ONLINE APPENDIX FOR:

Defensive Investments and the Demand for Air Quality: Evidence from the NOx Budget Program

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Appendix I: The NO_x Budget Trading Program and Particulate Matter

This appendix provides one explanation based in atmospheric chemistry (Pandis and Seinfeld 2006), as to why the NO_x Budget Trading Program might have limited effects on particulate matter. We begin by defining the relevant compounds:

NO_x: nitrogen oxides
NH_4NO_3: ammonium nitrate, the component of $PM_{2.5}$ and PM_{10} which NO_x can form
NO_3: nitrate, a derivative of NO_x
NH_4: ammonium
SO_4: sulfate, formed as a byproduct of electricity generation
NH_{4e}: excess ammonium, i.e., ammonium which remains after NH_4 has bonded with SO_4

For NO_x to become a component of particulate matter, NO_x must decompose to nitrate (NO_3). Nitrate then must undergo a reaction with excess ammonium (NH_{4e}) to form ammonium nitrate (NH_4NO_3). Ammonium nitrate is a component of particulate matter but nitrate and NO_x are not. So a necessary condition for NO_x to increase particulate matter is the presence of sufficient excess ammonium to convert nitrate into ammonium nitrate. But ammonium preferentially bonds with sulfate (SO_4), which is a byproduct of sulfur emissions, and this bonding prevents ammonium from bonding with nitrate to produce ammonium nitrate. In other words, if sulfate levels in the Eastern U.S. in 2003-2007 were great enough, they could have decreased levels of excess ammonium enough to limit the ability of NO_x to form particulates.

Appendix II: Medications as Defensive Investments

It is worth considering the extent to which medication purchases studied in this paper should be defined as defensive, rather than just another health expenditure. We argue that whether the drugs are taken before or after health conditions manifest themselves, the important issue is that drugs aim to mitigate a negative health condition in both instances. Indeed, a recent *New England Journal of Medicine* article underscores that the key to treating asthma is limiting exposure to ambient concentrations of air pollution *and* consumption of pharmaceuticals:

> Achieving good long-term control of asthma (infrequent asthmatic symptoms, an unrestricted level of activity, normal or near-normal lung function, and rare asthmatic attacks requiring emergency care) requires a multifaceted approach: avoidance of environmental stimuli that can provoke bronchoconstriction and acute and chronic airway inflammation . . . *and* [emphasis added] drug therapy (Fanta 2009, p. 1005).

Further there has been a substantial decline in asthma mortality and emergency department visits since the 1970s and 1980s, even as the incidence of asthma increased; a leading explanation is the more widespread use of asthma medications (Fanta 2009). The point is that these drugs reduce the incidence of negative health outcomes and that the failure to account for expenditures on them in the previous literature has led to downward biased measures of willingness to pay for ozone reductions.

Additionally, we believe the theoretical economics literature supports the interpretation of the medication results. Specifically, in the canonical model of health production function (see e.g., Graff-Zivin and Neidell (2013)), individual compensatory responses to ambient pollution levels are typically decomposed into averting activities (aimed at reducing the amount of ingested pollution) and mitigating activities (aimed at reducing the negative effect of ingested pollution), with the latter including healthcare costs and medication purchases. In this framework, it is clear that medication purchases are a defensive measure, not an outcome.

While these arguments suggest that all medications are defensive, we do provide one estimate which distinguishes short-acting medications (sometimes called “rescue” medications, taken after acute respiratory symptoms appear) from long-term control medications, which are taken regularly in order to prevent the appearance of symptoms. Using National Drug Codes, we attempted to distinguish “maintenance” respiratory medications that are taken every day or week to treat chronic respiratory conditions, from “rescue” respiratory medications that are taken once acute respiratory symptoms appear. We distinguish these medications using lists from Fanta (2009) and NHLBI (2007) of which respiratory medications are short-acting (i.e., rescue) versus long-acting (i.e., control). We also list a set of results which restricts regressions to mail-order purchases, since these are more likely to be focused on long-term control medications. We find evidence that the NBP decreased purchases of both short-acting and long-term control medications (Appendix Table 2). The point estimates for the overall sample indicate that the NBP decreased purchase of short-acting medications by 3.0 percentage points and decreased purchase of long-term control medications by 2.1 percentage points. The estimated coefficients are similar though less precise in the subset of counties with ozone monitors. Our estimates for mail-order purchases are similar to the overall estimates of NBP decreasing expenditure by about 1.6 percentage points.

Appendix III: Data and Methodology Details

This appendix provides additional information on the study sample construction and the definitions of the main variables.

Population Denominator

The main medication variable is the log of medication purchases per person. Because not all persons purchase medications, we count the number of individuals eligible to purchase medications from the enrollment files. We only count individuals who have a variable indicating that they recorded drug purchases, though this covers essentially all individuals in the firms and years we study. When the enrollment file has a missing value for an individual's county, we fill it with the county which is reported for that available in the nearest available lag; or if no lagged months have a reported county, then we fill it with the closest-available lead. We use the first month of a season to count the population in that season.

Medication Purchases

The MarketScan data report the purchase county, date, the medication's National Drug Code (NDC), and the money paid from consumer and insurer to the medication provider. 2007 is the last year of the MarketScan dataset available for this analysis, so that is the last year of data for the analysis. Reported medication payments vary substantially across individuals and include some negative values. To address measurement error in medication payments, we measure the mean medication payment for each National Drug Code. This calculation uses all positive recorded medication payments for observations in the main regression sample. The dependent variable in main regressions is the log of this mean price per person. We deflate all currency to real year 2015 values using the BLS CPI for urban consumers. Medication purchases are assigned to the county where they are recorded. We include only medication purchases from individuals recorded in the enrollment files as working for one of the firms in the sample. While the main analysis includes individuals in a balanced panel of 19 firms, sensitivity analyses in Appendix Table 2 reports estimates from a balanced panel of about 600,000 persons in these firms. For confidentiality reasons MarketScan does not identify the 19 firms. This table also reports a sensitivity analysis using the 14 firms which appear in all the years 2000-2007.

The main text describes several steps taken to define respiratory medications. This definition excludes a few treatments that are listed as used for treating respiratory conditions but are extremely broad (e.g., general anesthetics like nitric oxide). The respiratory definition also excludes a few categories of medications that are typically for colds and lower respiratory conditions, and are not primarily indicated for asthma, bronchitis, or chronic obstetric pulmonary disorder (COPD). These excluded categories include antihistamines, nonnarcotic antitussives, expectorants, and nasal decongestants.

It is worth noting that the medication expenditure estimates reported in Table 6 potentially suffer from re-transformation bias since the regression models are log-linear in expenditures, but Table 6 reports untransformed expenditures. When we apply the "smearing" estimator of Duan (1983) that corrects for re-transformation bias we obtain essentially the same estimates as the unadjusted ones in Table 6.

