Evaluation of Ozone Smog Alerts on Actual Ozone Concentrations:A Case study in North Carolina

Giovanis, Eleftherios

University of Verona, Department of Economics, Royal Holloway University of London, Department of Economics

2014

Evaluation of Ozone Smog Alerts on Actual Ozone Concentrations: A Case study in North Carolina

Eleftherios Giovanis

Abstract

Ground-level ozone is an important pollutant regulated under the Clean Air Acts that affects respiratory morbidity, decreases lung function, and negatively affects those with existing respiratory conditions like asthma. This study examines the “Clean Air Works” program on ozone concentration levels, which is operating in Charlotte area of North Carolina State. “Clean Air Works” is a voluntary program which educates people about the negative effects of air pollution on health. Moreover, this program encourages people to reduce air pollution by using voluntarily alternative transportation modes, such as carpooling and public transit, especially when a smog ozone alert is issued. The contribution of this study is that it examines three effects: The effectiveness of the “Clean Air Works” program and whether ozone smog alerts are more effective under this program. Finally, the effects on ozone levels coming from the change in the warning threshold from 80 particles per billion (ppb) to 75 ppb, which took place in 2008, are established. For this purpose a quadruple Differences (DDDD) estimator is applied. In both cases, we find reduction in ground-level ozone levels and improvement of the air quality in the treatment group where the “Clean Air Works” program is implemented. In addition, the air quality is improved when smog alerts are associated with the program. Finally, taken additionally into consideration the change of the threshold at 75 ppb the air quality is improved by 1.5 ppb in the treatment group relatively to the control group. This study suggests that the ozone warning system associated with voluntary programs can help to clean the air and improve the public health.

Keywords: Air Quality, Clean Air Works, Differences-in-Differences, Ozone concentrations, Quadruple DDDD, Regression Discontinuity Design, Smog alerts

Jel Codes: C23, I10, Q50, Q53, Q58

1. Introduction

Air pollution has long been recognized as a negative externality. Making regulations concerning ozone is an area of increasing importance. Environmental policy makers around the world increasingly rely on voluntary programs to improve environmental quality (Cutter and Neidell, 2009). For example, Moretti and Neidell (2011) provide direct evidence that people respond to information about air quality. In particular, when smog alerts are issued, attendance at major outdoor facilities in Los Angeles decreases by as much as 13 per cent. Most studies examine the effects of ozone forecasts to public health, traffic volume and transportation mode choice behaviour.

This paper studies the effectiveness of policy mechanisms in the context of the "Clean Air Works" program in the Charlotte Area of North Carolina State, which aims to motivate individuals to follow practices that reduce ozone pollution, especially on the smog alert days. The study period is 2000-2010. The contribution of this study is that the effectiveness of this program along with smog alerts is examined. In addition, this is the first study which establishes the effects of the change in the warning threshold from 80 parts per billion (ppb) to 75 ppb in 2008.

"Clean Air Works" is a program launched in spring of 2006, established in Charlotte Area of North Carolina and it is a collaboration of the Regional Air Quality Board, the City of Charlotte, Mecklenburg County, Charlotte Area Transit System (CATS), the Charlotte Chamber of Commerce, the Centralina Council of Governments, and the Catawba Regional Council of Governments. The purpose of this program is to educate employees about the effects of air pollution on public health and to provide a low or no cost transportation benefit. The purpose is to avoid federal penalties from not meeting air quality standards, as the imposition, by EPA, of $8,300 (in 2010 prices) per ton penalties on major sources of air pollution.

Partners of "Clean Air Works" have a variety of options from which to choose: from offering employees commute alternatives, making changes in the organization's operations and maintenance practices, creating a combination of programs based on individual business needs. "Clean Air Works" has developed a range of tools and policies, like carpooling, vanpooling and teleworking. Therefore, partners of "Clean Air Works" encourage people to use these tools when a smog alert is issued. In this case the treatment group includes counties participating in the program, while the control group contains the counties that do not participate in the program. The criteria of using the specific counties as control group are discussed in data section. The second aim is to establish whether the ozone smog alerts are more effective under the "Clean Air Works" programme. The ozone forecasts are based on daily frequency and the forecast season is from May 1st through September 30th. The third aim is to examine the impact of the change in the ozone standard issued by the Environmental Protection Agency (EPA).

In order to identify those effects a quadruple Differences (DDDD) estimator is applied. The results show a reduction on the ozone levels after the implementation of the "Clean Air Works" Project. Additionally, the ozone levels on alert days were reduced after the change of the threshold in both treatment and control. The air quality has been improved in the treatment group with the implementation of the program reducing the difference in ozone concentration levels by 1.3 ppb. In addition, the smog alerts are effective under the program regime where the above-mentioned difference becomes 1.8 ppb. Furthermore, the differences of ozone levels between the treatment and control groups are additionally decreased after the change in ozone warning threshold, by around 1.5 ppb when the program is implemented and it is associated with smog alerts. As such, information on air pollution does not seem to significantly reduce pollution level unless a program like "Clean Air Work", which facilitates steps reducing pollution, is in place.

The results are robust regarding the DDDD validity. The test for the common or parallel trend is accepted. More specifically, the common trend assumption states that changes in output, average ozone concentration levels in this case, for those treated if untreated would have been equal to the observed changes in output for the control group. Common trend assumption implies that in absence of treatment the treated and the controls would have had parallel trend paths. Another issue is the possible serial correlation. Many papers which apply differences-in differences (DID) strategy use data for many years before and after the implementation of a policy. The variables of interest in many of these setups only vary at a group level (ie. state level in the study by Card and Krueger, 1994) and outcome variables are often serially correlated. Thus, using conventional standard errors often severely understate the standard deviation of the estimators. In order, to account for serial correlation, the clustered standard errors on air monitoring stations are obtained as suggested by Bertrand et al. (2004) and where the monitoring level variation is examined.

The structure of the paper is as follows. In section 2 the literature review is provided. Section 3 describes the environmental policy and the "Clean Air Works" project, while section 4 reviews the methodology of the quadruple DID model used in this study. Section 5 presents the data, and the research sample used in the estimations, while in section 6 the empirical findings are reported. In the last section the general conclusions of the empirical findings are discussed.

2. Literature review

This section presents and discuses previous literature related to the current study. Initially, the studies examined the effects of public advisory programs on traffic are presented. These studies are related because "Clean Air Works" project encourages individuals to follow practises that reduce air pollution, such as public transit and carpooling, which affect the traffic pattern and resulting in changes on the ozone concentration levels.

One of the public advisory programs explored in previous studies is the "Spare the Air" (STA) program. "Spare the Air" was established by the Bay Area Air Quality Management District in order to educate Bay Area residents about air pollution and to encourage them to change their behaviour to improve air quality. As part of the Spare the Air program, the residents are asked to reduce pollution by making clean air choices every day; from walking and biking more often, to reducing energy consumption at home. Spare the Air days are declared for days in which levels of ground-level ozone are predicted to exceed the EPA's federal health-based standard: the air quality index (AQI) over 100. Moreover, on a Spare the Air day, Bay Area participants are asked through radio and television announcements to reduce their driving. This program is similar to Clean Air Works program examined in this study. Ozone warning announcements encourage people to reduce driving or using public transit and various kinds of ridesharing, such as carpool and vanpool, or using teleworking.

Schreffler (2003) focused on "Spare the Air" advisory and voluntary program by conducting a small telephone survey in the Bay Area that requested daily travel activities. Schreffler (2003) used data over two summer ozone seasons in Sacramento, allowing researchers to compare the travel behaviour of the same individuals on both Spare the Air and regular, summer days and of Spare the Air participants and non-participants. More specifically, the participants is a group of drivers who said that they purposely reduced trips because of Spare the Air, while non-participants is a control group of drivers who did not respond to the Spare the Air (STA) message. Schreffler (2003) found a statistically significant 4.8 per cent reduction in trips. The 4.8 per cent reduction in trips resulted in an emission reduction of 1.04 tons of ozone precursors.

