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Evaluation of the "Clean Air Works" program on actual ozone concentrations: A Case study in North Carolina

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Abstract

This study examines the effectiveness of the "Clean Air Works" program in the state of North Carolina on ozone concentration levels. "Clean Air Works" is a voluntary program which educates people about the negative effects of air pollution on health. The contribution of this study is that it examines three effects: The effectiveness of the "Clean Air Works" program in the Charlotte Area of North Carolina State 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. In all 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[1].

Keywords: Air Quality; Clean Air Works; Environmental Technology and Management; Quadruple Differences-in-Differences; Ozone concentrations; Smog alerts; Voluntary Programs

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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.

The aim of this study is to examine the effectiveness of the "Clean Air Works" program along with smog alerts. The second aim is to explore whether the ozone smog alerts are more effective under the "Clean Air Works" program. The third aim is to establish the impact of the change in the ozone warning threshold standard issued by the Environmental Protection Agency (EPA) from 80 ppb to 75 ppb which took place in 2008.

In order to identify those effects a quadruple Differences (DDDD) estimator is applied. The results show the air quality has been improved in the treatment group with the implementation of the "Clean Air Works" program reducing the difference in ozone concentration levels by 1.27 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 threshold by around 1.50 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 structure of the paper is the following: 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 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. These studies examine the effects of public advisory programs on traffic. Similarly, “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 of 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 leave their cars at home and to try an alternative commute. 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 they purposely reduced trips because of Spare the Air, while non-participant is a control group of drivers who did not respond to the 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. The precursors in this study are the nitrogen oxides (NO_X) and volatile organic compounds (VOCs). This program is similar to Clean Air Works program examined in this study. Ozone warning announcements encourage people to reduce driving or to use public transit and various kinds of ridesharing, such as carpool and vanpool, or to encourage teleworking.

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 compare the bay area, where the "Spare the Air" (STA) alert is issued, and the South Coast area, where the STA program is not applied. Cutter and Neidell (2009) estimate a regression discontinuity approach using a sample of observations within 2 and 1 ppb of the limit for a STA call and they show a statistically significant drop in vehicle usage of between 2,000 and 2,300 per day. 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.

Generally, 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 contributes to the previous literature by examining the effectiveness of the "Clean Air Works" voluntary program associated with smog alerts and the change in the threshold.

In addition, the weather data have been neglected in the previous studies, with the exception of the study by Welch et al. (2005) who use various weather conditions, such as temperature, days with light and heavy rain and extreme weather including thunderstorms and other extreme conditions. It is crucial to control for weather conditions for the following reasons: Firstly, the weather conditions affect the ozone formation and influence the traffic pattern and flow. 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). In addition, wind speed and direction are important factors for ozone, as previous researches found relationship between wind direction and speed 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.

3. Environmental Policy

3.1 Smog Alert and Ozone Forecasts

Air quality forecasts, measured in part per billion (ppb), are provided by the EPA, which sets the National Ambient Air Quality Standards (NAAQS). The Air Quality Index ranges from 0 to 500. From 1997 the national standard was set up at 80 ppb, corresponding to 111 of the revised AQI. In 2008 this standard was reduced to 75 ppb, corresponding to 100 of the 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 (Environmental Protection Agency, 2008).

Ozone forecast is distributed and it is available to the public through local media (television, radio, and newspaper). 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 ozone forecasts to the general public and their impact on health.

3.2 Clean Air Works Program

“Clean Air Works” program launched in spring of 2006 and it is a project of the Regional Air Quality Board, in collaboration with 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 partners of “Clean Air Works” project try to educate employees about the effects of air pollution on public health and to provide a low or no cost transportation benefit to employees. Also, this program encourages and educates employers to follow various policies, such as the use of low emission or alternatively fueled vehicles, and implementing energy conservation plans.