As discussed in the main text, the medication estimates are representative of Americans employed in large firms and their dependents, who appear in the MarketScan data; these people may have better baseline health than the average American, but may also have better health insurance and hence spend more on medications than the average American. Appendix Table 6 compares the characteristics of individuals in the MarketScan database with individuals in the January 2003 Current Population Survey (CPS) and the year 2000 Census. Compared to CPS respondents, MarketScan workers are about 11 percentage points more likely to be in a union, 7 percentage points more likely to receive a salary (rather than working for hourly wages), and 15 percentage points more likely to be full-time (rather than part-time). Heavy industry sectors are over-represented in MarketScan, relative to workers in the CPS, while the retail, finance, insurance, real estate, and services are under-represented in MarketScan.[1] The age distribution of MarketScan individuals is similar to the overall age distribution in the year 2000 census, except MarketScan excludes individuals aged 65 and older.[2]

Hospitalizations

We follow Marketscan's guide to identify inpatient and emergency outpatient episodes using a combination of place of service, type of service, and patient services indicators.[3] As mentioned in the main text, we classify hospitalizations according to the mode procedure for each visit. MarketScan codes the primary diagnosis for each service provided in a hospitalization episode. Patients admitted to the hospital typically receive numerous services, some of which may have distinct diagnosis codes.

Weather

We compiled weather data from records of the National Climate Data Center Summary of the Day files (File TD-3200). The key control variables for our analysis are the daily maximum and minimum temperature, total daily precipitation, and dew point temperature. In order to ensure accurate weather readings, and complete county-day data files, we construct our weather variables for a given year from the readings of all weather stations that report valid readings for every day in that year. The acceptable station-level data is then aggregated at the county level by taking an inverse-distance weighted average of all the valid measurements from stations that are located within a 200 km radius of each county's centroid, where the weights are the inverse of their squared distance to the centroid so that more distant stations are given less weight. This results in complete weather by county-day files that we can link with the other files in our analysis.

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[1] We follow NAICS industry codes to aggregate CPS industries into the groups listed in the table. We include "Misc. Manufacturing" and "Not Specified Manufacturing Industries" in durable manufacturing.

[2] Given the large sample sizes and differences in means, hypothesis tests reject equality of these characteristics between MarketScan and the other data sources at 99% significance level.

[3] See page 59 of MarketScan Research Databases User Guide and Database Dictionary Commercial Claims and Encounters Medicare Supplemental and COB Data Year 2006 Edition for complete details.

Dew point temperature values are sometimes missing in the raw data. We impute these missing values by regressing observed county-day dew point temperature on mean temperature, mean precipitation, year fixed effects, county fixed effects, a quartic polynomial in day-of-year, and interactions of the quartic polynomial separately with each of the following three variables: daily mean precipitation, daily mean temperature and precipitation*temperature. The regression uses 1997-2007 data. For each of the ten counties that are always missing dew point temperature, we assign a county fixed effect equal to the average county fixed effect of all adjacent counties (excluding adjacent counties that are among these 10). We replace missing dew point temperature values with these imputed values.

Pollution

We assign each ton of emitted pollution to the county where the emitting source is located. Counties with no recorded emissions are assigned emissions of zero. We use this approach because we observe all NBP-regulated pollution emissions and the information on their emitting source, so we record them as such without any kind of spatial averaging needed.

We convert pollution units using values from EPA (2015). For each pollutant, we calculate ambient levels in each monitor-day, then the unweighted average across monitors in each county-day, and finally aggregate up to county-season. Monitor readings flagged for extraneous circumstances (e.g. construction, natural disasters, or industrial accidents that occurred nearby) were excluded from this analysis. All ambient pollution regressions are GLS weighted based on the square root of the total number of underlying pollution readings.

Daily maximum 8 hour average ozone concentrations are computed generally following EPA (1998), with slight differences. Eight-hour rolling averages are computed for each station and hour of the year and are assigned to the first hour of the 8 hour period. If only 6 or 7 hours of data are available, the 8 hour average is computed using 6 or 7 as the denominator, respectively. If less than 6 hours of data is available, missing hours are assigned half the minimum detectible limit and 8 is used as the denominator. We retain these 8 hour averages with less than 6 hours of data regardless of their level, whereas EPA (1998) only retains them if they are greater than 80 ppb. EPA's selection rule is governed by their interest in determining if the 8-hour concentration clearly exceeds the nonattainment standard, whereas we seek the most accurate and comprehensive measure of ozone.

The abrupt beginning and end of the market on May 1 and October 1 makes a daily regression discontinuity estimator seem appealing. However, because ozone in the Eastern US mainly reaches high levels in July and August, the market is likely to have small effects on ambient pollution on April 30 or October 1. Although emitted pollution changed sharply around these dates (Figure 1), we detect no change in mean daily ambient pollution in small windows around these dates.

We did explore statistical models that separately estimate effects of the market on pollution (and health) outcomes in each month of summer. These specifications did not have statistical power to distinguish effects in different months of summer, and hence we focus on results that treat summer as homogenous. Modeling the market's impact on summer overall, rather than month-by-month, also produces medium-term estimates of the market's impact. This makes the results less susceptible to the concern that changes in air quality cause short-term displacement of mortality or medication purchases without changing their medium- or long-run values.

Econometric Approach

The instrumental variables estimates including all counties are computationally demanding given the three sets of fixed effects (county*year, county*season, season*year) and approximately 2,500 counties in the data. We implement these estimators using efficient optimization routines (Guimaraes and Portugal 2010). In smaller samples, these routines obtain numerically equivalent point estimates to those of conventional methods. The estimated confidence regions may be slightly conservative, since in these smaller samples they obtain standards errors that are a few percent larger than those estimated with conventional methods.

The fact that our counterfactual allows other changes such as NO_x regulations to be operating in the background can be seen from Appendix Figure 2. In both seasons and regions of the country, NO_x emissions were declining even before the NBP began, and for 2000-2002 the pre-trends were similar in both regions and seasons. The counterfactual analyzed here is if summertime NO_x emissions in the Eastern U.S. continued along the pre-trends observed before 2002, but did not experience the large 2002-2004 decline which the NBP generated.

Appendix IV: Additional Details about the NO_x Budget Trading Program

This Appendix describes additional details about the NO_x Budget Trading Program (NBP) not explained in the main text.

Our research design is based on comparing emissions in summer versus winter months. Because NO_x abatement technologies have substantial operating costs (Fowlie 2010), units begin operating them around May 1 and stop around September 30. Part of the operating cost comes from the "heat rate penalty" of selective catalytic reduction—the fact that they require a small amount of electricity to operate.

The NBP grew out of the Ozone Transport Commission (OTC), an organization of Northeast States formed in the 1990s. OTC studies found that ozone levels the Northeast U.S. had high ozone partly because prevailing winds transported NO_x from the industrial Midwest to the Northeast, where it produced ozone in the Northeast (OTC 1998). The OTC led to a version of the NBP that operated in 1999-2002 and produced small declines in summer NO_x emissions.[4] The OTC then created a more stringent version of the NBP which began in 2003 and operated until 2008.[5]

As described in the main text, the NBP included 19 states plus DC. Georgia was initially slated to enter the market in 2007 but the EPA eventually chose to exclude Georgia.