A similar work to the current study is by Cutter and Neidell (2009), who examined the effects of "Spare the Air" advisory program in the San Francisco bay area using a Regression Discontinuity (RD) design. More specifically, they compared the bay area, where the STA alert is issued, and the South Coast area, where the STA program is not applied. Cutter and Neidell (2009) estimated a regression discontinuity approach using a sample of observations within 2 and 1 parts per billion (ppb) of the limit for a STA call and they showed a statistically significant drop in vehicle usage of between 2,000 and 2,300 per day. Welch et al. (2005) examined the impact of ozone advisories on hourly public transit in Chicago, Illinois, and found mixed results. The overall effect of ozone action days on ridership is not significant, but there are statistically significant changes in hourly ridership pattern. Additionally, their findings show that ozone advisories systematically alter the travel behavior of a small proportion of Chicago area travelers making it possible to conclude that pollution advisories have the potential to affect transportation choice and thereby contribute substantially to voluntary reductions in ozone emissions. More specifically, ridership increases during the hours of 9–11 am and 5–9 pm on smog alert dates representing 0.03–0.13% hourly vehicles miles of travel reduction in Chicago traffic. On the other hand, Cummings and Walker (2000) examined a similar voluntary program in the Atlanta metropolitan area on hourly traffic volumes and found statistically insignificant effects.

Friedman et al. (2001) examined the changes in transportation choices and the effects in asthma hospitalizations during the 1996 Olympic Games in Atlanta. Atlanta's strategy included the development and use of an integrated 24-hour-day public transportation system, the addition of 1,000 buses for park and ride services, altered downtown delivery schedules, and public warnings of potential traffic and air quality problems among others. The authors compare the 17 days of the Olympic Games, with a baseline period of four weeks before and four weeks after the Olympic Games but do not have a control group. The authors found that the number of asthma emergency care visits and hospitalizations decreased from 4.23 events per day during the baseline period to 2.47 events per day during the Olympic period, a 41.6% overall decrease. Additionally, this reduction was even stronger during the critical morning period.

Even though the study by Friedman et al. (2001) examines the effects of public warnings on traffic and air quality, a control group is missing from the analysis; thus the effects are hindered by its absence. In addition, the previous studies examined the effectiveness of public advisory programs on traffic volume and ridership pattern; but the change in the ozone warning threshold has not been explored. Thus, the current study adds to the literature by applying a quadruple DID and examining the effectiveness of the "Clean Air Works" voluntary program associated with smog alerts. Moreover, the change of the warning threshold proposed by Environmental Protection Agency (EPA) is explored. Thus, the motivation of this study is to examine whether the smog alerts associated with additional incentives provided by the "Clean Air Works" are more effective for the air quality improvement. More specifically, Cutter and Neidell (2009) argue that the STAs warnings are not enough to improve significantly the air quality, if these are not associated with additional incentives, such as those provided by the program examined in this chapter.

In addition, the weather data have been neglected in the previous studies, with the exception of the study by Welch et al. (2005) who used various weather conditions, such as temperature, days with light and heavy rain and extreme weather including thunderstorms and other extreme conditions. Ground level ozone is formed in the air by the photochemical reaction of sunlight, high temperature and nitrogen oxides (NO_x), facilitated by a variety of volatile organic compounds (VOCs), which are photo-chemically reactive hydrocarbons (Crutzen, 1974; Derwent et al., 2003; Pudasainee et al., 2006). Thus, the regressions in this study control for solar radiation and temperature. In addition, wind speed and direction are important factors for ozone, as previous researches found relationship between these weather conditions and ground level ozone (Agudelo-Castaneda et al., 2013; Figueiredo et al., 2013). More specifically, wind speed cleans the air in an area and contributes to how quickly pollutants are carried away from their original source. However, strong winds do not always disperse the pollutants, as wind can transport pollutants to a larger area, such as the smoke from forest fires (Jacob et al., 1993; Baertsch-Ritter et al., 2004; Camalier et al., 2007; Dawson et al., 2007). Pugliese et al., 2014 found that areas are affected more by the ground level ozone when the wind speed is less than 120 km. Ozone also depends on wind direction. The wind direction plays a significant role in how much ozone is transported from one place to another (Jammalamadaka and Lund, 2006). Witcraft et al. (2006) found that one of the reasons explaining the low ozone levels in the Triad area in North Carolina during July of 2015 it was the dominant west to west-south wind direction.

Other studies include the exploration of the effects of pollution on infant mortality and yield mixed results. These studies are presented for the following reasons: To confirm and examine the effects of ozone reduction on mortality caused by the program and the smog alerts. In addition, the current study examines the effects of the air pollution reduction, caused by the "Clean Air Works" program, on the total, infant and elder (60 years and older) deaths. Woodruff et al. (1997) found that infants with high exposure (more than 170 micrograms per m^3) to particulate matter smaller than *10* micrometers (PM_{10}) are more likely to die in the post neonatal period. More specifically infants are categorized as having low, medium, or high PM_{10} exposure depending on whether their 2-month mean exposure was in the bottom one-third, middle one-third, or top one- third of the range of exposures. Overall post-neonatal mortality increased with increasing PM_{10} levels, from 3.1 in the low pollution category to 3.7 in the high category. Normal birth weight infants with high PM_{10} exposure were 45% more likely to die of respiratory causes than normal birth weight infants with low exposure. Lipfert et al. (2000) found negative effects of county-level pollution measures on infant mortality, but the PM_{10} risks appear to be higher for babies of smoking mothers. Currie and Neidell (2005) examined the effects of Carbon Monoxide (CO) and PM_{10} on infant mortality using data from California Birth Cohort files for 1989 to 2000. Their estimates imply that reductions in CO and PM_{10} over the time period they study saved over 1,000 infant lives in California alone. Based on the findings by Currie and Neidell (2005) and the estimates found in the current study the number of lives saved from the air quality improvement, under the "Clean Air Works project" associated with the change of the threshold and ozone smog alerts are presented in the results section.

3. Environmental Policy

3.1 Smog Alert and Ozone Forecasts

Air quality forecasts are provided by the EPA, which sets the National Ambient Air Quality Standards (NAAQS). The forecasts are published one day before by Division Air Quality ozone forecast Centre. This Air Quality Index ranges from 0 to 500 ppb and is categorized into the following: 0–50, good; 51–100, moderate; 101–150, unhealthy for sensitive groups; 151–200, unhealthy; 201–300, very unhealthy; and 301–500, hazardous (Environmental Protection Agency, 2008). From 1997 the national standard was set up at 80 ppb, corresponding to 111 on the revised AQI scale. In 2008 this standard was reduced to 75 ppb, corresponding to 100 on the revised AQI. EPA revised the threshold level to provide increased protection for children and other "at risk" populations against an array of ground-level ozone related adverse health effects that range from decreased lung function and increased respiratory symptoms to serious indicators of respiratory morbidity including emergency department visits and hospital admissions for respiratory causes (Environmental Protection Agency, 2008).

An initial idea of the magnitude on ozone concentration levels, by reducing the threshold by 5 ppb, would be a similar reduction on the ozone levels. This is initially confirmed by the data. More specifically, the average ozone concentration levels are 54 and 49 ppb before and after the change in threshold respectively, for both control and treatment group examined in this study. Secondly, the new air quality standards defined by the change of the warning threshold imply stricter and tighter regulations associated with fee penalties for violation of these standards. Thus, the local governments of the counties are responsible to take additional measures and policies to improve the air quality and avoid these costs from the fee penalties.

The air Awareness Program has been established in North Carolina in 1997. In particular, Air Awareness Program is a public outreach and education program of the North Carolina Division of Air Quality (DAQ). U.S. Environmental Protection Agency (EPA) has designated the DAQ as the lead agency for enforcing federal laws and regulations dealing with air pollution in North Carolina. The goal of the program is to reduce air pollution though voluntary actions by individuals and organizations.

