Impact of NO_x emission reduction policy on hospitalizations for respiratory disease in New York State

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ABSTRACT

Background / Objectives: To date, only a limited number of studies have examined the impact of ambient pollutant policy on respiratory morbidities. This accountability study examined the effect of a regional pollution control policy, namely, the U.S. Environmental Protection Agency's (EPA) NO_x Budget Trading Program (NBP) on respiratory health in New York State (NYS).

Methods: Time-series analysis using generalized additive models (GAM) was applied to assess the change in daily hospital admissions due to respiratory diseases in NYS after the implementation of the NBP policy. Respiratory endpoints in the summers during the baseline period (1997-2000) were compared to those during the post-intervention period (2004-2006). Stratified analyses were also conducted to examine if the health impacts of the NBP differed by socio-demographic, regional, or clinical characteristics.

Results: Following the implementation of EPA NBP's policy, there were significant reductions in mean ozone levels (-2% to -9%) throughout NYS. After adjusting for time-varying variables, $PM_{2.5}$ concentration, and meteorological factors, significant post-intervention declines in respiratory admissions were observed in the Central (-10.02, 95% CI:-14.10,-5.76), Lower Hudson (-11.33, 95% CI:-17.01,-5.25), and New York City Metro regions (-5.49, 95%CI: -7.26,-3.68), consistent with wind trajectory patterns. Stratified analyses suggest that admissions for asthma, chronic airway obstruction, among those 5-17 years old, self-payers, Medicaid-covered, and rural residents declined the most post-NBP.

Conclusions: This study suggests that the NO_x control policy may have had a positive impact on both air pollution levels statewide and respiratory health in some NYS regions. However, the effect varied by disease subgroups, region, and socio-demographic characteristics.

INTRODUCTION

Ambient ozone and one of its precursors, nitrogen oxides (NO_x), are major components of outdoor air pollution. NO_x are emitted from a variety of sources, including on-road mobile sources, electric generating units and off-road mobile sources such as construction vehicles and equipment, agriculture, and non-road transportation. In the presence of sunlight, NO_x undergoes a photochemical reaction to produce ozone; the transport and dispersal of ozone are also influenced by the prevailing meteorological conditions (Rao et al. 2008; U.S. EPA 2011a). Ozone is a notable pollutant for its potential to adversely impact human health both in areas of emissions sources and from pollution transport to areas from distant sources.

Under the provisions of the 1990 Clean Air Act Amendments, the U.S. Environmental Protection Agency (EPA) is required to work with state, local and tribal agencies to help states achieve National Ambient Air Quality Standards (NAAQS) for criteria pollutants. Some states, however, have had difficulties in meeting the NAAQS because pollution emitted upwind is transported into the receiving state's boundaries. As a result, the EPA has initiated regional programs to control the long-range transport of ozone. EPA's NOx Budget Trading Program (NBP), which was fully implemented in 2004, required 20 eastern states and Washington D.C. to reduce their summertime NO_x emissions from major sources, including electric utilities (U.S. EPA 2009a). Because NO_x is a precursor to ozone formation, region-wide reduction in NO_x emissions should lead to a subsequent decline in outdoor ozone concentrations, typically leading to reduced concentrations in downwind areas, depending on prevailing winds (Godowitch et al. 2009).

Numerous epidemiological studies have shown associations between ambient ozone concentrations and acute respiratory morbidities such as asthma and bronchitis, especially among susceptible individuals such as children and the elderly, those with existing chronic conditions, of low socioeconomic status, and living in close proximity to emission sources (Burnett et al. 1997; Lin et al. 2008; Peel et al. 2007; Zanobetti et al. 2006). However, only a limited number of previous studies have directly assessed the health impact of implementing an environmental policy, despite the need for evidence in support of their efficacy (Lobdell et al. 2011). The objective of this accountability study was to evaluate the impact of EPA's NBP control policy in NYS by examining respiratory hospitalizations before and after the policy went into effect. Specifically, we aimed to: 1) determine if ozone levels (i.e., as a surrogate for NO_x, being a byproduct) declined as expected after the NBP implementation, 2) determine if a corresponding decline in respiratory hospitalizations was observed, and 3) explore possible geographic and socio-demographic variation among observed health impacts in NYS.

METHODS

Hospital data and case definition

This time-series study was conducted among the entire NYS resident population, during the summers of 1997 through 2006. Hospital discharge data were obtained from the New York State Department of Health Statewide Planning and Research Cooperative System (SPARCS) database. SPARCS is a legislatively mandated database of discharges from all hospitals in the NYS (excluding psychiatric and federal hospitals), with coverage of approximately 97% of all hospitalizations statewide. The SPARCS dataset included the date of admission, principle diagnosis, date of birth, sex, and a unique identifier. All NYS residents were included in the analysis; records were excluded only if the patient address was out-of-state. The principle respiratory diagnoses included in analyses were asthma (International Classification of Disease, 9th Revision (ICD-9) code 493), chronic bronchitis (491), bronchitis, not specified as acute or chronic (490), emphysema (492), and chronic airway obstruction (496). For children 0-4 years, admissions for acute bronchitis and bronchiolitis (ICD-9 code 466) were also included they are both commonly occurring and difficult to distinguish from asthma in this age group. A combined respiratory disease group included all diagnoses, and each diagnosis was also examined separately. Control admissions were selected from principle diagnoses thought to be unrelated to air pollution and included those for gastrointestinal diseases (009) and non-traffic related accidental injury (E880-E888). Also extracted from the discharge record was the patient's street address, payer for the hospital stay (categorized as Medicaid, Medicare, private insurance, or self-paid), age (0-4, 5-17, 18-65, and ≥65 years), and race/ethnicity (categorized as non-Hispanic white, black, non-white Hispanic, and other race/ethnicity). Geo-coordinates were assigned to the patient's address from the hospital record for linkage with environmental and Census data.

Exposure Definition and Intervention Period

Based on the timing of the NBP regulation, three mutually exclusive time periods for the study were defined as follows: (1) summers of 1997-2000 (baseline period); (2) summers of

2001- 2003 (partial-implementation); and (3) summers of 2004-2006 (post-implementation). The total 10 year time frame (1997 through 2006) was selected because of the availability of the health data and because it spanned before and after the NBP implementation. The results from the partial-implementation time period are not described in this paper due to incomplete knowledge of emissions controls during that period. The post-implementation time period was selected to coincide with the full-implementation of the EPA's NBP program, which began in 2004. Also, while the NBP was implemented during the ozone season, from May 31st to September 30th, this study included only summer (June 1st-August 31st) in order to minimize influence from relatively high pollen counts in May, and high allergen levels and asthma peaks in September. It should be noted that high ozone levels in NYS are primarily observed from June to August.

Indicator variables for each of these time periods were generated for analysis, and the post-NBP period was compared to the baseline period. NYS was divided into eight regions for analysis based on those used by the NYS Department of Environmental Conservation (NYSDEC) for air quality forecasting, including: Long Island, New York City Metro, Lower Hudson, Upper Hudson, Adirondack, Central, Eastern Lake Ontario and Western New York regions (NYSDEC 2010). Daily and periodic hospital admission counts were aggregated to the region for analysis.

