435	30.5851	0.953413
TOTAL	17.286	36.4341	53.7201	0.956189
TAX:$0.25				
PEAK:	6.97769	14.7071	21.6848	0.899714
OFF-P:	9.12028	19.2231	28.3433	0.883532
TOTAL	16.098	33.9301	50.0281	0.890474
TAX:$0.50				
PEAK:	6.19993	13.0678	19.2677	0.799428
OFF-P:	7.91803	16.689	24.6071	0.767063
TOTAL	14.118	29.7568	43.8748	0.780948
RATIONING				
PEAK:	5.07995	10.7071	15.7871	0.655016
OFF-P:	6.1868	13.0401	19.2269	0.599349
TOTAL	11.2667	23.7472	35.014	0.62323

SENSITIVITY: HIGH
PRICE ASSUMPTION: HIGH

Table E-5

URBAN GASOLINE CONSUMPTION IN 1981, HIGH SENSITIVITY
(Billions of Gallons)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:$0.10				
PEAK:	8.29231	17.3763	25.6686	0.853487
OFF-P:	10.7314	22.4872	33.2186	0.829845
TOTAL	19.0237	39.8635	58.8871	0.839987
TAX:$0.25				
PEAK:	6.15707	12.9019	19.059	0.633717
OFF-P:	7.43075	15.5709	23.0016	0.574613
TOTAL	13.5878	28.4728	42.0606	0.599968
TAX:$0.50				
PEAK:	2.59833	5.44471	8.04304	0.267433
OFF-P:	1.92975	4.04372	5.97346	0.149225
TOTAL	4.52807	9.48843	14.0165	0.199936
RATIONING				
PEAK:	6.01472	12.6036	18.6184	0.619065
OFF-P:	7.21071	15.1098	22.3205	0.557597
TOTAL	13.2254	27.7135	40.9389	0.583967

CATEGORY: GAS

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table E-6

URBAN GASOLINE CONSUMPTION IN 1987, HIGH SENSITIVITY
(Billions of Gallons)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:$0.10				
PEAK:	9.96864	20.7849	30.7535	0.834189
OFF-P:	12.8427	26.7774	39.6201	0.807434
TOTAL	22.8114	47.5623	70.3737	0.818912
TAX:$0.25				
PEAK:	6.99646	14.5878	21.5843	0.585473
OFF-P:	8.2484	17.1961	25.4466	0.518585
TOTAL	15.2449	31.786	47.0308	0.54728
TAX:$0.50				
PEAK:	2.04283	4.25936	6.30219	0.170947
OFF-P:	0.591213	1.2327	1.82391	3.71701E-2
TOTAL	2.63405	5.49206	8.1261	9.45604E-2
RATIONING				
PEAK:	6.99646	14.5878	21.5843	0.585473
OFF-P:	8.2484	17.1981	25.4466	0.518585
TOTAL	15.2449	31.786	47.0308	0.54728

SENSITIVITY: HIGH
PRICE ASSUMPTION: HIGH

Table E-7

HIGH ESTIMATE OF GASOLINE CONSUMPTION
UNDER POLICIES AFFECTING GASOLINE DEMAND DIRECTLY
(Billions of Gallons)

Year	Policy	10 Km Cities	35 Km Cities	Rural	Total	As Percentage of Base Line Forecast
1975	$0.10/gal.	18.99	40.02	51.05	110.06	98.4
	$0.25/gal.	18.53	39.07	49.82	107.42	96.1
	$0.50/gal.	17.77	37.47	47.76	103.00	92.1
	Rationing ($2.64/gal.)	11.27	23.75	30.19	65.21	58.3
1981	$0.10/gal.	23.77	49.85	63.89	137.51	95.5
	$0.25/gal.	22.07	46.38	59.41	127.86	88.8
	$0.50/gal.	19.79	40.58	51.94	112.31	78.0
	Rationing ($1.06/gal.)	13.15	27.58	35.20	75.93	52.8
1987	$0.10/gal.	29.55	61.70	79.43	170.68	95.3
	$0.25/gal.	27.36	57.12	73.49	157.97	88.2
	$0.50/gal.	23.69	49.98	63.60	136.77	76.3
	Rationing ($1.06/gal.)	15.50	32.35	41.45	89.30	49.9

Assumes (1) low gasoline prices and (2) low sensitivity.

Table E-8

URBAN GASOLINE CONSUMPTION IN 1975, LOW SENSITIVITY
(Billions of Gallons)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:$0.10				
PEAK:	8.1548	17.1948	25.3496	0.985577
OFF-P:	10.8284	22.8323	33.6608	0.98325
TOTAL	18.9832	40.0272	59.0104	0.984249
TAX:$0.25				
PEAK:	7.9758	16.8174	24.7932	0.963943
OFF-P:	10.5517	22.2489	32.8006	0.958125
TOTAL	18.5275	39.0663	57.5938	0.960621
TAX:$0.50				
PEAK:	7.67746	16.1883	23.8658	0.927886
OFF-P:	10.0906	21.2765	31.3671	0.91625
TOTAL	17.768	37.4648	55.2328	0.921242
RATIONING				
PEAK:	5.12366	10.8035	15.9272	0.619233
OFF-P:	6.14297	12.9528	19.0958	0.557798
TOTAL	11.2666	23.7563	35.0229	0.584156

SENSITIVITY: LOW
PRICE ASSUMPTION: HIGH

Table E-9

URBAN GASOLINE CONSUMPTION IN 1981, LOW SENSITIVITY
(Billions of Gallons)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:$0.10				
PEAK:	10.2357	21.4729	31.7086	0.959285
OFF-P:	13.5304	28.3848	41.9152	0.952715
TOTAL	23.766	49.8577	73.6237	0.955534
TAX:$0.25				
PEAK:	9.58401	20.1059	29.6899	0.898213
OFF-P:	12.5231	26.2716	38.7947	0.881788
TOTAL	22.1071	46.3775	68.4846	0.888835
TAX:$0.50				
PEAK:	8.49794	17.8274	26.3254	0.796426
OFF-P:	10.8443	22.7497	33.5939	0.763577
TOTAL	19.3422	40.5771	59.9193	0.777669
RATIONING				
PEAK:	6.06512	12.7238	18.7889	0.568423
OFF-P:	7.08367	14.8605	21.9442	0.498783
TOTAL	13.1488	27.5843	40.7331	0.528659

SENSITIVITY: LOW

PRICE ASSUMPTION: HIGH

Table E-10

URBAN GASOLINE CONSUMPTION IN 1987, LOW SENSITIVITY
(Billions of Gallons)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:$0.10				
PEAK:	12.7288	26.5809	39.3097	0.956779
OFF-P:	16.8186	35.1214	51.94	0.949805
TOTAL	29.5474	61.7023	91.2497	0.952797
TAX:$0.25				
PEAK:	11.8663	24.7798	36.6461	0.891947
OFF-P:	15.4853	32.3372	47.8226	0.874512
TOTAL	27.3516	57.117	84.4687	0.881992
TAX:$0.50				
PEAK:	10.4288	21.7779	32.2067	0.783895
OFF-P:	13.2633	27.697	40.9603	0.749024
TOTAL	23.6921	49.4749	73.167	0.763983
RATIONING				
PEAK:	7.20876	15.0537	22.2624	0.541857
OFF-P:	8.28583	17.3029	25.5887	0.46793
TOTAL	15.4946	32.3566	47.8511	0.499645

SENSITIVITY: LOW
PRICE ASSUMPTION: HIGH

between a 41 percent reduction and a 48 percent reduction from their pre-tax levels. The excise tax of 50 cents per gallon leads, by 1987, under the assumptions leading to low gasoline consumption, to unrealistically low estimates of gasoline consumption. The implied reduction in gasoline consumption of almost 90 percent from the base line forecasts suggests that this estimate is clearly a lower bound, rather than a realistic estimate in itself. This estimate is unrealistic, at least in part, as a result of the available data, in that without any dramatic increases in price observed over the sample period it is difficult to estimate with great statistical precision the impact of large sustained increases in gasoline prices. This difficulty applies with still greater force to the problems of estimating the long-run adjustment pattern to higher gasoline prices. Consequently, even though the point estimates used to derive the best estimates shown in Tables 4-1 through 4-4 were reasonably precise by conventional statistical criteria, when the confidence intervals are applied to large price increases, the estimates diverge sharply in the later years. Nevertheless, for small increases in the price of gasoline, the estimates give remarkably similar results even by 1987. For example, the effect of a 10 cent per gallon tax ranges between a 5 percent reduction under the most extreme assumptions leading to high gasoline consumption as opposed to a 20 percent reduction under the assumptions leading to the lowest gasoline consumption, by 1987.

Carbon Monoxide Emissions

Tables E-11 to E-13 present the estimates of carbon monoxide emissions corresponding to the low forecast of gasoline consumption. The percentage reduction in emissions is quite similar to that for the corresponding gasoline policies (Table E-4 to Table E-6), with the same tendency for carbon monoxide emissions to fall slightly less rapidly than gasoline consumption. Tables E-14 to E-16 present the estimates corresponding to high gasoline consumption (Tables E-8 to E-10). Again, the pattern is the same as for the medium and low gasoline consumption forecasts.

Hydrocarbon Emissions

Tables E-17 to E-19 show hydrocarbon emissions under the assumptions leading to the minimum gasoline consumption, while Tables E-20 to E-22 show hydrocarbon emissions under the assumptions leading to high gasoline consumption. Again, these emissions follow the same percentage reduction pattern as do the percentage reductions of gasoline consumption shown in the corresponding tables in the text (Chapter 4).