Ozone forecast is published and distributed through local media (television, radio, and newspaper) to public. The ozone forecast gives the public important information about the next day's air quality in their area and how their health may be affected. The forecast is also displayed on the NCDAQ (North Carolina Division of Air Quality) web page. The ozone forecasts are expressed in the air quality index described before, defining various levels of ozone concentrations, as healthy and moderate to unhealthy. A smog alert is issued in the case where the forecast passes the threshold 80 ppb and 75 ppb for periods 2000-2007 and 2008-2010 respectively. In that case the North Carolina Air Awareness Program utilizes a wide range of web and media outlets to broadcast the message to the general public. These include state-wide radio messages covering open burning, clean air tips, and much more. Through both local coordinators and state representatives, the program regularly exhibits at health, environmental, and state fairs and festivals. Public information is distributed through the program website, which is available at NCDAQ web page or the individuals can call the toll-free air quality hotline. Information may also be obtained by sending enquiries to specific email address.

3.2 Clean Air Works Program

“Clean Air Works” program launched in March of 2006 with the primary purpose of testing what organizational approach and implementation elements and methods will produce quantifiable reductions in ozone-forming pollutants above those obtained through efforts before its implementation. Air pollution reductions were obtained from mobile, non-road mobile and operational sources through promotion of alternate modes of transportation, such as carpooling, vanpooling, telecommuting, riding transit, walking and biking. Moreover air quality improvement have been derived from changes in business operations e.g. cleaner fleets, delaying or postponing high-emission activities, such as construction work, lawn maintenance. In the beginning of the program around 90 largest companies secured participation in the program representing a minimum of 120,000 employees. The number of companies and partners has been increased at 118 in 2010. The incentives and practises of the program include trip reduction strategies, such as vanpool and public transit financial incentives, educational programs to employers and employees. Other incentives include alternative scheduling, such as flextime, where an employee can schedule arrival and departure times within an eight-hour day to best suit personal schedules on a daily basis, as well as, compressed work weeks, whereby an employee works more hours per day, but fewer days per week. Other incentives and practices include the postponing of high-emission activities in manufacturing, wherever possible, during the ozone warning days.

4. Methodology

4.1 Quadruple Differences-in-Differences Model

The ozone forecasts started with the Clean Air Act in 1997. None of the areas were considered as non-attainment based on ozone standards and the threshold of 84 ppb, which was applied before 1997. More precisely, the Clean Air Act and Amendments of 1990 defines a “non-attainment area” as a locality where ozone levels persistently exceed National Ambient Air Quality Standards, which standards have been presented in section 3.1. However, based on the ozone standard and the threshold of 80 ppb introduced in 1997, 11 areas encompassing over 30 counties are designated non-attainment; i.e. they do not satisfy the clean air regulations (Map 1). Grey zones in Map 1 represent the regions with ozone forecasts.

The counties treated are Lincoln, Mecklenburg, Rowan and Union in Charlotte Area, while the counties used as control group are the following: Forsyth, Caswell, Rockingham, Davie and Guilford Counties in Triad area, Raleigh County in Triangle area, Cumberland County in Fayeteville area, Buncombe County in Asheville area, Alexander and Caldwell Counties in Hickory area. One of the reasons for choosing the treated and non-treated counties is that all of them are considered as "non-attainment areas". Additionally, these counties share common demographic and economic characteristics. In table 1 the control and treated counties and the area they belong are presented, while in table 2 the date of the events is reported. As it is shown in table 2 EPA established the ozone standard and warning threshold at 80 ppb in 1st July of 1997. In 1st March, 2006 the "Clean Air Works" program has started to be implemented. In 27th May of 2008 the change of warning threshold from 80 ppb to 75 ppb, established by EPA, took effect.

Then a simple set-up of DID is presented in order to show the main ideas and problems of this strategy. The treatment variable, denoted by *treat* in the case examined, is binary, taking value 1 for the treatment group and 0 for the control. There are measurements of the various variables in two time periods, denoted here as *program*. *Program* zero indicates a time period before the treatment (pre-treatment period) and *program* one indicates a time period after the treatment took place (post-treatment period). Assuming that the treatment happens between the two periods means that every member of the population is untreated in the pre-treatment period. Thus the main point of interest is to discover the mean effect of switching *treat* from zero to one on some outcome variables, which is ozone levels in the study examined.

The model examined in this study is a quadruple DDDD. Difference-in-differences analysis controls for any omitted factors that influence ozone concentration levels differently for the treatment and control groups and that are constant across time. The important benefit of the quadruple differences analysis is that, in addition to controlling for those factors, it will also remove any omitted factors that influence ozone levels differently across time for counties in the treatment and control groups. The key variable in a DID strategy is frequently the outcome of interest in a period before the treatment took place. Thus, DID is appropriate in this study which allows us to evaluate the impact of the "Clean Air Works" program associated additionally with smog alerts and the change of the ozone warning threshold. The DDDD regression has the following form:

$$\begin{aligned}
&ozone_{i,j,k,t} = \beta_1 treat_{i,j,k,t} + \beta_2 program_{i,j,k,t} + \beta_3 warning_{i,j,k,t} + \beta_4 threshold_{i,j,k,t} + \\
&\beta_5 treat_{i,j,k,t} * program_{i,j,k,t} + \beta_6 treat_{i,j,k,t} * warning_{i,j,k,t} + \beta_7 treat_{i,j,k,t} * threshold_{i,j,k,t} + \\
&\beta_8 program_{i,j,k,t} * warning_{i,j,k,t} + \beta_9 program_{i,j,k,t} * threshold_{i,j,k,t} + \\
&\beta_{10} warning_{i,j,k,t} * threshold_{i,j,k,t} + \beta_{11} treat_{i,j,k,t} * program_{i,j,k,t} * warning_{i,j,k,t} + \\
&\beta_{12} treat_{i,j,k,t} * program_{i,j,k,t} * threshold_{i,j,k,t} + \beta_{13} program_{i,j,k,t} * warning_{i,j,k,t} * threshold_{i,j,k,t} + \\
&\beta_{14} treat_{i,j,k,t} * program_{i,j,k,t} * warning_{i,j,k,t} * threshold_{i,j,k,t} + W_{i,j,t} + \mu_i + l_j + z_k + \theta_t + \varepsilon_{i,j,k,t}
\end{aligned} \tag{1}$$

The dependent variable *ozone* stands for actual ozone levels in air monitoring station *i*, located in county *j*, in forecasting zone-region *k* and in time *t*. *Treat* denotes whether the counties belong to the *treatment* or control group, *program* takes value 1 since the "Clean Air Works" has been implemented on 1st March of 2006 and after and 0 otherwise. *Warning* is a dummy variable taking value 1 whether there is a smog alert and 0 otherwise, while *threshold* denotes the change of smog alert threshold from 80 ppb to 75 ppb and takes value 1 for 27th May of 2008 and after and 0 otherwise. The model controls for the day of the week, month, year, counties, ozone regions and weather conditions ($W_{i,j,t}$), such as temperature, wind speed, wind direction and solar radiation. Set (μ_i) denotes the monitoring station-fixed effects, (l_j) is a set of county fixed effects, (z_k) expresses the ozone forecasting zones-regions fixed effects and θ_t is a set of time-fixed effects. Finally, $\varepsilon_{i,j,k,t}$ expresses the error term. Clustered ozone monitoring sites are considered for robust standard errors. The model controls for time-invariant country which can determine the ozone level in the absence of the treatment. In addition, regression (1) control for year effect which is common among counties, which captures common shocks as the Great Recession, which caused by the housing bubble in August of 2007 and its effects became apparent in the beginning of 2008.

The interaction term *treat*program* is the diff-in-diff (DD) estimator which shows the effectiveness of the "Clean Air Works" project, while the interaction term, *treat*program*warning* is the DDD estimator which shows whether the smog alerts are more effective, on ozone levels reduction, under the "Clean Air Works" program. Finally, the interaction term *treat*program*warning*threshold* is the DDDD estimator which establishes the effectiveness of the smog alert threshold change in 2008 at 75 ppb. Therefore using the quadruple DDDD it becomes feasible to examine various effects.

4.2 Test of the Quadruple DDDD Model Validity

In this section the methodology followed for testing the validity of the DID model is discussed. Then in the results section the robustness checks are presented. More specifically, the key assumption for any DID strategy, the so-called "Common" or "Parallel" Trend Assumption. This assumption states that the differences in the expected potential non-treatment outcomes (ozone levels) over time are unrelated to belonging to the treated or control group in the post-treatment period. It implies that if the treated had not been subjected to the treatment, both treatment and control groups would have experienced the same time trends. Moreover, DID controls for other factors affecting outcome in both groups around the same time, such as the great recession which affected both groups and it is not a local effect.