Air Quality and Confounder Data

Daily maximum 8-hour average ozone concentration data were provided by the EPA, including ambient air quality data from Atmospheric Information Retrieval System (AIRS), Clean Air Status and Trends Network (CASTNet) and National Air Pollution Surveillance (NAPS) monitoring systems, which span the entire Northeastern U.S. and parts of Canada. A kriging method was used to interpolate the daily maximum 8-hour average ozone concentrations from observed data at air quality monitoring stations to a 12-km grid surface across NYS (Garcia et al. 2010). Daily averaged particulate matter < 2.5 microns in diameter ($PM_{2.5}$) concentrations were estimated using all available observations and modeled data as described by Hogrefe et al. (2009). In addition, NO_x emissions data from EPA's emissions inventory were examined (U.S. EPA 2011a). We obtained daily meteorological data, including ambient temperature, relative humidity, and wind speed from the National Center for Atmospheric Research, which maintains these data at various airports around NYS. For meteorological adjustment, we calculated universal apparent temperature (UAT); daily average temperature adjusted for relative humidity and wind speed (Steadman 1984). UAT was then aggregated to the regions. U.S. Census data (2000) was used to classify urbanicity (urban, suburban, and rural areas) on the basis of Rural Urban Commuting Area codes, and to control for socioeconomic variables in regionally pooled estimates, including population density, percent below poverty, and percent with less than high school education.

Statistical Methods

Descriptive analysis included the computation of daily, monthly, annual and periodic summertime admission counts and daily maximum 8-hour average ozone concentrations for assessment of trends. We compared region-specific counts of daily admissions for combined respiratory diagnoses and daily maximum 8-hour average ambient ozone concentrations during baseline and post-implementation periods. Generalized additive models (GAM) with a Poisson distribution were applied with the partial- and post-intervention periods (compared to baseline) as independent variables to investigate the impact of the NO_x intervention on respiratory hospitalizations. This approach of applying the intervention model separately is consistent with previous intervention studies (Naiman 2010; Peel 2010), and was necessary because ozone is highly correlated with the intervention term. GAM models did not adjust for a long-term trend as this would remove the intervention effect, the variable of interest in this study. Models were adjusted for dependency structures of both the temporal weekly and meteorological UAT effects on respiratory admissions by using four degrees of freedom for the smoothing parameters for the study period; one is taken up by the linear portion of the fit and three remain for the nonlinear spline portion. Models were adjusted for periodic effects within the 12-week summer, such as day of the week, week of the year, and the July 4th holiday. GAM models also controlled for potential confounding effects of region-specific $PM_{2.5}$ concentration (3-day moving average) and average daily UAT. For $PM_{2.5}$, a 3-day moving average of 0, 1 and 2-day lags were used; UAT was modeled with a 0-day lag structure. To reduce the strong autocorrelations in the residuals typically observed with hospitalization data, three lagged respiratory admissions variables of 1, 2 and 3-days were included. Thus, we considered the following GAM model, incorporating both linear and non-linear components:

$$\text{Log}(\text{Admissions}_t) = \alpha + \beta_1(\text{Monday}_t)\ldots. + \beta_6(\text{Saturday}_t) + \beta_7(\text{Holiday}_t) + \beta_8(\text{Partial NBP}_t) + \beta_9(\text{Full NBP}_t) + \beta_{10}(\text{3-day PM}_{2.5}\text{ moving average}_t) + \beta_{11}(\text{UAT}_t) + \beta_{12}(\text{Week}_t) + \phi_1(\text{Admissions}_{t-1}) + \ldots\ \phi_3(\text{Admissions}_{t-3})\ f_1(\text{UAT}_t) + f_2(\text{Week}_t) + \varepsilon_t$$

Model fit was evaluated via the Bartlett Kolgomov-Smirnov white-noise test statistic to ensure that no significant autocorrelation or time trend was left unaccounted for in the model residuals.

After controlling for subseasonal variations (i.e., temporal variation within the summer months), UAT, and $PM_{2.5}$, the post-implementation period was compared to the baseline time period to examine the effect of the intervention on admission counts. Parameter estimates (converted to percent change) and 95% confidence intervals (95%CI) for hospitalizations were computed for each region. To calculate the statewide estimate, region-specific estimates were pooled via random effects using inverse variance weighting and adjusted for mean-centered regional Census socio-economic covariates. Since a GAM uses daily admissions counts as the dependent variable, to adjust for confounding by individual-level variables and to assess their role as effect modifiers, we further examined the intervention effect after stratification by geographic region, race/ethnicity, age groups, disease subgroups, insurance coverage, and urbanicity. A quantile regression with ozone as the response variable was conducted to investigate whether the NBP implementation had a differential effect on ozone distribution after adjusting for intervention periods (versus baseline), region, sub-seasonal trends, and UAT. All geographical linkages were performed in MapInfo® (v. 8.5), and data analysis was conducted using SAS® (v. 9.2).

Results

Figure 1 describes the geographic differences (without adjustment for time-varying or other factors) in summertime daily maximum 8-hour average ozone concentrations, respiratory hospitalizations, and two types of control diseases between baseline and post-NBP summers in NYS. As described in Figure 1a, summertime mean daily maximum 8-hour average ozone concentrations declined statewide after the implementation of NBP. High ozone concentrations observed in the week of July 13 during the pre-NBP time period are due to a high ozone event that occurred between July 12 through July 17, 1997 (Bailey 1997). This event was accompanied by high temperatures and atmospheric stagnation conditions, and demonstrates the importance of accounting for meteorology in examining associations between ozone exposure and human health impacts. The mean statewide reduction in ozone concentration between the baseline and post-implementation periods was 5% (Figure 1a) or 2.47 ppb, with declines by region ranging from 1.32 ppb to 4.79 ppb (Table 1). Compared to the baseline period (Table 1), the greatest declines in average daily ozone concentration post-implementation were observed in the Long Island Region (-4.79 ppb), followed by declines of -3.15 ppb in the NYC Metro, Adirondack (-2.41 ppb), and Eastern Lake Ontario and Central regions (-2.22 and -2.10 ppb respectively).

There were 142,679 hospitalizations for respiratory disease over the study period. Compared to the baseline period, average daily summertime respiratory hospitalizations declined statewide in the post-implementation period by 0.76 % per year (data not shown). As shown in Figure 1b, declines in crude admissions counts after the NBP policy were greatest for the NYC Metro, Lower Hudson, and Central regions. After confounder adjustment, several statistically significant region-specific declines in respiratory hospitalizations were observed post-implementation (Table 1). These declines were observed in the Central (-10.18, 95% CI: -14.18,-6.01), Lower Hudson (-11.05, 95% CI: -16.54,-5.19), and NYC Metro regions (-5.71, 95%CI: -7.39,-4.00). However, significant increases in the number of daily hospitalizations were observed in the Adirondack and Upper Hudson regions (increases of 17.60 and 6.21%, respectively) during this same time period. When effects were pooled statewide, a small but non-significant decline (-0.15%) in admissions was observed.