Policymakers included some provisions to help smooth the start of the market. Regulators provided an additional set of initial allowances in 2003-2004 known as the Compliance Supplement Pool or CSP to help states begin compliance with the market without threatening electricity supply reliability. Ultimately many of these allowances were banked to future years. Unused allowances from the NBP could be transferred to the CAIR ozone season program which succeeded the NBP after 2008.

In 2002, summertime emissions from sources participating in this market totaled approximately 1 million tons, with a significant downward pre-trend that had similar magnitude in both the East and West (Appendix Figure 2). Compared to the level of NO_x emissions in 2002, the final cap of 550,000 tons would have decreased emissions by 45%. As discussion of our results later in the

[4] This market also goes under the name NO_x SIP Call. This smaller market also operated in May-September. The OTC market aimed to decrease summer NOx emissions by 76,000 tons (OTC 2003). NOx emissions from regulated NBP units in our data fell by 504,000 tons between 2002 and 2005, or about 6.6 times more than the OTC market. While in principle this earlier market could be a source of confounding variation for the pollution and mortality regressions which begin in 1997, those regressions have similar signs and significance as the pollution and mortality regressions beginning in 2001. The OTC market cap for most states did not change between 2000 and 2002, so this is not a potential source of confounding variation for our pre-period in those years. The only small change in the OTC market in these years is that some pollution sources in Maryland and DC entered the market in those years, and the cap in those states modestly increased to accommodate them (OTC 2003).

[5] 2007 is the last year of the MarketScan dataset available for this analysis, so that is the last year of data for the analysis. In 2009, the Clean Air Interstate Rule (CAIR) replaced this market. In 2010, the EPA proposed a Transport Rule which would combine this NO_x market with a market for SO_2 emissions. In July 2011, the EPA replaced this proposal with the Cross-State Air Pollution Rule, which regulates power plant emissions in 27 states with the goal of decreasing ambient ozone and particulate levels.

paper shows, accounting for the pre-trend and the fact that emitters banked allowances across years shows that the causal impact of the market was to decrease emissions by 39-52 percent.

One important question involves the geographic scope of the NBP's effects, and of our analysis. As discussed in the main text, the main analysis excludes states adjacent to the NBP region from the main results because their treatment status is ambiguous, though sensitivity analyses consider alternatives. The main analysis excludes Wisconsin, Iowa, Missouri, Georgia, Mississippi, Maine, New Hampshire, and Vermont. We do not exclude Arkansas or Florida because they share only small sections of border with the NBP area and because prevailing winds blow to the Northeast, away from these states. We exclude Maine even though it does not share a border with the NBP region because it is downwind and close to many NBP states. We define Alabama as an NBP state even though the southern region of the state did not participate in the market.

These exclusions have a basis in prevailing wind patterns and directions. On the 96 percent of days in the NBP region where windspeeds are below 6 meters per second, ozone and its precursors travel less than 300 miles (Husar and Renard 1997). This implies that on many days, emissions from the NBP region affect the states we exclude, but do not affect the states we include in the comparison group. Husar and Renard (1997) find that ozone and precursors travel up to 120 miles on days with windspeeds below 3 m/s and up to 300 miles on days with windspeeds below 6 m/s. We obtained raw windspeed readings from the National Climate Data Center's Summary of the Day – First Order (DSI-3210) files and measured average windspeed and directions across states for all states in the NBP region. Mean windspeeds are below 3 m/s on 61 percent of days and are 3-6 m/s on 34 percent of days. Although prevailing winds blow to the East, on many days wind blows in other directions. On 27 percent of days wind primarily blows to the north, on 35 percent of days it primarily blows to the East, on 21 percent to the South, and on 17 percent to the West.

Another interesting question is the extent to which any changes in NO_x or other pollution emissions occurred due to fuel conversion of units, for example from coal to natural gas. This is ambiguous from participation data available from the EPA's Air Markets Program Data, though the data do rule out large-scale closure of coal units. The number of coal units in the NBP actually grew from 845 in 2003 to 856 in 2008. At the same time, the number of gas units grew from 1,168 to 1,305 and the number of oil units fell from 471 to 463. So the absolute number of coal units rose, while the proportion of NBP units that are coal fell by 1.5 percentage points. Qualitatively similar patterns occur within the subset of NBP units that are owned by electric utilities, and within the subset that are industrial boilers. These statistics ignore the 1% of units that report multiple primary fuels.

We also explored whether the NO_x reductions produced any counterproductive outcomes, with mixed results. When an area has low concentrations of volatile organic compounds relative to NO_x, then decreasing NO_x can <u>increase</u> ozone levels. First, we identify a list of such "VOC-constrained" cities and states from Table 1 of Blanchard (2001). The table reports the frequency of VOC-constrained hours for monitored regions across the United States when ozone concentrations exceeded 80 ppb by volume. We consider a city or state in a monitored region "VOC-constrained" if more than half of the total monitored hours were VOC-constrained, although Blanchard (2001) later explains that certain sub-areas of these regions are locally unconstrained. Second, we define a county as VOC-constrained if its mean ratio of weekend/weekday ozone exceeds 1.05. The former approach finds that the change in ozone concentrations is similar in VOC-constrained and -unconstrained regions, although this may be due in part to the misassignment of VOC-limitation in certain sub-areas, as described above. The latter indicates that in VOC-constrained regions of the NBP, the decline in ozone was smaller than in the unconstrained areas. See rows 11 and 12 of Appendix Table 1.

While Figure 2 (A) shows the regression-adjusted event study graph of NO_x emissions, Appendix Figure 2 shows the raw emissions trends separately by season and year. Appendix Figure 2 (A) shows that the NBP led to sharp and discontinuous reductions in summer emissions in the Eastern U.S., starting in 2003 when the market began in 8 Northeastern states and Washington, DC. Emissions declined another 15-20 percent starting in May 2004, when the market added 11 more Eastern states. Winter emissions in the Eastern U.S. continued their gradual downward pre-2003 trend. In contrast, Appendix Figure 2 (B) reveals that summer and winter NO_x emissions in the non-NBP states evolved smoothly over time, with similar downward trends and no evidence of any discernible trend change in 2003 and 2004, when the NBP was implemented. In short, this Appendix Figure shows that NO_x emissions declined in exactly the areas, months, and years that the market design would predict.

Appendix V: Additional Sensitivity Analyses

All of the ambient and emitted pollution results are further evaluated and probed in Appendix Table 1, which considers a wide range of specifications, including changes in the method used to compute the standard errors and alternative sample selection rules. In addition, we estimated models that also allowed for differential pre-existing trends in the NBP states during the summer. In general, the models fail to reject the null of no difference in pre-existing trends and cause the standard error on the parameter of interest, γ_1, to increase by a factor of 2 to 3. The only substantive change is that the impact on ozone concentrations is larger in magnitude although the 95% confidence intervals of the estimates from specifications with and without the differential trends overlap.

