APPENDIX A

CASE STUDY OF THE NEW YORK METROPOLITAN REGION

In order to give concreteness to the investigation, the oxidant problem of the New York metropolitan region has been examined in further detail.[20] The entire Northeast has a severe problem with photochemical smog. The national ambient air quality standard for ozone is violated for virtually the entire Northeast region. Summer peak oxidant levels downwind of New York attain levels four to six times the primary standard of.12 ppm. In part, this is the result of the high concentration of population and industry in the area. It has been estimated that over fifty percent of all man-made HC and NO_x emissions are generated in the Northeast region. Transport is also critically important. Prevailing summer winds from the southwest are heavily laden with oxidants and precursors from the mid-Atlantic industrial belt, and carry pollutants from the New York metropolitan region across western Connecticut and Massachusetts, sometimes as far north as southern New Hampshire and Maine. Violations of ambient air quality standards in rural New England area are often entirely attributable to transported materials.[21] NO_x emissions from the New York area are also implicated in the formation of nitric acid and the acidification of precipitation in New England and Canada.

Oxidant control strategy in the New York metropolitan region has concentrated almost entirely on the abatement of hydrocarbon emission. For example, the 1979 revisions to State Implementation Plans, required as policy changes to bring about attainment of national standards, imposed new controls only on hydrocarbon sources. Reasonably Available Control Technologies (RACT) were imposed on fifteen major stationary sources of HC emissions. Vehicle Inspection and Maintenance Programs were either installed or strengthened throughout the region as additional controls on mobile HC emission sources.[22] This policy has been sustained, despite scientific warnings that due to the superabundance of hydrocarbons in the atmosphere, ozone levels seem insensitive to such abatement efforts.[23]

Despite substantial control efforts, there has been little long-term improvement in oxidant measurements in the metropolitan region. Moreover, simulations attempting to estimate the consequences of recent additional abatement measures adopted in 1979, as well as further possible steps aimed mainly at hydrocarbon emissions, indicate that there is little prospect that the region will come into compliance with national standards in the forseeable future.[24]

Isocost-Abatement-Possibilities

In New York, larger reductions in current emissions levels would be required to approach national air quality standards. These cuts would go far beyond those available at small cost into the realm of abatement measures with high and rapidly increasing incremental costs. Consideration of the behavior of these costs is crucial in policy analyses.

Two kinds of information contribute to the derivation of isocost abatement possibilities. The first concerns available control measures relevant to specific kinds of emission sources of hydrocarbons and NO_x, and their cost-effectiveness, in terms of dollars per ton of material removed. Typically, there will be several control options for each emissions source. These will differ both in control efficiency (percentage of uncontrolled emissions removed) and cost. These control options for all sources of a pollutant can be arrayed from cheapest (in cost per ton abated) to most expensive.

In order to derive incremental and total abatement cost schedules from these data, the distribution, or inventory, of emissions by source category must also be known. Such an inventory consists of estimates, in tons per year, of emissions from a disaggregated list of source types that correspond to the categories for which control costs are available. Such an inventory has been compiled for the New York Metropolitan region. There are considerable elements of projection and estimation in these inventories. Even large stationary sources have not been accurately enumerated; smaller ("area") sources are estimated indirectly, through data on population, employment, fuel consumption and other means. Rarely are emissions actually measured. Typically, they are estimated through the use of "emissions factors", which represent average or otherwise representative emissions rates for specific types and sizes of sources. Further, baseline inventories incorporate the projected future effects of past emission control regulations that have not yet fully been reflected in actual emissions levels. An important example is the baseline projection of vehicle emissions, which depends on the scrapping rate of older cars not subject to the federal motor vehicle emissions standards, the growth of new car registrations, the rate of deterioration of emissions control efficiencies as cars age, and changes in traffic volumes and patterns.

The baseline inventories for HC and NO_x are presented in Table A-1 and A-2 respectively.[25] These are intended to reflect changes in emissions resulting from regulations promulgated prior to 1979, but not from the changes made in the 1979 revisions to State Implementation Plans, because those changes are included among the abatement possibilities for which cost-effectiveness calculations have been made. The exception to this distinction in the final reduction in NO_x vehicular emissions standards to 1.0 grams per mile. Although this reduction was mandated in the 1977 Clean Air Act Amendments, its implementation has been .PA

Table A-1. New York Metropolitan Region:
Baseline Hydrocarbons Emissions Inventory

Source Category	Tons/Year
Vehicle Surface Coating	13,831
Metal Can Coating	8,705
Coil Coating	153
Wire Coating	179
Fabric Coating	14,900
Paper Coating	6,110
Metal Furniture Coating	90
Miscellaneous Metal Parts Coating	26,000
Flat Wood Coating	94
Manufacture of Synthetic Pharmaceuticals	13,700
Manufacture of Rubber Tires	1,570
Graphic Arts Processes	3,800
Dry Cleaning	4,200
Degreasing Operations	9,883
Miscellaneous Refinery Losses	4,540
Fixed Roof HC Storage Tanks	8,270
Floating Roof HC Storage Tanks	1,800
Petroleum Bulk Plants	68,495
Gas Terminals	124,537
Gas Stations	47,464
Fuel Combustion	25,031
Other Stationary Sources	212,117
SUBTOTAL	610,458
Vehicle Emissions	164,922
TOTAL	730,391