In contrast to the declines in both ozone and respiratory disease admissions in the post-NBP implementation time period, control hospitalizations counts showed increases of 67% and 22% respectively (Figures 1c, 1d), compared to the baseline period. These increases were consistent across all regions of NYS. The Central region and Lower Hudson regions, where significant reductions in respiratory admissions were observed post-NBP implementation, had moderate to large percent increases in these control hospitalizations during the same period.

Subseasonal differences in the NBP effect were observed. The greatest differences in average daily admissions counts between baseline and post-implementation occurred during the late summer (Figure 2a). The largest decline in ozone concentrations during post-implementation also appeared to occur during the late summer (Figure 2b). Comparing the post-NBP ozone concentrations to baseline in quantile regressions further showed that the largest reductions in outdoor ozone occurred in the 80^{th} percentile of ozone concentrations and higher, where the reduction was in excess of 4 ppb (data not shown), a result that is consistent with those of Godowitch et al. (2009).

Table 2 describes and compares the estimated effects of the NBP policy on respiratory hospitalizations by disease subgroups and socio-demographic characteristics. Stratified analyses showed differences between disease subgroups, i.e., there were significant declines only in hospitalizations for asthma (-3.10%, 95%CI: -4.88,-1.29) and unspecified airway obstruction (-72.07%, 95%CI: -75.31,-68.41) following the NBP (Table 2). Significant decreases in admissions were also observed for all age groups (from -4.81% to -12.47%) with the largest percent reduction among individuals 5-17 years old (-12.47%), except among those 65 years and older. Hospitalizations declined among white, black, and other racial/ethnic groups (from -2.69 to -14.88%), but significantly increased among non-white Hispanics during the post-implementation period. By health insurance coverage, admissions significantly declined among the uninsured/self-payers (-42.65%), stays paid for by Medicaid (-20.23%) and Medicare (-3.28%), but not among those whose hospitalization was covered by private insurance. Significant declines in respiratory admission were observed in all geographic areas regardless of urbanicity (-5.25 to -27.67%) post-NBP, but with the greatest reduction apparent in rural areas across NYS (-27.67%).

Discussion

We found that the impact of the NBP on health was complex and region-specific, e.g., significant reductions were observed in respiratory admissions in half of NYS regions, including the Central, Lower Hudson, and New York City Metropolitan regions (range from -6% to -11%) after the NBP. These findings are consistent with major transport patterns seen in the Northeastern U.S. by Garcia et al. (2011), who examined the association between respiratory hospitalizations and transported air masses from the Ohio River Valley (ORV) area where NBP-targeted NO_x emissions are largest. Garcia et al. (2011) showed that when transported pollution from the ORV area is targeted, six of the eight NYS regions show significant and beneficial health effects, including the NYC Metro Area, Lower Hudson, and Eastern Lake Ontario regions.

Notably, post-NBP respiratory hospitalizations declines were greatest during the late summer, which is both consistent with observed ozone declines and biologically plausible. These subseasonal differences in NBP effects also demonstrate the cumulative impacts of implementing emission controls. After summertime controls are put in place (e.g., selective catalytic reduction), NO_x emissions and subsequent ozone formation would be expected to decline as the summer progresses.

There are relatively few published studies assessing the health impacts of changes in ambient air pollution or emission reduction policies available to directly compare with our findings. Friedman et al. (2001) found that road traffic reduction strategies in Atlanta, Georgia during the 1996 summer Olympic Games resulted in a 27.9% drop in peak daily ozone concentration and up to a 41.6% decline in childhood asthma events up to 4 weeks after the Olympic Games. In an expanded analysis, Peel et al. (2010) confirmed a short-term reduction in traffic and outdoor ozone concentrations, but saw little decline in total respiratory emergency department visits. Estimating potential health-related benefits of attaining the 8-hour ambient ozone standard, Hubbell et al. (2005) found that the average 3-year of health impacts included significant reductions in respiratory-related hospital admissions and emergency department visits. Another study conducted by West et al. (2009) reported greater mortality reductions in North America outside of NO_x source regions than within them, pointing to the role of pollution transport in health impacts. Although most of the control policies evaluated showed some beneficial effects, none of these studies directly assessed the impact of the NBP, nor examined both air quality and health outcomes over a long time period. Most prior accountability studies have assessed impacts on mortality (Chay and Greenstone 2003) rather than morbidity, or were conducted outside the U.S. (Li et al. 2010).

One interesting finding is that the observed effects of the environmental intervention differed by socio-demographic characteristics and disease subgroups. Consistent reductions were observed after the NBP implementation in respiratory hospitalizations among all age groups except for those $\geq$ 65 years old who may spend less time outdoors than other age groups, and subsequently would have been less impacted by a change in outdoor environmental policy. A post-intervention decline in admissions was also found across all racial/ethnic groups except for among Hispanics, which may be explained by the disproportionate growth among the NYS Hispanic population over the last decade, mimicking national trends (U.S. Census Bureau, 2011).

Since our GAM models used count data and could not adjust for this shift in the Hispanic population, hospitalizations may have been artificially inflated for this group. Individuals with low income, as indicated by both Medicaid coverage or uninsured/self-paying individuals, showed the largest proportional reductions in respiratory admissions (-20% and -42%), which agrees with previous studies demonstrating a stronger association between air pollutant exposure and respiratory hospitalizations among those of low socio-economic status (Lin et al. 2002, Sacks et al. 2010). It could also be partially attributed to increasing hospitalization costs, which may lead people to delay or avoid hospital care.

The effect of the NBP also differed by urbanicity; the smallest admissions reductions were observed in urban areas, which have more local emissions than rural and suburban areas to influence observed associations. Our finding of the largest reduction in hospitalizations in rural areas is also consistent with the impetus of the NBP, i.e., that regional poor air quality is largely due to transport of NO_x from neighboring states or upwind areas. This intended impact is supported by studies that found that ozone reductions are evident after NBP implementation in rural areas as compared to urban areas (Gego et al. 2008; U.S. EPA 2009b). Ozone concentrations are spatially-homogeneous in rural areas, which should minimize exposure misclassification even though monitoring sites are sparser (OTAG 1997).

Finally, while most respiratory admissions significantly declined after the NBP implementation, admissions for chronic bronchitis increased which may reflect the continuous increase in chronic bronchitis hospitalizations since 1997 in NYS and nationally (Bernstein et al. 2003). As such, the frequency of these hospitalizations might have been even greater without the NBP. These reductions in chronic airway obstruction and asthma admissions are also biologically plausible, since there is sufficient evidence from the literature that these two diseases are associated with ambient air pollution (Stieb et al. 2009; Schikowski et al. 2005).

