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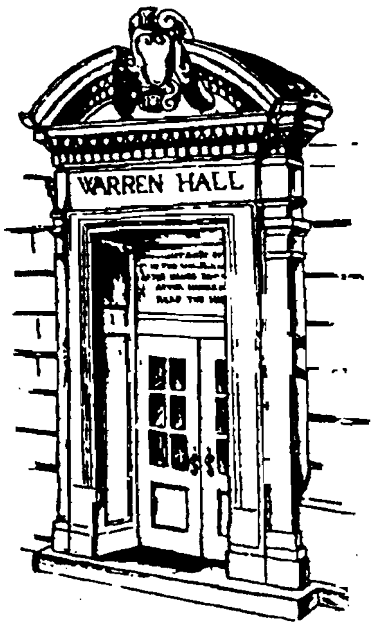

Working Paper

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REDESIGNING ENVIRONMENTAL STRATEGIES TO REDUCE THE COST OF MEETING URBAN AIR POLLUTION STANDARDS

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Redesigning Environmental Strategies to Reduce the Cost of Meeting Standards for Tropospheric Ozone

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This paper addresses the problem of non-attainment for ozone by integrating a photochemical model of ozone production into an economic framework for controlling emissions of the precursors of ozone. Results from a series of photochemical model simulations are synthesized into a statistical representation of ozone formation. This integrated framework makes it possible to assess the cost of reducing ozone concentrations in a specified region and to answer policy questions on the cost effectiveness of alternative strategies. The modeling framework also establishes a basis for determining inter-species and inter-regional emission weights for trading, with constraints to maintain air quality standards.

An example of the approach is applied to the northeastern region of the USA, with a primary focus on the Greater New York Metropolitan Area (GNYMA). The results are specific to a single ozone episode using the Regional Oxidant Model (ROM) under the assumption that substantial reductions in the emissions of nitrogen oxides and volatile organic compounds will be achieved under existing regulations by the year 2005. From this base, the objective of the analysis is to identify cost effective ways of obtaining additional reductions of ozone concentrations in the GNYMA. The results show that efficient policies should focus on controlling ground-level emissions along the eastern seaboard from mobile and off-road sources, and controlling elevated emissions from utility and industrial boilers in upwind regions to the south and west of the GNYMA. The cost of these additional controls is shown to be substantially lower than the cost of regulatory proposals for meeting ozone standards in the Northeast.

1. Introduction

There are many contributors to air pollution in urban areas. This paper focuses on one of the most intractable problems in the United States, tropospheric ozone. The primary problem associated with high concentrations of ozone are health effects to humans[1] and damage to vegetation and crops[2]. From an economic perspective, the social cost of increased morbidity due to respiratory ailments is the most important[3]. These health effects tend to be more serious in urban areas because the density of population is higher. The presence of other pollutants in urban smog, such as acid aerosols and fine particles, exacerbates the effects of high concentrations of ozone[4]. In 1989, the U.S. Environmental Protection Agency (EPA) reported that approximately 67 million people lived in regions that exceeded the ambient air standard for ozone[5]. The maximum allowed 1-hr concentration for ozone established by EPA is 0.12 ppm[6].

The problem of non-attainment for ozone is most severe in the Los Angeles basin, which has been classified as an "Extreme" area for ozone under the Clean Air Act Amendments (CAAA) of 1990, but four other regions (New York City, Chicago, Atlanta, and Houston) have been classified as "Severe" for ozone with the peak 1-hour ozone concentration reaching over 0.18 ppm on a number of occasions[7]. The relative isolation of the Los Angeles air basin makes local strategies for controlling emissions effective. However, most airsheds are

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[1] (Krupnick et al. 1990)
[2] (Adams et al. 1986)
[3] (Krupnick and Portney 1991), (Hall et al. 1992)
[4] (Ostro and Rothchild 1989), (Barnes 1994)
[5] (National Academy Sciences 1991)
[6] Given scientific knowledge of health effects, the current standard may be too high. (Roth et al. 1993)
[7] (National Academy Sciences 1991)

difficult to define spatially, and unlike watersheds, they are not necessarily stable over time. The challenge for environmental policy-makers is to find viable solutions for improving air quality in urban areas, recognizing the fact that much of the pollution causing the problem comes from surrounding regions. The primary objective of this paper is to identify strategies that are economically efficient in reducing ambient ozone levels and to compare them with typical strategies proposed by regulating agencies. The Northeast region, centered on the Greater New York Metropolitan Area (GNYMA), is used to illustrate how one can develop cost effective strategies to reduce ozone concentrations.

The production of tropospheric ozone is dependent on the presence of precursor pollutants that are generally categorized as Volatile Organic Compounds (VOC) and Nitrogen Oxides (NO_X)[8]. For given concentrations of these ozone precursors, the rate of ozone production is dependent on the amount of sunlight. Hence, ozone concentrations are generally highest in the late afternoon on hot summer days when air masses are stagnant, contributing to a build up of pollutant levels. Primary sources of anthropogenic VOCs are gasoline engines and solvents. The principal sources of NO_X emissions are internal combustion engines and industrial and electric utility boilers. Therefore, policies for reducing emissions of the precursor pollutants (NO_X and VOCs) need to consider transportation, off-road engines, manufacturing activities and electric utilities. Thus, the sources of ozone precursors are very

[8] The reactivity of precursor emissions is dependent on the VOC/NO_X ratio which makes the process of ozone formation relatively complicated. For example, NO_X emissions consume ozone at very low ratios (less than 6). In addition, different VOC species exhibit significantly different reactivities for ozone formation (Seinfeld 1986).

diverse, and consequently, the goal of any environmental policy should be to determine a balance of controls among different sectors of the economy.

The federal standard for ozone falls under the regulatory authority of the EPA, but the responsibility for developing attainment strategies to achieve the standard rests with state governments. In contrast to previous legislation, the 1990 CAAA gives states more flexibility to develop innovative solutions for the control of ozone precursors in specific regions. The problem of finding efficient solutions is complicated because (1) ozone is a secondary pollutant and its rate of production is sensitive to meteorological conditions as well as to the concentrations of precursors, (2) ozone exceedences are episodic by nature, and (3) affected regions often do not conform with State boundaries. To deal with these issues in the Northeast, the 1990 CAAA established an Ozone Transportation Region (OTR) which includes 11 states from Maryland to Maine and the District of Columbia. States in the OTR have representatives on the Northeast Ozone Transportation Commission (OTC) which identifies control strategies and acts in an advisory capacity to state governments for attaining the ozone standard by the statutory deadlines. For example, the ozone standard must be attained in the GNYMA by the year 2007.

In the past, the major focus of regulatory policy for ozone attainment was on reducing emissions of VOC[9]. Since this approach has not been sufficient to reach attainment, recent policies in the 1990 CAAA have put a greater emphasis on reducing emissions of NO_X, particularly from power plants. Therefore, this new strategy not only requires additional controls throughout the OTR on VOC and NO_X emissions from transportation sources (through improvements in

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[9] (Sciences 1991)

engine performance, introduction of alternative fuels for vehicles and enhanced forms of reformulated gasoline), but also controls on NO_x emissions from utility and industrial boilers. In this study, we have assumed that effective emission control measures for other sources of VOC, such as solvents and paints, are implemented as prescribed under Title III of the 1990 CAAA, and increases in VOC emissions from these sources will be restricted by requiring offsets for expanded production of VOC from any specific site in the OTR.

The 1990 CAAA requires that "...the best available air quality monitoring and modeling techniques be used... " in determining "*...the contribution of sources in one area to concentrations in another which is in nonattainment for ozone.*" Over the past decade, the scientific community has made substantial progress toward understanding the processes that contribute to the formation of tropospheric ozone. Photochemical models have grown increasingly sophisticated in accounting for the atmospheric chemistry and meteorology involved in ozone production and accumulation.

To date, the results from photochemical modeling have not been fully integrated with the corresponding economic analyses[10]. However, modeling techniques have improved sufficiently to make it practical to develop an analytical framework, in the spirit of Morgan and Henrion[11], which integrates the science of ozone production with an economic evaluation of control strategies. This framework can be used to develop control strategies that are effective in meeting a given ozone standard and are efficient in the sense of meeting the ozone standard at least cost. Application of this framework to the GNYMA suggests that a more regionally specific control policy is significantly

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[10] (Kosobud et al. 1993)
[11] (Morgan and Henrion 1990)

less costly than previously proposed emission control policies that rely on uniform emission regulations throughout the OTR.