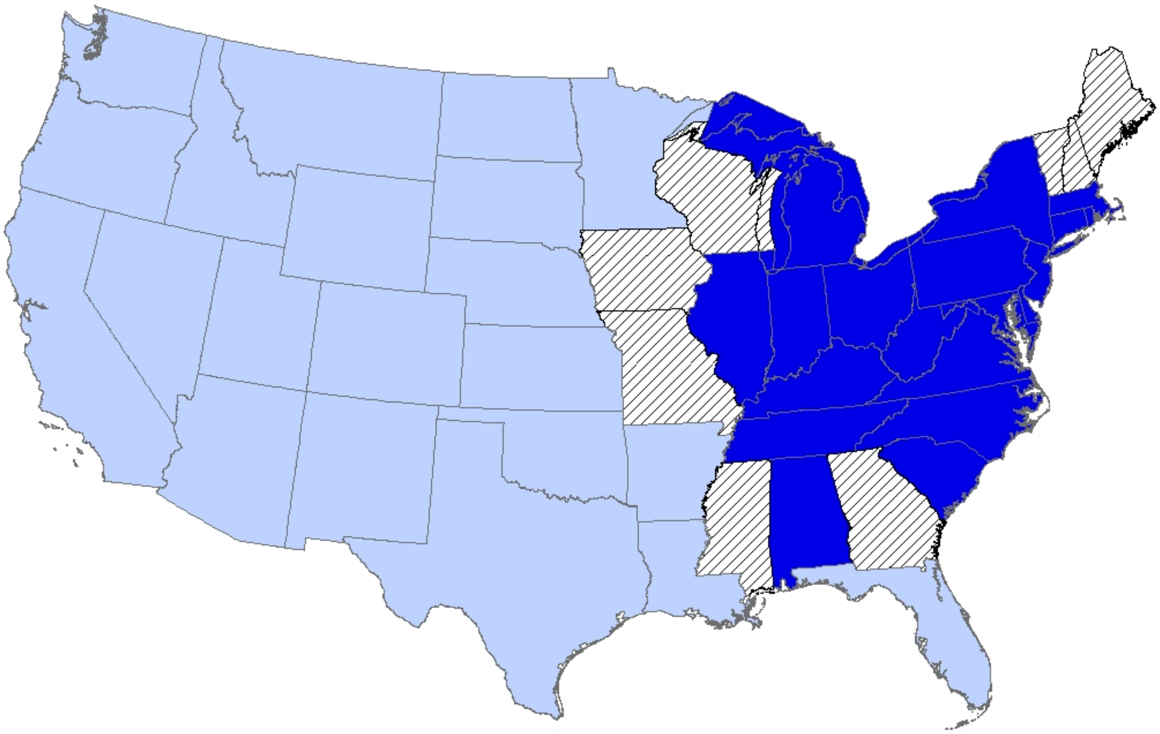
Appendix Table 2 reports medication results from a series of robustness checks, none of which alter the qualitative conclusions from Table 3. For example, Row 13 shows that defining the dependent variable as the log of copayments per person rather than as the log of mean medication costs per person results in a decrease in medication costs per person of 1.5 percent, as opposed to the 1.6 percent effect in the main sample.

Appendix Table 4 discusses similar sensitivity analyses for the effect of the NBP on mortality. The qualitative conclusions are similar under these alternative estimates.

Appendix Table 5, column (1) explores heterogeneity in the magnitude of the NBP's effect on ambient ozone across different sub-parts of the NBP. The NBP caused a larger decline in ozone for the eight northeastern states plus Washington D.C. which entered the market in 2003, which is unsurprising since these states entered the market a year earlier than other states did and since prevailing winds blow to the northeast. The NBP also caused a larger decline in ozone for counties which had relatively high ozone in 2002, which fits with the finding of Figure 2 (B) that most of the decline was from days with the highest ozone levels. Overall, the general conclusions from this table are similar to those in the main text results, though not all are precisely estimated.

Appendix VI: Supplementary Figures and Tables

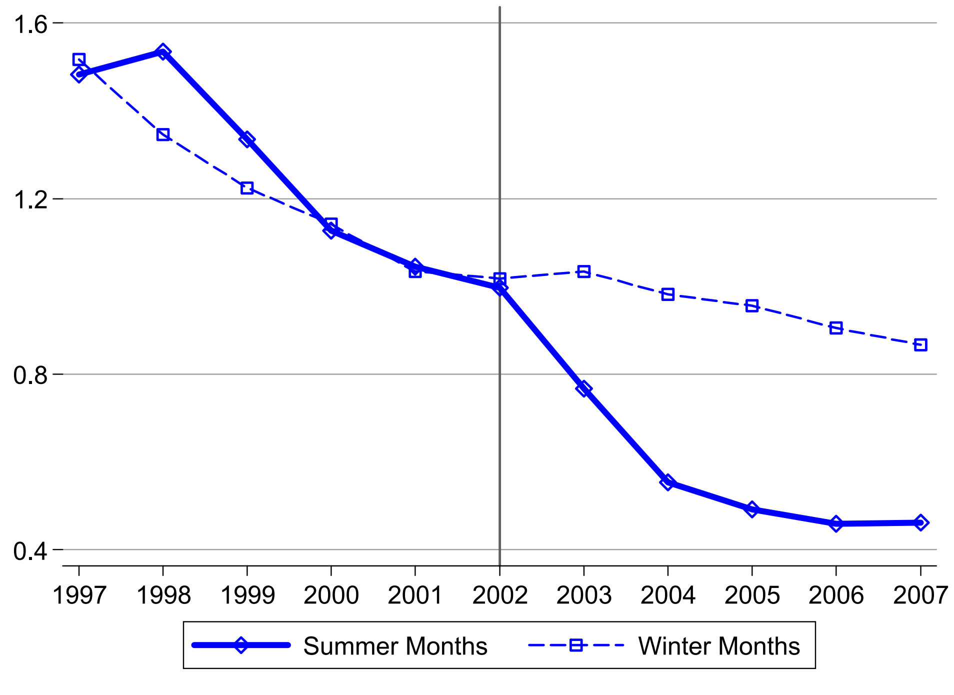
Appendix Figure 1. Participation in NBP by State