Nitrogen Oxide Emissions

Tables E-23 to E-25 show nitrogen oxide emissions corresponding to the low estimates of gasoline consumption, while Tables E-26 to E-28 show nitrogen oxide emissions corresponding to the high estimates of gasoline consumption. These tables show the same pattern as the medium estimate; i.e., the percentage reductions in nitrogen oxides under the different policies follow the

Table E-11

URBAN CARBON MONOXIDE EMISSIONS IN 1975, HIGH SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	4231.23	9045.12	13276.4	0.961043
OFF-P:	5039.62	10729.3	15768.9	0.953745
TOTAL	9270.85	19774.4	29045.3	0.957067
TAX:$0.25				
PEAK:	3973.76	8495.34	12469.1	0.902608
OFF-P:	4672.93	9948.67	14621.8	0.884365
TOTAL	8646.69	18444.2	27090.9	0.892669
TAX:$0.50				
PEAK:	3544.64	7579.04	11123.7	0.805217
OFF-P:	4061.78	8648.14	12709.9	0.768729
TOTAL	7606.42	16227.2	23833.6	0.785338
RATIONING				
PEAK:	2926.71	6259.57	9186.28	0.664973
OFF-P:	3181.72	6775.07	9956.79	0.602213
TOTAL	6108.43	13034.6	19143.1	0.630781

CATEGORY: CO

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table E-12

URBAN CARBON MONOXIDE EMISSIONS IN 1981, HIGH SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	TO KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	1148	2459.22	3607.22	0.860031
OFF-P:	1251.91	2667.34	3919.25	0.831853
TOTAL	2399.91	5126.56	7526.47	0.845124
TAX:$0.25				
PEAK:	867.455	1859.17	2726.63	0.65008
OFF-P:	872.192	1858.7	2730.89	0.579626
TOTAL	1739.65	3717.87	5457.52	0.612808
TAX:$0.50				
PEAK:	399.874	859.095	1258.97	0.300163
OFF-P:	239.334	510.981	750.315	0.159253
TOTAL	639.208	1370.08	2009.28	0.225616
RATIONING				
PEAK:	848.752	1819.17	2667.92	0.636084
OFF-P:	846.878	1804.79	2651.67	0.562811
TOTAL	1695.63	3623.96	5319.59	0.59732

CATEGORY: CO

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table E-13

URBAN CARBON MONOXIDE EMISSIONS IN 1987, HIGH SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	619.203	1343.09	1962.29	0.847499
OFF-P:	570.134	1231.2	1801.33	0.812219
TOTAL	1189.34	2574.29	3763.63	0.830239
TAX:$0.25				
PEAK:	451.938	980.705	1432.64	0.618748
OFF-P:	372.346	804.286	1176.63	0.530542
TOTAL	824.284	1784.99	2609.28	0.575594
TAX:$0.50				
PEAK:	173.164	376.731	549.895	0.237495
OFF-P:	42.6982	92.7672	135.465	6.10812E-2
TOTAL	215.862	469.498	685.36	0.151187
RATIONING				
PEAK:	451.938	980.705	1432.64	0.618748
OFF-P:	372.346	804.286	1176.63	0.530542
TOTAL	824.284	1784.99	2609.28	0.575594

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table E-14

URBAN CARBON MONOXIDE EMISSIONS IN 1975, LOW SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	4489.32	9600.33	14089.7	0.985994
OFF-P:	5373.53	11444.6	16818.1	0.983371
TOTAL	9862.85	21044.9	30907.8	0.984565
TAX:$0.25				
PEAK:	4393.59	9395.83	13789.4	0.964983
OFF-P:	5237.19	11154.3	16391.5	0.958425
TOTAL	9630.78	20550.1	30180.9	0.961411
TAX:$0.50				
PEAK:	4234.04	9055.01	13289.1	0.929968
OFF-P:	5009.95	10670.5	15680.5	0.91685
TOTAL	9243.99	19725.5	28969.5	0.922821
RATIONING				
PEAK:	2868.28	6137.55	9005.83	0.630228
OFF-P:	3064.84	6528.97	9593.81	0.560959
TOTAL	5933.12	12666.5	18599.6	0.59249

SENSITIVITY: LOW

PRICE ASSUMPTION: HIGH

Table E-15

URBAN CARBON MONOXIDE EMISSIONS IN 1981, LOW SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	1304.4	2796.96	4101.36	0.961107
OFF-P:	1458.56	3110.98	4569.54	0.953274
TOTAL	2762.96	5907.94	8670.9	0.956963
TAX:$0.25				
PEAK:	1225.14	2627.25	3852.39	0.902764
OFF-P:	1351.28	2882.27	4233.55	0.883182
TOTAL	2576.42	5509.52	8085.94	0.892404
TAX:$0.50				
PEAK:	1093.04	2344.39	3437.43	0.805522
OFF-P:	1172.49	2501.09	3673.58	0.766364
TOTAL	2265.53	4845.48	7111.01	0.784806
RATIONING				
PEAK:	797.141	1710.79	2507.93	0.587705
OFF-P:	772.005	1647.24	2419.25	0.504691
TOTAL	1569.15	3358.03	4927.18	0.543787

SENSITIVITY: LOW

PRICE ASSUMPTION: HIGH

Table E-16

URBAN CARBON MONOXIDE EMISSIONS IN 1987, LOW SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	703.617	1528.34	2231.96	0.960248
OFF-P:	669.499	1447.9	2117.4	0.951052
TOTAL	1373.12	2976.24	4349.36	0.955749
TAX:$0.25				
PEAK:	659.895	1433.47	2093.36	0.900622
OFF-P:	617.797	1336.13	1953.93	0.877627
TOTAL	1277.69	2769.6	4047.29	0.889372
TAX:$0.50				
PEAK:	587.024	1275.35	1862.37	0.801243
OFF-P:	531.628	1149.86	1681.49	0.755258
TOTAL	1118.65	2425.21	3543.86	0.778746
RATIONING				
PEAK:	423.793	921.152	1344.95	0.578631
OFF-P:	338.609	732.598	1071.21	0.481144
TOTAL	762.402	1653.75	2416.15	0.530937

SENSITIVITY: LOW

PRICE ASSUMPTION: HIGH

Table E-17

URBAN HYDROCARBON EMISSIONS IN 1975, HIGH SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	563.306	1208.14	1771.45	0.961321
OFF-P:	731.485	1567.88	2299.37	0.953989
TOTAL	1294.79	2776.02	4070.81	0.957166
TAX:$0.25				
PEAK:	529.279	1135.25	1664.53	0.9033
OFF-P:	678.551	1454.46	2133.01	0.88497
TOTAL	1207.83	2589.71	3797.54	0.892912
TAX:$0.50				
PEAK:	472.567	1013.77	1486.34	0.8066
OFF-P:	590.329	1265.44	1855.77	0.769945
TOTAL	1062.9	2279.21	3342.11	0.785826
RATIONING				
PEAK:	390.903	838.844	1229.75	0.667354
OFF-P:	463.289	993.244	1456.53	0.604305
TOTAL	854.192	1832.09	2686.23	0.631623

CATEGORY: HC

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table E-18

URBAN HYDROCARBON EMISSIONS IN 1981, HIGH SENSITIVITY

(Millions of Kilograms)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $0.10				
PEAK:	277.983	594.468	872.451	0.960947
OFF-PEAK:	355.921	760.476	1118.697	0.955853
TOTAL:	633.904	1354.944	1991.148	0.9558078
TAX: $0.25				
PEAK:	261.079	558.258	819.337	0.902445
OFF-PEAK:	329.759	704.489	1034.248	0.883696
TOTAL:	590.838	1262.747	1853.585	0.891887
TAX: $0.50				
PEAK:	232.640	497.828	730.468	0.804562
OFF-PEAK:	286.233	611.456	897.689	0.767016
TOTAL:	518.873	1109.284	1628.157	0.783418
RATIONING:				
PEAK:	169.241	362.271	531.512	0.585425
OFF-PEAK:	188.720	403.188	591.908	0.505746
TOTAL	357.961	765.459	1123.420	0.540554

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table E-19

URBAN HYDROCARBON EMISSIONS IN 1987, HIGH SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	144.774	307.548	452.322	0.840466
OFF-P:	170.612	361.343	531.955	0.809604
TOTAL	315.386	668.891	984.277	0.8235
TAX:$0.25				
PEAK:	103.512	220.024	323.536	0.601167
OFF-P:	110.409	233.897	344.306	0.524013
TOTAL	213.921	453.921	667.842	0.558753
TAX:$0.50				
PEAK:	34.7412	74.1494	108.891	0.202331
OFF-P:	10.0705	21.4861	31.5566	4.80273E-2
TOTAL	44.8116	95.6355	140.447	0.117506
RATIONING				
PEAK:	103.512	220.024	323.536	0.601167
OFF-P:	110.409	233.897	344.306	0.524013
TOTAL	213.921	453.921	667.842	0.558753

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table E-20

URBAN HYDROCARBON EMISSIONS IN 1975, LOW SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	597.551	1282.05	1879.6	0.986095
OFF-P:	779.81	1672.1	2451.91	0.983458
TOTAL	1377.36	2954.15	4331.51	0.984601
TAX:$0.25				
PEAK:	584.899	1254.94	1839.84	0.965235
OFF-P:	760.129	1629.91	2390.04	0.958642
TOTAL	1345.03	2884.85	4229.88	0.961498
TAX:$0.50				
PEAK:	563.813	1209.75	1773.56	0.930464
OFF-P:	727.326	1559.6	2286.93	0.917283
TOTAL	1291.14	2769.35	4060.49	0.922994
RATIONING				
PEAK:	383.317	822.971	1206.29	0.632855
OFF-P:	446.54	957.76	1404.3	0.563263
TOTAL	829.857	1780.73	2610.59	0.593416

SENSITIVITY: LOW

PRICE ASSUMPTION: LOW

Table E-21

URBAN HYDROCARBON EMISSIONS IN 1981, LOW SENSITIVITY

(Millions of Kilograms)

	10 km	35 km	Total	FRACTION OF BASE
TAX: $0.10				
PEAK:	244.518	522.364	766.882	0.859344
OFF-PEAK:	305.520	652.032	957.552	0.832396
TOTAL:	550.038	1174.396	1724.434	0.844169
TAX: $0.25				
PEAK:	184.337	394.055	578.392	0.648128
OFF-PEAK:	213.116	454.723	667.839	0.580549
TOTAL:	397.453	848.778	1246.231	0.610072
TAX: $0.50				
PEAK:	841.428	180.327	264.4698	0.296356
OFF-PEAK:	588.937	125.9853	184.8790	0.160714
TOTAL:	1430.365	306.312	449.348	0.219971
RATIONING:				
PEAK:	180.350	385.569	565.919	0.634151
OFF-PEAK:	206.853	441.615	648.468	0.563710
TOTAL:	387.203	827.184	1214.387	0.594483

SENSITIVITY: LOW

PRICE ASSUMPTION: HIGH

Table E-22

URBAN HYDROCARBON EMISSIONS IN 1987, LOW SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	165.576	352.217	517.793	0.958416
OFF-P:	200.848	426.009	626.857	0.950369
TOTAL	366.424	778.226	1144.65	0.953993
TAX:$0.25				
PEAK:	154.79	329.303	484.093	0.896039
OFF-P:	185.111	392.643	577.754	0.875925
TOTAL	339.901	721.946	1061.85	0.884982
TAX:$0.50				
PEAK:	136.813	291.113	427.926	0.792076
OFF-P:	158.883	337.034	495.917	0.751853
TOTAL	295.696	628.147	923.843	0.769964
RATIONING				
PEAK:	96.5461	205.567	302.113	0.5592
OFF-P:	100.132	212.469	312.601	0.47393
TOTAL	196.678	418.036	614.714	0.512325