2.0 The Analytical Framework

Photochemical grid models estimate ozone formation and transport[12]. The large computational demand in running photochemical models effectively limits them as an analytical tool for selecting emission control strategies. An alternative approach is to develop a statistical representation of the photochemical model called a Multivariate Ozone Response Surface (MORS). This statistical representation of ozone formation provides a tractable link to economic models that estimate the cost of controlling emissions of the precursors of ozone. Through MORS, an integrated framework, referred to as the Regional Economic Model for Ozone Compliance (REMOC), is developed that incorporates both physical/chemical relationships and economic criteria. In addition, REMOC supports the evaluation of conventional command and control strategies as well as other less traditional market approaches. It is tractable because it provides rapid and reliable estimates of the results for a given photochemical model for a selected set of meteorological conditions[13].

The photochemical model used for the analysis is the Regional Oxidant Model (ROM), which is the model accepted by the EPA for analyzing ozone concentrations in the Northeastern OTR. The model domain, however, covers all states in the eastern half of the country. The meteorological conditions, which determine one set of inputs for the ROM, correspond to a severe ozone

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[12] Photochemical models define the physio-chemical processes of ozone formation in terms of mathematical equations which describe the chemical reactions. A three dimensional grid of cells determines flux rates and concentrations of chemical species across large geographic areas.
[13] The response surfaces focus on predicting ozone concentrations over a series of most likely emission control strategies. Predicted ozone values for emission reductions beyond the range of the fitted surface may be biased.

episode in July 1988. ROM is run using hourly time steps, covering a period of about one week, to simulate the ozone episode.

The experimental design of the scenarios that determine the emission inputs for ROM are constructed from a series of programs for reducing emissions of NO_X and VOC which are selected in terms of estimated cost effectiveness. This design provides a high resolution of information in the MORS around a set of emission reductions that have a direct economic interpretation. It is assumed for this analysis that states in the Northeast are interested in evaluating the most cost effective strategies for controlling emissions in the GNYMA beyond the planned Federal emission control programs in the 1990 CAAA. Consequently, the scenarios represent incremental emission reductions beyond the Federal controls for the year 2005. The baseline inventory for 2005 includes RACT on boilers in the OTR, Title IV controls on boilers beyond the OTR, Federal Tier I and II controls for vehicles, and Title III controls on hazardous emissions[14]. The 2005 baseline inventory represents substantial reductions from the 1990 inventory. Elevated and ground-level NO_X are reduced by over 45% and VOC by over 35% from the levels in the 1990 EPA inventory. It is assumed implicitly that these regional reductions will be sufficient to meet ozone standards for most of the OTR. Evidence from other analyses by the New York State Department of Environmental Conservation demonstrates that ozone standards will still be violated in the GNYMA. This evidence provides the rationale for focusing our analysis on reducing ozone concentrations in the GNYMA. Even though the

[14] This inventory has been called the Cornell 2005 inventory because it is derived by incorporating the effects of Federal control programs into the adjusted 1990 EPA emissions inventory and corrects what are perceived by the authors as short-comings in the EPA 2005 inventory.

domain for ROM covers all eastern states, incremental policies for reducing emissions beyond Federal controls are limited in our analysis to the four states surrounding the GNYMA.

2.1 Multivariate Ozone Response Surface

The generation of the MORS follows a series of photochemical model simulations over a set of emission reduction programs and then uses regression techniques to fit the response surface(s)[15]. To estimate a MORS, a measure of ozone concentrations must be specified (e.g., the maximum 1-hr or 8-hr concentration in the GNYMA for a selected episode), and emissions must be grouped by source and location. The general functional form for MORS specified for the GNYMA can be represented as follows:

$$O_3 = f[(\Sigma_j NO_X1_{jk}, \Sigma_j NO_X2_{jk}, \Sigma_j VOC_{jk})\ j= 1, 2,\ldots,6\ k=1,2,\ldots,6), Z] + \varepsilon \qquad (1)$$

O_3 : specified measure of ambient ozone concentration

NO_X1 : daily tons of ground-level Nitrogen Oxides emitted by economic sector j in region k .

NO_X2 : daily tons of aloft Nitrogen Oxides emitted by economic sector j in region k

VOC : daily tons of Volatile Organic Compounds emitted by economic sector j in region k

j : corresponding to economic sectors: 1) transportation, 2) industrial, 3) commercial, 4) residential, and 5) utility

k : location corresponding to 1) upstate NY (UNY), 2) greater NY metropolitan area (GNYMA), 3) northeast NJ to Philadelphia PA (NJP), 4) western NJ and northeastern PA, (E-PA) 5) Connecticut (CT), and 6) western PA (W-PA)

Z : meteorological characteristics of the episode

ε : stochastic residual, or error term

The groupings of emissions identify three different types of emissions for each of the six different sub-regions to give a total of 18 distinct sources. For the

[15] (McKay and W. Conover 1979)

purposes of developing a response surface, VOC and NO_X emissions from different economic sectors are aggregated into two physical forms: ground-level and elevated. Ground-level NO_X emissions include all area, mobile, and small point sources, which are unlikely to penetrate the morning mixing layer. This leaves large electric utility and industrial boilers as sources of elevated NO_X emissions. All VOC emissions are classified as ground-level emissions. To represent the spatial effects, the Northeast is partitioned into six different sub-regions centered around GNYMA (Figure 1). These sub-regions reflect the new concept of air "corridors" that have been incorporated into the current State Implementation Plan (SIP) for ozone in the OTR. The further divisions of sub-regions within the corridor are by clusters of counties with similar transportation characteristics, industrial profiles, and pollutant concentrations.

MORS provides an estimate of ozone formation that converts each distinct source of emissions into a unit of ozone removed per ton of emissions reduction. This is illustrated in the next section following a brief discussion of the base inventory of emissions for 2005. The specific definition of ozone used can vary to reflect the objectives of the analysis. In this paper, the definition used is the maximum 1-hour concentration of ozone in the GNYMA. However, the same method could be used to model the effects of emissions on ozone concentrations for any sub-region. In other words, the same set of scenario runs for a selected ozone episode can be used to estimate a set of MORS for different regions in the model's domain, as well as for different definitions of ozone concentrations.

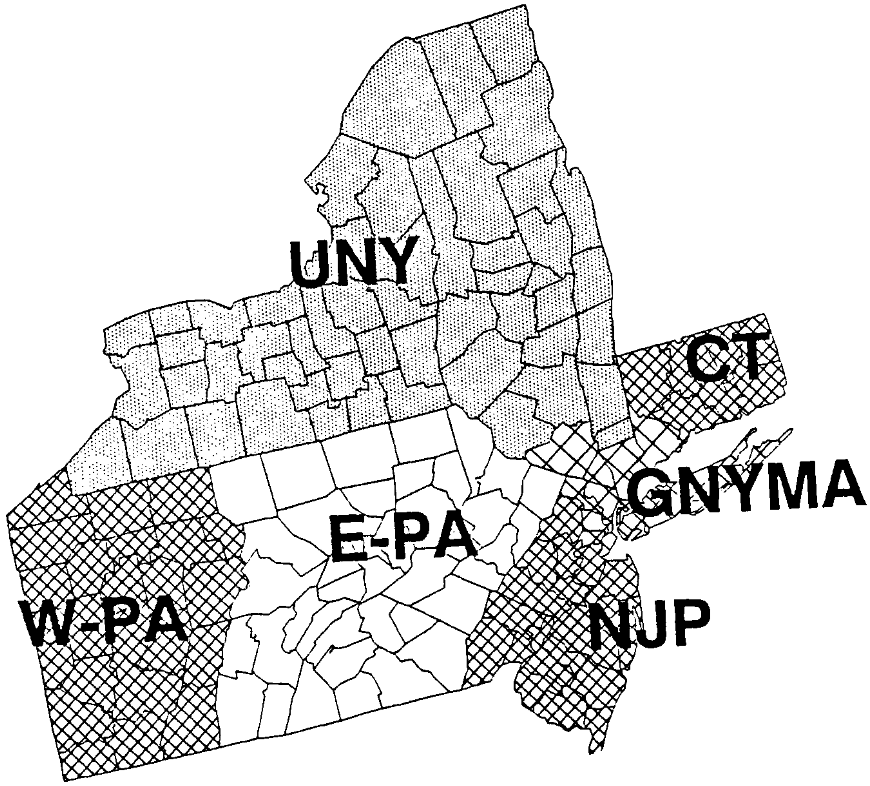

Figure 1: **Map defining the six Northeast Regions used to evaluate the spatial effects of emission reductions on ozone concentrations.**