4. Methodology

4.1 Quadruple Differences-in-Differences Model

The model examined in this study is a quadruple DDDD, which 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*. Variable *treat* denotes whether the counties belong to the *treatment* or control group and it captures aggregate factors that would cause changes in ozone levels even in the absence of the program implementation, such as the Great Recession. Variable *program* takes value 1 since the "Clean Air Works" has been implemented in 1st March of 2006 and after and 0 otherwise and it captures possible differences between the treatment and control groups prior to the program implementation. *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. It takes value 1 for 27th May of 2008 and after and 0 otherwise. At the same time the model controls for the day of the week, month, year, counties, ozone regions, and weather data ($W_{i,j,t}$), such as temperature, wind speed, wind direction and solar radiation. Set (μ_i) includes dummy variables for the monitoring stations, (l_j), is a set including county dummies, (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 differences-in-differences method can be implemented according to table 2 (Angrist and Pischke, 2008, p. 169-174):

(Insert table 1 around here)

Variable *y* is the outcome-actual concentration ozone levels expressed ppb in this case-, while *g* and *t* denote the group and time respectively. More specifically, the dummy variable *treat*program,* captured by the coefficient β_{5}, shows possible differences in ozone levels between the treatment and control groups prior to policy change (before the implementation of the "Clean Air Works" program) and after. The normal difference is defined as (y_{B1}- y_{A1}), which is the difference of the average ozone levels between the treatment and control group before the implementation of the program. The expression (y_{B2}- y_{A2}) indicates the normal difference plus the treatment effect of the program implementation. The difference-in-differences estimate is shown in table 2 and it is β_{5} =(y_{B2}- y_{B1})-(y_{A2}- y_{A1}). Therefore, the essential idea of the double DID) estimator is to compare samples of the treated counties and control counties before and after the intervention ("Clean Air Works"). The DD calculates the difference between the "after" and "before" values of the mean outcomes (ozone levels) for each of the treatment and control group. Then the difference between these two mean differences is the impact estimate of the intervention. In a similar fashion the triple DDD estimator (expressed by the coefficient β_{11}) and the quadruple DDDD estimator (expressed by the coefficient β_{14}) are defined.

In figure 1 a hypothetical DID plot is presented as an example. More specifically, before the policy both groups face the same average trend, while after the policy the trend change in the treatment group, as the effects on the outcome jump downwards, represented by the dashed line. The grey line shows that the average effect would be the same in both groups with the absence of the policy or in the case that the policy would not be significant.

Thus, in plain words DID strategy is based on comparing four groups. These groups are the treated before the treatment or policy implementation and it is defined as the pre-treatment treated, the non-treated or the control group in the period before the treatment occurs to the treated, which is the pre-treatment non-treated or control. The third group is the non-treated or control in the current period, which is the post-treatment non-treated. Finally, the last group is the one which already received the treatment or where the policy (Clean Air works in this case) is implemented and it is defined as the post-treatment treated. Therefore, the idea of this empirical strategy is that the average changes of the outcome variable for the control group over time are added to the average level of the outcome variable for the treated group prior the implementation of the policy to obtain the average outcome that the treated group would have experienced if it had not been subject to the policy or the treatment.

(Insert figure 1 around here)

In addition, another advantage of this model is that it controls for additional factors, such as for weather conditions. Thus, this section presented the main framework of the DID strategy, along with its advantages over simple statistical analysis, such as simple averages and standard deviations of the actual and predicted ozone levels before and after the program implementation.

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 common trend or parallel growth-trend assumption is examined. This assumption states that the differences in the expected potential non-treatment outcomes over time are unrelated to belonging to the treated or control group in the post-treatment period. This is the key assumption of the DID approach. 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.