Table A-2. New York Metropolitan Region:
Baseline NO_x Emissions Inventory

Area & Mobile Sources t/y	Tons/Year
Residential Coal	190
Residential Oil	1,234
Distillate Oil	17,459
Natural Gas	7,459
L.P.G.	122
Wood/Other	9
Commercial Coal	--
Residential Oil	22,071
Distillate Oil	4,793
Natural Gas	3,825
L.P.G.	--
Wood/Other	--
Industrial Coal	--
Residential Oil	7,719
Distillate Oil	13,076
Natural Gas	4,155
L.P.G.	--
Wood/Other	--
Aircraft	10,834
Railroad	7,330
Vessels	15,920
Off-Highway Vehicles (gas, diesel)	45,635
Burning	3,505
TOTAL AREA	165,100
Light-duty Autos	285,180
Trucks	39,321
Heavy-duty Gas	23,418
Diesel	29,944
Motorcycles	2,351
TOTAL MOBILE	380,214

Table A-2. (Continued)

Boilers, electrical generating	314,605
Boilers, industrial	41,387
Boilers, comm./inst.	21,509
Space Heaters, industrial	7
Space Heaters, comm./inst.	3
Other fuel combustion	455
Solid waste/govt.	812
Solid comm./inst.	77
Solid End.	154
Waste Solvent Recovery	
Stationary, i.e., engines	2,335
N.C.R.	306
TOTAL POINT	381,650

postponed and is still not completely certain. The costs of successive reductions from 3.0 to 2.0 and from 2.0 to 1.0 grams per mile have been included in the NO_x incremental abatement cost calculations.

It is clear that the sources of NO_x emissions are more concentrated than those of hydrocarbons. Fuel combustion, mainly in large industrial and electrical utility boilers, accounts for by far the major part of stationary source emissions. Emissions attendant on industrial processes are relatively unimportant. Most of the remaining NO_x emissions stem from internal combustion gasoline or diesel engines, predominantly vehicular. The industrial sources of hydrocarbon emissions are more varied. Substantial evaporative losses to the atmosphere occur during coating operations using petroleum-based solvents, and in degreasing operations using solvents. The bulk of HC losses are transportation-related however, either through direct vehicle emissions or through losses that occur while sorting, transporting, or transferring petroleum products. For both HC and NO_x, substantial aggregate emissions are attributable to a variety of relatively small, "area sources" and estimated with considerable imprecision.

Complementary to these data is information on the possibilities for abatement of emissions, category by category, and the associated resources costs. Estimates of control efficiencies and costs are very approximate, and their inaccuracy reflects the inherent limitations of the regulatory processes. This information is rarely tendered by regulated sources, for whom such data are internal, if not confidential. Estimates are made by the regulatory agencies or their consultants, and invariably represent conditions facing average, representative or typical sources within a category, since efforts to estimate cost-effectiveness for the "typical" example may be quite inaccurate even when categories are narrowly defined. The actual data available refer to rather broad categories as Table A-1 and A-2 demonstrate. The estimates, incremental abatement cost curves and isocost curves derived from them, should thus be regarded as approximate figures indicating general tendencies.

Incremental costs schedules for hydrocarbon and NO_x abatement are presented in Tables A-3 and A-4, respectively.[26] Each control measure has two dimensions: an estimated cost per ton abated, and an estimate of the tonnages that can be controlled by the measure. The costs include annualized capital costs and annual operating, maintenance and other costs, including credits for materials recovery and penalties for energy losses.

Both incremental cost schedules share two distinctive features. The first is that some emissions can be abated at negative cost. Substantial tonnages of hydrocarbons emissions can be prevented at actual cost savings, because for evaporative losses from bulk storage facilities and other high-volume operations, the value of the hydrocarbon material recovered would exceed the cost of the equipment needed for recovery. Savings from abatement of NO_x emissions from fuel combustion arise from improvements in burner efficiency. The second distinctive

Table A-3. Incremental Cost Schedule for Hydrocarbon Abatement in the NY Metropolitan Region

Source Category	Cost ($/ton)	Tons/Year
petroleum tank truck terminals	-273	123,292
cutback asphalt	-128	8,214
dry cleaning	-111	2,110
refinery leakages	-107	1,777
misc. refinery sources	- 88	2,033
degreasing operations	- 80	2,965
gasoline bulk storage	14	55,481
rotogravure & printing	18	2,470
upgraded vehicle I & M (NJ)	30	15,384
automobile coating	38	11,203
paper coating	53	5,988
fabric coating	59	14,155
coil coating	91	138
can coating	108	7,834
wire coating	137	170
flat wood coating	317	82
gas stations	331	23,732
misc. metal parts coating	359	20,800
metal furniture coating	563	81
can coating	754	783
coil coating	1016	7
gas stations	1100	17,562
new I & M program (CT)	1139	8,061
auto coating	1428	1,245
new I & M program (NY)	1720	4,728
intensified I & M, regional	2653	3,180
auto coating	4150	691
bulk storage	5800	12,329
advanced I & M, regional	5982	3,817