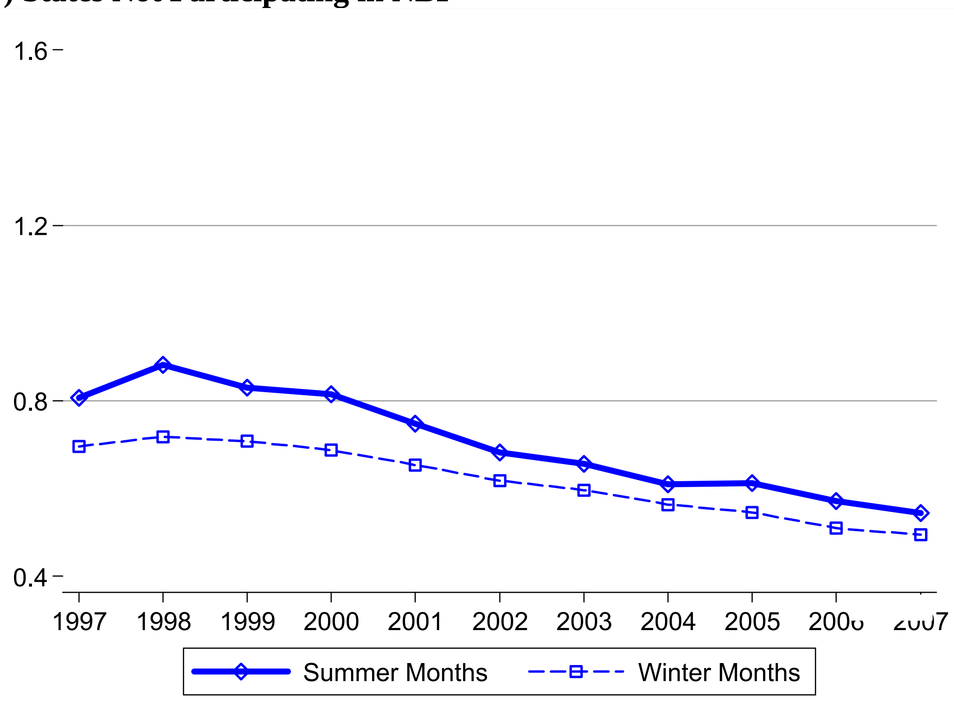
Notes: Dark blue states are participating in NBP during the 2003-2007 period (referred as 'NBP states' in the text). Light blue states are not participating (non-NBP states). Shaded states are excluded from the main analysis sample.

Appendix Figure 2. Summer-Equivalent Seasonal NO_x Emissions (Mil. Tons)

(A) States Participating in NBP



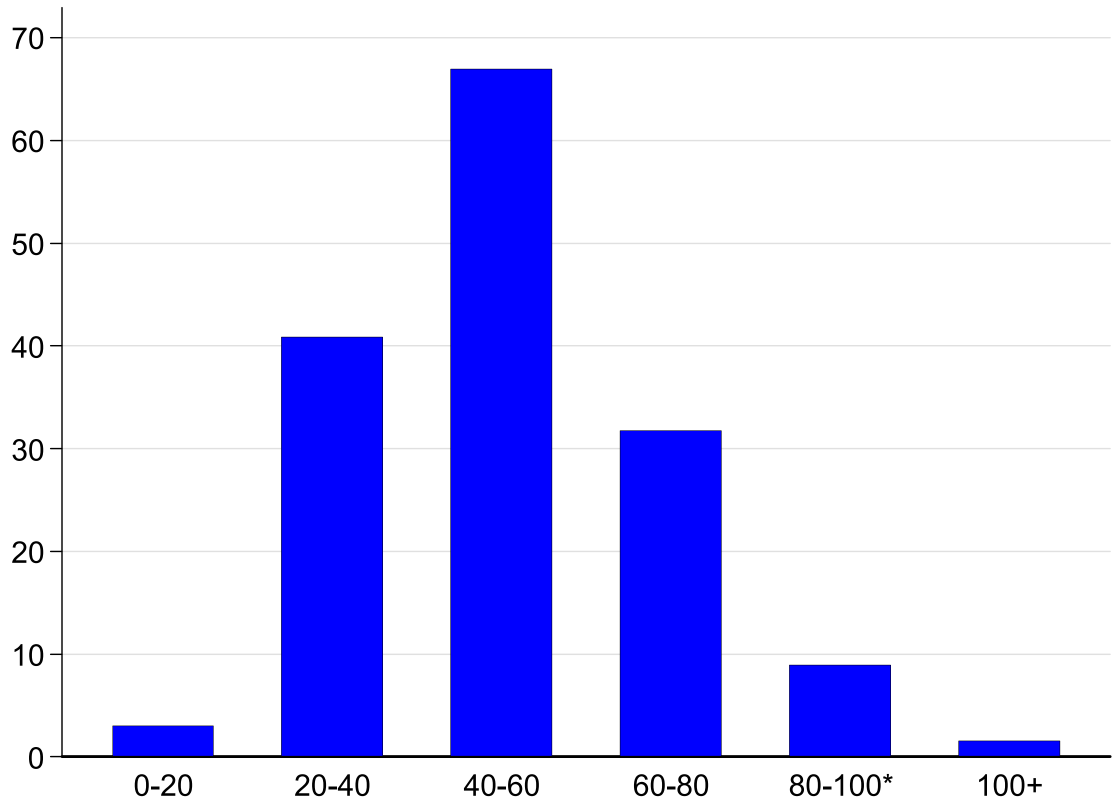
(B) States Not Participating in NBP



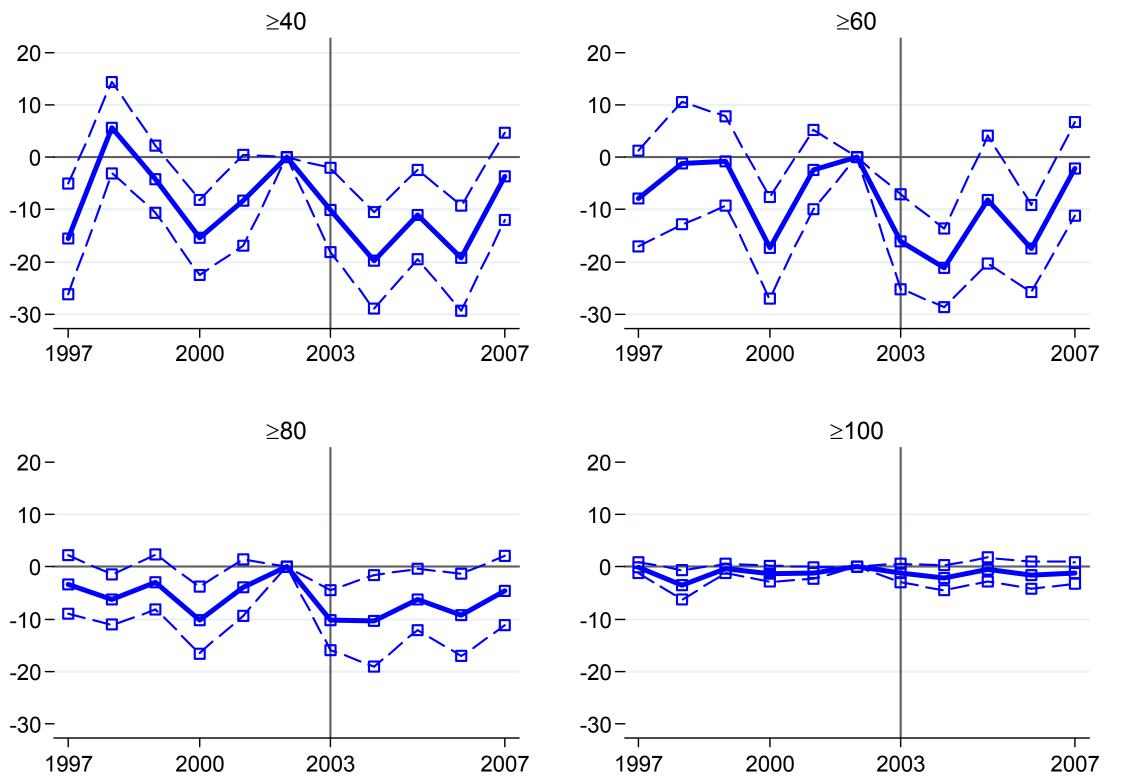
Notes: The data underlying Appendix Figure 2 is expressed as summer-equivalent since the summer period has 5 months while the winter period has 7 months. Specifically, the summer equivalent of winter emissions is actual winter emissions multiplied by 5/7. These graphs show summary statistics describing total emissions, not regression results. Summer defined as May-September, winter as January-April and October-December. NBP participating states include: Alabama, Connecticut, Delaware, District of Columbia, Illinois, Indiana, Kentucky, Maryland, Massachusetts, Michigan, Missouri, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, South Carolina, Tennessee, Virginia, and West Virginia. States not participating in NBP include: Arkansas, Arizona, California, Colorado, Florida, Idaho, Kansas, Lousiana, Minnesota, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, Wyoming. Alaska, Georgia, Hawaii, Iowa, Maine, Mississippi, Missouri, New Hampshire, Vermont, and Wisconsin are excluded from the main analysis sample.