In order to test the parallel or common trend assumption is to place placebo dummies before the treatment. More precisely, the DID is estimated assuming that the "Clean Air Works" project took place before 2006. More specifically, we assume that the policy took place in 2004 instead of 2006 and the basic DD model is estimated using data from 2000-2005:

$$ozone_{i,j,k,t} = \beta_1 treat_{i,j,k,t} + \beta_2 program_{i,j,k,t} + \beta_3 treat_{i,j,k,t} * program_{i,j,k,t} + W_{i,j,t} + \mu_i + l_j + z_k + \theta_t + \varepsilon_{i,j,k,t} \tag{2}$$

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, as it has been discussed in section 4.1. 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.

The second test of the DID validity is to include a set of lags and leads into the basic DID model (2). 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:

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

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 (4) allow for *m* lags, (β_{-1}, β_{-2},.....,β_{-m}) defining the post-treatment effects and *q* leads ((β_{+1}, β_{+2},.....,β_{+q}) defining the anticipatory effects (Angrist and Pischke, 2008, p. 177-178).

5. Data

The actual ozone concentrations are measured at county level, while the ozone forecasts are assigned on regions – group of counties. The counties treated are Lincoln, Mecklenburg, Rowan and Union in Charlotte Area, while the counties used as control group are the following: Forsyth, Rockingham and Guilford Counties in Triad area, Raleigh County in Triangle area, Cumberland County in Fayeteville area, Buncombe County in Asheville area and Caldwell County 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". 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, as it has been discussed in section 3.

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. 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. The data are based on daily frequency and the period examined is 2000-2010. In table 2 the summary statistics for actual ozone concentrations are reported.

(Insert table 2 around here)

The ozone levels have been reduced also in the control area for the following reasons: Firstly, by reducing the threshold by 5 ppb in 2008, a similar reduction on the ozone levels is expected. This is because 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. However, an additional reduction in ozone levels is observed in the treatment group. The reason is that the treated counties benefit from the "Clean Air Works" as it has been discussed in the previous section.

6. Empirical results

In this section the quadruple DDDD estimates are presented. As it has been discussed in the previous sections, the purpose of applying the quadruple DDDD is to examine the effectiveness of the "Clean Air Works" Project, 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.

The estimated regression (1) is presented in table 3. The first coefficient of interest is the coefficient β_5. This is expressed by the interaction term *treat*program-* indicates whether the program was efficient or not, which is statistically significant and equal at -1.268 and it. This result shows that the difference of the average ozone levels 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 estimated average ozone level in the treatment and control group before the "Clean Air Works" implementation was respectively 54.344 ppb and 52.250 ppb resulting to a difference equal at -2.094 ppb (54.344-52.250). After the implementation of the program the average ozone levels are 51.936 and 51.110 in the treatment and control group respectively with a difference equal at 0.826 ppb (51.936-51.110). Thus, based on table 2 the difference-in-difference –DD estimator- is the difference between 0.826 ppb and 2.094 ppb (-1.268 ppb), which has been discussed in the methodology part. 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.

The second main coefficient of interest is the triple DDD estimator (coefficient β_{11}), which is expressed by the interaction term *treat*program*warning*. The coefficient is negative and significant and it is equal at -1.833. This shows that the smog alerts are more effective under the program regarding air quality improvement. More specifically, using equation (2) the first term is the double DID in the treatment group, which is -4.5 ppb and it is derived as: The average ozone levels in the treatment group, when a smog alert is issued are 59.01 ppb (standard deviation: 14.823) and 64.75 ppb (standard deviation: 15.111) in the post-treatment and pre-treatment periods respectively, resulting to a difference -5.73 ppb (59.01 ppb-64.75 ppb). Similarly for the non-smog alert days the difference is -1.23 ppb (50.11 ppb-51.33 ppb) and it is the second term of the first squared bracket in relation (2). The double DID for the treatment group is the difference between -5.73 ppb and -1.23 ppb (-4.5 ppb). Thus, the average ozone levels between the smog-alert and non-smog alert days have been reduced in the treatment group by 4.5 ppb after the implementation of the program. Similarly, for the control group the double DID is the difference of -3.8 ppb and -1.18 ppb (-2.62 ppb). Therefore, the triple DDD is the differences between the double DD of the treatment and control group and it is equal at -1.88 ppb (-4.5 ppb - (-) 2.62 ppb).