Though accountability studies are growing in number, this remains one of the few studies which attempted to quantify the long-term public health impact of a continuous federal requirement related to outdoor air pollution. The large NYS population is racially/ethnically, geographically, and socio-economically diverse. Therefore, use of statewide data allowed us to examine the potential modifying effects of these factors with air pollutants on health, which help identify vulnerability. In addition to a measure of morbidity, we were also able to quantify air pollutants in this study to identify the plausible beneficial pathway through which reductions in outdoor ozone concentration affect health. The restriction of our analysis to summer months helped address seasonal variation in outdoor ozone concentrations and the expected asthma peak typically observed in autumn (Lin et al. 2011), and corresponded to the targeted summer period of the NBP. Time-series analysis was used to effectively control for relevant time-varying factors and meteorological confounders. To reduce correlations, ambient ozone concentration was not parameterized in GAM models. Instead we modeled the intervention time period as the "exposure" variable based on the study hypothesis, under which ozone would be a causal intermediate on the NBP-hospitalization pathway. Sensitivity analyses which adjusted for ozone concentration did not substantially change the magnitude or significance of intervention parameter estimates.

The modest impact of the NBP seen on respiratory hospitalizations in this study is also scientifically plausible. Because the etiology of respiratory diseases is multifactorial, other outdoor exposures such as local proximity to traffic or other pollutant sources which were unmeasured in this study could have additionally influenced hospitalization risk. In addition, unmeasured indoor environmental factors, family history of the disease, and disease management (Jones 2000) could have changed during the study period and impact respiratory health apart from outdoor ozone concentration. As expected for plausibility considerations, we found no evidence of NBP's beneficial effect on hospitalizations for control outcomes.

Other indirect evidence of the significant positive association between ozone concentration and respiratory diseases supports our conclusion. In a sensitivity analysis, we found that average daily respiratory hospitalizations increased 1.73% (95%CI: 0.44%-3.03%) per 10 ppb increase in 3-day moving average ozone. A previous study (Lin et al. 2008) from 1991-2001 also demonstrated a positive relationship between ambient ozone concentrations and respiratory admissions in multiple regions of NYS.

Of all the factors potentially affecting respiratory hospitalization that we could readily evaluate, air quality, especially ozone concentration, remains the possible reason for the decline in acute respiratory events. This study found consistent declines in statewide ambient ozone concentrations of up to 9% following EPA actions to mitigate transport of ozone and its precursors into NYS. The reduction in outdoor ozone concentration after the implementation of the NBP is consistent with a previous study by Gego et al. (2008), which found that median ozone levels were 3% lower than those in 2002 within the U.S. regions most affected by the

NBP, and confirms a recent EPA evaluation which identified a 10% reduction in outdoor ozone in the eastern U.S. since 2001 (U.S. EPA 2010). In the U.S., air quality is managed at the state level, but contributions to pollution levels do not necessarily arise within that state. In particular, an estimated 77% of each state's ozone and particulate matter concentrations are found to be caused by emissions from other states or upwind states (Bergin et al. 2007). NO_x emissions from these contributing upwind states have significantly declined between the two time periods (Gego et al. 2007; U.S. EPA 2011a). Local emissions as well as transport from neighboring states jointly contribute to outdoor ozone levels in NYS (Garcia et al. 2011), therefore a decline associated with a pollutant-transport policy is in line with our findings. Our quantile regression findings are also consistent with the previous evaluation, which found that emission controls affected the highest end of the distribution of ozone (Gego et al. 2008; Godowitch et al. 2009). This finding is expected, as ozone concentrations would not likely drop below a low threshold (i.e., tropospheric background concentration). However, the most beneficial impacts to public health would also be expected to occur at the highest concentrations, reinforcing the importance of this result.

Another immediate question is if the declines we observed in respiratory admissions were due to other concurrent environmental or public health policies rather than the NBP. The Ozone Transport Commission (OTC), a regional trading program to reduce summertime NO_x emissions in the Northeast, was in effect from 1999 through 2003 and was replaced by the NBP as a continuous program. We found no significant changes in either ozone concentration or respiratory hospitalizations in NYS over this time period (data not shown), suggesting there would be no significant impact of OTC policy on this NBP-related health assessment. Another environmental policy, EPA's Acid Rain Program, was implemented prior to our 1997 study start and spans our entire study period, thus any impact on our findings should be minimal. Another concurrent policy was a comprehensive NYS indoor smoking ban, to which a decline of 8% in hospitalizations for acute myocardial infarction has been attributed (Juster et al. 2007). On the other hand, Shetty et al. (2009) found that indoor smoking bans in the U.S. were not significantly associated with declines in respiratory/cardiovascular hospitalizations. Since data on smoking status for the admission cases in our study was unavailable, we could not control for a potential confounding effect of this concurrent anti-smoking policy which may have influenced indoor exposures. However, our age-stratified analyses showed the largest declines in hospitalization post-NBP occurred even among children, who are less likely to be affected by the smoking ban. In other words, the health benefits we observed may still be partially attributable to the NBP, although the impact of the smoking ban cannot be excluded. We are unaware of other statewide environmental policies which might have impacted ambient ozone concentrations, or of substantial changes in respiratory disease management or treatments during the study period which could further mask our results.

Another potential limitation arises from pooling together urban, suburban, and rural areas across the state, which assumes their homogeneity statewide with respect to environmental and other factors. To address this concern, we also examined associations in several non-pooled rural, suburban, and urban regions and found similar impacts of the NBP, though sample sizes limited the precision of these estimates. Also of concern is if the observed reductions of respiratory diseases are due to population mobility (leaving NYS) or change in population composition. We evaluated temporal trends for changes in all demographic variables during the study period and found none except for among the Hispanic population. We also demonstrated that neither the size of the NYS population nor use of hospital services changed substantially during the study period.

The NBP was a multi-state effort from federal/regional policy to reduce NO_x emissions in the northeastern states and transport from neighboring states. The public health significance of such a policy is likely to be reflected in multiple health endpoints, including respiratory and cardiovascular disease, and possibly others. Since hospitalizations may capture only the most severe health impacts, the observed health benefits in our study were likely underestimates of the total effect of the NBP. The policy's benefits included not only improved air quality and human health in participating states, but also neighboring states (Gego et al. 2008). The success of the NBP may also serve as a demonstration for other countries with air quality and related health concerns. Furthermore, the vulnerable groups we identified support the need for future accountability studies to target high-risk groups for environmental intervention.

In summary, declines in ozone concentration were consistently observed in all NYS regions during the post-intervention period, indicating that the NBP was successful from the standpoint of a reduction in ambient pollutant concentration levels. The declines in respiratory hospitalizations were region-specific and fairly consistent with known patterns of transport for NO_x emissions into NYS from neighboring upwind states. Overall, these findings suggest that regional air pollutant reduction policies may have beneficial effects on both outdoor pollution levels and respiratory health, which may be modified by the prevailing atmospheric transport patterns and socio-demographic characteristics of the population impacted.

Disclaimer

Although this paper has been reviewed and approved for publication, it does not necessarily reflect the views and policies of the U.S. Environmental Protection Agency.