Table A-4. Incremental Cost Schedule for NO_x Abatement in the NY Region

Source Category	Abatement Level or Method	Cost $/t	Tons/ Year
industrial boilers, residual oil	LEA	-2306	3,559
industrial boilers, distillate oil	LEA	-1554	83
industrial boilers, natural gas	LEA	-1225	497
commercial boilers, natural gas	LEA	-1225	108
commercial boilers, distillate oil	LEA	-1000	387
utility boilers, oil & gas	LEA	- 487	45,303
industrial process furnaces	LEA	- 397	41
utility boilers, coal	LEA	- 173	1,258
non-utility boilers, oil & gas	SCA	0	13,507
utility boilers, coal	LNB	72	3,775
industrial boilers, natural gas	RAP	87	248
industrial process furnaces	ABD	101	41
heavy-duty diesel vehicles		152	22,458
stationary i.c. engines	SCR (dry)	245	2,101
heavy-duty gas vehicles		343	17,563
utility boilers, oil & gas	SCA	441	75,505
non-utility boilers, natural gas	RAP & SCA	490	1,263
utility boilers, oil & gas	SCR (PF)	508	60,404
industrial boilers, residual oil	LNB	665	7,119
light-duty vehicles	EGR	785	94,109
industrial boilers, residual oil	NH_3 Inj.	890	1,780
industrial boilers, residual oil (area)	NH_3 Inj.	980	3,859

Table A-4. (continued)

Source Category	Abatement Level or Method	Cost $/t	Tons/ Year
industrial process furnaces	SCR (dry)	1037	66
industrial process furnaces	RAP & FGR	1079	745
utility boilers, oil & gas	SCR (MB)	1133	30,202
utility boilers, coal	SCR (dry)	1230	6,292
industrial boilers, distillate oil	LNB	1398	166
light-duty vehicles, advanced I&M programs		1400	15,280
industrial boilers, residual oil	SCR (MB)	1816	14,237
industrial boilers, distillate oil	FGR	1833	41
commercial boilers, residual oil (area)	NH_3 Inj.	1880	11,036
utility boilers, oil and gas	NH_3 Inj.	2250	60,404
light-duty vehicles, advanced emissions controls		2276	87,860
non-utility boilers, natural gas	SCR (FPB)	2812	1,067
industrial boilers, distillate oil	RAP & LNB	2958	124
industrial area sources distillate oil	LNB	3206	6,538
commercial boilers, residual oil	NH_3 Inj.	3250	3,925
industrial boilers, distillate oil	RAP & FGR	3484	41
light-duty trucks, advanced NO_x controls		3520	9,830
industrial area sources, distillate oil	FGR	3564	654
industrial area sources, natural gas	RAP & LNB	3650	2,908
industrial area sources, natural gas	RAP & FGR	4243	208
commercial area sources, natural gas	RAP & LNB	4460	2,678
commercial area sources, distillate oil	LNB	6194	2,396

Table A-4. (continued)

Source Category	Abatement Level or Method	Cost $/t	Tons/ Year
commercial boilers, distillate oil	FGR	7333	1,742
industrial boilers, distillate oil	SCR (FRB)	10117	124
transport controls		17200	1,670
commercial boilers, residual oil	SCR(PF)	20434	6,281
commercial boilers, distillate oil	SCR (PFB)	40857	1,355

Control Device Abbreviations and Codes

	Codes
LEA = Low Excess Air	01
SCA = Staged Combustion Air	02
LNB = Low NO_x Burners	03
NH_3 Inj. = Ammonia Injection	04
SCR (PF) = Selective Catalytic Reduction (Parallel Flow)	05
SCR (MB) = Selective Catalytic Reduction (Moving Bed)	06
FGR = Flue Gas Recirculation	07
RAP = Reduced Air Preheat	08
RAP + FGR	09
RAP + LNB	10
SCR (FPB) = Selective Catalytic Reduction (Fixed Pack Bed)	11
RAP + SCA	12
RAP + NH_3 Inj.	13
Dry SCR	14
Water Injection	15
Fine Tuning and Changing the Air/Fuel Ratio	16
Advanced Design Burner	17
Chilled Absorption	18

feature of both incremental cost schedules is that the insert incremental costs mount very rapidly after "easy" abatement possibilities have been exhausted, and more technologically complex and capital-intensive abatement methods have to be employed.

These features give definite form to the isocost abatement possibilities functions. Examples of such functions for the New York metropolitan region are provided in Figure a-1. Isocost schedules bend outward from the axes, reflecting the cost savings that can be obtained from the initial increments of abatement of both pollutants. This makes it likely that it would be cost-effective to control both precursors to some extent, but a mixed control strategy would still not necessarily be efficient, since reduced emissions, especially of NO_x, can sometimes increase ozone concentrations.