Regarding the DDD, the assumption is that in absence of the treatment, the average difference in ozone levels for the treatment group between the smog alert and non-smog alert days is the same as the average difference in the ozone levels for the control between the smog alert and non-smog alert days. Thus, the triple DDD assumes that a common trend is thought to exist across the smog alert days and non-smog alert days in the two groups. In a similar fashion the quadruple DDDD is defined, which is the difference between the triple DDD for treatment and control groups, considering additionally the change in the ozone warning threshold.

In order to test the parallel or common trend assumption is to place placebo dummies before the treatment. If the effect captured by the "Clean Air Works" program were not causal, we would expect the coefficient on years prior to the program implementation to be as large and significant as that in which the program occurs. More precisely, the DID is estimated assuming that the "Clean Air Works" project took place before 2006. In particular, we assume that the policy took place in 2004 instead of 2006 and the basic DD model is estimated using data from 2000-2005:

$$\begin{aligned} ozone_{i,j,k,t} &= \beta_1 treat_{i,j,k,t} + \beta_2 program_{i,j,k,t} + \beta_3 treat_{i,j,k,t} * program_{i,j,k,t} + \\ & W_{i,j,t} + \mu_i + l_j + z_k + \theta_t + \varepsilon_{i,j,k,t} \end{aligned} \quad (2)$$

The reason why in model (2) only the double DID is examined is because the only difference between the control and treated group is the implementation of the "Clean Air Works" program. On the other hand the smog alert advisory program and the change of threshold are applied in both groups. Thus, it is only necessary to test the validity of the double DID, which refers to the effectiveness of the "Clean Air Works" program examined and which differentiates the treatment and control groups. Moreover, the results remain robust whether the placebo test is applied in other years instead of 2004.

The second test of the DID validity is to include a set of lags and leads into the basic DID model (2) in order to examine the dynamics of the program and to test whether the leads and lags of the treatment are significant or not. Including leads into the DID model is a way to analyse pre-trends, while lags can be included in order to analyse whether the treatment effect changes over time after the implementation of the "Clean Air Works" program. Regression (2) is written as:

$$\begin{aligned} ozone_{i,j,k,t} &= \beta_1 treat_{i,j,k,t} + \beta_2 program_{i,j,k,t} + \sum_{p=0}^{m} \beta_{-p} D_{i,j,k,t-p} + \sum_{p=1}^{q} \beta_{-p} D_{i,j,k,t+p} + \\ & W_{i,j,t} + \mu_i + l_j + z_k + \theta_t + \varepsilon_{i,j,k,t} \end{aligned} \quad (3)$$

Regression (3) is testing for causality in the framework of Granger (1969) and $D_{i,j,k,t}$ is defined as the interaction term *treat*program* defined in regressions (1) and (2). More specifically, Granger causality test is a check on whether past $D_{i,j,k,t}$ predicts the ozone while future $D_{i,j,k,t}$ does not, conditional on county and year effects. The sums on the right hand side of equation (3) allow for *m* lags, ($\beta_{-1}, \beta_{-2},.....,\beta_{-m}$) defining the post-treatment effects and *q* leads (($\beta_{+1}, \beta_{+2},.....,\beta_{+q}$) defining the anticipatory effects (Angrist and Pischke, 2008). In addition, the lagged variables are of substantive interest, because the causal effects might grow, fade or remain stable through time.

5. Data

The data for forecasting ozone concentrations have been retrieved from the North Carolina Department of Environment and Natural Resources (http://daq.state.nc.us). Ozone forecasts are made daily during the ozone forecast season, from May 1st through September 30th , by meteorologists who use a set of criteria from historic meteorological data, ozone measurements, and ozone prediction models to make these predictions. When they forecast an Ozone Action Day, the North Carolina Division of Air Quality contacts officials in the affected area notify local media, government, business, and industry. The actual ozone concentrations are measured at county level, while the ozone forecasts are assigned on regions – group of counties. More specifically the regions are defined as in map 1, which are the Asheville, Hickory, Triad, Triangle, Charlotte, Rocky Mount and Fayetteville.

The meteorological data have been kindly provided by the State Climate Office of North Carolina (www.nc-climate.ncsu.edu). The weather data used in the estimates are the average daily temperature, wind speed, wind direction and solar radiation. A negative association between wind speed and actual ozone levels is expected, while a positive relationship between temperature, solar radiation and observed ozone concentrations is anticipated. The data are based on daily frequency and the period examined is 2000-2010 and during the ozone forecast period which is between months May-September.

In table 3 the summary statistics for actual ozone concentrations are reported, while in table 4 the exceedance days over periods 2000-2005 (before Clean Air Works program implementation), 2006-2007 (when Clean Air Works program is implemented and before the change in threshold) and 2008-2010 (when the threshold is set up at 75 ppb). Exceedance days are defined as the days where the actual ozone concentration levels are higher than the smog alert threshold. In the regression analysis the ozone concentration levels expressed in parts per billion are used. It can be observed that the number of exceedance days has been reduced, especially in Charlotte and Triangle areas. In addition, the number of exceedance days for the treatment and control group is provided in table 4. Based on tables 3 and 4 the conclusion is that the ozone levels have been reduced in the period 2008-2010. It should be noticed that the exceedance days, regarding the various areas reported in table 4, refer to counties, which are not included in the control and treatment groups.

In figure 1 the distribution of actual ozone concentration levels in parts per billion (ppb) over periods 2000-2007 and 2008-2010 is presented. Based on this figure a clear drop in ozone concentrations is observed, where the average ozone levels range around 55 ppb in the period 2000-2007, while the average value becomes 51 ppb during the period 2008-2010. In figure 2 the average ozone levels and the number of the exceedance days for the treatment and control group over the period 2000-2010 are reported. More specifically, the black and grey lines represent the average ozone levels in the treatment and control group respectively. The black and grey dots represent the number of the exceedance days for the treatment and control group respectively. It is observed, that during the period 2000-2005, without the implementation of the "Clean Air "Works project the ozone levels are similar in both groups. Also the number of exceedance days is similar between the two groups. On the other hand, during the periods 2006-2010, with the implementation of the "Clean Air "Works project, there is an increase in the gap, regarding the average ozone levels and the exceedance days, which are lower in the treatment group. Generally, the graph also indicates that there was a reduction in the average ozone levels and in the number of the exceedance days during period 2008-2010.

6. Empirical results

In this section the quadruple DDDD estimates are presented. The purpose of applying the quadruple DDDD is to examine the effects of the “Clean Air Works” Project on ozone levels, to explore whether or not smog alerts are significant under the program regime and to establish the effects of the change in threshold by EPA from 80 ppb to 75 ppb.

In table 5 the DDDD estimates are reported. Based on these the ozone concentration levels are higher in the treatment group over the period 2000-2010. The average pollution in treatment group is 1.121 ppb higher than in the control group and it is statistically significant. Therefore, the average ozone level in treatment and control group is 53.00 (standard deviation: 16.559) and 51.88 (standard deviation: 15.552) ppb respectively. After the implementation of the program the average ozone level has been reduced by 2.445 ppb in both groups. The interaction term *treat*program,* which is the DD estimator, is negative, significant and equal at -1.268. This indicates that the difference of the average ozone between the treatment and control group, has been reduced after the implementation of the Clean Air Works” program by 1.268 ppb. More specifically, the average ozone level in the treatment and control group before the “Clean Air Works” implementation was respectively 54.344 ppb (standard deviation: 17.244) and 52.250 ppb (standard deviation: 16.627). After the implementation of the program the average ozone levels were 51.936 (standard deviation: 14.476) and 51.110 (standard deviation: 13.951). Thus, the difference-in-difference –DD estimator- is the difference between 0.826 ppb (51.936-51.110) and 2.094 ppb (54.344-52.250) resulting to the estimate -1.268 (0.826-2.094). Therefore, based on the first main coefficient of interest, the DD estimator, the “Clean Air Works” is effective on improving air quality in the treatment group.