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Table 1. Estimated effects of the NO_x Budget Trading Plan (NBP) implementation on summertime* ozone concentrations (ppb) and average daily respiratory admissions in NYS, by region.

	Ozone		Respiratory admissions	
Region	**Average Daily Difference (ppb) and 95% CI**		**Percent Change[a] and 95% CI**	
Adirondack	**-2.41**	**(-4.25, -0.56)**	**17.60**	**(8.27, 27.74)**
Central	**-2.10**	**(-3.98, -0.21)**	**-10.18**	**(-14.18, -6.01)**
Eastern Ontario	**-2.22**	**(-4.32, -0.13)**	5.50	(-1.02, 12.45)
Long Island	**-4.79**	**(-7.29, -2.28)**	1.17	(-2.59, 5.07)
Lower Hudson	-1.90	(-4.14, 0.33)	**-11.05**	**(-16.54, -5.19)**
NYC Metro	**-3.15**	**(-5.68, -0.63)**	**-5.71**	**(-7.39, -4.00)**
Upper Hudson	-1.83	(-3.73, 0.06)	**6.21**	**(0.41, 12.35)**
Western	-1.32	(-3.40, 0.75)	-0.38	(-5.09, 4.56)
Statewide**	**-2.47**	**(-3.22, -1.72)**	**-0.15**	**(-9.83, 10.55)**

* June – August.
** Pooled over the individual regions via random effects using inverse variance weighting and mean-centered regional socio-economic covariates.
[a]Estimates from the GAM models; change from baseline period (1997-2000) to post-NBP (2004-2006). Adjusted for 3-day moving daily average $PM_{2.5}$, universal apparent temperature (daily average), relative humidity, and weekday, holiday, and subseasonal trend.

Table 2. Estimated effects of the NO_x Budget Trading Plan (NBP) implementation on summertime* daily respiratory admissions in NYS, stratified by disease subgroups and socio-economic indicators.

	Respiratory admissions			
	Average daily admissions Baseline	**Average daily admissions Post-NBP**	**Percent Change[a]**	**95% CI**
Diagnosis Subgroup				
Acute bronchitis & bronchiolitis[b]	4.38	4.33	-0.84	(-8.02, 6.90)
Chronic bronchitis	51.69	62.61	**9.24**	**(6.68, 11.85)**
Asthma	79.95	71.38	**-3.10**	**(-4.88, -1.29)**
Chronic airway obstruction	16.45	3.50	**-72.07**	**(-75.31,-68.41)**
Age Group				
0-4 years	18.71	15.91	**-6.47**	**(-10.03, -2.78)**
5-17 years	10.30	7.47	**-12.47**	**(-17.18, -7.49)**
18-65 years	66.50	58.58	**-4.81**	**(-6.75, -2.84)**
65+ years	61.80	61.87	0.03	(-1.95, 2.05)
Race/Ethnicity				
White	79.48	73.54	**-5.35**	**(-7.07, -3.59)**
Black	36.25	32.93	-2.69	(-5.31, 0.01)
Hispanic	19.07	21.06	**7.13**	**(3.44, 10.95)**
Other	22.52	16.29	**-14.88**	**(-18.25, -11.37)**
Health Insurance Group				
Medicare	62.17	59.30	**-3.28**	**(-5.24, -1.29)**
Medicaid	41.53	27.46	**-20.23**	**(-22.59, -17.81)**
Private insurance company	45.44	52.38	**5.14**	**(2.73, 7.61)**
Uninsured/ Self Pay	7.57	4.04	**-42.65**	**(-46.89, -38.06)**
Urbanicity				
Rural	3.88	2.76	**-27.67**	**(-33.94, -20.80)**
Suburban	19.57	16.55	**-13.69**	**(-17.01, -10.24)**
Urban	133.60	116.22	**-5.25**	**(-6.63. -3.84)**

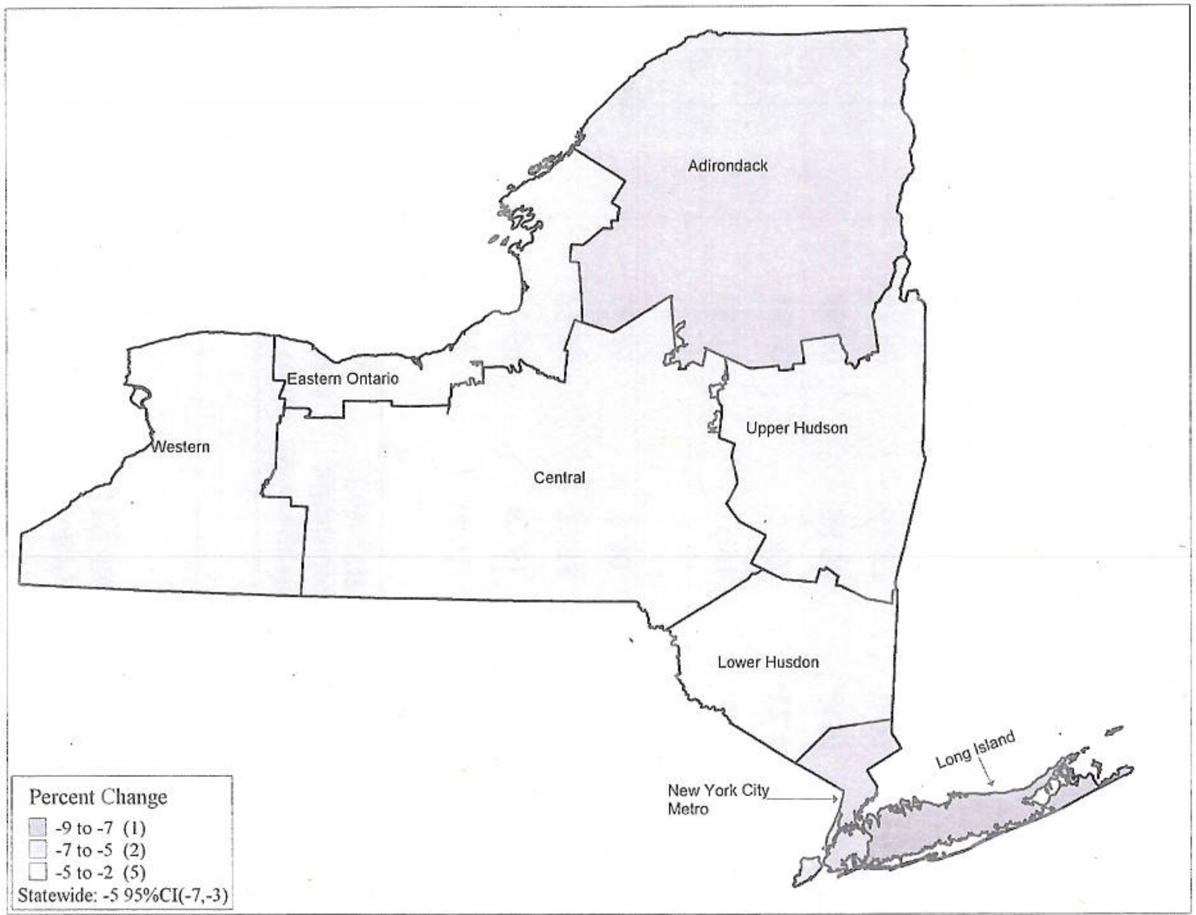
* June – August.