2.2 Regional Emission Weights

Since the GNYMA is the most severe non-attainment sub-region for ozone in the Northeast, a MORS has been developed to relate emissions by type and location to ozone concentrations in the GNYMA. A linear form of MORS has been estimated for illustrative purposes. The coefficients measure the marginal contribution of a mass of emissions to the maximum one hour concentration of ozone in the GNYMA in units of parts per quadrillion (ppqd) per summer ton of emissions[16]. Estimates of the reduction in maximum ozone concentration are simply the product of the coefficient and the mass removed of

[16] This is similar to Carter's definition of incremental reactivity.

the corresponding type of emissions. Development of a more mathematically sophisticated measure of ozone response to reductions of emissions would probably increase the accuracy of the MORS, but it would also require running many more simulations of the photochemical model to capture interaction effects among different types of emissions[17].

The coefficients are determined from a series of 18 ROM photochemical modeling runs using the projected 2005 emissions inventory and meteorological conditions for an extreme ozone episode in July 1988. Although the coefficients presented in Table 1 are for the GNYMA, it should be recognized that the same output from the photochemical model could be used to estimate a MORS for another region or a particular grid cell. The 18 simulations are based on specified emission reduction programs selected in terms of estimated cost effectiveness. This provides additional information about the effects on ozone concentrations of a set of emission reduction programs that have a direct economic interpretation.

Table 1: **Coefficients for a MORS for the GNYMA.** (The coefficients measure reductions in the peak ozone concentration for GNYMA in parts per quadrillion (ppqd) per summer ton of emission removed.)

Region	NO_x1 (Ground)	NO_x 2 (Elevated)	VOC (Ground)
UNY	5	10	0
GNYMA	122	0	93
NJ/Phil	229	328	36
E-PA	144	200	5
CT	0	0	0
W-PA	18	179	0

[17]The computational costs and computational time photochemical modeling become the limiting factor in introducing additional complexity into MORS. A typical ozone episode for the Northeast takes a week of computer time to simulate nine days.

The coefficients presented in Table 1 are developed by first determining a MORS for each grid cell in GNYMA and then taking a weighted average of these coefficients by applying equation 2[18]. The weighting scheme gives larger weights to cells with high concentrations of ozone or high population densities.

$$\beta_k = \sum_{i=1}^{I} \frac{\beta_k^i}{2} \frac{O_3^i}{\sum_{i=1}^{I} O_3^i} + \sum_{i=1}^{I} \frac{\beta_k^i}{2} \frac{pop^i}{\sum_{i=1}^{I} pop^i} \qquad \begin{array}{l} k = 1,2,\ldots,6; \\ i = number\ of\ grid\ cells\ in\ sub-region \end{array} \tag{2}$$

In this particular episode, elevated NO_X emissions from regions to the west and south of GNYMA have a significant impact on ozone formation. This is consistent with the westerly and south-westerly direction of the aloft windfield commonly associated with regional ozone episodes[19]. The Atlantic ocean also acts as a thermal boundary that channels precursor emissions and ozone along the coast to the GNYMA. Directly upwind of GNYMA, New Jersey and Philadelphia (NJP) has the highest marginal contribution of 328. Emissions from the tall smoke stacks of Western Pennsylvania (W-PA) have similar effects to the aloft emissions from Eastern Pennsylvania (E-PA), but the coefficients of around 200 are lower than the value for NJP. The effects of aloft NO_X emissions within GNYMA are very small since most of these emissions remain above the ground-level morning mixing layer. However, the lower mixing layer expands by the late afternoon to capture some of these emissions. During these hours, the VOC to NO_X ratio decreases sufficiently to exhibit a small scavenging effect

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[18] The coefficients for NO_X2 were reduced slightly to diminish the instantaneous mixing effect of ROM by raising the coefficient to the 0.85 power.
[19] A westerly direction refers to winds that travel from west to east and similarly a south-westerly direction refers to winds that travel from the south-west to the north-east.

on ozone concentrations in some grid cells. This scavenging contributes to an average of zero over the GNYMA.

Although previous studies have not evaluated ozone reductions in terms of marginal contributions, the relative magnitude of the marginal effects of ground-level NO_X versus the effects of VOC in the Amtrak corridor[20] appears to be greater than previously expected. The strong southerly component of the surface windfield produces the largest effect for emissions from NJP. The effects of NO_X reductions on ozone concentrations are highly sensitive to the local VOC/NO_X ratio. The Federal and regional emission reduction programs implemented from 1990 to 2005 reduce NO_X more than VOC and increase the VOC/NO_X. This change increases the benefit of NO_X reductions[21]. The NJP coefficients of 229 for NO_X ground-level versus 36 for VOC indicate that NO_X ground-level is potentially a limiting factor for ozone production. For GNYMA, elevated NO_X emissions primarily remain above the ground level mixing layer (and travel down-wind to Connecticut), but these emissions do produce a scavenging effect in some grid cells and contribute to ozone formation in others. The overall effect produces an elevated NO_X coefficient of zero for GNYMA. However, ground level NO_X in GNYMA still has a positive coefficient of 122, slightly larger than the marginal contribution of 93 for VOCs. For the relatively rural E-PA, the ground-level NO_X coefficient of 144 indicates

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[20] The term Amtrak corridor refers to the metropolitan regions along the eastern seaboard from Philadelphia to Boston.

[21] Adjustments to the mobile emissions inventory in creased VOC emissions by approximately a factor of 2 to align the inventory VOC/NO_X emissions ratio for 1990 with ambient measurements. This procedure has been widely used to adjust emission inventories. (Fujita et al. 1994)

that NO_x is limiting, and VOC ground-level emissions have little effect on ozone production in GNYMA[22]. Ground-level emissions from W-PA tend to precipitate out before reaching the GNYMA and consequently have a small coefficient. The lack of influence of ground-level emissions from Connecticut and upstate New York on ozone in the GNYMA primarily results from the strong southern component of the ground-level windfield.

2.3 Emission Control Cost Methodology

Since Title I of the 1990 CAAA grant states the flexibility to design emission control initiatives to best address ozone compliance, it is important to have a consistent framework to measure emission abatement costs. Emission abatement costs in different sectors are determined in terms of dollars per ton of emissions removed during the summer, to reflect the seasonal nature of ozone production. Emission reduction programs that operate annually receive credits for off-season emission reductions proportional to their estimated market value or to their estimated ecological and health benefits. These credits account for other benefits derived from emissions abatement such as reduced cancer risk from lower VOC emissions and less acid rain. This method of measuring costs balances the seasonal, health, environmental and temporal benefits of a wide range of control programs and provides a consistent basis to evaluate their costs.

Costs for any control program include the net present value (NPV) in 1994 dollars of total costs minus the NPV of an environmental credit divided by

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[22] This is consistent with other results studies which show rural areas as highly NO_x limited.

the NPV of summer tons removed (see Equation 3). Summer emissions are defined for the period June 15 to September 15.

$$ControlCost = \frac{NPV(Capital + Variable) - NPV(Health\ \&\ Environmental\ Credit)}{NPV(Summer\ Tons\ \mathrm{Removed})} \qquad (3)$$

Total costs included capital and variable cost expenditures and, when applicable, the loss in consumer welfare from an increase in retail prices. All costs are discounted to account for the time value of expenditures. The health and environmental credits are discounted (at a much smaller rate) to reflect the differences in risks and accrued health and environmental benefits over time[23].