Isocost curves are also severely bowed out, at higher expenditure levels nearly squared off in shape, because marginal abatement costs rise so rapidly for both precursors. This feature also militates against a strategy of controlling only one precursor to reduce ozone concentrations. Finally, also because of rapidly increasing incremental costs, there are sharply diminishing returns to rising expenditures on precursor abatement. A substantial reduction in emissions can be obtained for zero net expenditures, because of the cost savings obtainable on initial abatement possibilities. However, expenditure of as much as $100 million in annualized costs obtains relatively little additional abatement.

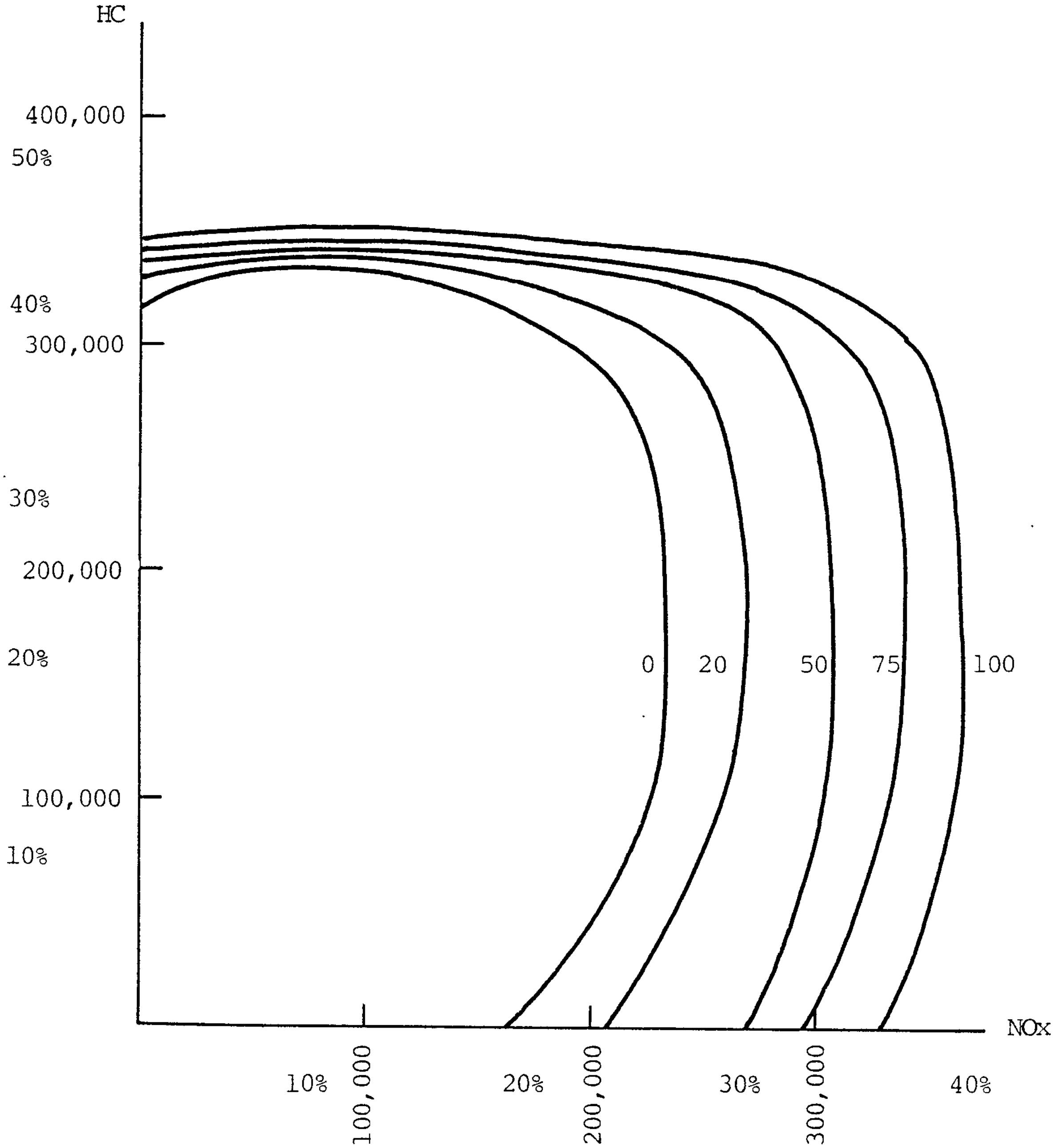

Figure A-1. Isocost Lines for Hydrocarbon and NO_x Control

Isopleths of Precursor-Ozone Abatement Possibilities

The relative effects of NO_x and HC abatement on oxidant formation, as indicated by maximum ozone concentrations, were estimated through use of an EKMA (Empiririical Kinetic Modeling Approach) -- OZIPP (Ozone Isopleth Plotting Package) analysis for the entire region.[27] Because of the area-wide, relatively uniform photochemical oxidant problem throughout the region, ozone concentrations were predicted at only one location, represented by the monitory unit at Derby, Connecticut. OZIPP models a column of air containing initial concentrations of ozone and precursors moving along a fixed trajectory, picking up fresh emissions en route. Reactions occur in the column, depending on concentrations and solar energy, yielding predicted ozone levels at the design destination. EKMA then predicts the effects of specified percentage reductions in precursor concentrations.