[a]Estimates from the GAM models; change from baseline period (1997-2000) to post-NBP (2004-2006). Adjusted for 3-day moving daily average $PM_{2.5}$, universal apparent temperature (daily average), relative humidity, and weekday, holiday, and subseasonal trend.

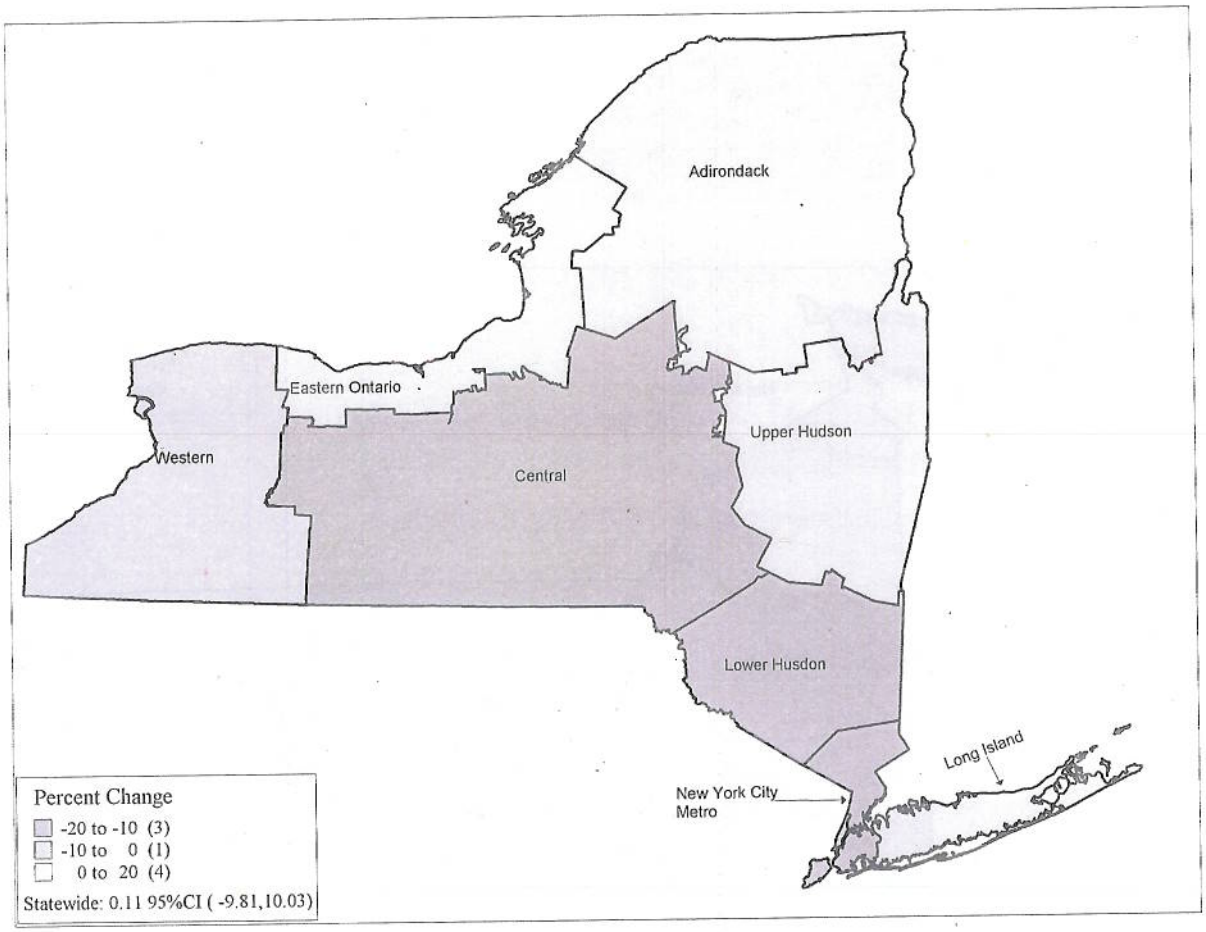
[b]Only among children aged 0-4 years.

Figure 1. Change in average daily summertime a) ozone concentration (ppb), b) respiratory hospitalizations, c) gastroenteritis hospitalizations (control), d) accidental (non-traffic related) injury hospitalizations (control), baseline (1997-2000) versus post-NO_x Budget Trading Program (NBP) (2004-2006).

a.