SENSITIVITY: LOW

PRICE ASSUMPTION: HIGH

Table E-23

URBAN NITROGEN OXIDES EMISSIONS IN 1975, HIGH SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	348.366	737.14	1085.51	0.960207
OFF-P:	447.965	946.621	1394.59	0.953499
TOTAL	796.331	1683.76	2480.09	0.956423
TAX:$0.25				
PEAK:	326.704	691.323	1018.03	0.900517
OFF-P:	415.192	877.373	1292.57	0.883745
TOTAL	741.896	1568.7	2310.59	0.891057
TAX:$0.50				
PEAK:	290.602	614.96	905.562	0.801034
OFF-P:	360.571	761.96	1122.53	0.767491
TOTAL	651.173	1376.92	2028.09	0.782114
RATIONING				
PEAK:	238.615	504.999	743.614	0.657779
OFF-P:	281.916	595.766	877.682	0.600084
TOTAL	520.531	1100.77	1621.3	0.625237

CATEGORY: NOX

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table E-24

URBAN NITROGEN OXIDES EMISSIONS IN 1981, HIGH SENSITIVITY

	(Millions of Kilograms)			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	167.943	352.719	520.662	0.854159
OFF-P:	213.848	448.77	662.618	0.830022
TOTAL	381.791	801.489	1183.28	0.840472
TAX:$0.25				
PEAK:	124.923	262.391	387.314	0.635398
OFF-P:	148.155	310.919	459.074	0.575054
TOTAL	273.078	573.31	846.388	0.601181
TAX:$0.50				
PEAK:	53.2234	111.844	165.067	0.270797
OFF-P:	38.6672	81.1671	119.834	0.150109
TOTAL	91.8905	193.011	284.902	0.202363
RATIONING				
PEAK:	122.055	256.369	378.424	0.620814
OFF-P:	143.776	301.729	445.505	0.558057
TOTAL	265.831	558.098	823.929	0.585229

CATEGORY: NOX

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table E-25

URBAN NITROGEN OXIDES EMISSIONS IN 1987, HIGH SENSITIVITY

	Millions of Kilograms			FRACTION
	10 KM	35 KM	TOTAL	OF BASE
TAX:$0.10				
PEAK:	84.6256	175.642	260.268	0.832665
OFF-P:	112.544	234.001	346.545	0.807052
TOTAL	197.17	409.643	606.813	0.817842
TAX:$0.25				
PEAK:	59.1259	122.685	181.811	0.581661
OFF-P:	72.1875	150.081	222.268	0.517631
TOTAL	131.313	272.766	404.079	0.544605
TAX:$0.50				
PEAK:	16.6263	34.4239	51.0503	0.163323
OFF-P:	4.92651	10.2141	15.1406	3.52602E-2
TOTAL	21.5529	44.638	66.1909	8.92098E-2
RATIONING				
PEAK:	59.1259	122.685	181.811	0.581661
OFF-P:	72.1875	150.081	222.268	0.517631
TOTAL	131.313	272.766	404.079	0.544605

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table E-26

URBAN NITROGEN OXIDES EMISSIONS IN 1975, LOW SENSITIVITY

	Millions of Kilograms			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	369.819	782.835	1152.65	0.985692
OFF-P:	477.723	1009.9	1487.62	0.983281
TOTAL	847.542	1792.74	2640.28	0.984332
TAX:$0.25				
PEAK:	361.765	765.793	1127.56	0.964232
OFF-P:	465.538	984.142	1449.68	0.958202
TOTAL	827.303	1749.94	2577.24	0.960831
TAX:$0.50				
PEAK:	348.342	737.389	1085.73	0.928463
OFF-P:	445.229	941.213	1386.44	0.916403
TOTAL	793.571	1678.6	2472.17	0.921661
RATIONING				
PEAK:	233.439	494.255	727.694	0.622288
OFF-P:	271.386	573.744	845.13	0.55861
TOTAL	504.825	1068.	1572.82	0.586371

SENSITIVITY: LOW

PRICE ASSUMPTION: LOW

Table E-27

URBAN NITROGEN OXIDES EMISSIONS IN 1981, LOW SENSITIVITY

	Millions of Kilograms			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	191.789	403.25	595.039	0.959471
OFF-P:	249.555	524.293	773.848	0.952765
TOTAL	441.344	927.543	1368.89	0.955668
TAX:$0.25				
PEAK:	179.636	377.702	557.338	0.89868
OFF-P:	230.996	485.304	716.3	0.881912
TOTAL	410.632	863.006	1273.64	0.889172
TAX:$0.50				
PEAK:	159.38	335.123	494.503	0.797362
OFF-P:	200.064	420.323	620.387	0.763823
TOTAL	359.444	755.446	1114.89	0.778344
RATIONING				
PEAK:	114.006	239.744	353.75	0.570404
OFF-P:	130.777	274.764	405.541	0.499304
TOTAL	244.783	514.508	759.291	0.530088

SENSITIVITY: LOW

PRICE ASSUMPTION: LOW

Table E-28

URBAN NITROGEN OXIDES EMISSIONS IN 1987, LOW SENSITIVITY

	Millions of Kilograms			FRACTION OF BASE
	10 KM	35 KM	TOTAL	
TAX:$0.10				
PEAK:	97.4673	202.623	300.09	0.956381
OFF-P:	132.808	276.565	409.373	0.949709
TOTAL	230.275	479.188	709.463	0.95252
TAX:$0.25				
PEAK:	90.8017	188.759	279.561	0.890954
OFF-P:	122.258	254.594	376.852	0.874263
TOTAL	213.06	443.353	656.413	0.881294
TAX:$0.50				
PEAK:	79.6924	165.652	245.344	0.781907
OFF-P:	104.677	217.977	322.654	0.748529
TOTAL	184.369	383.629	567.998	0.76259
RATIONING				
PEAK:	54.8076	113.893	168.701	0.537645
OFF-P:	65.2932	135.954	201.247	0.466876
TOTAL	120.101	249.847	369.948	0.496689

SENSITIVITY: LOW

PRICE ASSUMPTION: LOW

percentage reductions in gasoline consumption almost exactly, except that for the large percentage reduction in gasoline consumption, the percentage reductions in nitrogen oxides are somewhat greater.

Concentrations of Pollutants

Tables E-29 to E-32 show concentrations of the different pollutants under the high elasticity assumptions, while Tables E-33 to E-36 show the same information under the low elasticity assumptions. With the exception of oxidants, these follow the corresponding gasoline consumption tables reasonably closely.

Table E-29

RELATIVE 1 HOUR CARBON MONOXIDE CONCENTRATIONS FOR 13 CITY AVERAGES

(as percentage of base line concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$0.10/gal.	96.2	96.6
	$0.25/gal.	90.4	91.4
	$0.50/gal.	80.8	82.9
	Rationing ($1.27/gal)	67.0	70.6
1981	$0.10/gal.	83.2	88.5
	$0.25/gal.	58.0	71.3
	$0.50/gal.	17.5	42.6
	Rationing ($0.39/gal)	56.4	70.1
1987	$0.10/gal.	79.5	89.7
	$0.25/gal.	48.8	74.4
	$0.50/gal.	8.7	50.5
	Rationing ($0.37/gal)	48.8	74.4

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburgh, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and high sensitivity assumptions.

Table E-30

RELATIVE 8 HOUR CARBON MONOXIDE CONCENTRATIONS FOR 13 CITY AVERAGES

(as percentage of base line concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$0.10/gal.	73.2	77.8
	$0.25/gal.	68.4	73.8
	$0.50/gal.	60.3	67.1
	Rationing ($1.27/gal)	48.6	57.4
1981	$0.10/gal.	62.2	78.9
	$0.25/gal.	40.8	66.9
	$0.50/gal.	7.0	47.4
	Rationing ($0.39/gal)	39.3	66.1
1987	$0.10/gal.	58.8	84.7
	$0.25/gal.	32.2	74.9
	$0.50/gal.	0	63.0
	Rationing ($0.37/gal)	32.2	74.9

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburgh, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and high sensitivity assumptions.

Table E-31

RELATIVE ANNUAL AVERAGE NITROGEN OXIDE CONCENTRATIONS FOR 13 CITY AVERAGES

(as percentage of base line concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$0.10/gal.	95.9	98.8
	$0.25/gal.	89.6	96.9
	$0.50/gal.	79.2	93.8
	Rationing ($1.27/gal)	64.2	89.3
1981	$0.10/gal.	81.6	97.2
	$0.25/gal.	54.1	92.9
	$0.50/gal.	8.2	85.9
	Rationing ($0.39/gal)	52.3	92.7
1987	$0.10/gal.	76.8	98.2
	$0.25/gal.	41.9	95.4
	$0.50/gal.	0.0	92.1
	Rationing ($0.37/gal)	41.9	95.4

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburgh, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and high sensitivity assumptions.

Table E-32

RELATIVE 1 HOUR OXIDANT CONCENTRATIONS
FOR 13 CITY AVERAGES

(as percentage of base line concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$0.10/gal.	78.2	87.3
	$0.25/gal.	62.5	78.5
	$0.50/gal.	67.5	81.2
	Rationing ($1.27/gal)	41.8	75.4
1981	$0.10/gal.	45.6	65.2
	$0.25/gal.	0.6	39.7
	$0.50/gal.	0.2	38.6
	Rationing ($0.39/gal)	48.4	66.8
1987	$0.10/gal.	0.0*	75.3
	$0.25/gal.	0.0*	58.2
	$0.50/gal.	0.0*	58.0
	Rationing ($0.37/gal)	0.0*	74.2

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburgh, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and high sensitivity assumptions.

* Values of 0.0 denote model limitations.

Table E-33

RELATIVE 1 HOUR CARBON MONOXIDE CONCENTRATIONS FOR 13 CITY AVERAGES

(as percentage of base line concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$0.10/gal.	98.6	98.8
	$0.25/gal.	96.6	96.9
	$0.50/gal.	93.1	93.9
	Rationing ($1.27/gal)	63.6	67.5
1981	$0.10/gal.	96.2	97.4
	$0.25/gal.	90.4	93.4
	$0.50/gal.	80.8	86.9
	Rationing ($0.39/gal)	59.3	72.1
1987	$0.10/gal.	96.3	98.1
	$0.25/gal.	90.6	95.3
	$0.50/gal.	81.2	90.6
	Rationing ($0.37/gal)	60.2	80.1

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburgh, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on low gasoline prices and low sensitivity assumptions.

Table E-34

RELATIVE 8 HOUR CARBON MONOXIDE CONCENTRATIONS
FOR 13 CITY AVERAGES

(as percentage of base line concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$0.10/gal.	75.3	79.5
	$0.25/gal.	73.5	78.1
	$0.50/gal.	70.6	75.7
	Rationing ($1.27/gal)	45.7	55.0
1981	$0.10/gal.	73.2	85.0
	$0.25/gal.	68.3	82.3
	$0.50/gal.	60.1	77.7
	Rationing ($0.39/gal)	41.8	67.5
1987	$0.10/gal.	73.2	90.1
	$0.25/gal.	68.4	88.3
	$0.50/gal.	60.2	85.3
	Rationing ($0.37/gal)	42.0	78.5

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburgh, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on low gasoline prices and low sensitivity assumptions.