Appendix Figure 3. NBP Market Impact on Ambient Ozone Pollution, Detail

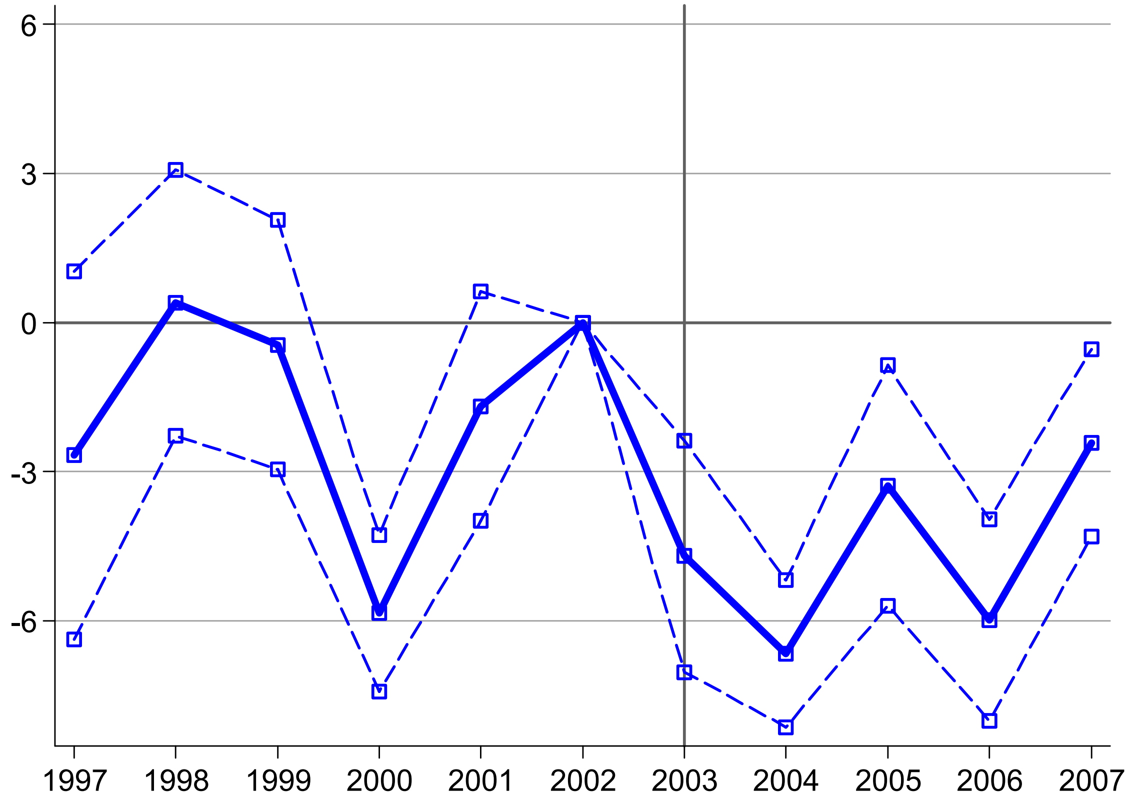
(A) Number of Summer Days in 6 Ozone Bins, NBP Participating States, 1997-2002



(B) NBP Market Impact on Number of Summer Days with Ozone above 40, 60, 80 or 100 ppb



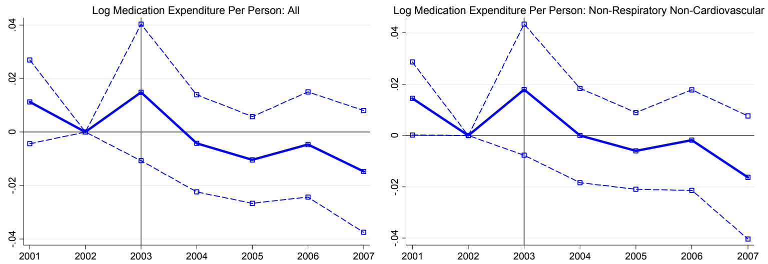
(C) Event Study for Daily Ozone 8-Hour Values, 1997-2007