3. The Regulatory Base Strategy

Major region-wide emission control initiatives have been proposed for the OTR and endorsed by the OTC. The main components of the original policy included 1) aggressive NO_X point source controls (e.g., an emission rate limit of 0.15 lb/MBtu), 2) California Low Emission Vehicles (Cal LEV), and 3) California Reformulated Gasoline II (Cal Gas). These command and control regulations form the Regulatory Base Strategy for our analysis. This strategy will be compared to a broader set of emission control programs that include specific controls for the sub-regions in Figure 1 and market-based measures. It is assumed in all cases that the additional controls are increments to the Federal controls that are built into the emissions inventory for 2005.

[23] We used a rate of 9 percent for expenditures and 4 percent for emissions to discount back to 1994. (Nordhaus 1990)

3.1 NO_X Point Sources

The Cornell Carnegie Mellon University (CCMU)[24] model is used to estimate the costs of controlling NO_X emissions from large industrial and utility point sources. Cost estimates are determined for a wide range of emission controls beyond the Federal emission standards under Title IV of the 1990 CAAA[25]. These control technologies consider any economically efficient combination of combustion modification technologies and post-combustion technologies. Control costs also include an environmental credit for reducing acid rain at $150/ton. This credit represents one-half the estimated value of SO_2 allowances in 2000[26] and assumes that acid deposition damage from NO_X is half that from SO_2. (Including the credits for acid rain results in relatively small reductions of total costs.) Emissions reductions are calculated over an expected life of 20 years for control equipment.

The analysis for utility point sources did not include the behavioral dynamics of reduced electricity demand as a result of more stringent emission controls and the associated increase in the price charged for electricity. In addition, no attempt was made to estimate behavioral responses to current reforms in electricity markets and time-of-use metering which will also effect the demand for electricity and the distribution of emissions. These short-comings are overshadowed by the general inaccuracies in the emissions inventory data. Although the data for NO_X point source are considered more robust than the area and mobile source inventory, the omission of combustion

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[24] The CCMU model inputs for NO_X control have been subject to peer review by the New York Public Service Commission and several New York State electric utilities.
[25] These are approximately 0.44 lb/MBtu.
[26] Power November 1994.

turbine emissions for UNY and GNYMA raises concerns about accuracy and underscores the general uncertainty of the results that follow.

Control costs for emissions from elevated sources of NO_X are shown in Table 2 and correspond to an across-the-board emissions limit of 0.15 lb NO_X/MBtu. The average removal costs for utility sources is over $2000/ton with the highest cost in NJP of almost $7000/ton, and the lowest cost in W-PA of about $1000/ton[27]. The economies of scale achieved in large utility plants are not commonly possible in non-utility point sources. This loss of scale economies combined with the seasonal nature of thermal demand raises the average cost of emission reductions for these sectors to over $8000/ton. The total cost for controls of elevated NO_X for NY, NJ and PA are about $150 million per year with over 60% of these costs born by the utility sector.

3.2 California Low Emissions Vehicle

The central programs endorsed by the OTC for control of ground-level emissions are the Cal LEV program and Cal Gas[28]. The Cal LEV program implies significant reductions in VOC and NO_X emissions by requiring a set of emission standards for new types of vehicles with mandated sales levels. The Cal LEV program establishes categories for low emission vehicles, including transitional low emission vehicles (TLEVs), low emission vehicles (LEVs), ultra-low emission vehicles (ULEVs), and zero emission vehicles (ZEVs). Target levels of sales of these vehicles are phased in over the next decade.

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[27] B. Minsker and G. Dorris, Final Report for NiMo Contract #LC66765AML, (1995).

[28] Since Title III mandates control of air toxins which includes hazardous VOC emissions from chemical manufacturing, storage and most industrial solvents, the largest outstanding source of VOC emissions is gasoline vehicles.

To estimate the cost of reducing emissions, the focus is on the difference between the costs of Cal LEV and Federal Tier I and Tier II vehicles. Control costs for the Cal LEV program are computed using Equation 1. Emission reductions are based on MOBIL 5 model runs and draw upon a MARAMA 1992 and a NESCAUM 1991 study evaluating the LEV program[29]. It should be noted that the evaluation of Cal LEV does not account for changes in reactivity of VOC emissions[30]. Determination of incremental control costs for larger catalysts, engine design modifications, vehicle design modifications, and health benefits derived from the Cal LEV emission standards are enshrouded in a great deal of controversy. The major parties concerned, the automobile and petroleum industries and the government, have yet to agree on a consistent methodology for measuring the incremental costs of control technologies for vehicles. We adopt the reasoning of New York States Department of Environmental Conservation that considers the automotive industry's methods based on "part-pricing"[31] as subject to bias, and use the California Air Resources Board's (CARB) values for incremental costs and health credits[32].

Estimates of average emission reduction costs for the Cal LEV program shown in Table 2 range from nearly $3000/ton for GNYMA to less than $1500/ton for NJP. The differences in costs between regions result principally from the differences in miles traveled per vehicle and the type of driving

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[29](NESCAUM 1991); (Pechan 1992)

[30]However, the longer chain VOC's which are more photochemically reactive have a greater tendency to react with a catalyst leaving less photochemically reactive VOCs as exhaust.

[31] "Part-pricing" is a cost accounting technique of estimating the individual component costs and associated over-head.

[32] CARB also uses a 50% cost credit for reduced cancer risks from lower VOC emissions.

conditions. The total annual cost of the Cal LEV program for the three states is over $200 million[33].

3.3 California Reformulated Gasoline

Using reformulated gasoline has been popular as a control strategy because it addresses the control of both the reactivity and total mass of VOC emissions[34]. Following the logic of Equation 2, the additional cost of producing reformulated gasoline for Cal Gas is measured from the cost of Federal Phase II reformulated gasoline. The lower reactivity of VOC emissions from Cal Gas is determined from the weighted reactivity of total organic gas emissions based upon results of chamber experiments[35]. The costs of Cal Gas are measured by the loss in consumer surplus. Using the change in consumer surplus as a measure of cost, the cost calculation captures the out-of-pocket costs plus the additional cost of consuming less gasoline when it is more expensive. The price effect is greater in GNYMA and NJP because of the availability of public transportation as a substitute for driving. For this study, an incremental cost of 9 cents/gallon, developed by the Auto/Oil Industry Study is used, and the estimated health credit is 25% of the incremental fuel costs.

Reformulated gasoline increases the variable cost of driving during the summer ozone season providing an economic incentive consistent with the objective of reducing summer emissions. This differs from the Cal LEV program that raises the cost of purchasing a new vehicle, but does not provide an economic incentive for people to drive less. Cal Gas accounts for about 30

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[33] Including other health benefits derived from the Cal LEV program the cost is $219 million per year.

[34] Gasoline and the exhaust from conventionally fueled vehicles are highly reactive in the atmosphere because they are rich in aromatics and alkenes.

[35] (AQIRP 1993); (Croes and Holmes 1992)

percent of the reductions of VOC but only 10 percent of the reductions of ground-level NO_X in the three states. Even though the behavioral responses to higher prices are included, Cal Gas has an average cost of over $5000/ton, which is more than twice as high as the cost for the Cal LEV program.

4. Additional Control Programs

The Regulatory Base Strategy has a relatively narrow focus with only three principal emission control programs (NO_X from point sources, Cal LEV, Cal Gas). It is important to develop and evaluate additional control measures, especially on sources that currently have limited emission controls, as well as behavioral control programs. Additional engineering controls are evaluated for previously uncontrolled and moderately controlled sources. Additional behavioral control measures focus on reducing emissions from transportation sources in the GNYMA and NJP. These control measures are potentially valuable sources of additional emission reductions as well as potentially more cost effective alternatives to the three programs in the Regulatory Base Strategy.

4.1 Engineering Controls

Additional engineering controls go beyond the Regulatory Base Strategy and apply combustion and post-combustion controls to sources which are relatively uncontrolled at the present time. California Air Resources Board (CARB) has evaluated and put into law a series of engineering control measures for off-road mobile sources and heavy duty diesel vehicles. Off-road mobile sources do not represent a significant source of emissions compared with gasoline vehicles, but reducing emissions from sources with little or no emission control equipment is relatively inexpensive compared to controlling emissions from the transportation and electric utility sectors.