Table E-35

RELATIVE ANNUAL AVERAGE NITROGEN OXIDE CONCENTRA-
FOR 13 CITY AVERAGES

(as percentage of baseline concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$0.10/gal.	98.5	99.5
	$0.25/gal.	96.2	98.9
	$0.50/gal.	92.3	97.7
	Rationing ($1.27/gal)	59.5	87.9
1981	$0.10/gal.	95.7	99.3
	$0.25/gal.	89.1	98.3
	$0.50/gal.	78.3	96.7
	Rationing ($0.39/gal)	53.9	92.9
1987	$0.10/gal.	95.6	99.6
	$0.25/gal.	88.9	99.1
	$0.50/gal.	77.8	98.2
	Rationing ($0.37/gal)	52.9	96.3

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburgh, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on low gasoline prices and low sensitivity assumptions.

Table E-36

RELATIVE 1 HOUR OXIDANT CONCENTRATIONS
FOR 13 CITY AVERAGES

(as percentage of baseline concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$0.10/gal.	95.4	98.5
	$0.25/gal.	101.3	101.4
	$0.50/gal.	91.2	97.2
	Rationing ($1.27/gal)	44.2	72.2
1981	$0.10/gal.	86.3	97.2
	$0.25/gal.	82.9	96.7
	$0.50/gal.	68.0	93.4
	Rationing ($0.39/gal)	40.6	69.2
1987	$0.10/gal.	82.6	96.5
	$0.25/gal.	85.3	96.6
	$0.50/gal.	56.2	90.8
	Rationing ($0.37/gal)	0.0*	80.0

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburgh, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on low gasoline prices and low sensitivity assumptions.

*Value of 0.0 denote model limitations.

APPENDIX F

This appendix presents the results of the analysis of the policies of Chapter 5, under different assumptions about elasticity and parameter estimates. These assumptions are shown in Table D-1.

Gasoline Consumption

Tables F-1 to F-3 show the detailed gasoline consumption forecasts of the central estimates. These tables were not thought to show enough additional information to warrant inclusion in the text. Tables F-4 to F-7 show gasoline consumption under the assumptions leading to the lowest plausible consumption, while Tables F-8 to F-11 show the corresponding information for the assumptions leading to the highest plausible gasoline consumption. These tables show that, in 1975, the most severe policies lead to a reduction in consumption of between only 4 and 10 percent, although by 1987 the policy of requiring a sales-weighted average of 22.5 miles per gallon leads to a reduction of between 26 and

Table F-1

GASOLINE CONSUMPTION IN 1975, MEDIUM SENSITIVITY
(Billions of Gallons)

		10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:	$50				
	PEAK:	7.77278	16.3882	24.1609	1.00245
	OFF-P:	10.3456	21.8127	32.1583	1.00245
	TOTAL	18.1184	38.2009	56.3192	1.00245
TAX:	$100				
	PEAK:	7.7599	16.361	24.1209	1.00079
	OFF-P:	10.3284	21.7766	32.105	1.00079
	TOTAL	18.0884	38.1376	56.2259	1.00079
TAX:	$200				
	PEAK:	7.73704	16.3128	24.0498	0.997843
	OFF-P:	10.298	21.7124	32.0104	0.997843
	TOTAL	18.035	38.0252	56.0602	0.997843
MPG:	17.5				
	PEAK:	7.7269	16.2914	24.0183	0.996535
	OFF-P:	10.2845	21.6339	31.9685	0.996536
	TOTAL	18.0114	37.9754	55.9868	0.996535
MPG:	20.0				
	PEAK:	7.52642	15.8688	23.3952	0.970681
	OFF-P:	10.0177	21.1214	31.139	0.97068
	TOTAL	17.5441	36.9901	54.5342	0.970681
MPG:	22.5				
	PEAK:	7.31493	15.4228	22.7378	0.943404
	OFF-P:	9.73618	20.5278	30.264	0.943403
	TOTAL	17.0511	35.9507	53.0018	0.943403

SENSITIVITY: MEDIUM
PRICE ASSUMPTION: HIGH

Table F-2

GASOLINE CONSUMPTION IN 1981, MEDIUM SENSITIVITY
(Billions of Gallons)

		10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:	$50				
	PEAK:	9.58665	20.2126	29.7992	0.990831
	OFF-P:	12.7599	26.903	39.6628	0.990832
	TOTAL	22.3465	47.1155	69.462	0.990832
TAX:	$100				
	PEAK:	9.43251	19.8876	29.3201	0.974899
	OFF-P:	12.5547	26.4704	39.0251	0.9749
	TOTAL	21.9872	46.3579	68.3451	0.9749
TAX:	$200				
	PEAK:	9.18645	19.3688	28.5552	0.949468
	OFF-P:	12.2272	25.7799	38.0071	0.949468
	TOTAL	21.4136	45.1486	66.5623	0.949468
MPG:	17.5				
	PEAK:	9.2845	19.5755	28.86	0.959602
	OFF-P:	12.3577	26.055	38.4127	0.959602
	TOTAL	21.6422	45.6305	67.2727	0.959602
MPG:	20.0				
	PEAK:	8.16965	17.225	25.3946	0.844377
	OFF-P:	10.8738	22.9264	33.8003	0.844377
	TOTAL	19.0435	40.1514	59.1949	0.844377
MPG:	22.5				
	PEAK:	7.2367	15.2579	22.4946	0.747952
	OFF-P:	9.63207	20.3083	29.9404	0.747952
	TOTAL	16.8688	35.5662	52.435	0.747952

SENSITIVITY: MEDIUM
PRICE ASSUMPTION: HIGH

Table F-3

GASOLINE CONSUMPTION IN 1987, MEDIUM SENSITIVITY
(Billions of Gallons)

		10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:	$50				
	PEAK:	11.5375	24.3258	35.8633	0.972791
	OFF-P:	15.3565	32.3776	47.7341	0.972791
	TOTAL	26.894	56.7034	83.5973	0.972791
TAX:	$100				
	PEAK:	11.2665	23.7544	35.0209	0.949942
	OFF-P:	14.9957	31.6171	46.6129	0.949942
	TOTAL	26.2623	55.3715	81.6338	0.949942
TAX:	$200				
	PEAK:	10.828	22.8298	33.6577	0.912966
	OFF-P:	14.4121	30.3865	44.7985	0.912966
	TOTAL	25.24	53.2162	78.4563	0.912966
MPG:	17.5				
	PEAK:	11.184	23.5804	34.7644	0.942985
	OFF-P:	14.8859	31.3856	46.2715	0.942985
	TOTAL	26.0699	54.966	81.0359	0.942985
MPG:	20.0				
	PEAK:	9.23152	19.4638	28.6953	0.77836
	OFF-P:	12.2872	25.9063	38.1935	0.77836
	TOTAL	21.5187	45.3701	66.8883	0.77836
MPG:	22.5				
	PEAK:	7.57105	15.9628	23.5339	0.638357
	OFF-P:	10.0771	21.2466	31.3237	0.638357
	TOTAL	17.6481	37.2094	54.8575	0.638357

SENSITIVITY: MEDIUM
PRICE ASSUMPTION: HIGH

Table F-4

LOW ESTIMATE OF GASOLINE CONSUMPTION
UNDER POLICIES AFFECTING NEW-CAR SALES
(Billions of Gallons)

Year	Policy	10 Km Cities	35 Km Cities	Rural	Total	As Percentage of Base line Forecast
1975	$50/MPG	18.10	38.17	48.68	104.95	100.2[1]
	$100/MPG	18.07	38.09	48.58	104.74	100.0[1]
	$200/MPG	17.99	37.94	48.38	104.31	99.6
	17.5 SWMPG	17.94	37.83	48.24	104.01	99.3
	20.0 SWMPG	16.93	35.69	45.51	98.13	93.7
	22.5 SWMPG	16.27	34.29	43.73	94.29	90.0
1981	$50/MPG	22.15	46.70	59.55	128.40	98.2
	$100/MPG	21.68	45.71	58.29	125.67	96.1
	$200/MPG	20.79	43.83	55.89	120.54	92.2
	17.5 SWMPG	21.50	45.33	57.81	124.64	95.3
	20.0 SWMPG	17.81	37.54	47.87	103.22	78.9
	22.5 SWMPG	15.56	32.81	41.84	90.22	69.0
1987	$50/MPG	26.55	55.99	71.40	153.94	96.0
	$100/MPG	25.75	54.28	69.22	149.25	93.1
	$200/MPG	24.17	50.96	64.99	140.12	87.4
	17.5 SWMPG	25.48	53.72	68.51	147.72	92.2
	20.0 SWMPG	18.69	39.42	50.26	108.38	67.6
	22.5 SWMPG	13.93	29.37	37.45	80.74	50.4

NOTE: Detail may not add to total because of independent rounding.

[1]Figure negligibly less than corresponding baseline figure, but rounding error causes the discrepancy.

Table F-5

GASOLINE CONSUMPTION IN 1975, HIGH SENSITIVITY
(Billions of Gallons)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	7.76686	16.3757	24.1425	1.00169
OFF-P:	10.3377	21.7961	32.1338	1.00169
TOTAL	18.1046	38.1718	56.2763	1.00169
TAX: $100				
PEAK:	7.75124	16.3428	24.094	0.999676
OFF-P:	10.3169	21.7523	32.0692	0.999675
TOTAL	18.0682	38.095	56.1632	0.999675
TAX: $200				
PEAK:	7.71928	16.2754	23.9946	0.995552
OFF-P:	10.2744	21.6626	31.9369	0.995552
TOTAL	17.9936	37.9379	55.9316	0.995552
MPG: 17.5				
PEAK:	7.69707	16.2286	23.9256	0.992689
OFF-P:	10.2448	21.6002	31.8451	0.992689
TOTAL	17.9419	37.8288	55.7707	0.992689
MPG: 20.0				
PEAK:	7.26201	15.3113	22.5733	0.93658
OFF-P:	9.66576	20.3793	30.0451	0.93658
TOTAL	16.9278	35.6906	52.6184	0.93658
MPG: 22.5				
PEAK:	6.9777	14.7118	21.6895	0.899911
OFF-P:	9.28733	19.5815	28.8688	0.899911
TOTAL	16.265	34.2933	50.5583	0.899911

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table F-6

GASOLINE CONSUMPTION IN 1981, HIGH SENSITIVITY
(Billions of Gallons)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	9.50192	20.0339	29.5358	0.982074
OFF-P:	12.6471	26.6652	39.3123	0.982074
TOTAL	22.149	46.6991	68.8481	0.982074
TAX: $100				
PEAK:	9.29982	19.6078	28.9076	0.961185
OFF-P:	12.3781	26.098	38.4761	0.961186
TOTAL	21.6779	45.7058	67.3837	0.961186
TAX: $200				
PEAK:	8.9176	18.8019	27.7195	0.921681
OFF-P:	11.8693	25.0254	36.8947	0.921681
TOTAL	20.7869	43.8273	64.6142	0.921681
MPG: 17.5				
PEAK:	9.22397	19.4479	28.6718	0.953346
OFF-P:	12.2771	25.8852	38.1623	0.953346
TOTAL	21.5011	45.333	66.8341	0.953346
MPG: 20.0				
PEAK:	7.63861	16.1053	23.7439	0.789491
OFF-P:	10.167	21.4362	31.6032	0.789491
TOTAL	17.8056	37.5415	55.3471	0.789491
MPG: 22.5				
PEAK:	6.67651	14.0768	20.7533	0.690052
OFF-P:	8.88644	18.7362	27.6227	0.690052
TOTAL	15.563	32.813	48.376	0.690052