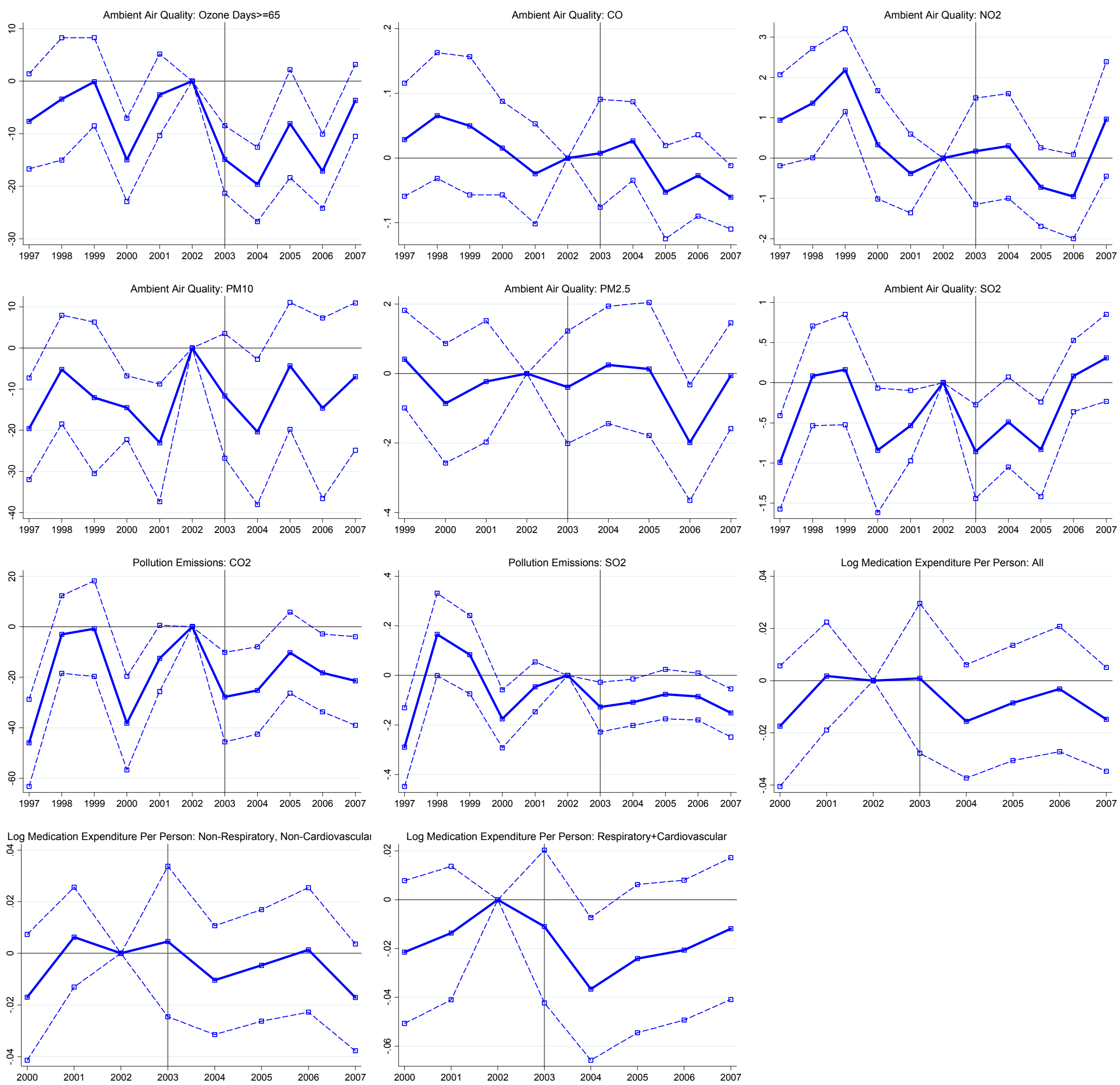
Notes: Ozone 8-hour value is measured as the maximum rolling 8-hour mean of hourly values within in each day, which is the statistic used in EPA nonattainment designations. Panel A shows the average number of summer days (out of a possible 153 days) in 6 bins for daily ozone 8-hour value in the NBP states in 1997-2002 (pre-NBP period). The asterisk on the 80-100 category denotes the nonattainment air quality standard during the NBP years (85 ppb). Panel B shows the estimated impact of NBP on the number of summer days in 4 of these categories for daily ozone 8-hour value. Panel C shows the coefficients from an event study regression for ozone 8-hour values where the estimates for year 2002 are restricted to have a value of 0. All regressions include detailed weather controls and a full set of county*year, season*year, and county*season fixed effects, and are weighted by the number of ozone monitors in each county. The standard errors underlying the confidence intervals (dashed lines) are clustered at the state-season level.

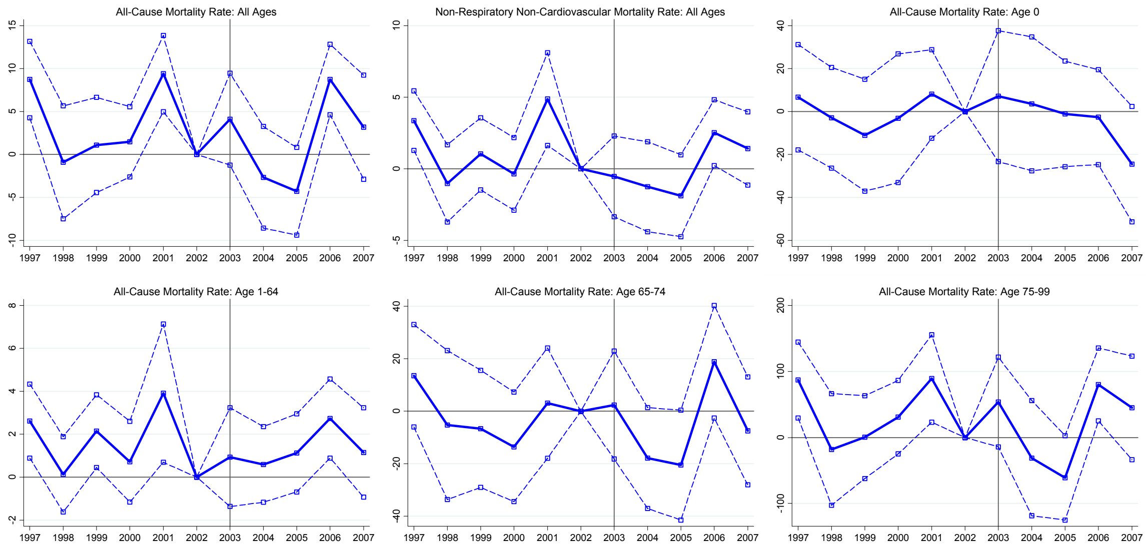
Appendix Figure 4. Event Study Graphs for All Outcomes

(A) Beginning in Year 2001



(B) Beginning in 1997 or Earliest Year Available





Notes: Appendix Figure 4 reports the coefficients from event study regressions for all outcomes where the estimates for year 2002 are restricted to have a value of 0. All regressions include detailed weather controls and a full set of county*year, season*year, and county*season fixed effects, and are weighted by the relevant variable for a specific outcome (number of ozone monitors in each county, population in each county). The standard errors underlying the confidence intervals (dashed lines) are clustered at the state-season level. See Appendix Figure 1 notes or text for NBP participation status designation.