Off-road sources include a large variety of small gasoline engines. These engines range from small two stroke engines for lawn and garden care to heavy duty diesel engines used extensively for construction. Removal costs for small two stroke off-road engines cost less than \$100/ton for VOC emissions, but can cost in excess \$2000/ton for NO_X emissions for off-road diesel vehicles.

California controls for on-road heavy duty diesel vehicles go beyond Federal emissions standards, but these controls are relatively expensive. The cost for NO_X controls on urban transit buses is over \$15,000/ton and over \$10,000/ton for large diesel trucks. Although the annual health and environmental benefits of reduced NO_X emissions are perceived to be small, there is a complementary benefit of reduced particulates under the CARB standards. Consequently, a 25% cost credit also applies to these controls.

4.2 Behavioral Controls

Behavioral programs differ from command and control regulations by introducing economic incentives to induce a change in behavior or a switch to less polluting activity. Control costs were estimated for a series of behavioral programs designed to reduce vehicle emissions from automobiles in GNYMA and NJP. Behavioral programs use both the carrot and the stick to induce changes. The carrot is offered through reduced usage costs or tax credits such as lower public transit fares or a tax credit toward the conversion to or purchase of a natural gas vehicle. The stick has several different forms including usage fees, consumption taxes, permits and out right bans. Since viable alternatives to driving exist in GNYMA and NJP, additional costs can be charged to drivers to reflect the costs they impose upon society for polluting and congestion in urban areas. Incentives include the imposition of usage fees such as increased tolls, emission based registration fees, metered parking, and a consumption tax on gasoline. Behavioral controls developed for GNYMA are more extensive and offer greater emission reductions than for NJP. This can be attributed to the extensive availability to public transportation as a viable substitute for driving in GNYMA. However, in most cases the costs per ton of reducing emissions using behavioral controls are substantially higher than they are for engineering controls.

5. Economic Evaluation of Alternative Control Strategies

The Regulatory Base Strategy reflects the traditional regulatory approach of requiring emission reductions across a broad region (e.g., throughout the OTR). This uniformity in law is also predicated upon some degree of fairness with each region having approximately the same average removal costs for emissions. Average control costs for emissions in the five sub-regions in Table 2 range from between a low of $2200/ton for W-PA to a high of $3,600/ton for UNY. The relatively small range of control costs satisfies the policy-maker's decision criterion for fairness, but this criterion ignores the science of ozone formation. In particular, the policy-maker's criterion fails to include the marginal contribution of different emission sources to ozone formation. This results in a form of equity where precursor removal costs are relatively equal but the marginal costs in terms of ozone concentrations at a specific location may vary dramatically.

An underlying assumption of our analysis is that existing federal programs (e.g., Tier I and II for transportation and RACT for point sources) will be sufficient to meet ozone standards for most of the Northeastern region. However, standards will continue to be violated in the urban corridor along the eastern seaboard (the Amtrak corridor). Consequently, the objective is to determine which additional control programs are needed for ozone attainment in this sub-region (specified as GNYMA in the analysis). Given this objective, it is appropriate to use a Regional Economic Model for Ozone Compliance (REMOC) to evaluate alternative strategies. REMOC evaluates control programs in terms of the cost per unit of ozone reduced in GNYMA. By dividing the emission weights of the MORS (O_3/ton) into the marginal cost of reducing emissions in $/ton, this quotient yields an equivalent measure in terms of lower concentrations of ozone ($/$O_3$-ppb). REMOC makes it possible to evaluate the potential advantages of inter-regional trading of NO_X and VOC in terms of reductions in ozone concentrations. Thus, the market clearing price for emissions would reflect the marginal cost of ozone reductions for the GNYMA.

The economic efficiency of the Regulatory Base Strategy is evaluated using REMOC for the five sub-regions. Average removal costs are found to range from $22 million per ppb of O_3 for NJP to $904 million per ppb of O_3 for UNY (Table 2). This range is much larger than the range for the costs per ton of controlling the precursors of ozone, and it implies that more cost-effective controls for reducing ozone concentrations in GNYMA can be found. The focus should be on precursor emissions in the regions neighboring and upwind of GNYMA that have high marginal contributions to ozone formation in GNYMA. In spite of the wide scope of the Regulatory Base Strategy, the ozone concentration in GNYMA is reduced by only 14 ppb at a cost of $526 million per year in the three states (NY, NJ and PA). (If health and environmental benefits are ignored, the adjusted cost is $678 million per year.)

5.1 Economically Efficient Strategies

REMOC can be used to develop economically efficient strategies by ranking control programs in terms of $\$/O_3$-ppb removed in the GNYMA[36]. By selecting additional control programs with the lowest marginal costs, an efficiency frontier can be developed for a range of reductions in ozone concentrations in the GNYMA. Emission control strategies on this frontier can be considered as "Integrated Strategies" because they integrate the economics of reducing emissions with the physio-chemical aspects of ozone formation.

The Integrated Strategies can achieve an equivalent level of ozone reduction to the Regulatory Base but at a significantly lower cost. The total cost for the three states is roughly $90 million per year compared to over $500 million for the Regulatory Base. (Excluding the credits for environmental and health benefits, the cost for the Integrated Strategies is $124 million compared to $678 million for the Regulatory Base.) The Integrated Strategy has an average control cost of $1,000/ton of precursors versus almost $3000/ton for the Regulatory Base. Some of the cost reductions in the Integrated Strategy is achieved through selecting control programs that are not included in the Regulatory Base, such as emissions from off-road engines. However, the principal cost reductions of the Integrated Strategies are achieved by concentrating on ground-level controls in the Amtrak corridor and allowing for trading among point sources in the upwind regions. To achieve the same reduction of ozone in GNYMA, an average cost of $7 million per O_3-ppb removed is incurred with the Integrated Strategy versus $39 million per O_3-ppb removed for the Regulatory Base.

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[36] Additional constraints are placed to maintain air quality at the baseline levels in the other five Regions.

Emission control programs selected under the Integrated Strategy diverge sharply from the controls in the Regulatory Base. The emission controls selected under the Integrated Strategy focus primarily on GNYMA, NJP, and E-PA with no emission controls from UNY and only aloft NO_X controls for W-PA. Emission reduction programs adopted by the industrial, commercial, and residential sectors focus on reductions in ground-level VOC and NO_X emissions. Reductions in VOC emissions in the residential and commercial sectors are achieved primarily through adopting controls on small engines used in lawn and garden equipment. Reductions in ground-level NO_X emissions focus on off-road diesel engines used in the industrial and commercial sectors. Emission reductions from the transportation sector increase in NJP under the Integrated Strategy and remain relatively constant in GNYMA. Beyond these two sub-regions, transportation controls are not very cost effective in reducing ozone concentrations in GNYMA. Reductions of elevated NO_X emissions are actually over 20% higher in the Integrated Strategy than they are in the Regulatory Base for E-PA and W-PA.

Points on the frontier of Integrated Strategies for a range of ozone reductions in GNYMA are summarized in Table 4 ranging from 9.7 ppb to 27.4 ppb of ozone removed in GNYMA. A graphical representation of these results is also given in Figure 2. In Figure 2, the dark bold line represents the least cost frontier of the Integrated Strategies. The components of the frontier are grouped by sub-region and type of emissions and are stacked vertically to show the cumulative costs by source. The pattern of emission reductions begins with modest controls levied across nearly every sector of the economy in GNYMA, NJP and E-PA plus controls on utility point sources in W-PA. This implies that it is efficient to reduce emissions of NO_X from elevated sources in distant regions to deal with the ozone problem in GNYMA. As ozone removal increases from 9.7 ppb to 15.7 ppb, the primary changes are for transportation (Cal LEV) in NJP, and utility point sources in NJP. At 15.7 ppb, LEV controls are selected for GNYMA and NJP, but Cal Gas is not selected until later. The next step to 20.4 ppb involves transportation controls (Cal LEV) in GNYMA and E-PA and controls on utility point sources in E-PA. The final steps to 27.4 ppb involve additional controls on utility point sources in E-PA and W-PA and inclusion of Cal Gas in GNYMA. The behavioral controls on transportation are still too costly at this point and are not selected. At 27.4 ppb, 298 emission control programs have been selected from 1103 potential control programs. The remaining 800 emission control programs would provide an additional 7 ppb reduction in ozone at a cost of $1,970 billion or a 370 percent increase in costs for an additional 20 percent increase in ozone removed.