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table F-7

GASOLINE CONSUMPTION IN 1987, HIGH SENSITIVITY
(Billions of Gallons)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	11.3917	24.0184	35.4101	0.960499
OFF-P:	15.1624	31.9685	47.1309	0.960499
TOTAL	26.5541	55.9869	82.541	0.960499
TAX: $100				
PEAK:	11.0448	23.2869	34.3317	0.931248
OFF-P:	14.7007	30.9949	45.6956	0.931248
TOTAL	25.7455	54.2819	80.0273	0.931248
TAX: $200				
PEAK:	10.369	21.8621	32.2311	0.874269
OFF-P:	13.8012	29.0985	42.8997	0.874268
TOTAL	24.1702	50.9606	75.1307	0.874268
MPG: 17.5				
PEAK:	10.9313	23.0476	33.9789	0.921677
OFF-P:	14.5496	30.6764	45.2259	0.921677
TOTAL	25.4808	53.7239	79.2048	0.921677
MPG: 20.0				
PEAK:	8.0201	16.9096	24.9297	0.676218
OFF-P:	10.6748	22.5067	33.1815	0.676219
TOTAL	18.6949	39.4164	58.1112	0.676219
MPG: 22.5				
PEAK:	5.97496	12.5976	18.5726	0.503782
OFF-P:	7.95269	16.7675	24.7202	0.503782
TOTAL	13.9277	29.3651	43.2928	0.503782

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table F-8

HIGH ESTIMATE OF GASOLINE CONSUMPTION
UNDER POLICIES AFFECTING NEW-CAR SALES
(Billions of Gallons)

Year	Policy	10 Km Cities	35 KM Cities	Rural	Total	As Percentage of Base line Forecast
1975	$50/MPG	19.34	40.77	51.99	112.10	100.3[1]
	$100/MPG	19.32	40.73	51.94	111.99	100.2[1]
	$200/MPG	19.23	40.55	51.71	111.49	99.7
	17.5 SWMPG	19.26	40.60	51.77	111.63	99.8
	20.0 SWMPG	18.98	40.00	51.01	109.98	98.4
	22.5 SWMPG	18.53	39.08	49.83	107.44	96.1
1981	$50/MPG	24.61	51.89	66.17	142.67	99.3
	$100/MPG	24.32	51.27	65.38	140.97	98.1
	$200/MPG	23.75	50.07	63.84	137.66	95.8
	17.5 SWMPG	24.00	50.60	64.53	139.14	96.8
	20.0 SWMPG	22.03	46.45	59.24	127.73	88.9
	22.5 SWMPG	20.07	42.32	53.96	116.35	81.0
1987	$50/MPG	30.11	63.49	80.97	174.57	97.7
	$100/MPG	29.60	62.40	79.58	171.58	96.1
	$200/MPG	28.58	60.26	76.85	165.69	92.8
	17.5 SWMPG	29.49	62.17	79.28	170.94	91.7
	20.0 SWMPG	26.10	55.04	70.19	151.33	84.7
	22.5 SWMPG	22.77	48.01	61.23	132.02	73.9

NOTES: Detail may not add to total because of independent rounding. Assumptions: low sensitivity, low prices.

[1]Consumption under the policy is estimated to be slightly less than the baseline forecast, but rounding error causes the discrepancy.

Table F-9

GASOLINE CONSUMPTION IN 1975, LOW SENSITIVITY
(Billions of Gallons)

	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	8.29553	17.4904	25.7859	1.00254
OFF-P:	11.0414	23.2797	34.3211	1.00254
TOTAL	19.2369	40.77	60.1069	1.00254
TAX: $100				
PEAK:	8.28724	17.4729	25.7601	1.00154
OFF-P:	11.0303	23.2564	34.2868	1.00154
TOTAL	19.3176	40.7293	60.0469	1.00154
TAX: $200				
PEAK:	8.25039	17.3952	25.6456	0.997083
OFF-P:	10.9813	23.153	34.1343	0.997082
TOTAL	19.2317	40.5482	59.7799	0.997083
MPG: 17.5				
PEAK:	8.26097	17.4175	25.6785	0.998362
OFF-P:	10.9954	23.1827	34.1781	0.998361
TOTAL	19.2563	40.6002	59.8565	0.998361
MPG: 20.0				
PEAK:	8.1388	17.1599	25.2987	0.983596
OFF-P:	10.8327	22.8398	33.6726	0.983596
TOTAL	18.9715	39.9997	58.9713	0.983596
MPG: 22.5				
PEAK:	7.95113	16.7642	24.7153	0.960916
OFF-P:	10.583	22.3132	32.8962	0.960916
TOTAL	18.5341	39.0774	57.6115	0.960916

SENSITIVITY: LOW

PRICE ASSUMPTION: LOW

Table F-10

GASOLINE CONSUMPTION IN 1981, LOW SENSITIVITY
(Billions of Gallons)

		10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:	$50				
	PEAK:	10.5581	22.2607	32.8188	0.992873
	OFF-P:	14.0528	29.6291	43.6819	0.992873
	TOTAL	24.6109	51.8898	76.5007	0.992873
TAX:	$100				
	PEAK:	10.4323	21.9955	32.4278	0.981043
	OFF-P:	13.8854	29.276	43.1614	0.981043
	TOTAL	24.3177	51.2715	75.5892	0.981043
TAX:	$200				
	PEAK:	10.1868	21.4779	31.6648	0.957959
	OFF-P:	13.5587	28.5872	42.1459	0.957959
	TOTAL	23.7455	50.0651	73.8106	0.957959
MPG:	17.5				
	PEAK:	10.2965	21.7092	32.0057	0.968273
	OFF-P:	13.7047	28.895	42.5996	0.968273
	TOTAL	24.0011	50.6041	74.6053	0.968273
MPG:	20.0				
	PEAK:	9.45219	19.9291	29.3812	0.888876
	OFF-P:	12.5809	26.5256	39.1065	0.888876
	TOTAL	22.0331	46.4547	68.4878	0.888876
MPG:	22.5				
	PEAK:	8.61012	18.1536	26.7637	0.809688
	OFF-P:	11.4601	24.1625	35.6226	0.809688
	TOTAL	20.0702	42.3161	62.3863	0.809688

SENSITIVITY: LOW

PRICE ASSUMPTION: HIGH

Table F-11

GASOLINE CONSUMPTION IN 1987, LOW SENSITIVITY
(Billions of Gallons)

		10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:	$50				
	PEAK:	12.9185	27.2375	40.1561	0.977378
	OFF-P:	17.1946	36.2532	53.4478	0.977379
	TOTAL	30.1132	63.4908	93.6039	0.977379
TAX:	$100				
	PEAK:	12.6972	26.7709	39.4681	0.960632
	OFF-P:	16.9	35.6321	52.5321	0.960633
	TOTAL	29.5972	62.4029	92.0001	0.960633
TAX:	$200				
	PEAK:	12.2614	25.852	38.1134	0.927661
	OFF-P:	16.32	34.4091	50.729	0.927661
	TOTAL	28.5814	60.2611	88.8424	0.927661
MPG:	17.5				
	PEAK:	12.6501	26.6715	39.3215	0.957066
	OFF-P:	16.8373	35.4998	52.337	0.957066
	TOTAL	29.4873	62.1712	91.6586	0.957066
MPG:	20.0				
	PEAK:	11.1987	23.6113	34.81	0.847257
	OFF-P:	14.9054	31.4267	46.3321	0.847257
	TOTAL	26.1041	55.038	81.1421	0.847257
MPG:	22.5				
	PEAK:	9.76959	20.5983	30.3678	0.739138
	OFF-P:	13.0033	27.4163	40.4197	0.739138
	TOTAL	22.7729	48.0146	70.7875	0.739138

SENSITIVITY: LOW

PRICE ASSUMPTION: HIGH

50 percent. The policies imposing excise taxes on new cars have very little effect. By 1987 a tax of $200 per mile per gallon below 20 results in a decrease in consumption of between 7 and 13 percent.

Emissions

Tables F-12 to F-29 present the estimates of urban emissions of carbon monoxide, hydrocarbons, and nitrogen oxides, under the assumptions that lead to high and low estimates of gasoline consumption, for the three years 1975, 1981,and 1987. The patterns shown in these tables follow quite closely the patterns discussed in Chapter 5, except that, of course, the levels of emissions depend on the vehicle miles traveled implied by the corresponding gasoline forecasts.

Concentrations

Tables F-30 to F-33 present the estimated concentrations of the different pollutants corresponding to the low estimates of gasoline consumption, while Tables F-34 to F-37 show the corresponding information for the high estimates of gasoline consumption. With the exception of oxidants, these reflect the changes in gasoline consumption.