Finally, the third main coefficient is the DDDD estimator, which is captured by the coefficient β_{14} and is expressed by the interaction term *Treat* Program*Warning*Threshold*. The coefficient is negative and significant and 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 by 1.493 ppb when smog alerts are associated with the implementation of the program and the change of the warning threshold.

Thus, the results support the effectiveness of the “Clean Air Works” project, while the smog alerts are additionally improving air quality when they are associated with the program, based in the triple DDD estimator. Finally, the DDDD estimator established the effects of the warning threshold change on actual ozone levels. The change of the threshold additionally improves the air quality in the treatment group relatively to the control group. This also can be confirmed by the fact that forecasting and actual ozone levels differ significantly. Firstly, this is due to weather conditions. More specifically, the meteorologists use past weather conditions for the ozone predictions. However, as it has been discussed in the literature review section, weather also can influence traffic flow and patterns, which traffic volume is not used in their models. Thus, by controlling for weather conditions along with the “Clean Air Works” program it is possible to capture these effects on traffic volume which results in changes of ozone levels. Secondly, by controlling for time and county effects, the effects of the program on ozone levels are captured. More specifically, the objectives of this program, as is has been discussed in previous section, is to encourage individuals, employees and employers, to follow various practices in order to reduce the air pollution, especially when a smog alert is issued. This has as a result to affect the actual ozone levels, even if the ozone forecasts are different. Regarding the change of the ozone threshold, the actual and forecasting ozone values differ in both groups. This is because reducing the ozone threshold, additional warnings can be issued. Thus, the local governments in both groups have to take measures in order to improve air quality as it has been discussed in section 3. However, the difference is higher in the treatment group, because of the program implementation, as the estimates have shown.

(Insert table 3 around here)

Next the robustness checks, discussed in the methodology part, are presented. In table 4 the estimated results of regression (2), using placebo dummies before the treatment are reported. It becomes clear that the parallel trend assumption is accepted because the DD estimator, 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. This assumption holds whenever the placebo dummies change eg. whether the program took place in 2001 or 2002.

(Insert table 4 around here)

In figure 2 the DID estimates for the "Clean Air Works" program and regression (3) including lags and leads of order 1, 2 and 3, 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.

(Insert figure 2 around here)

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 in the trend of the observed outcomes (average ozone levels) in the treated group from the trend of the observed outcomes in the control (untreated) group are directly attributed to the effect of the treatment as it is shown in the figure 2.

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.

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).

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Table 1. Differences-in-differences implementation

Outcome (y_{gt})	Pre-treatment (t = 1)	Post-treatment (t = 2)	Time difference (y_{g2} - y_{g1})
Control group (g = A)	y_{A1}	y_{A2}	common trend (y_{A2} - y_{A1})
Treatment group (g = B)	y_{B1}	y_{B2}	common trend+ treatment effect (y_{B2} - y_{B1})
Group difference (y_{Bt} - y_{At})	normal difference (y_{B1}- y_{A1})	normal difference + treatment effects (y_{B2}- y_{A2})	treatment effect=(y_{B2}- y_{B1})- (y_{A2}- y_{A1}) Or (y_{B2}- y_{A2})- (y_{B1}- y_{A1})