6. Limitations

A shortcoming of focusing on the non-attainment problem in GNYMA is the implicit discounting of downwind areas. For example, elevated NO_X controls in GNYMA remain at the Federal RACT standard that may adversely affect downwind regions compared to implementing more stringent NO_X controls. This shortcoming can be resolved through imposing an additional constraint in the REMOC to maintain air quality at the same level as the Regulatory Base in the downwind region. Applying this constraint, the net cost of reducing ozone by 13.5 ppb (Table 3) increases from $92 million per year to about $115 million per year, still only a quarter of the corresponding cost in the Regulatory Base (Table 2).

The gains in efficiency achieved through the Integrated Strategy are the result of synthesizing a complex photochemical model into a simple statistical representation, and combining it with an economic component representing the costs of controlling emissions. The general shortcomings of this approach are the uncertainties that abound with photochemical modeling of extreme ozone episodes, with measuring the actual costs of emission reductions, and with the quality of the emissions inventory data. These types of shortcomings are present in any modeling exercise. For our analyses, the emission weights in Table 1 represent the link between the cost of controlling emissions and the ozone concentrations predicted by the photochemical model. The main limitation of these weights is that they describe a single ozone episode (July 1988) using a single model (ROM). Furthermore, the high costs of running ROM limited the number of runs so that standard statistical procedures for measuring the accuracy of the emission weights could not be used. An important objective of future research should be to determine how robust the emission weights are to different ozone episodes and to different photochemical models. In addition, more runs of the photochemical models are needed so that confidence intervals for the emission weights can be calculated[37].

7. Policy Implications

The regulation of air pollutants in the U.S. has largely followed broad-based standards established by the EPA. As these standards have grown increasingly more stringent, the benefit of setting uniform emission regulations in different regions becomes questionable. The economic inefficiencies associated with uniform regulation tend to increase as the marginal costs of

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[37] Simulation of a seven day ozone episode on ROM takes approximately seven days of computing time on Sun work station.

reducing emissions increase. Inefficiencies arise when the marginal costs of controlling emissions in different regions diverge. In these situations, regionally tailored control policies can be significantly more cost effective.

Uniform regulations persist because there are costs to the regulatory agencies for developing regionally adaptive control policies. These costs consist of additional expenses to develop, implement, and enforce the policies. However, if the costs of meeting uniform regulations are sufficiently high for the economy as a whole, reducing these costs may justify making the extra regulatory effort to use regionally adaptive controls.

In our analysis of the Northeastern OTR, the baseline inventory of emissions in 2005 is derived under the assumption that a number of uniform regulations are enforced throughout the ROM domain (eastern half of the country). These regulations correspond to substantial reductions of total emissions of NO_X and VOC from the levels in 1990 (see Section 2.0). However, the marginal costs of reducing emissions further increase from hundreds of dollars per ton to thousands of dollars per ton relatively quickly. As a result, there are substantial economic gains from trading among sources of emissions.

The emission weights in Table 1 link the costs of reducing emissions by type and location to the effects on ozone concentrations in GNYMA. In essence, these weights form an exchange rate for trading emissions among sources and among the specified sub-regions in Figure 1. For elevated sources of NO_X from utility and industrial boilers, there are substantial gains from trading within the sub-regions[38]. This type of trading is incorporated into the Integrated Strategies shown in Figure 2. In contrast, the Regulatory Base assumes that emission

[38] This is equivalent to putting regional caps on emissions.

standards are set for each point source. The economic inefficiencies of the uniform standards assumed in the 2005 inventory are relatively small because the associated costs are also relatively small. However, the marginal costs of going beyond these initial standards are high enough and vary enough among point sources to make trading worthwhile[39].

The economic advantages of trading emissions of NO_X within the sub-regions can be seen by comparing the reductions of NO_X and the associated costs for the industrial and utility sectors in Tables 2 and 3. The reductions of total NO_X *in* NJP, E-PA and W-PA are substantially greater in the Integrated Strategy (Table 3) than they are in the Regulatory Base (NO_X Point in Table 2). Nevertheless, the corresponding costs in the Integrated Strategy are much less (<60%, <70% and <50% of the corresponding annual costs in the Regulatory Base for NJP, E-PA and W-PA, respectively). In other words, trading NO_X within sub-regions is an important way to reduce the costs of controlling emissions from point sources. Such a policy could be implemented by setting regional caps for NO_X from point sources.

The emission weights for NO_X point sources place greater emphasis on regions that are up-wind of the GNYMA. A natural extension of these results is to consider weighted emissions trading for point sources that are further upwind, such as sources in Maryland, Virginia, West Virginia, and Ohio. Emissions from these upwind sources are likely to contribute to the ozone non-attainment problem in population centers along the eastern seaboard. As mentioned earlier, emissions from NO_X point sources in the GNYMA are

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[39] In particular, the marginal costs per ton of NO_X removed is high for installing SCR on boilers.

upwind of the non-attainment regions in New England, and a similar argument could be made for setting emission weights greater than zero in GNYMA if a broader geographic measure of ozone was used.

The main savings in cost from the Regulatory Base for ground-level sources of emissions come from limiting the additional controls to the Amtrak corridor. In addition, relatively inexpensive controls on off-road engines are included in the Integrated Strategies but are not part of the Regulatory Base. Given the relatively low emission weights for VOC (Table 1), reducing both NO_X and VOC by introducing low emission vehicles is more cost effective than Cal Gas, which primarily reduces VOC emissions. Both types of control for transportation are, however, included in the most stringent of the Integrated Strategies in Table 4.

The transportation sector contributes over 50% of the anthropogenic emissions emitted within the Amtrak corridor along the eastern seaboard. Ozone attainment in the Northeast will require additional emission controls from the transportation sector. Although this analysis considered an extensive set of engineering and behavioral control measures, it did not consider boarder planning issues of private automobiles versus public transit. Improvements in the infrastructure for transportation in the Amtrak corridor offer the potential for further cost effective reductions of ozone concentrations in GNYMA. Such improvements could, for example, make it more convenient to use public transportation and to operate and alternate fueled vehicles.

8. Conclusions

The methodology presented for designing Integrated Strategies provides a tractable means to identify cost effective policies and address a persistent and complex problem of ambient air quality. It narrows the gap between the scientific knowledge of ozone formation and the corresponding cost of reducing ozone concentrations by controlling emissions of NO_X and VOC. The structure of the approach applied in this study makes it relatively easy to incorporate improvements in cost and emissions data as well as representing an innovative way to use photochemical models.

The photochemical model ROM evaluated the effects of emission reductions in the Northeast on ozone concentrations in the GNYMA. The analysis is specific to a single ozone episode and emission reduction programs beyond the existing federal control initiatives for the year 2005. It is assumed that these control initiatives bring most of the OTR into compliance, but GNYMA will remain in excess of the ozone standard. Results from a series of photochemical model simulations are synthesized into a statistical representation of ozone formation. This statistical representation of ozone formation serves as the link between the science of ozone formation and economic models of emission control costs. The modeling framework achieves the policy-makers' objective to identify cost effective strategies to reduce ozone concentrations in the GNYMA.

The principal findings establish a basis for the Northeast to develop regional air pollution control districts with more focused and carefully targeted control programs. Specifically, we find a net cost saving of 80 percent reduction in costs compared to the proposed Regulatory Base Strategy. This efficient solution is called an Integrated Strategy for the tri-state area of New York, New Jersey, and Pennsylvania. Some of the cost reductions in the Integrated Strategy are achieved through selecting control programs that are not included in the Regulatory Base, such as emissions from off-road engines. However, the principal cost reductions of the Integrated Strategies are achieved by concentrating on ground-level controls in the Amtrak corridor and allowing for trading among point sources in the upwind regions. Another significant source of cost reductions is achieved by eliminating emission controls on sources that contribute modestly to ozone formation in the GNYMA. In general, the spatial effects result in control of elevated NO_X emissions from sources to the south and west of the GNYMA. Since elevated NO_X emissions from Western Pennsylvania have a relatively high marginal contribution, extending controls on point sources further west and south of the three-state region may be cost effective. Control of ground-level NO_X and VOC emissions are selected over a more narrow corridor to the south and west than the Regulatory Base. The principal focus of ground-level controls is directly upwind of GNYMA in New Jersey and the Philadelphia metropolitan area. For transportation, the analysis implies that focusing on low emission vehicles should be the first priority. Introducing advanced reformulated gasoline in the Amtrak corridor is also selected for high levels of ozone reductions.