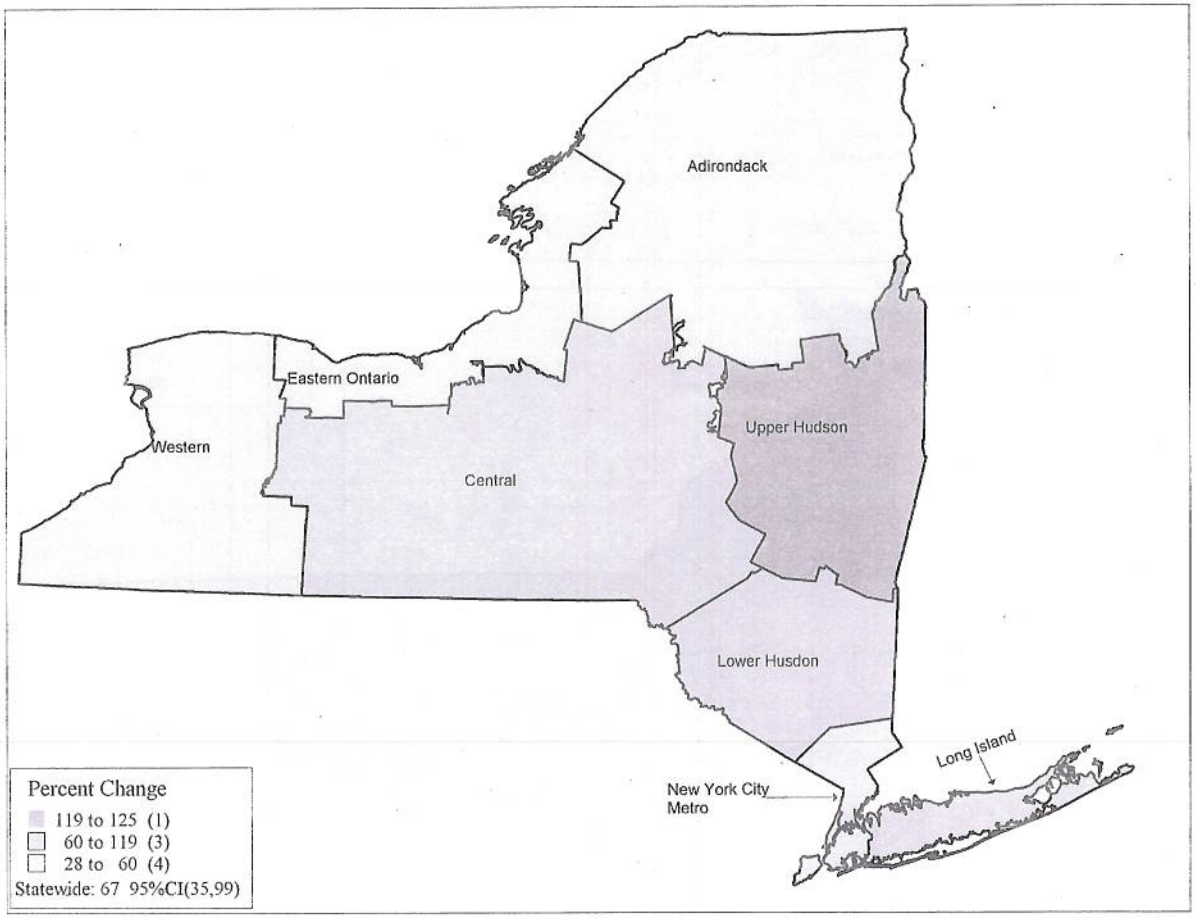


b.



Adirondack
Eastern Ontario
Western
Central
Upper Hudson
Lower Husdon
Long Island
New York City
Metro
Percent Change
-20 to -10 (3)
-10 to 0 (1)
0 to 20 (4)
Statewide: 0.11 95%CI (-9.81,10.03)

c.


Adirondack
Eastern Ontario
Western
Central
Upper Hudson
Lower Husdon
New York City Metro
Long Island
Percent Change
119 to 125 (1)
60 to 119 (3)
28 to 60 (4)
Statewide: 67 95%CI(35,99)

d.