Regarding the 2008-2010 period, after the change in threshold, the average pollution level decreased by 3.352 ppb in both groups. Therefore, the average ozone level in the pre-period 2000-

2007 and post-period 2008-2010 is 54.35 (standard deviation: 15.642) and 50.98 (standard deviation: 13.286) ppb respectively. The coefficient of *warning* is positive and equal at 6.15, indicating that the average pollution level in both groups is 50.60 (standard deviation: 14.111) ppb in non-smog alert days, and 56.75 (standard deviation: 18.588) during the smog alert days. The interaction term *treat*warning* shows when a smog alert is issued in the treatment group the ozone levels become lower by 0.855 ppb in comparison with the control group and during the period 2000-2010.

The second main coefficient of interest is the DDD estimator which is expressed by the interaction term *treat*program*warning* and it is equal at -1.833 ppb. This shows that the smog alerts are more effective under the program regarding air quality improvement reducing the difference of ozone levels between the two groups. Thus, the results so far support the effectiveness of the "Clean Air Works" project during the whole period of ozone forecast, while the effects are further increased when smog alerts are associated with the program, based on the DDD estimator.

The next interaction terms are *treat*threshold*, *program*threshold* and *warning*threshold.* The first term shows that the difference of the average ozone levels between the treatment and control group have been reduced by 1.545 ppb after the change of the warning threshold. The term *program*threshold* shows that the average ozone levels have been reduced when the "Clean Air Works" is associated with the change of threshold from 80 ppb to 75 ppb. Finally, after the change of the threshold when a smog alert is issued the average ozone levels are lower by 4.259 ppb. The interaction term *treat*program*threshold* is negative and significant indicating that the ozone levels have been reduced in the treatment group after the implementation of the "Clean Air Works" program and the change of the threshold.

The interaction term *treat*warning*threshold* is negative and significant equal at -2.124. In this case the difference of the ozone levels between the treatment and control group have been reduced after the change of the smog alert threshold at 75 ppb, which took place in 2008, and when a smog alert is issued. More specifically, before the change of the threshold the average ozone levels, considering only the days when a smog alert is issued, are 59.677 ppb (standard deviation: 14.808) and 56.375 ppb (standard deviation: 16.276) in the treatment and control group respectively. The respective values after the change in the threshold become 54.722 ppb (standard deviation: 12.383) and 53.545 ppb (standard deviation: 15.776).

Finally, the DDDD estimator which is expressed by the interaction term *Treat* Program*Warning*Threshold* is negative and significant; equal at -1.493. In that case the air quality has been improved in the treatment group in comparison to control group after the implementation of the "Clean Air Works" project and the change of the threshold and when an ozone warning is issued. The DDDD estimator shows that the differences of the ozone levels between the two groups are reduced with the implementation of the program, the change of the threshold and when a smog alert is issued.

Next the robustness checks, discussed in the methodology part, are presented. In table 6 and panel A the robustness check using placebo dummies before the treatment are reported. It becomes clear that the parallel trend assumption is accepted because the DD estimator in panel A of table 6 expressed by the interaction term *treat*program,* is statistically insignificant. This indicates that in the absence of the "Clean Air Works" program the treatment and control group would have the same average trend in ozone levels.

In panel B of table 6 the estimates of regression (3) are reported. More specifically, three estimates are presented, including lags and leads of order 1, 2 and 3. In all cases the leads of $D_{i,j,k,t}$ are statistically insignificant supporting the robustness of our DID estimates. On the other hand, when the treatment is entered with lags is significant in all cases. In conclusions, the results show that the leads are insignificant indicating no evidence for anticipatory effects. Thus, the common trends assumption is accepted. On the contrary, the lags are significant and they show that the effect decreases the ozone levels during the first years of the treatment and the impact on ozone reduction remains significant in the years followed and it is slightly increased at -1.42 ppb. This small increase can be due the fact that the number of "Clean Air Works" program partners has been increased during the period 2006-2010, from 90 to 120.

In figure 3 the DID estimates for the "Clean Air Works" program are presented. More specifically, the black line represents the treatment group without treatment (untreated), while the grey line represents the control group. The black dot-line represents the treatment group after the implementation of the program. The period is expressed in 3 different time lines. The first indicates the beginning of the sample used in this study which is 2000, while the second period indicates the period where the "Clean Air Works" program has been established on 1st March of 2006. Finally, period 3 indicates the establishment of the change of the ozone warning threshold, which took place on 27th May of 2008.

It becomes obvious that the trend before the treatment on the average ozone levels is the same between control and treatment groups. After the implementation of the "Clean Air Works" program the average ozone levels are reduced in a higher rate in the treated group than in the control group. Therefore, based on the robustness checks the common trend assumption is not violated indicating that the deviation of the trend of the observed outcomes (average ozone levels) of the treated from the trend of the observed outcomes of the control (untreated) group are directly attributed to the effect of the treatment as it is shown in the figure 3.

With the DDDD it is possible to examine different cases and differences between control and treatment group. One concluding remark of this study the "Clean Air Works" is effective on improving the air quality in the treatment group. Secondly, smog alerts have additionally significant effects on ozone reduction, when they are associated with the program examined in this study. Thirdly, the quadruple DDDD results show that reducing the threshold from 80 ppb to 75 ppb, a reduction in ozone levels is observed for both treatment and control groups. Moreover, the change of the threshold provides an additional reduction in ozone emission levels, when it is associated with a voluntary program, like "Clean Air Works".

Based on the previous estimates a rough estimate of the number of lives saved from the air quality improvement, under the “Clean Air Works project” associated with the change of the threshold and ozone smog alerts, is presented. Currie and Neidell (2005) find that a one-unit decrease in carbon monoxide (CO) saves 16.5 infant lives per 100,000 births and over 1,000 infants lives are saved from the air pollution reduction during the period 1989-2000, while Knittel et al. (2011) find that it saves 17 lives. Chay and Greenstone (2003a; 2003b) results suggest between 7-15 and 13-23 less deaths per unit decrease of PM_{10}. The literature gives little guidance about when in pregnancy pollution is likely to be most harmful. Currie and Neidell (2005) used pollution measured in the first month of pregnancy, the last trimester of pregnancy and the first trimester of pregnancy. However, because these data are unavailable in this study and the exact time of pregnancy is unknown, pollution measured in trimester basis with one lag (Currie and Neidell, 2005). They find that when the last trimester is used rather than the last month of pregnancy, the air pollution effects are stronger. Similarly, the same interval is taken for the total death and the death rates for elder people.

The death statistics data from the North Carolina State Center of Health statistics are used. The total population during the period 2006-2010 in the treatment group was 1,366,373. Thus, regarding the total deaths, and based on the estimates of table 8 the lives saved by the clean air work program, over the period, are around 425. Respiratory diseases include asthma, bronchitis and pneumonia among others and it is well known that deaths resulted by those diseases are caused by air pollution.

Regarding the effects on infant lives and based on the number of births which was 98,591 during period 2006-2010 it is found that around 211 infant lives have been saved. Finally, the elder population was 33,133. Based on the estimates 38 lives are saved. The remaining deaths belong to the other age groups, including children, but also individuals who suffer from respiratory diseases, which is not possible to identify them based on the available data. Therefore, these estimates are not precise and they could be improved by considering daily and detailed hospitalization, episode statistics and death rates data including gender, race, education level, individual’s habits like smoking and alcohol consumption, individual's zip code location and the distance between an air monitor, age and medical background history among others. In addition, as Currie and Neidell (2005) point out in their study and in other studies too, in this case examined as well, outdoor air quality is measured using a fixed monitor. Actual personal exposures are affected by the time the individual spends indoors and outdoors. Therefore one might expect, for example, that infants spend little time outdoors, so that outdoor air quality might not be relevant.

7. Conclusions

This paper examined the effects of the "Clear Air Works" program implementation on the ozone concentration levels in Charlotte Area in North Carolina State. Moreover, using a DDDD model the effects of the smog alerts under this program additionally associated with the change of the ozone warning threshold from 80 ppb to 75 ppb have been examined.