Reduction in emission control costs can be achieved either through careful selection of emission control programs or weighted emissions trading. However, market forces tend to be more efficient at minimizing costs as conditions change over time, and weighted emissions trading combines the advantage of markets while meeting air quality goals. The emission weights (Table 1) account for species reactivity and spatial effects of pre-cursor emissions. Implementation of weighted emissions trading requires the establishment of boundaries to define each sub-region. Specifically, the results suggest that the concept of corridors introduced in the SIP filing of November 1994 is appropriate. Hence, the definition of the Amtrak corridor combined with existing state boundaries should be adequate for defining appropriate regions for trading.

Emissions trading of VOC offsets for point sources exists under current EPA regulations, but the small spatial scale of the trading domains and the inability to execute inter-species trading undermines the effectiveness of this program. Inter-regional and inter-species trading from NO_X and VOC point sources offer significant cost advantages. Since the number of utility and industrial point sources is relatively small, such a policy would be relatively easy to implement. However, emissions trading is difficult to implement for the transportation sector. The results suggest regulatory control initiatives for transportation should focus on the Amtrak corridor. In addition to encouraging the use of low emission vehicles and introducing advanced reformulated gasoline in the Amtrak corridor, there is a need to consider additional initiatives like alternate fueled vehicles and an improved public transit system.

Future research efforts should focus on reducing uncertainty about the trading weights. Uncertainty can be reduced by developing a more robust emissions inventory and meteorological inputs, testing alternative photochemical models and evaluating additional ozone episodes. A finer resolution of ground-level and aloft plume movement is required to estimate an ozone response surface more accurately. Research efforts to better understand control costs to companies and consumers could also reduce the overall level of uncertainty about the acceptability of a policy to the public. Finally, integrating human exposure would enable policy-makers to assess the trade-off between the marginal cost and marginal benefit of different emission control strategies.

Even applying state-of-the-art photochemical modeling techniques with a significantly more robust emissions inventory and meteorological inputs may not be adequate to answer important policy questions. Nevertheless, the approach outlined in this article can be adapted to new information and modeling techniques as they become available. To the degree that the Integrated Strategy selects cost-effective strategies which fairly and efficiently places the cost burden on the polluter, the political appeal of the regulations is improved. Emission control strategies to reduce ozone concentrations will work best if they are designed to reflect regional characteristics accurately. These economic issues are important when the marginal costs of controlling emissions are high. When costs are relatively low, traditional across-the-board controls may be appropriate. Hence, the cost savings of the Integrated Strategies result from looking at controls beyond the existing federal controls when substantial reductions of emissions have already been implements.

Table 2: Regulatory Base Strategy*; Removal, Cost, & Effectiveness

Region & Sector Type	Ground Tons_VOC	Ground Tons_NOX1	Aloft Tons_NOX2	Average $/ton	Net Cost** $million/yr	Reductions in Ozone (ppb)	Average $million/O3 (ppb)	Total $million/yr
UNY	17,209	9,381	10,027	$3,766	$130	0.1	904	$163
Transportation	17,209	9,217		$3	$85	0.0	2,055	$117
Inustrial		76	2,701	$8,810	$24	0.0	880	$25
Inst/Comm		88	341	$4,099	$2	0.0	455	$2
Utility			6,985	$2,704	$19	0.1	266	$20
GNYMA	30,831	13,069	12,248	$3,160	$170	4.5	38	$230
Transportation	30,831	12,583		$3	$135	4.4	31	$193
Inustrial		162	275	$5,442	$2	0.0	121	$2
Inst/Comm		325	1,059	$4,002	$6	0.0	140	$6
Utility			10,914	$2,476	$27	0.0	247,601	$29
NJP	17,523	9,343	3,162	$2,478	$85	3.8	22	$108
Transportation	17,523	8,451		$2	$59	2.6	23	$80
Inustrial		556	651	$6,374	$8	0.3	23	$8
Inst/Comm		336	6	$5,615	$2	0.1	24	$2
Utility			2,505	$6,712	$17	0.8	20	$17
E-PA	14,427	6,771	5,778	$2,603	$66	2.1	31	$86
Transportation	14,427	6,682		$2	$51	1.0	53	$70
Inustrial		77	619	$7,792	$5	0.1	40	$6
Inst/Comm		13	56	$4,974	$0	0.0	26	$0
Utility			5,104	$1,711	$9	1.0	9	$9
W-PA	11,332	5,644	16,212	$3,154	$74	3.0	25	$92
Transportation	11,332	5,626		$2	$42	0.1	411	$57
Inustrial		11	1,325	$11,828	$16	0.2	67	$16
Inst/Comm		8	59	$5,615	$0	0.0	35	$0
Utility			14,828	$1,111	$16	2.7	6	$19
3 State Total	91,322	44,209	47,427	$2,872	$526	13.6	39	$678
Transportation	91,322	42,558		$2,778	$372	8.1	46	$517
Inustrial		882	5,571	$8,641	$56	0.8	73	$57
Inst/Comm		769	1,521	$4,337	$10	0.1	68	$10
Utility			40,335	$2,180	$88	4.6	19	$94

*The Regulatory Base Strategy consists of Cal LEV, Cal Reformulated Gasoline, & NOx point source controls.

**Net Costs include environmental and health benefits for off-season reduction of emissions

Table 3: Integrated Strategy (13.5 ppb O_3); Removal, Costs & Effectiveness

Region & Sector Type	Tons_VOC1	Tons_NOX1	Tons_NOX2	Average dollars/ton	Maringal $/ton	Net Cost* million/yr	Reduction Ozone (ppb)	Average $millions/O3-ppb	Total Cost $million/yr
UNY	no emission controls selected								
GNYMA	8,416	11,729	-	$853	$1,800	$17	2.2	$8	$22
Transportation	963	2,159	-	$1,042	$1,800	$3	0.4	$9	$4
Industrial	1,209	4,404	-	$1,267	$1,515	$7	0.6	$11	$9
Inst/Comm	879	2,829	-	$1	$1,800	$3	0.4	$0	$3
Residential	5,366	2,336	-	$540	$1,328	$4	0.8	$5	$5
Utility	-	-	-			-	0.0		-
NJP	16,055	16,906	3,460	$1,316	$5,542	$48	5.5	$9	$69
Transportation	13,064	9,753	-	$1,386	$1,800	$32	2.7	$12	$50
Industrial	566	4,464	349	$1,658	$5,415	$9	1.1	$8	$11
Inst/Comm	413	1,686	-	$1	$2,330	$2	0.4	$0	$2
Residential	2,012	1,002	-	$352	$713	$1	0.3	$4	$1
Utility	-	-	3,111	$1,413	$5,542	$4	1.0	$4	$5
E- PA	1,824	5,524	7,006	$848	$2,487	$12	2.2	$6	$15
Transportation	-	1,112	-	$1,194	$1,800	$1	0.2	$8	$2
Industrial	-	2,820	-	$1,236	$1,515	$3	0.4	$9	$4
Inst/Comm	-	644	14	$1	$2,487	$0	0.1	$0	$1
Residential	1,824	949	-	$303	$713	$1	0.1	$6	$1
Utility	-	-	6,992	$863	$2,116	$6	1.4	$4	$7
W-PA	0	0	19,868	$762	$2,863	$15	3.6	$4	$18
Transportation	-	-	-			-	0.0		-
Industrial	-	-	-			-	0.0		-
Inst/Comm	-	-	-			-	0.0		-
Residential	-	-	-			-	0.0		-
Utility	-	-	19,868	$762	$2,863	$15	3.6	$4	$18
Three State Total	26,295	34,159	30,333	$1,018	$5,542	$92	13.5	$7	$124
Transportation	14,027	13,024	-	$1,339	$1,800	$36	3.2	$11	$55
Industrial	1,775	11,688	349	$1,413	$1,515	$20	2.1	$9	$24
Inst/Comm	1,292	5,159	14	$1	$2,330	$5	0.9	$0	$6
Residential	9,201	4,287	-	$449	$713	$6	1.2	$5	$8
Utility	-	-	29,970	$853	$5,542	$26	6.0	$4	$30

*Net Costs include environmental and health benefits for off-season reduction of emissions.