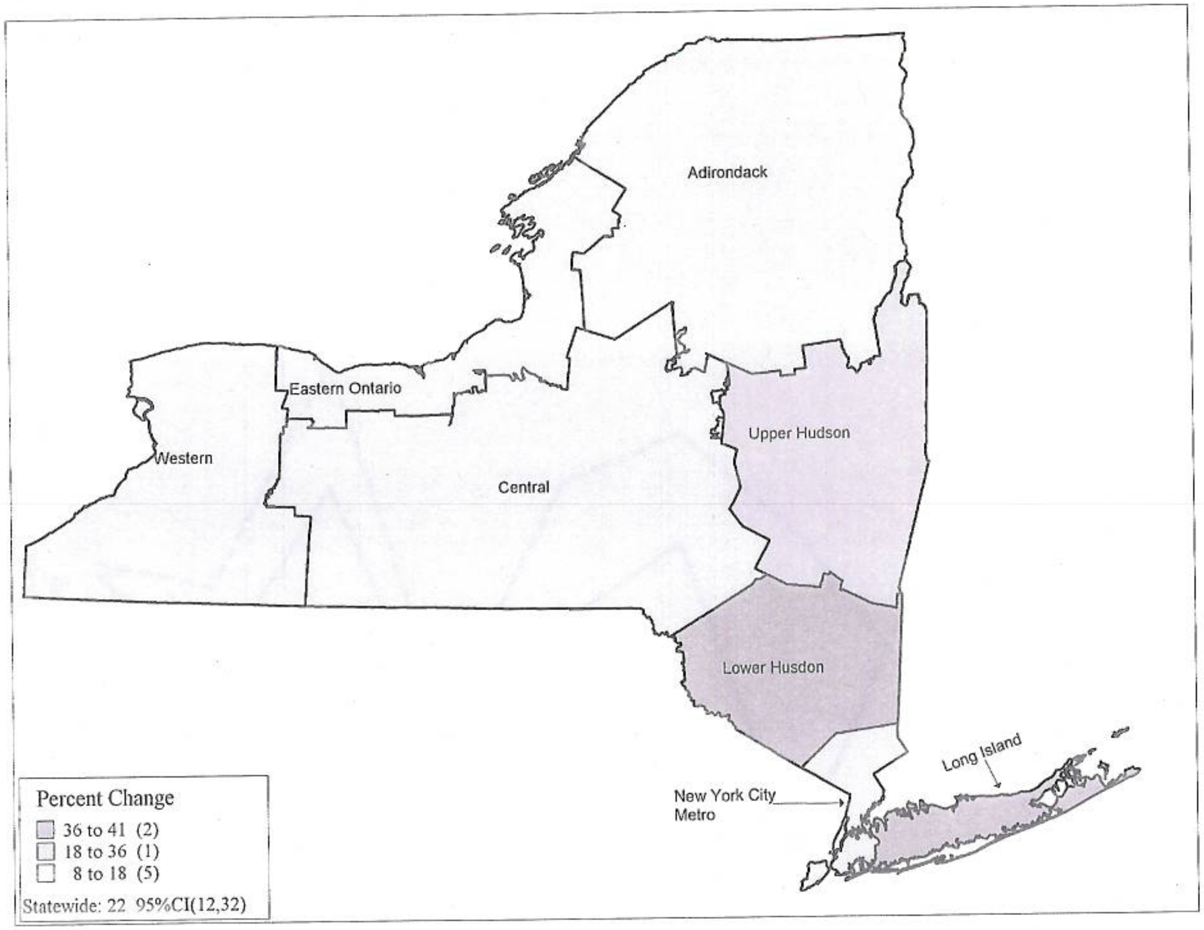
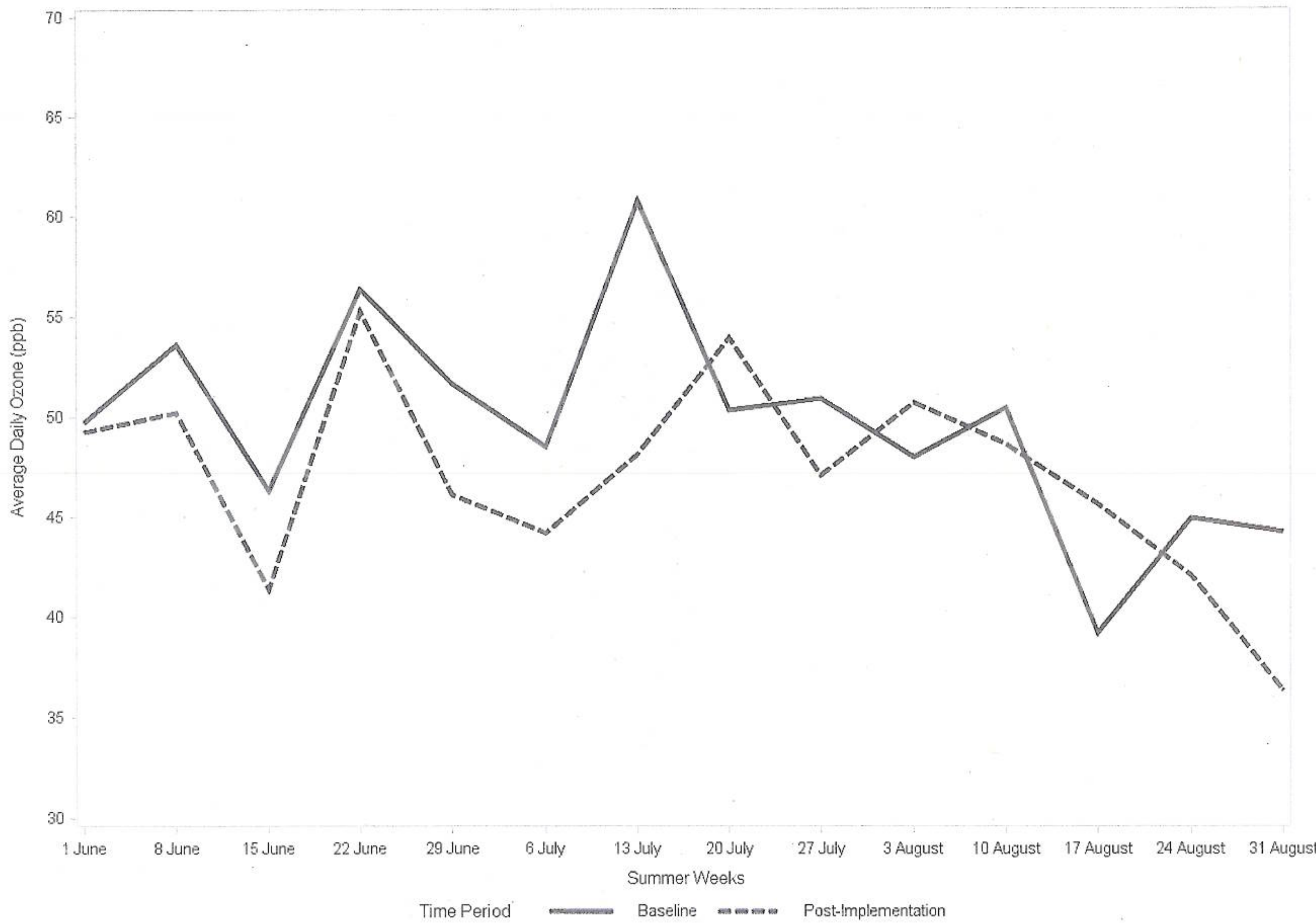
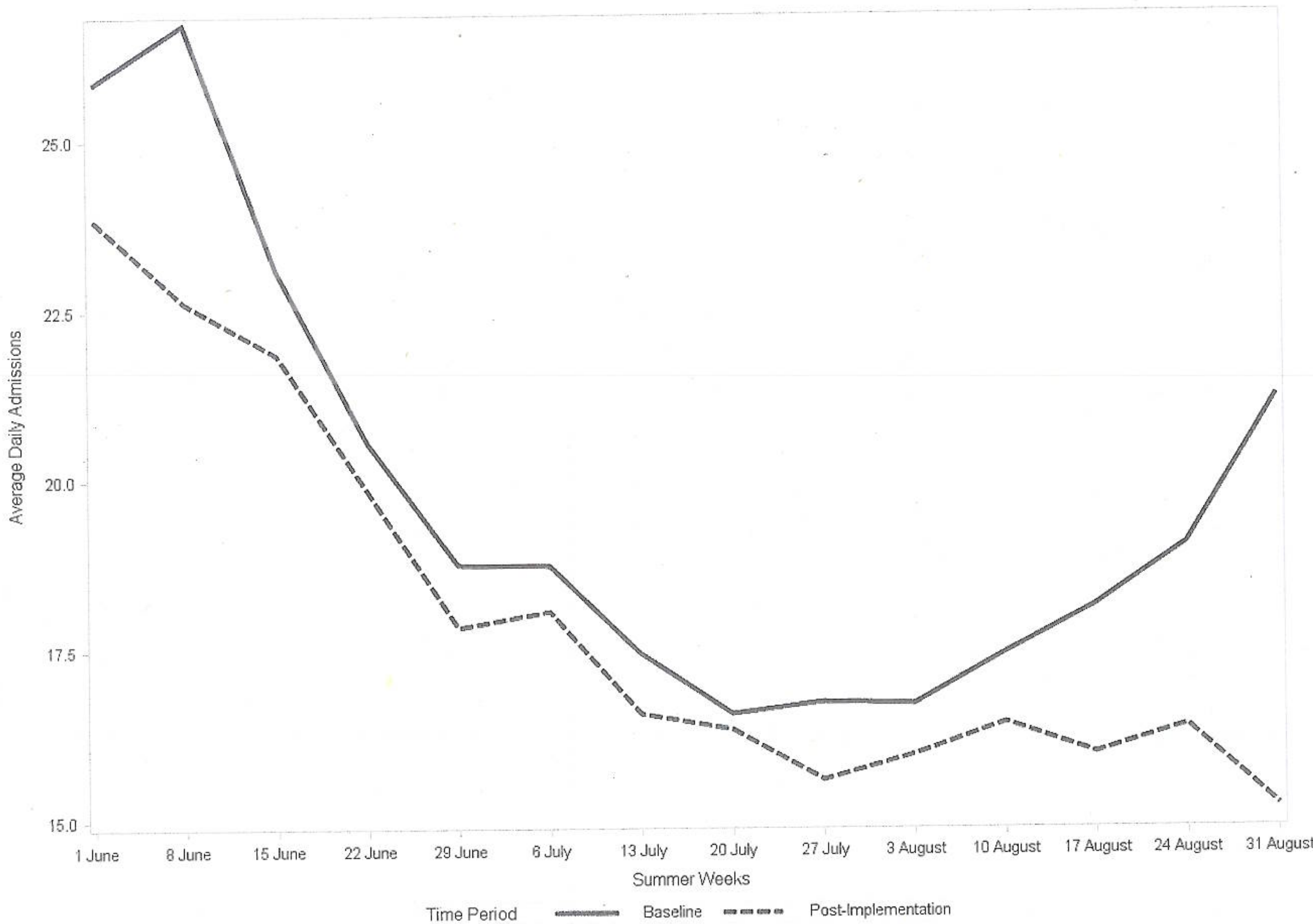

Adirondack
Eastern Ontario
Western
Central
Upper Hudson
Lower Husdon
Long Island
New York City
Metro
Percent Change
36 to 41 (2)
18 to 36 (1)
8 to 18 (5)
Statewide: 22 95%CI(12,32)

Figure 2. Weekly trends in summertime average daily a) ambient ozone concentration (ppb), b) respiratory hospitalizations, baseline (1997-2000) and post-NO_x Budget Trading Program (NBP) (2004-2006).

a.



b.



Average Daily Admissions
25.0
22.5
20.0
17.5
15.0
1 June
8 June
15 June
22 June
29 June
6 July
13 July
20 July
27 July
3 August
10 August
17 August
24 August
31 August
Summer Weeks
Time Period
Baseline
Post-Implementation