Based on the estimates, the difference in ozone levels between the treatment and control group has been reduced after the establishment of the "Clear Air Works" program and the smog alerts have an additional effect under this program. The results are consistent with the study by Cutter and Neidell (2009). More specifically the fact that individuals respond to STAs suggests that such voluntary information programs have a potential role in regulatory policy, but such programs alone do not appear to be enough for detecting improvements in air quality; additional incentives appear necessary. Thus, the implication of this program is that additional incentives are required, besides the smog ozone days, in order to improve air quality, such as teleworking, carpool, vanpool, bicycling, public transit and others.

The advisory ozone programs warn the public about forecasted high ozone days, and ask for voluntary actions to reduce emissions of ozone forming pollutants. However, the additional incentives provided by the "Clear Air Works" program are apparently more efficient. Therefore, other areas in North Carolina and other states in USA can implement and follow the example and practices of the specific program. Incentives can include carpool and vanpool programs sponsored by the local governments. Other practices can include incentives to the employers. More specifically, employers can get a tax deduction by giving their employees up to $130 per month to commute via public transit or vanpool. Another incentive is the encouragement of teleworking practices. In this case the employees can save money and time and be less stressful by working at home and at the same time the air quality, through the traffic reduction, can be further improved.

Furthermore, the effects of the air quality improvement, through the program implementation, on mortality have been presented. Concluding, as policy makers discuss ways to improve air quality, the adoption of voluntary programs, such as the "Clean Air Works" program, might be potentially an efficient mechanism. Ultimately, as the results showed about the effects of air quality on mortality, achieving attainment for ozone -air quality better than the national standard- will result in a healthier environment for the region's citizens and work force, and make it more attractive for economic development.

There is one major potential limitation of the analysis. The individual behaviour on transportation mode choice is not examined. Especially, in the case of "Clean Air Works" project, where carpool and vanpool programs, as well as public transit is encouraged and other policies are proposed, the traffic volume is not explored. As it was mentioned, the purpose of this study is the investigation of the effectiveness of the "Clean Air Works" Project the direct examination of ozone forecasts and smog alerts to actual ozone concentrations and their association with "Clean Air Works". Additionally, other studies have already examined the effects of ozone warnings on traffic volume and public health (Cutter and Neidell, 2009; Moretti and Neidell, 2011).

References

Agudelo-Castaneda, D., Teixeira, E., Rolim, S., Pereira, F., and Wiegand, F., 2013. Measurement of Particle Number and Related Pollutant Concentrations in an Urban Area in South Brazil, *Atmospheric Environment*, 70, pp. 254–262.

Angrist, J.D. and Pischke, J.S., 2008. *Mostly harmless econometrics: An empiricist's companion*. Princeton university press.

Baertsch-Ritter, N., Keller, J., Dommen, J. and Prevot, A.S.H., 2004. Effects of various meteorological conditions and spatial emission resolutions on the ozone concentration and ROG/NOx limitation in the Milan area (I), *Atmospheric Chemistry and Physics*, 4, pp. 423–438.

Bertrand, M., Duflo, E. and Mullainathan, S., 2004. How much should we trust differences-in-differences estimates? *The Quarterly Journal of Economics*, 119(1), pp. 249–275.

Camalier, L., Cox, W. and Dolwick, P., 2007. The Effects of Meteorology on Ozone in Urban Areas and their use in Assessing Ozone Trends, *Atmospheric Environment*, 41, pp. 7127–7137.

Card, D. and Krueger, A.B. 1994., Minimum Wages and Employment: A Case Study of the Fast-Food Industry in New Jersey and Pennsylvania. *American Economic Review*, 84(4), pp. 772-793.

Chay, K.Y. and Greenstone, M., 2003a. Air Quality, Infant Mortality, and the Clean Air Act of 1970. NBER Working Paper No. 10053, Cambridge, MA.

Chay, K.Y. and Greenstone, M., 2003b. The Impact of Air Pollution on Infant Mortality: Evidence from Geographic Variation in Pollution Shocks Induced by a Recession. *Quarterly Journal of Economics*, 118(3), pp. 1121-1167.

Crutzen, P.J., 1974. Photochemical reaction initiated by and influencing ozone in unpolluted tropospheric air. *Tellus*, 26, pp. 44–55.

Cummings, R.G. and Walker, M.B., 2000. Measuring the effectiveness of voluntary emission reduction programs. *Applied Economics,* 32, pp. 1719–1726.

Currie, J. and Neidell, M., 2005. Air Pollution and Infant Health: What Can We Learn from California's Recent Experience? *The Quarterly Journal of Economics*, 120 (3), pp. 1003-1030.

Cutter, W.B. and Neidell, M., 2009. Voluntary information programs and environmental regulation: Evidence from ‘Spare the Air’. *Journal of Environmental Economics and Management,* 58, pp. 253–265.

Dawson, J. P., Adams, P. J. and Pandis, S.N., 2007. Sensitivity of Ozone to Summertime Climate in the Eastern USA: A Modeling Case Study, *Atmospheric Environment*, 41, pp. 1494–1511.

Derwent, R.G., Jenkin, M.E., Saunders, S.M., Pilling, M.J., Simmonds, P.G., Passant, N.R., Dollard, G.J., Dumitrean, P. and Kent, A., 2003. Photochemical ozone formation in North West Europe and its control. *Atmospheric Environment*, 37(14), pp. 1983–1991.

Environmental Protection Agency, 2008. Air Quality Criteria for Ozone and Related Photochemical Oxidants Washington, DC: Environmental Protection Agency.

Figueiredo, M., Monteiro, A., Lopes, M., Ferreira, J., and Borrego, C., 2013. Air Quality Assessment of Estarreja, an Urban Industrialized Area, in a Coastal Region of Portugal, *Environmental Monitoring and Assessment*, 185, pp. 5847–5860.

Friedman, M.S., Powell K.E., Hutwagner L., Graham, L.M. and Teague, G.W., 2001. Impact of Changes in Transportation and Commuting Behaviors During the 1996 Summer Olympic Games in Atlanta on Air Quality and Childhood Asthma, *Journal of the American Medical Association,* 285, pp. 897–905.

Granger, C. W. J., 1969. Investigating Causal Relation by Econometric and Cross-Sectional Method. *Econometrica*, 37, pp. 424-438.

Jacob, D., Logan, J., Gardner, G., Yevich, R., Spivakovsky, C. and Wofky, S., 1993. Factors Regulating Ozone over the United States and its Export to the Global Atmosphere. *Journal of Geophysical Research*, 98, pp. 14817–14826.

Jammalamadaka, S.R. and Lund, U.J., 2006. The effect of wind direction on ozone levels -a case study. *Environmental and Ecological Statistics*, 13(3), pp. 287-298.

Knittel, R., Miller, D.L. and Sanders, N.J., 2011. Caution Drivers! Children Present: Traffic, Pollution and Infant Health. NBER Working Paper 17222, Cambridge.

Lipfert, F. W., Zhang, J. and Wyzga, R. E., 2000. Infant Mortality and Air Pollution: A Comprehensive Analysis of Us Data for 1990. *Journal of the Air and Waste Management Association*, 50 (8), pp. 1350-1366.

Moretti, E. and Neidell, M., 2011, Pollution, Health, and Avoidance Behavior Evidence from the Ports of Los Angeles. *Journal of Human Resources*, 46(1), pp. 154-175.

Pudasainee, D., Sapkota, B., Shrestha, M.L., Kaga, A. Kondo, A., Inoue, Y., 2006. Ground level ozone concentrations and its association with NOx and meteorological parameters in Kathmandu valley, Nepal. *Atmospheric Environment*, 40, pp. 8081–8087.

Pugliese, S. C., Murphy, J.G., Geddes, J.A. and Wang, J.M., 2014. The impacts of precursor reduction and meteorology on ground-level ozone in the Greater Toronto Area. *Atmospheric Chemistry and Physics*, 14, pp. 8197–8207.