Table 4: Efficiency Frontier for the Integrated Strategies

Region & Sector Emiss Reduction Costs	$1,000 net levelized 9.7 ppb	13.5	15.7 ppb	20.4 ppb	24.2 ppb	27.4 ppb	Reg Base 13.6 ppb
UNY	-	-	-	-	-	-	$130,488
Transportation	-	-	-	-	-	-	$85,370
Industrial	-	-	-	-	-	-	-
Inst/Comm	-	-	-	-	-	-	$26,227
Residential	-	-	-	-	-	-	-
Utility	-	-	-	-	-	-	$18,891
GNYMA	$9,361	$17,181	$35,181	$115,090	$115,090	$115,090	$169,973
Transportation	$862	$3,255	$19,334	$99,243	$99,243	$99,243	$135,036
Industrial	$2,000	$7,114	$7,114	$7,114	$7,114	$7,114	-
Inst/Comm	$2,374	$2,655	$2,870	$2,870	$2,870	$2,870	$7,915
Residential	$4,126	$4,156	$5,862	$5,862	$5,862	$5,862	-
Utility	-	-	-	-	-	-	$27,022
NJP	$14,094	$47,927	$80,624	$82,730	$116,167	$118,830	$85,001
Transportation	$2,572	$31,631	$31,823	$31,823	$31,823	$31,823	$58,575
Industrial	$5,255	$8,920	$11,670	$11,670	$39,172	$39,172	-
Inst/Comm	$1,917	$1,917	$4,203	$4,203	$4,203	$4,203	$9,615
Residential	$1,062	$1,062	$2,637	$2,637	$3,172	$2,668	-
Utility	$3,288	$4,396	$30,292	$32,398	$37,797	$40,964	$16,811
E-PA	$11,102	$12,171	$18,972	$70,238	$82,236	$108,309	$65,668
Transportation	$259	$1,328	$2,044	$26,081	$26,081	$26,081	$51,174
Industrial	$3,486	$3,486	$7,844	$10,315	$10,315	$10,671	-
Inst/Comm	$484	$484	$484	$717	$717	$763	$5,760
Residential	$840	$840	$443	$443	$840	$443	-
Utility	$6,033	$6,033	$8,157	$32,682	$44,284	$70,351	$8,734
W-PA	$14,661	$15,144	$15,259	$15,624	$80,334	$187,451	$74,381
Transportation	-	-	-	$228	$228	$228	$41,730
Industrial	-	-	-	$136	$2,487	$3,051	-
Inst/Comm	-	-	-	-	$333	$692	$16,177
Residential	-	-	-	-	-	-	-
Utility	$14,661	$15,144	$15,259	$15,259	$77,286	$183,481	$16,474
Three State Total	$49,218	$92,423	$150,037	$283,682	$393,827	$529,680	$525,511
Transportation	$3,693	$36,214	$53,201	$157,375	$157,375	$157,375	$371,884
Industrial	$10,741	$19,520	$26,628	$29,235	$59,088	$60,009	-
Inst/Comm	$4,775	$5,057	$7,558	$7,791	$8,124	$8,528	$65,694
Residentail	$6,027	$6,058	$8,942	$8,942	$9,874	$8,973	-
Utility	$23,982	$25,573	$53,708	$80,339	$159,367	$294,796	$87,933
*Net Costs	$49,218	$92,423	$150,037	$283,682	$393,827	$529,680	$525,511
Total Costs	$60,556	$123,819	$194,920	$388,753	$508,016	$646,893	$678,368

*Net costs include environmental and health benefits for off-season reductions of emissions.

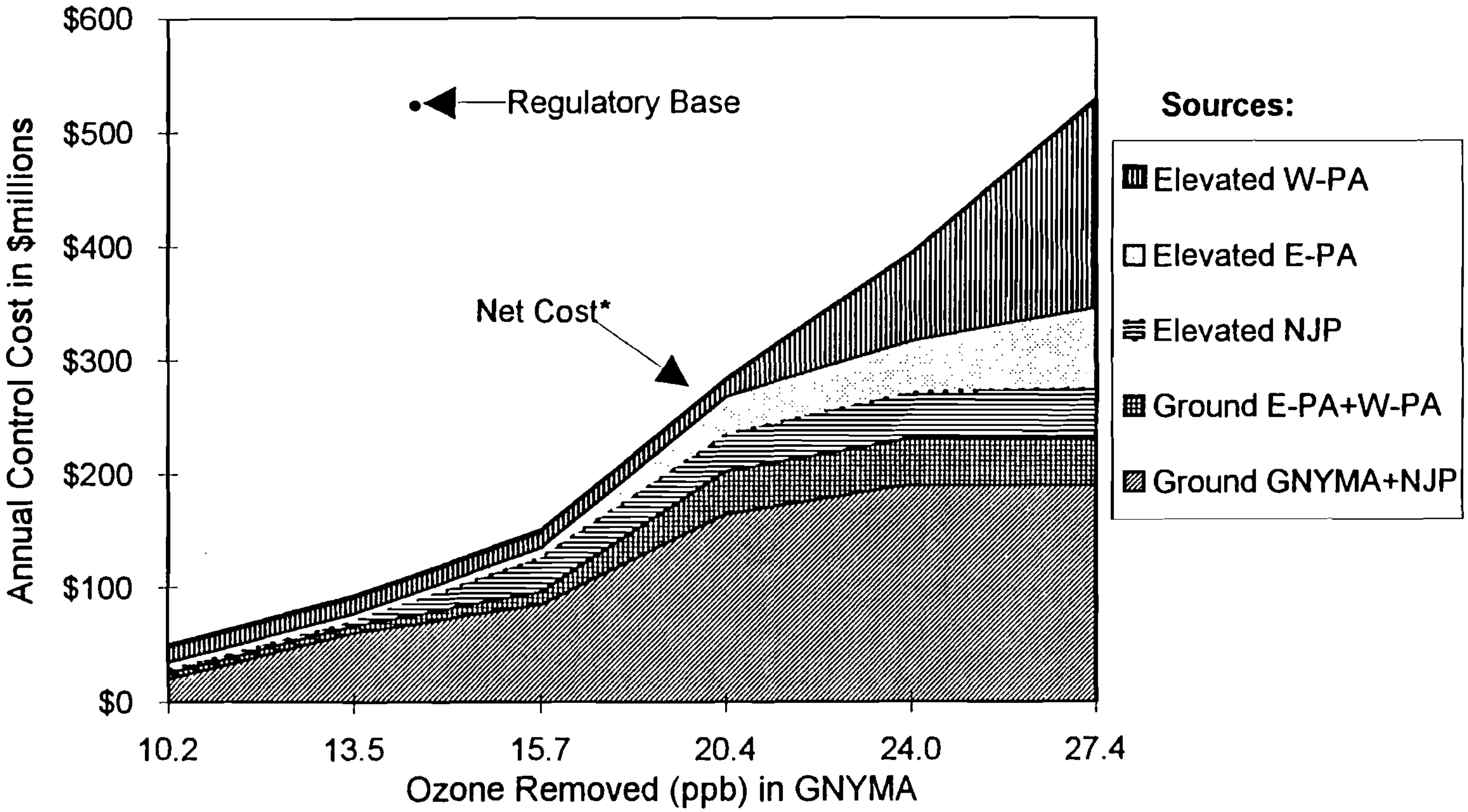

Figure 2 Cumulative Cost by Source on the Efficiency Frontier for the Integrated Strategies

*Environmental and health benefits are included

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