Local conditions were used to construct isopleths specific to the New York region, as follows:

- 10 hour simulations, from 8 AM TO 6 PM;
- assumed reactivity of the nonmethan hydrocarbon mix equivalent to 25% propylene (ppmC), which is comparable to automobile exhaust;
- aldehydes at 5% of the initial NMHC mix;
- photolytic rate constants that vary in accordance with the diurnal variation in sunlight intensity on 7/21/77, the day the ozone design value was measured;
- an atmospheric dilution rate of 3%/hr. which lifted the mixing height from 500 m at 8 AM to 1300 m at 3 PM:
- daytime emission rates appropriate for a NY to Hartford trajectory;
- ozone aloft at 0.085 ppm, and negligible transported NO, and NMHC:

- normalized hourly variations in emission rates;
- exponential spatial decay of emission rates beyond the urban core.

Using the ozone isopleths thus derived, the EKMA procedure predicts future maximum hourly ozone concentrations after specified abatement of precursors. The procedure is calibrated using an ozone design value for the region of .323 ppm, the second highest concentration recorded at Derby, Connecticut and the ration of NMHC to NO_x emissions and 760,400 tons per year of hydrocarbon emissions, represents a 13% reduction of NO_x and a 25% reduction in the EKMA ozone design value. These reductions estimate the impacts of regulatory measures taken prior to the 1979 revisions of State Implementation Plans in the region, and for assumed growth rates and retirement rates in important sources of emissions.

The Nature of the Least-Cost Control Strategy

Figure a-2 superimposes the isopleths generated by the EKMA-OZIPP analysis for the New York metropolitan region, with emissions reductions expressed as percentage reductions n the baseline levels. Two isocost lines, representing total abatement expenditures of $20 million and $75 million annually are reproduced. The implications of nonconvexity in the damage function is immediately apparent in Figure a-2. Both the isocost schedules and the isopleths of ambient impact have the same general curvature. This means that the potential exists for "corner solutions," emphasizing only NO_x control or only HC control, to be cost effective. However, due to the strong