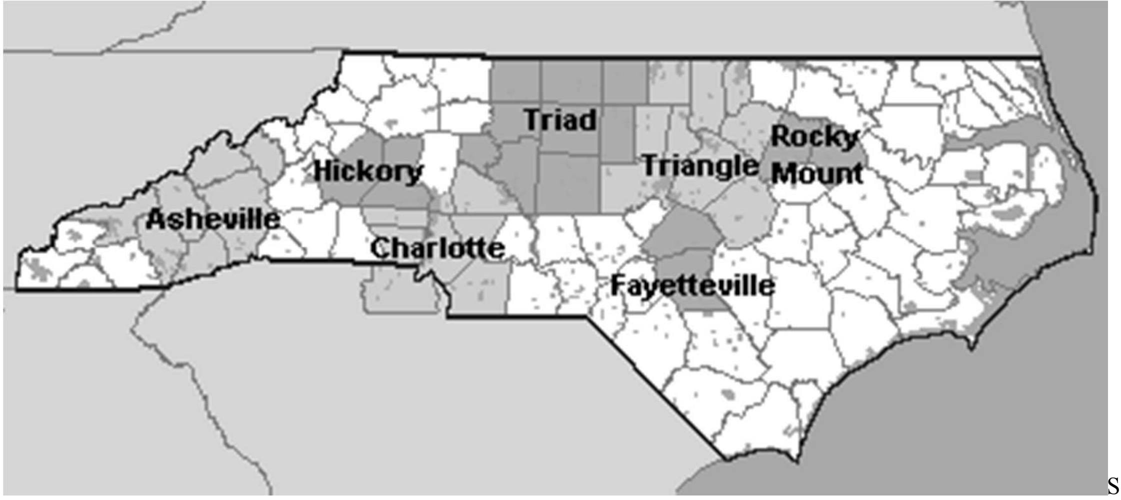
Schreffler, E., 2003. Quantification methods for identifying emission reductions resulting from seasonal and episodic public education programs. Air Resource Board Final Research Report.

Welch, E., Gu, X. and Kramer, L., 2005. The effects of ozone action day public advisories on train ridership in Chicago. *Transportation Research Part D, Transport and Environment,* 10, pp. 445–458.

Witcraft, N., Bridgers, G., Do, B., O'Reill, P. and Marufu, L., 2006. Case Study of the Late July 2005 Ground-Level Ozone Episode in North Carolina. *Eighth Conference on Atmospheric Chemistry*, 28 January-2 February.

Woodruff, T.J., Grillo, J. and Schoendorf, K.C., 1997. The Relationship Between Selected Causes of Postneonatal Infant Mortality and Particulate Air Pollution in the United States. *Environmental Health Perspectives*, 105(6), pp. 608-612.

Map 1. Ground-Level Ozone Forecast Zones-Areas in North Carolina



Source: North Carolina Department of Environment and Natural Resources (http://daq.state.nc.us).

Table 1. Treatment and Control Group

Treated Counties	**Control Counties**
Lincoln (Charlotte area)	Forsyth (Triad area)
Mecklenburg (Charlotte area)	Rockingham (Triad area)
Rowan (Charlotte area)	Guilford (Triad area)
Union (Charlotte area)	Raleigh (Triangle area)
	Cumberland (Fayetteville area)
	Buncombe (Asheville area)
	Caldwell (Hickory area)

Table 2. Date of the events

Date of the Event	**Event**
1st July 1997	Ozone warning threshold at 80 ppb
1st March 2006	Introduction and Establishment of the "Clean Air Works" program
27th May 2008	Change of ozone warning threshold from 80 ppb at 75 ppb

Table 3. Summary Statistics for Actual Ozone Concentrations expressed in Parts Per Billion (ppb)

	No. observations	Mean	Standard Deviation	Min	Max
Period 2000-2010					
Ground Level Ozone	70,457	51.573	15.160	0	128
Period 2000-2007					
Ground Level Ozone	46,634	53.118	15.642	2	128
Period 2008-2010					
Ground Level Ozone	23,823	49.269	13.285	0	101
Treatment group Period 2000-2010					
Ground Level Ozone	12,684	52.986	16.559	0	128
Treatment group Period 2000-2007					
Ground Level Ozone	8,436	54.272	17.193	2	128
Treatment group Period 2008-2010					
Ground Level Ozone	4,248	51.446	13.314	0	101
Control group Period 2000-2010					
Ground Level Ozone	22,779	51.368	15.552	3	115
Control group Period 2000-2007					
Ground Level Ozone	14,989	52.665	15.768	3	115
Control group Period 2008-2010					
Ground Level Ozone	7,790	50.564	13.538	0	93

Table 4. Exceedance Days of Air Quality Threshold for Ground Level Ozone Concentrations

	Number of exceedance days during period 2000-2005	Number of exceedance days during period 2006-2007	Number of exceedance days during period 2008-2010
Asheville Area	231	20	36
Charlotte Area	683	206	136
Fayeteville	100	11	13
Hickory	44	11	9
Triad	414	87	103
Triangle	425	45	65
Treatment group	648	146	92
Control group	675	198	141

Figure 1. Distribution for Actual Ozone Concentrations Measured in Part Per Billion (ppm) during Period 2000-2010 in Treatment and Control Groups

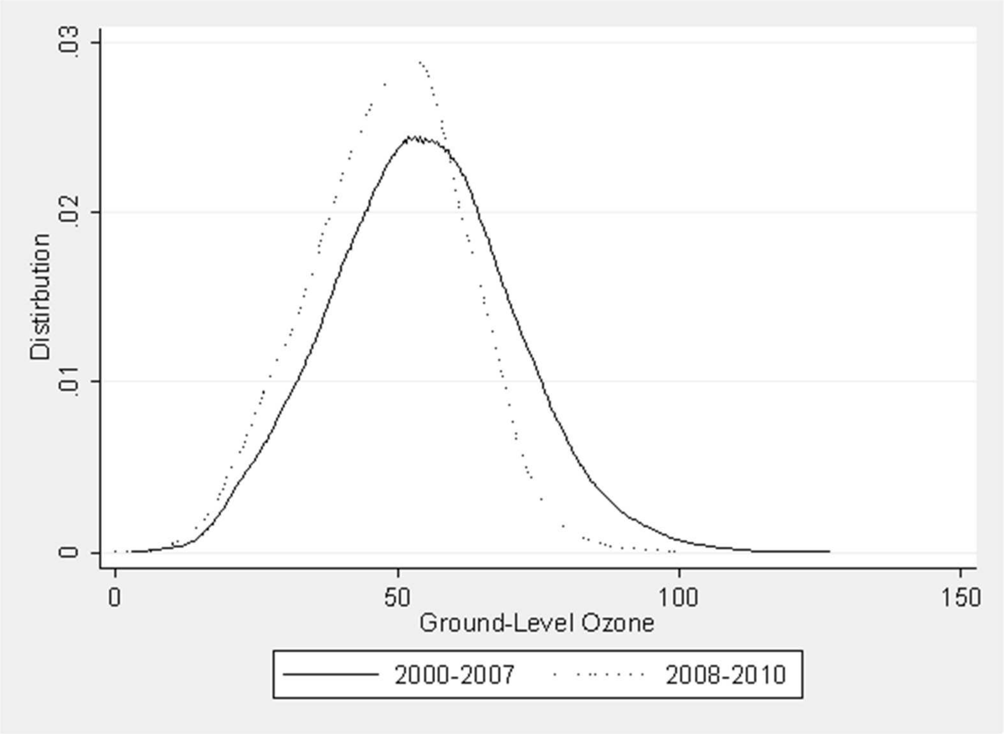


Figure 2. Average Ozone Levels and Number of Exceedance Days in Treatment and Control Group during Period 2000-2010