Table F-12

URBAN CARBON MONOXIDE EMISSIONS IN 1975, HIGH SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	4460.92	9538.74	13999.7	1.0134
OFF-P:	5353.89	11401.9	16755.8	1.01343
TOTAL	9814.81	20940.6	30755.5	1.01342
TAX: $100				
PEAK:	4478.62	9576.55	14055.2	1.01742
OFF-P:	5375.3	11447.4	16822.7	1.01748
TOTAL	9853.92	21024.	30877.9	1.01745
TAX: $200				
PEAK:	4508.59	9640.53	14149.1	1.02422
OFF-P:	5411.68	11524.8	16936.5	1.02436
TOTAL	9920.27	21165.3	31085.6	1.0243
MPG: 17.5				
PEAK:	4500.18	9622.57	14122.8	1.02231
OFF-P:	5401.56	11503.3	16904.9	1.02245
TOTAL	9901.74	21125.9	31027.6	1.02239
MPG: 20.0				
PEAK:	4364.86	9333.09	13698.	0.991562
OFF-P:	5239.73	11158.5	16398.2	0.991808
TOTAL	9604.59	20491.6	30096.2	0.991696
MPG: 22.5				
PEAK:	4272.21	9134.81	13407.	0.970502
OFF-P:	5129.17	10922.9	16052.1	0.970871
TOTAL	9401.38	20057.7	29459.1	0.970703

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table F-13

URBAN CARBON MONOXIDE EMISSIONS IN 1981, HIGH SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	1757.5	3772.78	5530.28	1.31853
OFF-P:	2044.79	4368.61	6413.4	1.36123
TOTAL	3802.29	8141.39	11943.7	1.34112
TAX: $100				
PEAK:	1803.34	3870.12	5673.46	1.35266
OFF-P:	2102.82	4491.55	6594.37	1.39964
TOTAL	3906.16	8361.67	12267.8	1.37752
TAX: $200				
PEAK:	1863.43	3997.32	5860.75	1.39732
OFF-P:	2180.58	4655.93	6836.51	1.45104
TOTAL	4044.01	8653.25	12697.3	1.42574
MPG: 17.5				
PEAK:	1973.81	4233.87	6207.68	1.48003
OFF-P:	2310.78	4933.69	7244.47	1.53762
TOTAL	4284.59	9167.56	13452.2	1.5105
MPG: 20.0				
PEAK:	2105.54	4511.61	6617.15	1.57766
OFF-P:	2486.1	5303.34	7789.44	1.65329
TOTAL	4591.64	9814.95	14406.6	1.61767
MPG: 22.5				
PEAK:	2211.77	4735.51	6947.28	1.65637
OFF-P:	2627.84	5602.12	8229.96	1.74679
TOTAL	4839.61	10337.6	15177.2	1.7042

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table F-14

URBAN CARBON MONOXIDE EMISSIONS IN 1987, HIGH SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	715.059	1568.12	2283.18	0.986087
OFF-P:	686.946	1499.95	2186.9	0.986069
TOTAL	1402.01	3068.07	4470.08	0.986078
TAX: $100				
PEAK:	701.808	1539.06	2240.87	0.967814
OFF-P:	674.216	1472.15	2146.37	0.967794
TOTAL	1376.02	3011.21	4387.23	0.967804
TAX: $200				
PEAK:	674.051	1478.19	2152.24	0.929536
OFF-P:	647.55	1413.93	2061.48	0.929519
TOTAL	1321.6	2892.12	4213.72	0.929528
MPG: 17.5				
PEAK:	725.986	1592.09	2318.08	1.00116
OFF-P:	697.442	1522.87	2220.31	1.00114
TOTAL	1423.43	3114.96	4538.39	1.00115
MPG: 20.0				
PEAK:	596.171	1307.4	1903.57	0.822138
OFF-P:	572.732	1250.56	1823.29	0.82212
TOTAL	1168.9	2557.96	3726.86	0.822129
MPG: 22.5				
PEAK:	481.217	1055.31	1536.53	0.663614
OFF-P:	462.297	1009.43	1471.73	0.6636
TOTAL	943.514	2064.74	3008.25	0.663607

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table F-15

URBAN CARBON MONOXIDE EMISSIONS IN 1975, LOW SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	4611.42	9860.62	14472.	1.01275
OFF-P:	5534.26	11786.1	17320.4	1.01274
TOTAL	10145.7	21646.7	31792.4	1.01274
TAX: $100				
PEAK:	4625.59	9890.92	14516.5	1.01587
OFF-P:	5551.22	11822.2	17373.4	1.01584
TOTAL	10176.8	21713.1	31889.9	1.01585
TAX: $200				
PEAK:	4635.59	9912.32	14547.9	1.01806
OFF-P:	5563.15	11847.6	17410.8	1.01802
TOTAL	10198.7	21759.9	31958.7	1.01804
MPG: 17.5				
PEAK:	4622.99	9885.37	14508.4	1.01529
OFF-P:	5548.14	11815.6	17363.7	1.01527
TOTAL	10171.1	21701.	31872.1	1.01528
MPG: 20.0				
PEAK:	4628.46	9897.06	14525.5	1.0165
OFF-P:	5554.64	11829.5	17384.1	1.01647
TOTAL	10183.1	21726.6	31909.7	1.01648
MPG: 22.5				
PEAK:	4583.05	9799.97	14383.	1.00652
OFF-P:	5500.11	11713.3	17213.4	1.00648
TOTAL	10083.2	21513.3	31596.4	1.0065

SENSITIVITY: LOW

PRICE ASSUMPTION: LOW

Table F-16

URBAN CARBON MONOXIDE EMISSIONS IN 1981, LOW SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	1803.78	3872.26	5676.04	1.33012
OFF-P:	2098.09	4482.6	6580.69	1.37283
TOTAL	3901.87	8354.86	12256.7	1.35271
TAX: $100				
PEAK:	1861.79	3995.83	5857.62	1.37267
OFF-P:	2169.76	4634.79	6804.55	1.41953
TOTAL	4031.55	8630.62	12662.2	1.39746
TAX: $200				
PEAK:	1979.79	4247.23	6227.02	1.45923
OFF-P:	2315.38	4944.05	7259.43	1.51443
TOTAL	4295.17	9191.28	13486.5	1.48843
MPG: 17.5				
PEAK:	1868.83	4011.62	5880.45	1.37802
OFF-P:	2174.98	4646.61	6821.59	1.42309
TOTAL	4043.81	8658.23	12702.	1.40186
MPG: 20.0				
PEAK:	1977.27	4243.13	6220.4	1.45768
OFF-P:	2306.76	4926.89	7233.65	1.50905
TOTAL	4284.03	9170.02	13454.1	1.48486
MPG: 22.5				
PEAK:	2018.74	4331.17	6349.91	1.48803
OFF-P:	2359.28	5038.16	7397.44	1.54322
TOTAL	4378.02	9369.33	13747.4	1.51723

SENSITIVITY: LOW

PRICE ASSUMPTION: LOW

Table F-17

URBAN CARBON MONOXIDE EMISSIONS IN 1987, LOW SENSITIVITY

		(Millions of Kilograms)			
		10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:	$50				
	PEAK:	723.187	1585.95	2309.14	0.993453
	OFF-P:	694.754	1517	2211.75	0.993432
	TOTAL	1417.94	3102.95	4520.89	0.993443
TAX:	$100				
	PEAK:	712.488	1562.49	2274.98	0.978757
	OFF-P:	684.476	1494.55	2179.03	0.978732
	TOTAL	1396.96	3057.04	4454.	0.978745
TAX:	$200				
	PEAK:	690.437	1514.13	2204.57	0.948464
	OFF-P:	663.291	1448.3	2111.59	0.948443
	TOTAL	1353.73	2962.43	4316.16	0.948454
MPG:	17.5				
	PEAK:	760.095	1666.89	2426.99	1.04415
	OFF-P:	730.211	1594.42	2324.63	1.04413
	TOTAL	1490.31	3261.31	4751.62	1.04414
MPG:	20.0				
	PEAK:	764.908	1677.44	2442.35	1.05076
	OFF-P:	734.835	1604.51	2339.35	1.05074
	TOTAL	1499.74	3281.95	4781.69	1.05075
MPG:	22.5				
	PEAK:	740.587	1624.11	2364.7	1.01736
	OFF-P:	711.469	1553.49	2204.96	1.01733
	TOTAL	1452.06	3177.6	4629.66	1.01734

SENSITIVITY: LOW

PRICE ASSUMPTION: LOW

Table F-18

URBAN HYDROCARBON EMISSIONS IN 1975, HIGH SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	592.743	1271.48	1864.22	1.01167
OFF-P:	775.407	1662.32	2437.73	1.01139
TOTAL	1368.15	2933.8	4301.95	1.01151
TAX: $100				
PEAK:	594.004	1274.13	1868.13	1.01379
OFF-P:	776.975	1665.61	2442.59	1.01341
TOTAL	1370.98	2939.74	4310.72	1.01358
TAX: $200				
PEAK:	596.013	1278.33	1874.34	1.01716
OFF-P:	779.455	1670.78	2450.24	1.01658
TOTAL	1375.47	2949.11	4324.58	1.01683
MPG: 17.5				
PEAK:	595.964	1278.24	1874.2	1.01709
OFF-P:	779.458	1670.81	2450.27	1.0166
TOTAL	1375.42	2949.05	4324.47	1.01681
MPG: 20.0				
PEAK:	573.685	1230.25	1803.94	0.978952
OFF-P:	750.006	1607.38	2357.39	0.978062
TOTAL	1323.69	2837.63	4161.32	0.978448
MPG: 22.5				
PEAK:	558.636	1197.84	1756.48	0.953197
OFF-P:	730.118	1564.55	2294.67	0.952041
TOTAL	1288.75	2762.39	4051.14	0.952542

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table F-19

URBAN HYDROCARBON EMISSIONS IN 1981, HIGH SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	306.557	658.953	965.51	1.081921
OFF-P:	395.904	850.185	1246.09	1.082955
TOTAL	702.461	1509.14	2211.6	1.082500
TAX: $100				
PEAK:	308.874	663.748	972.622	1.089890
OFF-P:	398.841	856.24	1255.08	1.090770
TOTAL	707.715	1519.99	2227.7	1.090382
TAX: $200				
PEAK:	310.519	666.986	977.505	1.095362
OFF-P:	400.886	860.229	1261.12	1.096013
TOTAL	711.405	1527.21	2238.62	1.095726
MPG: 17.5				
PEAK:	334.792	719.333	1054.13	1.181221
OFF-P:	432.951	929.368	1362.32	1.183968
TOTAL	767.743	1648.7	2416.44	1.182764
MPG: 20.0				
PEAK:	324.588	696.318	1020.91	1.143996
OFF-P:	418.862	897.608	1316.47	1.144122
TOTAL	743.45	1593.93	2337.38	1.144064
MPG: 22.5				
PEAK:	321.608	689.187	1010.8	1.132666
OFF-P:	414.687	887.652	1302.34	1.131841
TOTAL	736.295	1576.84	2313.13	1.132199

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table F-20

URBAN HYDROCARBON EMISSIONS IN 1987, HIGH SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	181.981	391.134	573.115	1.06491
OFF-P:	224.427	481.148	705.575	1.07384
TOTAL	406.408	872.282	1278.69	1.06982
TAX: $100				
PEAK:	179.041	384.825	563.866	1.04773
OFF-P:	220.885	473.574	694.459	1.05693
TOTAL	399.926	858.399	1258.33	1.05278
TAX: $200				
PEAK:	172.208	370.141	542.349	1.00775
OFF-P:	212.516	455.64	668.156	1.01689
TOTAL	384.724	825.781	1210.51	1.01277
MPG: 17.5				
PEAK:	189.071	406.473	595.544	1.10659
OFF-P:	233.882	501.605	735.487	1.11937
TOTAL	422.953	908.078	1331.03	1.11361
MPG: 20.0				
PEAK:	153.229	329.366	482.595	0.896717
OFF-P:	189.349	406.014	595.363	0.906107
TOTAL	342.578	735.38	1077.96	0.901879
MPG: 22.5				
PEAK:	123.4	265.232	388.632	0.722123
OFF-P:	152.528	327.04	479.568	0.729874
TOTAL	275.928	592.272	868.2	0.726384