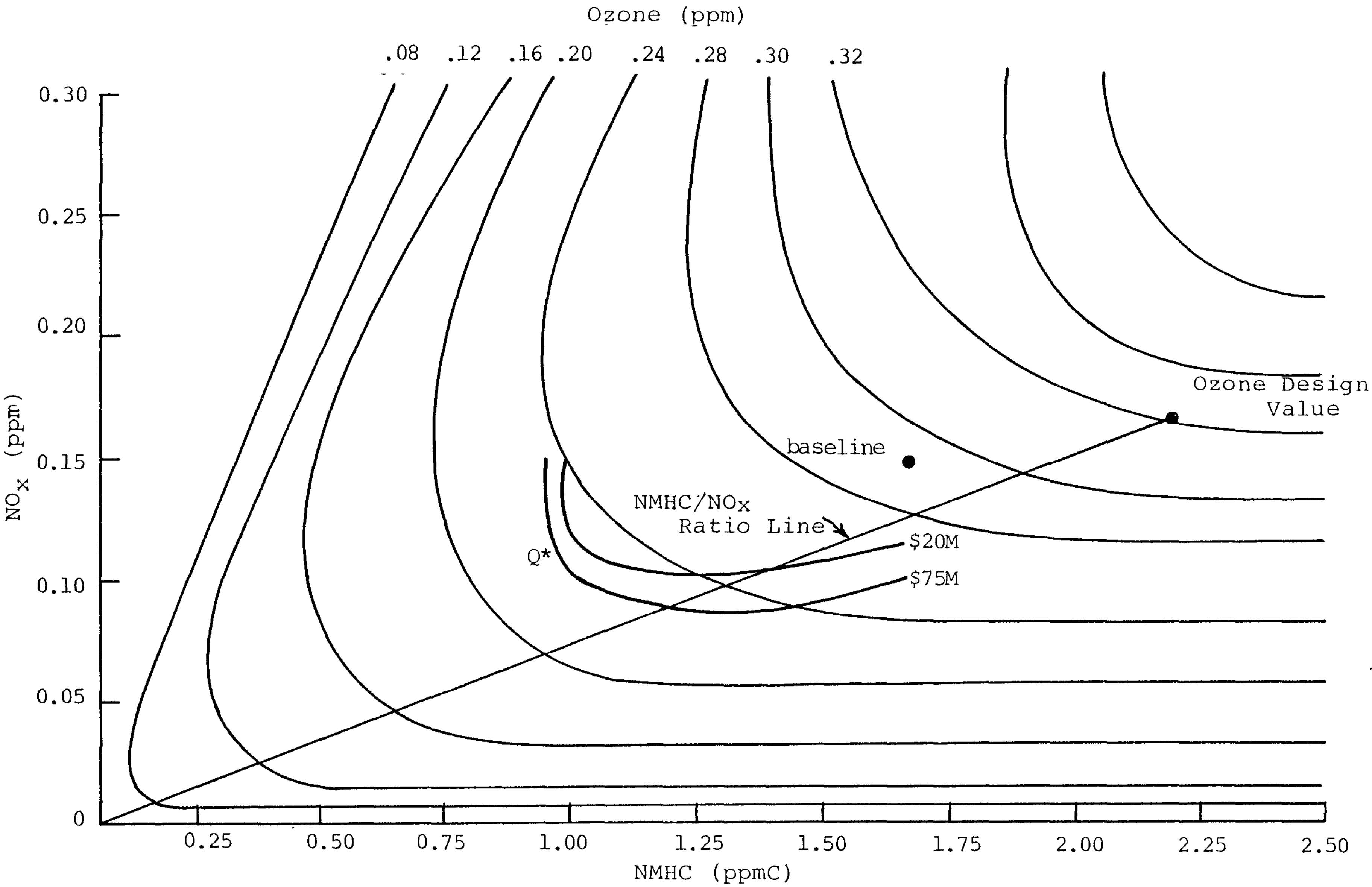

Figure A-2. Isopleth and Isocost Schedules: N.Y. Metropolitan Region convexity in the isocost function, a reflection of sharply rising marginal control costs for both pollutants, it appears that a cost-effective control strategy in this case would still be to exercise some degree of control over both precursors. Point Q*, representing about a one-third reduction in baseline NO_x emissions and a forty percent cut in hydrodynamic emissions, would be a cost-effective way of employing $75 million for reducing peak ozone concentrations. It is to be noted, however, as other investigators have pointed out, that such an attainment and effort level would fall far short of that required to meet the national ambient air quality standard for ozone of .12 ppm.

This finding illustrates the need for attention both to effectiveness and cost parameters in exploring issues of cost-effectiveness. Despite the strong nonconvexities, it appears that the inflexibilities of marginal costs still dictate, within the range of the New York data, at least, a mixed control strategy. However, Figure a-2 illustrates another implication of nonconvexity. The isocost line parallels the isopleth contours over a wide range of control combinations. This means that the marginal conditions for a least-cost strategy are nearly fulfilled by a wide range of abatement options. The least-cost strategy is thus not robust, in the sense that small changes in the cost or effectiveness parameters could imply large shifts in the efficient control strategy. Figure a-3 illustrates one such possibility. Since the net cost of hydrocarbon control in control options involving product recovered, a substantial increase in hydrocarbon prices would shift the isocost line