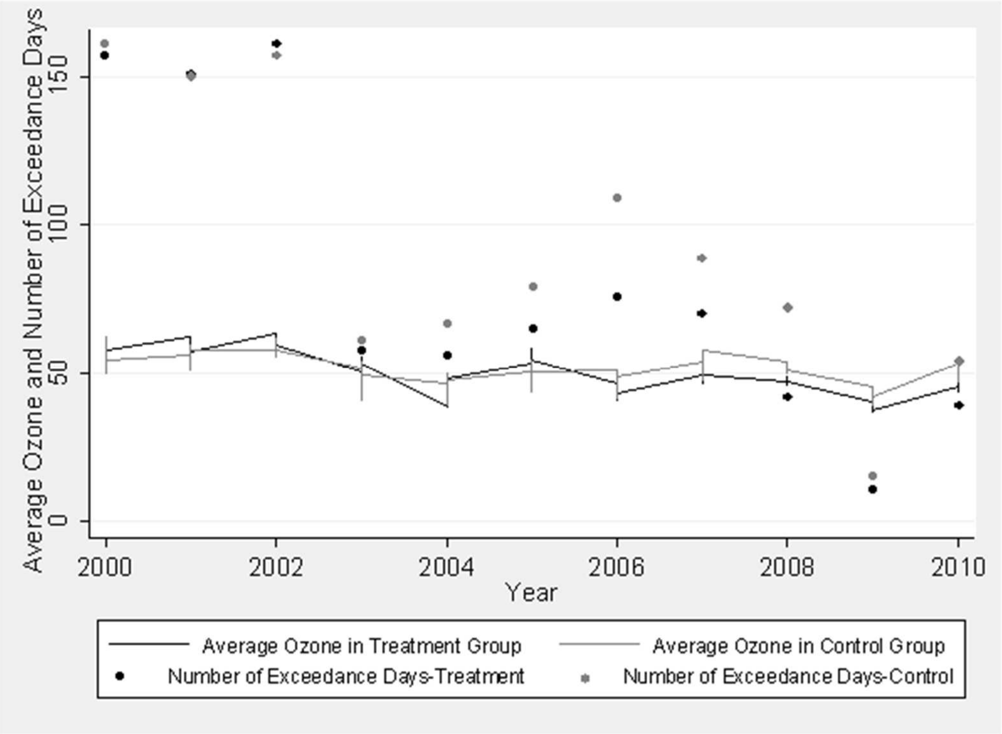


Table 5. Quadruple DDDD Estimates for Equation (1)

Treat	1.121 (0.2274)***	Treat*Program*Warning (DDD effectiveness of smog alerts under Clean Air Works Regime)	-1.833 (0.7553)**
Program (1 for 2006 and after and 0 otherwise	-2.445 (1.2042)**	Treat*Threshold	-1.545 (0.3745)***
Warning (1 for smog alert and 0 otherwise)	6.149 (0.6004)***	Program *Threshold	-1.271 (0.2739)***
Threshold (1 for 2008 and after and 0 otherwise)	-3.352 (0.2808)***	Warning*Threshold	-4.259 (2.235)*
Treat*Program (DD effectiveness of Clean Air Works Program)	-1.268 (0.3887)***	Treat* Program*Threshold	-3.248 (0.3002)***
Treat*Warning	-0.855 (0.4155)**	Treat* Warning*Threshold	-2.124 (0.5153)***
Program* Warning	-1.325 (0.3841)***	Treat* Program*Warning*Threshold (DDDD establishment of the threshold change effect)	-1.493 (0.1131)***
No. obs.	35,463	R^2	0.3790

a. Standard errors are reported between brackets, clustered standard errors at ozone monitoring site

b. ***, ** and * denote significance at the 1%, 5% and 10% level

c. The control variables are: day of the week, month, year, ozone monitoring sites, counties, ozone forecasting regions-areas, average temperature, wind speed, wind direction and solar radiation.

Table 6. Robustness checks for DID regression

	Panel A:Robustness Check Using Placebo Dummies Before the Treatment Regression (2)		
Treat*Program (DD effectiveness of Clean Air Works Program)	0.482 (0.6512)	R^2	0.3347
No. obs.	20,912		

	Panel B:Robustness Check Using Leads and Lags Regression (3)		
$D_{i,j,k,t-1}$	-1.304 (0.621)**	-1.309 (0.628)**	-1.203 (0.623)**
$D_{i,j,k,t-2}$		-1.381 (0.632)**	-1.385 (0.638)**
$D_{i,j,k,t-3}$			-1.422 (0.701)**
$D_{i,j,k,t+1}$	-0.389 (7.671)	-0.373 (8.238)	-0.372 (8..239)
$D_{i,j,k,t+2}$		-0.683 (5.901)	-0.637 (8.337)
$D_{i,j,k,t+3}$			0.525 (5.902)
No. obs.	35,441	35,423	35,402
R^2	0.3426	0.3426	0.3427

a. Standard errors are reported between brackets, clustered standard errors at ozone monitoring site

b. ** denotes significance at the 5% level

c. The dependent variable is the actual ozone levels and the control variables are: day of the week, month, year, ozone monitoring sites, counties, ozone forecasting regions-areas, average temperature, wind speed, wind direction and solar radiation.

Figure 3. DID Estimates for the "Clean Air Works" Program

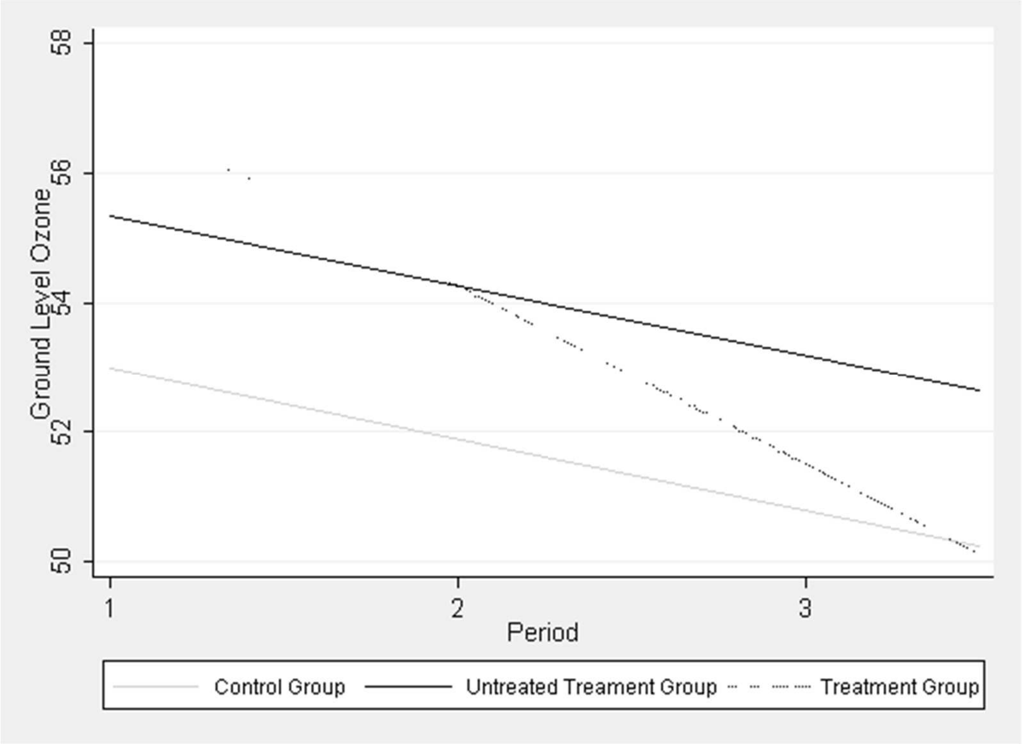


Table 7. Ozone Effects on Deaths Caused by Respiratory and Pneumonia Diseases.

DV: Respiratory Diseases	
Panel A: Total Deaths	
Ozone	0.0156 (0.0002)***
Obs	60
R squared	0.1586
Panel B: Infant Deaths	
Ozone	0.0885 (0.0018)***
Obs	60
R squared	0.2284
Panel C: Elder Deaths (60 years and older)	
Ozone	0.0511 (0.0023)***
Obs	60
R squared	0.0934

a. Standard errors are reported between brackets, clustered standard errors at ozone monitoring site
b. *** denotes significance at the 1% level
c. The dependent variable is the number of deaths caused by respiratory diseases levels and the control variables are: year, ozone monitoring sites, counties, ozone forecasting regions-areas, average temperature, wind speed, wind direction and solar radiation.