Figure 1. DID plot example

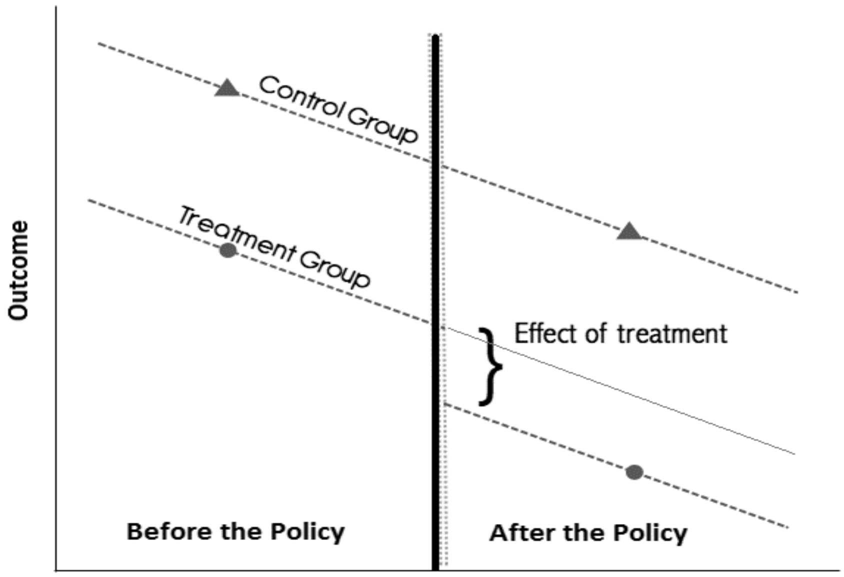

Table 2. Summary statistics for daily actual ozone concentrations expressed in ppb

	No. observations	Mean	Standard Deviation	Min	Max
Treatment group Period 2000-2010					
Ground Level Ozone	22,684	52.986	16.559	0	128
Treatment group Period 2000-2007					
Ground Level Ozone	15,436	54.272	17.193	2	128
Treatment group Period 2008-2010					
Ground Level Ozone	7,248	51.446	13.314	0	101
Control group Period 2000-2010					
Ground Level Ozone	47,773	52.186	14.768	3	115
Control group Period 2000-2007					
Ground Level Ozone	31,198	52.665	15.202	3	115
Control group Period 2008-2010					
Ground Level Ozone	16,575	50.564	13.538	0	93

Table 3. Quadruple DDDD Estimates for Equation (1)

Variables (Coefficients)	**Estimated Coefficients**	**Variables (Coefficients)**	**Estimated Coefficients**
Treat (β_1)	1.121 (0.2274)***	Program* Warning (β_8)	-1.325 (0.3841)***
Program (1 for 2006 and after and 0 otherwise (β_2)	-2.445 (1.2042)**	Program *Threshold (β_9)	-1.271 (0.2739)***
Warning (1 for smog alert and 0 otherwise) (β_3)	6.149 (0.6004)***	Warning*Threshold (β_{10})	-4.259 (2.235)*
Threshold (1 for 2008 and after and 0 otherwise) (β_4)	-3.352 (0.2808)***	Treat*Program*Warning (DDD effectiveness of smog alerts under Clean Air Works Regime) (β_{11})	-1.833 (0.7553)**
Treat*Program (DD effectiveness of Clean Air Works Program) (β_5)	-1.268 (0.3887)***	Treat* Program*Threshold (β_{12})	-3.248 (0.3002)***
Treat*Warning (β_6)	-0.855 (0.4155)**	Program* Warning*Threshold (β_{13})	-2.124 (0.5153)***
Treat*Threshold (β_7)	-1.545 (0.3745)***	Treat* Program*Warning*Threshold (DDDD establishment of the threshold change effect) (β_{14})	-1.493 (0.1131)***
No. obs.	42,043	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 4. Placebo Robustness check for DID regression (3)

Variable (Coefficient)	Estimated coefficient	Summary Statistics	
Treat*Program (DD effectiveness of Clean Air Works Program) (β_3)	0.882 (0.6512)	R Square	0.3347
		No. of observations	23,912

a. Standard errors are reported between brackets, clustered standard errors at ozone monitoring site
b. 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 2. DID Estimates for the "Clean Air Works" Program using Leads and Lags