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table F-21

URBAN HYDROCARBON EMISSIONS IN 1975, LOW SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	613.928	1316.94	1930.87	1.01299
OFF-P:	803.191	1721.92	2525.11	1.01282
TOTAL	1417.12	3038.86	4455.98	1.01289
TAX: $100				
PEAK:	614.917	1319.02	1933.94	1.0146
OFF-P:	804.42	1724.49	2528.91	1.01434
TOTAL	1419.34	3043.51	4462.85	1.01445
TAX: $200				
PEAK:	614.537	1318.12	1932.66	1.01393
OFF-P:	803.796	1723.03	2526.83	1.01351
TOTAL	1418.33	3041.15	4459.48	1.01369
MPG: 17.5				
PEAK:	617.299	1324.17	1941.47	1.01855
OFF-P:	807.708	1731.61	2539.32	1.01852
TOTAL	1425.01	3055.78	4480.79	1.01853
MPG: 20.0				
PEAK:	615.144	1319.48	1934.62	1.01496
OFF-P:	804.7	1725.07	2529.77	1.01469
TOTAL	1419.84	3044.55	4464.39	1.01481
MPG: 22.5				
PEAK:	607.818	1303.72	1911.54	1.00285
OFF-P:	795.03	1704.27	2499.3	1.00247
TOTAL	1402.85	3007.99	4410.84	1.00263

SENSITIVITY: LOW

PRICE ASSUMPTION: LOW

Table F-22

URBAN HYDROCARBON EMISSIONS IN 1981, LOW SENSITIVITY

	(Millions of Kilograms) 10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	320.174	688.419	1008.59	1.111304
OFF-P:	414.111	889.585	1303.7	1.113600
TOTAL	734.285	1578.	2312.29	1.112395
TAX: $100				
PEAK:	325.134	698.924	1024.06	1.128349
OFF-P:	420.548	903.202	1323.75	1.130730
TOTAL	745.682	1602.13	2347.81	1.129482
TAX: $200				
PEAK:	332.674	714.731	1047.41	1.154069
OFF-P:	430.078	923.12	1353.2	1.155883
TOTAL	762.752	1637.85	2400.6	1.154881
MPG: 17.5				
PEAK:	359.622	774.148	1133.77	1.249228
OFF-P:	468.16	1007.12	1475.28	1.260164
TOTAL	827.782	1781.27	2609.05	1.255161
MPG: 20.0				
PEAK:	345.387	742.474	1087.86	1.198644
OFF-P:	447.081	960.227	1407.31	1.202103
TOTAL	792.468	1702.7	2495.17	1.200395
MPG: 22.5				
PEAK:	340.819	732.28	1073.1	1.182379
OFF-P:	440.541	945.641	1386.18	1.184056
TOTAL	781.36	1677.92	2459.28	1.183110

SENSITIVITY: LOW

PRICE ASSUMPTION: LOW

Table F-23

URBAN HYDROCARBON EMISSIONS IN 1987, LOW SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	187.634	403.365	590.999	1.09392
OFF-P:	231.954	497.436	729.39	1.10582
TOTAL	419.588	900.801	1320.39	1.10046
TAX: $100				
PEAK:	187.271	402.639	589.91	1.0919
OFF-P:	231.89	497.398	729.288	1.10566
TOTAL	419.161	900.037	1319.2	1.09947
TAX: $200				
PEAK:	182.703	392.845	575.548	1.06532
OFF-P:	226.466	485.818	712.284	1.07988
TOTAL	409.169	878.663	1287.83	1.07333
MPG: 17.5				
PEAK:	217.943	469.006	686.949	1.27152
OFF-P:	272.566	585.403	857.969	1.30076
TOTAL	490.509	1054.41	1544.92	1.28759
MPG: 20.0				
PEAK:	204.205	439.12	643.325	1.19077
OFF-P:	253.341	543.543	796.884	1.20815
TOTAL	457.546	982.663	1440.21	1.20032
MPG: 22.5				
PEAK:	194.971	419.203	614.174	1.13681
OFF-P:	241.511	518.054	759.565	1.15157
TOTAL	436.482	937.257	1373.74	1.14492

SENSITIVITY: LOW

PRICE ASSUMPTION: LOW

Table F-24

URBAN NITROGEN OXIDES EMISSIONS IN 1975, HIGH SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	366.19	775.116	1141.31	1.00957
OFF-P:	474.102	1002.19	1476.29	1.00936
TOTAL	840.292	1777.31	2617.6	1.00945
TAX: $100				
PEAK:	366.377	775.532	1141.91	1.0101
OFF-P:	474.253	1002.53	1476.78	1.0097
TOTAL	840.63	1778.06	2618.69	1.00987
TAX: $200				
PEAK:	366.587	776.016	1142.6	1.01071
OFF-P:	474.353	1002.77	1477.12	1.00993
TOTAL	840.94	1778.79	2619.73	1.01027
MPG: 17.5				
PEAK:	366.135	775.055	1141.19	1.00946
OFF-P:	473.786	1001.57	1475.36	1.00872
TOTAL	839.921	1776.63	2616.55	1.00905
MPG: 20.0				
PEAK:	350.643	742.335	1092.98	0.966816
OFF-P:	453.414	958.571	1411.99	0.965394
TOTAL	804.057	1700.91	2504.96	0.966014
MPG: 22.5				
PEAK:	340.113	720.098	1060.21	0.937832
OFF-P:	439.548	929.307	1368.86	0.935906
TOTAL	779.661	1649.41	2429.07	0.936745

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table F-25

URBAN NITROGEN OXIDES EMISSIONS IN 1981, HIGH SENSITIVITY

		(Millions of Kilograms)			
		10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:	$50				
	PEAK:	195.871	414.322	610.193	1.00104
	OFF-P:	254.814	538.4	793.214	0.993612
	TOTAL	450.685	952.722	1403.41	0.996826
TAX:	$100				
	PEAK:	197.759	418.338	616.097	1.01072
	OFF-P:	257.168	543.394	800.562	1.00282
	TOTAL	454.927	961.732	1416.66	1.00624
TAX:	$200				
	PEAK:	199.58	422.234	621.814	1.0201
	OFF-P:	259.35	548.041	807.391	1.01137
	TOTAL	458.93	970.275	1429.21	1.01515
MPG:	17.5				
	PEAK:	211.11	446.62	657.73	1.07902
	OFF-P:	274.352	579.738	854.09	1.06987
	TOTAL	485.462	1026.36	1511.82	1.07383
MPG:	20.0				
	PEAK:	210.647	445.744	656.391	1.07683
	OFF-P:	273.304	577.613	850.917	1.06589
	TOTAL	483.951	1023.36	1507.31	1.07063
MPG:	22.5				
	PEAK:	212.18	449.071	661.251	1.0848
	OFF-P:	274.929	581.119	856.048	1.07232
	TOTAL	487.109	1030.19	1517.3	1.07772

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table F-26

URBAN NITROGEN OXIDES EMISSIONS IN 1987, HIGH SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	105.397	221.279	326.676	1.04512
OFF-P:	144.395	303.643	448.038	1.04341
TOTAL	249.792	524.922	774.714	1.04413
TAX: $100				
PEAK:	103.882	218.099	321.981	1.0301
OFF-P:	142.32	299.278	441.598	1.02842
TOTAL	246.202	517.377	763.579	1.02913
TAX: $200				
PEAK:	100.386	210.759	311.145	0.995435
OFF-P:	137.53	289.205	426.735	0.993803
TOTAL	237.916	499.964	737.88	0.99449
MPG: 17.5				
PEAK:	108.228	227.223	335.451	1.0732
OFF-P:	148.273	311.798	460.071	1.07144
TOTAL	256.501	539.021	795.522	1.07218
MPG: 20.0				
PEAK:	91.6913	192.506	284.197	0.909222
OFF-P:	125.616	264.154	389.77	0.907717
TOTAL	217.307	456.66	673.967	0.908351
MPG: 22.5				
PEAK:	76.0942	159.76	235.854	0.75456
OFF-P:	104.247	219.218	323.465	0.753302
TOTAL	180.341	378.978	559.319	0.753832

SENSITIVITY: HIGH

PRICE ASSUMPTION: HIGH

Table F-27

URBAN NITROGEN OXIDES EMISSIONS IN 1975, LOW SENSITIVITY

		(Millions of Kilograms)			
		10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX:	$50				
	PEAK:	378.776	801.748	1180.52	1.00953
	OFF-P:	490.433	1036.7	1527.13	1.0094
	TOTAL	869.209	1838.45	2707.66	1.00945
TAX:	$100				
	PEAK:	378.888	801.998	1180.89	1.00984
	OFF-P:	490.518	1036.9	1527.42	1.00958
	TOTAL	869.406	1838.9	2708.3	1.00969
TAX:	$200				
	PEAK:	377.648	799.399	1177.05	1.00655
	OFF-P:	488.794	1033.28	1522.07	1.00605
	TOTAL	866.442	1832.68	2699.12	1.00627
MPG:	17.5				
	PEAK:	379.431	803.137	1182.57	1.01127
	OFF-P:	491.264	1038.46	1529.72	1.01111
	TOTAL	870.695	1841.6	2712.29	1.01118
MPG:	20.0				
	PEAK:	378.551	801.292	1179.84	1.00894
	OFF-P:	490.049	1035.91	1525.96	1.00862
	TOTAL	868.6	1837.2	2705.8	1.00876
MPG:	22.5				
	PEAK:	373.829	791.311	1165.14	0.99637
	OFF-P:	483.879	1022.88	1506.76	0.99593
	TOTAL	857.708	1814.19	2671.9	0.996122

SENSITIVITY: LOW

PRICE ASSUMPTION: LOW

Table F-28

URBAN NITROGEN OXIDES EMISSIONS IN 1981, LOW SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	200.109	423.282	623.391	1.00519
OFF-P:	260.342	550.075	810.417	0.997789
TOTAL	460.451	973.357	1433.81	1.00099
TAX: $100				
PEAK:	202.648	428.672	631.32	1.01797
OFF-P:	263.562	556.896	820.458	1.01015
TOTAL	466.21	985.568	1451.78	1.01354
TAX: $200				
PEAK:	207.749	439.5	647.249	1.04366
OFF-P:	270.03	570.596	840.626	1.03498
TOTAL	477.779	1010.1	1487.88	1.03874
MPG: 17.5				
PEAK:	206.194	436.16	642.354	1.03576
OFF-P:	268.235	566.758	834.993	1.02805
TOTAL	474.429	1002.92	1477.35	1.03139
MPG: 20.0				
PEAK:	212.955	450.485	663.44	1.06976
OFF-P:	276.919	585.129	862.048	1.06136
TOTAL	489.874	1035.61	1525.49	1.065
MPG: 22.5				
PEAK:	213.463	451.58	665.043	1.07235
OFF-P:	277.495	586.364	863.859	1.06359
TOTAL	490.958	1037.94	1528.9	1.06738