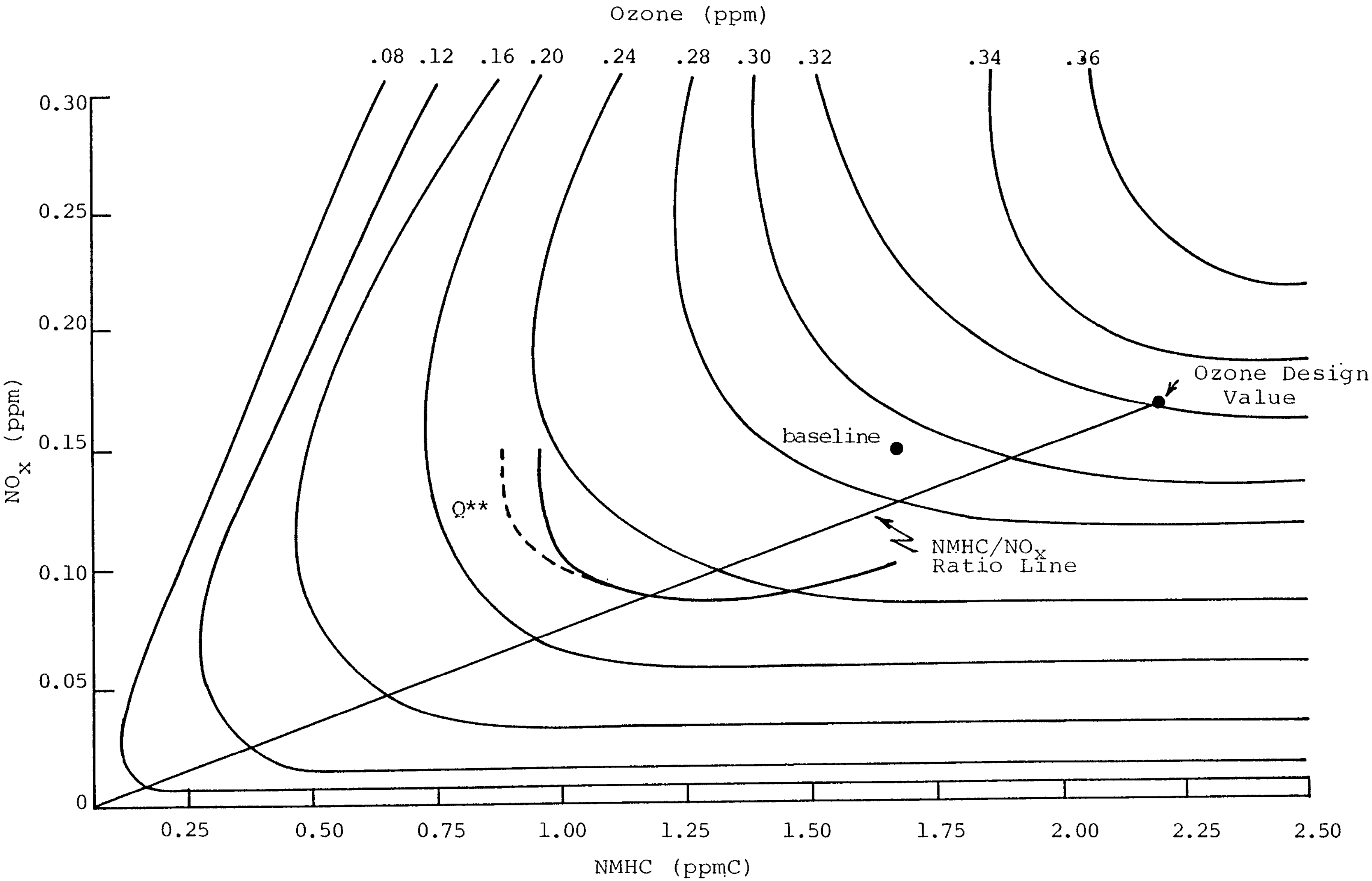

Figure A-3. Sensitivity Analysis of Least-cost Solution: Higher HC Prices outward in the manner indicated in Figure a-3, making the initial steps to control hydrocarbons disproportionately cheaper. This might well have the effect of shifting the least-cost control strategy substantially toward hydrocarbon control, and away from NO_x control, to a point like Q^{**}.

The cost of NO_x abatement is sensitive to the treatment of damages averted other than effects on peak ozone concentrations. Reductions in NO_x emissions have been shown to result in downwind abatement of a variety of other photochemical oxidation products, including nitrogen dioxide, nitric acid, PAN and sulfates.[28] These pollutants are implicated in crop damage, visibility impairment, acid precipitation, eye irritation and other effects. If the resource costs of NO_x abatement were credited with a monetary estimate of benefits from reduction of other damages, the net cost per ton of NO_x control might be substantially reduced. While knowledge by which to quantify and value these secondary damages is lacking, conceptually the result is to shift outward the isocost line as indicated in Figure a-4. NO_x control strategies are made relatively more attractive, since reductions in HC emissions, at least in the NY region, have been shown not to be as closely related to downwind concentrations of these secondary pollutants. It is apparent from Figure a-4 that the result might well be to shift the preferred control strategy sharply in the direction of NO_x abatement, as indicated by a point like Q^{***}.

The tendency of nonconvexity to produce all-or-nothing control strategies, therefore, is here muted somewhat by the

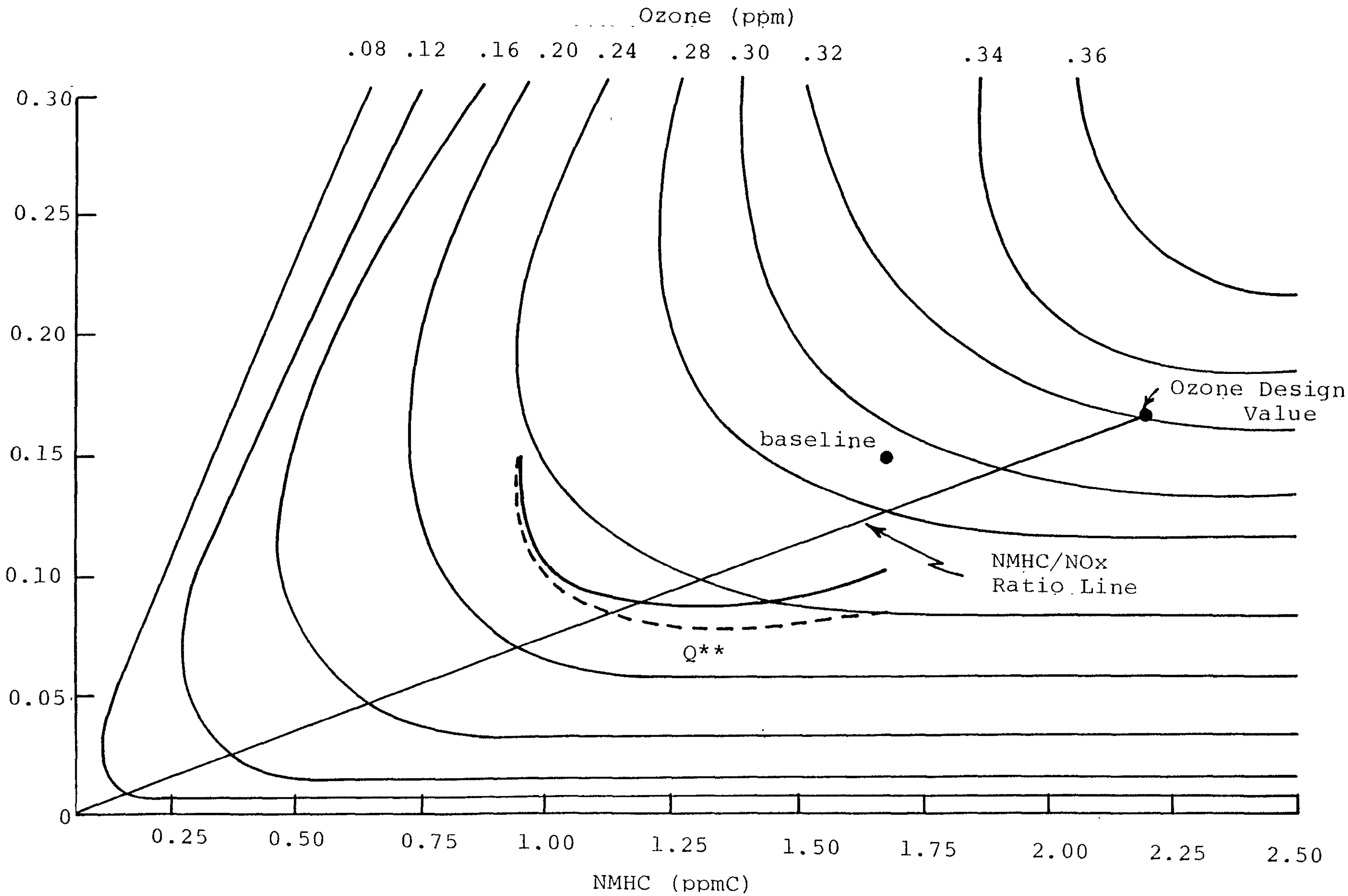

Figure A-4. Sensitivity of least-cost solution: credits for other effects of NO_x abatement extreme convexity of abatement costs. However, least-cost control strategies remain highly sensitive to relatively small variations in either costs or effects. In that sense, knowledge of the convexity does not in this case greatly simplify the decision problem. However, it does simplify the process in one sense. Figure a-2 suggests an additional implication, that the burden of excess costs from a non-optimal or inefficient control strategy remain moderate even for wide deviations from the least-cost option. The price for choosing mostly NO_x batement strategy or a mostly HC strategy when a more balanced strategy would have been preferable is not too high, by comparison to other allocational problems not characterized by nonconvexities. In view of the extreme complexity of the decisions involved, this may provide some comfort to policy-makers.

NOTES

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2. Currently, due to Executive Order 12291, cost-benefit analysis is required in important regulatory decisionmaking. See "Federal Regulation," Executive Order 12291, Weekly Compilation of Presidential Documents, Vol. 17, (February 23, 1981), pp. 124130.

3. See, for example, D. Starrett, Fundamental Nonconvexities in "The Theory of Externalities," Journal of Economic Theory, IV, (1) February, 1972; 180-199; J.S. Winnick, "Convexity and Corner Solutions in the Theory of Externality," Journal of Environmental Economics and Management, IX (1), March, 1982; 29-41.

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6. R. Zeckhauser and A. Fisher, "Averting Behavior and External Diseconomics" Discussion Paper, Kennedy School of Government, Harvard University, April, 1976: also, R. Porter and P. Courant, "Averting Expenditure and the Cost of Pollution," Journal of Environmental Economies and Management, VIII (4), December, 1981; 321329.

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8. To Breathe Clean Air, pp. 3429.

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12. M.C. Dodge, "Combined Use of Modeling Techniques and Smog Chamber Data to Derive OzonePrecursor Relationships," EPA, International Conference on Photochemical Oxidant Pollution and its Control, Proceedings, Research Triangle Park, N.C., 1977; B. Dimitriades, "An Alternative to the AppendixJ Method for Calculating Oxidant and NO_2Related Control Requirements," ibid.

13. R. Dervent and O. Hov, "Computer Modeling Studies of the Impact of Vehicle Exhaust Emission Controls on Photochemical Air Pollution Formation in the U.K.," Environmental Science and Technology, VIII (9), Sept. 1975; 811826.

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16. Report of the Photochemical Oxidant Panel to the National Commission on Air Quality, Washington, D.C., 1981 (mimeo).

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19. W. Cleveland and T. Graedel, "Photochemical Air Pollution in the Northeast United States," Science, CCIV, June 22, 1979; 1273-1278.

20. This section draws on work performed by GCA Corp., Technology Division for the National Commission for Air Quality on the Northeastern U.S. Regional Study of Air Pollution Control.

21. C. Spicer, D. Joseph, P. Sticksel, and G. Ward, "Ozone Sources and Transport in the Northeastern U.S.," Environmental Sciences and Technology, XXIII (8), August, 1979; 975-985.

22. GCA, New York Metropolitan Region Study, Vol. 10; Bedford, MA.

23. Cleveland and Graedel, op. cit.

24. GCA, op. cit. Vol. IX

25. These inventories were compiled from data contained in the State Implementation Plans of the tri-state region, from EPA's National Emissions Data System, and from inventory data collected by GCA. For discussion of inventory quality, see GCA, op. cit., Vol. 2.

26. Cost-effectiveness data for NO_x abatement were supplied by James Wilson, Energy and Environment Analysis, Inc., of Arlington, VA, Data on hydrocarbon control costs stems from GCA, op. cit., Vols. IX and X.

27. The EKMA-OZIPP analysis of ozone formation was performed by GCA, and made available for this study. See GCA, op. cit. Vol. X.

28. Cleveland and Graedel, op. cit.