SENSITIVITY: LOW

PRICE ASSUMPTION: LOW

Table F-29

URBAN NITROGEN OXIDES EMISSIONS IN 1987, LOW SENSITIVITY

	(Millions of Kilograms)			
	10 KM	35 KM	TOTAL	FRACTION OF BASE
TAX: $50				
PEAK:	106.79	224.205	330.995	1.05487
OFF-P:	146.304	307.657	453.961	1.05315
TOTAL	253.094	531.862	784.956	1.05388
TAX: $100				
PEAK:	105.814	222.155	327.969	1.04523
OFF-P:	144.966	304.843	449.809	1.04352
TOTAL	250.78	526.998	777.778	1.04424
TAX: $200				
PEAK:	103.962	218.267	322.229	1.02694
OFF-P:	142.428	299.507	441.935	1.02525
TOTAL	246.39	517.774	764.164	1.02596
MPG: 17.5				
PEAK:	112.415	236.014	348.429	1.11044
OFF-P:	154.01	323.861	477.871	1.10862
TOTAL	266.425	559.875	826.3	1.10938
MPG: 20.0				
PEAK:	114.009	239.362	353.371	1.12619
OFF-P:	156.194	328.454	484.648	1.12434
TOTAL	270.203	567.816	838.019	1.12512
MPG: 22.5				
PEAK:	111.162	233.383	344.545	1.09806
OFF-P:	152.292	320.249	472.541	1.09625
TOTAL	263.454	553.632	817.086	1.09701

SENSITIVITY: LOW

PRICE ASSUMPTION: LOW

Table F-30

RELATIVE 1 HOUR CARBON MONOXIDE
FOR 13 CITY AVERAGES

(as percentages of base line concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$ 50/MPG	98.3	98.5
	$100/MPG	98.7	98.8
	$200/MPG	99.3	99.4
	17.5 SWMPG	99.2	99.3
	20.0 SWMPG	96.3	96.7
	22.5 SWMPG	94.4	95.0
1981	$ 50/MPG	128.1	119.2
	$100/MPG	131.8	121.7
	$200/MPG	136.7	125.1
	17.5 SWMPG	144.8	130.6
	20.0 SWMPG	156.5	138.6
	22.5 SWMPG	166.0	145.2
1987	$ 50/MPG	92.0	96.0
	$100/MPG	90.4	95.2
	$200/MPG	87.0	93.5
	17.5 SWMPG	93.6	96.8
	20.0 SWMPG	77.7	88.8
	22.5 SWMPG	63.6	81.8

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburg, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and high sensitivity assumptions.

TABLE F-31

RELATIVE 8 HOUR CARBON MONOXIDE

FOR 13 CITY AVERAGES

(as percentages of base line concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$ 50/MPG	95.3	96.1
	$100/MPG	95.6	96.4
	$200/MPG	96.3	96.9
	17.5 SWMPG	96.1	96.8
	20.0 SWMPG	93.4	94.5
	22.5 SWMPG	91.5	92.9
1981	$ 50/MPG	123.9	113.4
	$100/MPG	127.6	115.4
	$200/MPG	132.7	118.3
	17.5 SWMPG	140.6	122.7
	20.0 SWMPG	152.7	129.4
	22.5 SWMPG	162.6	135.0
1987	$ 50/MPG	81.6	93.2
	$100/MPG	80.1	92.6
	$200/MPG	77.1	91.5
	17.5 SWMPG	82.9	93.7
	20.0 SWMPG	68.9	88.5
	22.5 SWMPG	56.4	83.9

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburg, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and high sensitivity assumptions.

Table F-32

RELATIVE ANNUAL AVERAGE NITROGEN OXIDES CONCENTRATIONS FOR 13 CITY AVERAGES

(as percentages of base line concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$ 50/MPG	99.7	99.9
	$100/MPG	99.7	99.9
	$200/MPG	99.7	99.9
	17.5 SWMPG	99.7	99.9
	20.0 SWMPG	95.3	98.6
	22.5 SWMPG	92.3	97.7
1981	$ 50/MPG	98.2	99.7
	$100/MPG	99.1	99.9
	$200/MPG	100.0	100.0
	17.5 SWMPG	105.9	100.9
	20.0 SWMPG	105.9	100.9
	22.5 SWMPG	106.8	101.1
1987	$ 50/MPG	104.6	100.4
	$100/MPG	103.2	100.3
	$200/MPG	99.9	100.0
	17.5 SWMPG	107.8	100.6
	20.0 SWMPG	92.5	99.4
	22.5 SWMPG	78.2	98.3

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburg, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and high sensitivity assumptions.

TABLE F-33

RELATIVE 1 HOUR OXIDANT

FOR 13 CITY AVERAGES
(as percentages of base line concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$ 50/MPG	112.6	102.2
	$100/MPG	112.9	102.4
	$200/MPG	113.4	102.7
	17.5 SWMPG	113.5	102.7
	20.0 SWMPG	106.9	99.0
	22.5 SWMPG	101.9	96.2
1981	$ 50/MPG	331.4	62.8
	$100/MPG	332.4	63.0
	$200/MPG	330.3	63.1
	17.5 SWMPG	383.0	66.8
	20.0 SWMPG	354.9	65.0
	22.5 SWMPG	333.9	64.4
1987	$ 50/MPG	122.8	84.7
	$100/MPG	113.9	84.0
	$200/MPG	194.0	82.4
	17.5 SWMPG	135.3	86.0
	20.0 SWMPG	116.1	78.1
	22.5 SWMPG	7.9	71.6

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburg, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on high gasoline prices and high sensitivity assumptions.

TABLE F-34

RELATIVE 1 HOUR CARBON MONOXIDE

FOR 13 CITY AVERAGES

(as percentages of base line concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$ 50/MPG	98.3	98.4
	$100/MPG	98.5	98.7
	$200/MPG	98.8	98.9
	17.5 SWMPG	98.5	98.7
	20.0 SWMPG	98.6	98.8
	22.5 SWMPG	97.7	98.0
1981	$ 50/MPG	129.2	120.0
	$100/MPG	133.6	123.0
	$200/MPG	142.6	129.1
	17.5 SWMPG	134.0	123.3
	20.0 SWMPG	142.4	129.0
	22.5 SWMPG	146.0	131.5
1987	$ 50/MPG	92.7	96.4
	$100/MPG	91.4	95.7
	$200/MPG	88.7	94.3
	17.5 SWMPG	97.5	98.8
	20.0 SWMPG	98.5	99.3
	22.5 SWMPG	95.9	97.9

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburg, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on low gasoline prices and low sensitivity assumptions.

TABLE F-35

RELATIVE 8 HOUR CARBON MONOXIDE

FOR 13 CITY AVERAGES

(as percentages of base line concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$ 50/MPG	95.2	96.0
	$100/MPG	95.5	96.3
	$200/MPG	95.7	96.4
	17.5 SWMPG	95.5	96.2
	20.0 SWMPG	95.6	96.4
	22.5 SWMPG	94.7	95.6
1981	$ 50/MPG	124.9	113.9
	$100/MPG	129.4	116.4
	$200/MPG	138.3	121.4
	17.5 SWMPG	129.7	116.6
	20.0 SWMPG	138.0	121.2
	22.5 SWMPG	141.6	123.3
1987	$ 50/MPG	82.2	93.4
	$100/MPG	81.0	93.0
	$200/MPG	78.6	92.1
	17.5 SWMPG	86.5	95.0
	20.0 SWMPG	87.4	95.3
	22.5 SWMPG	85.0	94.4

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburg, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on low gasoline prices and low sensitivity assumptions.

Table F-36

RELATIVE ANNUAL AVERAGE NITROGEN OXIDES CONCENTRATIONS FOR 13 CITY AVERAGES

(as percentages of base line concentration

Year	Policy	Light-Duty Vehicle	Total
1975	$ 50/MPG	98.3	99.5
	$100/MPG	98.4	99.5
	$200/MPG	98.0	99.4
	17.5 SWMPG	98.5	99.6
	20.0 SWMPG	98.3	99.5
	22.5 SWMPG	97.1	99.1
1981	$ 50/MPG	97.3	99.6
	$100/MPG	98.5	99.8
	$200/MPG	100.9	100.1
	17.5 SWMPG	100.4	100.1
	20.0 SWMPG	103.8	100.6
	22.5 SWMPG	104.2	100.7
1987	$ 50/MPG	104.1	100.3
	$100/MPG	103.2	100.3
	$200/MPG	101.4	100.1
	17.5 SWMPG	109.7	100.8
	20.0 SWMPG	111.6	100.9
	22.5 SWMPG	109.3	100.7

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburg, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on low gasoline prices and low sensitivity assumptions.

TABLE F-37

RELATIVE 1 HOUR OXIDANT

FOR 13 CITY AVERAGES
(as percentages of base line concentrations)

Year	Policy	Light-Duty Vehicle	Total
1975	$ 50/MPG	113.5	102.7
	$100/MPG	113.8	102.8
	$200/MPG	113.7	102.8
	17.5 SWMPG	114.7	103.4
	20.0 SWMPG	113.9	102.9
	22.5 SWMPG	111.8	101.7
1981	$ 50/MPG	374.2	64.7
	$100/MPG	381.5	65.4
	$200/MPG	388.6	66.4
	17.5 SWMPG	467.5	71.7
	20.0 SWMPG	417.7	68.6
	22.5 SWMPG	405.9	67.8
1987	$ 50/MPG	155.8	85.9
	$100/MPG	162.7	85.9
	$200/MPG	152.9	84.9
	17.5 SWMPG	225.2	88.3
	20.0 SWMPG	152.5	82.0
	22.5 SWMPG	123.8	78.3

The cities for which the concentrations are averaged are:

Portland, ME
New York, NY
Nashville, TN
Pittsburg, PA
Little Rock, AR
Oklahoma City, OK
Tampa, FL
Miami, FL
Spokane, WA
Denver, CO
Seattle, WA
San Francisco, CA
Los Angeles, CA

Note: Based on low gasoline prices and low sensitivity assumptions.

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16. ABSTRACT

A number of policies have been designed to reduce gasoline consumption by automobiles, including: gasoline rationing; increases in the federal excise tax on gasoline; excise taxes on new cars, in inverse proportion to their fuel economy; and regulations to set minimum levels on average fuel economy of new cars.

This study is addressed to two questions dealing with these proposed policies. First, what will be the impact on fuel consumption by automobiles and by other competing modes of transportation, if different levels of these policies are put into effect? Second, what impact would these policies have on emissions and concentrations of automotive pollutants?

The major conclusions of this study are:

- Increases in the federal excise tax on gasoline and gasoline rationing are considerably more effective in conserving fuel than excise taxes and fuel economy restrictions on new cars, especially in the early years of the policies.
- The policies aimed at new cars also lead, within several years of the date of the policy, to significant increases in emissions relative to base case emissions.
- The effect of all of the policies will be small in the first year of the policy, but the effects will become more pronounced over time.

This study presents quantitative estimates of gasoline consumption, automotive emissions and concentrations for several levels of the different policies.

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