Appendix Table 1. Sensitivity Analysis: Emitted and Ambient Pollution

	Emitted Pollution			Air Quality (Ambient Pollution)						
	NO_x	SO_2	CO_2	Ozone	Ozone Days ≥65ppm	CO	$PM_{2.5}$	PM_{10}	SO_2	NO_2
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1. Baseline Sample	-0.33	-0.07	-12.66	-3.38	-9.55	-0.02	-0.45	-1.20	0.16	-0.78
State-Season Clusters	(0.07)	(0.03)	(6.48)	(0.56)	(2.63)	(0.02)	(0.32)	(1.17)	(0.19)	(0.39)
County Clusters	(0.08)	(0.05)	(7.67)	(0.57)	(2.46)	(0.03)	(0.29)	(1.51)	(0.24)	(0.52)
State Clusters	(0.09)	(0.04)	(9.22)	(0.78)	(3.71)	(0.03)	(0.45)	(1.66)	(0.27)	(0.55)
State-Year Clusters	(0.05)	(0.04)	(6.57)	(1.12)	(3.89)	(0.03)	(0.48)	(1.77)	(0.18)	(0.43)
County-Season Clusters	(0.05)	(0.04)	(5.42)	(0.40)	(1.76)	(0.02)	(0.21)	(1.07)	(0.17)	(0.37)
Firm-County Clusters	(0.06)	(0.05)	(7.88)	(0.57)	(2.36)	(0.03)	(0.27)	(1.45)	(0.22)	(0.47)
2. Counties With Ozone	-0.22	-0.21	-62.22	-3.38	-9.55	-0.03	-0.79	-0.70	0.18	-0.77
Monitors	(0.11)	(0.21)	(37.45)	(0.56)	(2.63)	(0.03)	(0.48)	(6.91)	(0.23)	(0.65)
3. Non-NBP Border States	-0.24	-0.05	-10.37	-3.36	-9.49	-0.02	-0.46	-0.29	0.13	-0.64
Assigned to NBP	(0.06)	(0.03)	(5.76)	(0.55)	(2.59)	(0.02)	(0.30)	(1.09)	(0.19)	(0.39)
4. Limit to Most Comparable	-0.31	-0.04	-6.82	-3.35	-10.73	-0.04	-0.60	-1.75	0.16	-0.95
Non-NBP States	(0.06)	(0.03)	(7.13)	(0.60)	(2.81)	(0.02)	(0.38)	(1.37)	(0.26)	(0.44)
5. Post = 1.0 in Year 2003	-0.32	-0.09	-16.44	-3.90	-11.15	-0.02	-0.63	-1.42	0.02	-0.85
	(0.06)	(0.03)	(6.66)	(0.69)	(2.68)	(0.02)	(0.38)	(1.18)	(0.18)	(0.39)
6. Post = 0.0 in Year 2003	-0.26	-0.04	-6.54	-2.26	-6.28	-0.02	-0.21	-0.69	0.24	-0.59
	(0.05)	(0.03)	(5.18)	(0.45)	(2.15)	(0.02)	(0.24)	(1.06)	(0.17)	(0.32)
7. Drop Year 2003	-0.34	-0.08	-14.54	-4.17	-12.88	-0.02	-0.66	-0.94	0.08	-1.04
	(0.07)	(0.03)	(6.69)	(0.70)	(2.98)	(0.03)	(0.36)	(1.23)	(0.20)	(0.41)
8. Exclude Dew Point	-0.34	-0.07	-13.22	-3.19	-8.28	-0.02	-0.50	-0.35	0.19	-0.69
Temperature	(0.07)	(0.03)	(6.32)	(0.54)	(2.36)	(0.02)	(0.31)	(0.94)	(0.14)	(0.41)
9. Diff-in-Diff for NBP States	-0.32	-0.07	-4.65	-4.75	-11.35	0.05	0.41	-1.86	0.06	-1.55
	(0.05)	(0.03)	(3.51)	(0.41)	(2.54)	(0.02)	(0.24)	(0.81)	(0.12)	(0.57)
10. Monitors Operating	---	---	---	-3.31	-12.21	-0.02	-0.60	-0.42	0.12	-0.56
≥ 30 Weeks	---	---	---	(0.45)	(1.90)	(0.02)	(0.30)	(1.09)	(0.17)	(0.36)
11. Main Effect	---	---	---	-3.60	-15.04	---	---	---	---	---
	---	---	---	(1.29)	(5.42)	---	---	---	---	---
Summer*Post*NBP *VOC-	---	---	---	1.11	4.66	---	---	---	---	---
Constrained	---	---	---	(1.12)	(4.68)	---	---	---	---	---
12. Main Effect	---	---	---	-3.93	-12.01	---	---	---	---	---
	---	---	---	(0.64)	(3.03)	---	---	---	---	---
Summer*Post*NBP*	---	---	---	1.49	6.67	---	---	---	---	---
(High Weekend O_3)	---	---	---	(0.58)	(2.45)	---	---	---	---	---

Notes: The entries in Appendix Table 1 are the coefficient estimates on the Summer*Post*NBP variable from separate DDD regressions (unless noted otherwise). The reported standard errors are clustered at the state-season level (unless noted otherwise). The regressions use the specification and sample of Table 2 column (4) (unless otherwise noted). The entries after row 1 present different levels of clustering for standard errors. Row 3 takes eight non-NBP states that border the NBP area (Iowa, Georgia, Maine, Missouri, Mississippi, New Hampshire, Vermont, and Wisconsin) and assigns them to the NBP area. Row 4 limits non-NBP states to the half with ozone data which have the smallest Euclidean distance from NBP states, defined from year 2002 mean ozone, NO_x emissions per square mile, medication costs per capita, and temperature. The non-NBP comparison states selected by this criterion are: Arkansas, California, Colorado, Kansas, Nevada, New Mexico, Oklahoma, and Texas. "Monitors Operating ≥ 30 weeks" uses a monitor selection rule which requires each monitor to have valid readings in 30 weeks of each year in the data, rather than the 47-week rule used in the main results. "Summer*Post*NBP*VOC-Constrained" reports the interaction of the main triple-difference term with an MSA indicator for being VOC constrained based on Blanchard (2001). "Summer*Post*NBP*(High Weekend O3)" interacts the main triple-difference term with an indicator for whether the weekend/weekday ozone ratio of a county exceeds 1.05. This provides an alternative indicator of VOC-constrained regions. Regressions use 2001-2007 data.

Appendix Table 2. Sensitivity Analysis: Medications

	All	Respiratory or Cardiovascular	Non-Respiratory and Non-Cardiovascular
	(1)	(2)	(3)
1. Baseline Sample	-0.016	-0.023	-0.015
State-Season Clusters	(0.006)	(0.008)	(0.006)
County Clusters	(0.006)	(0.007)	(0.007)
State Clusters	(0.009)	(0.012)	(0.009)
State-Year Clusters	(0.007)	(0.008)	(0.007)
County-Season Clusters	(0.004)	(0.005)	(0.005)
Firm-County Clusters	(0.006)	(0.006)	(0.007)
2. Non-NBP Border States Assigned to NBP	-0.017	-0.021	-0.016
	(0.005)	(0.007)	(0.005)
3. Limit to Most Comparable Non-NBP States	-0.017	-0.021	-0.017
	(0.008)	(0.009)	(0.008)
4. Post = 1.0 in Year 2003	-0.011	-0.017	-0.010
	(0.007)	(0.008)	(0.007)
5. Post = 0.0 in Year 2003	-0.017	-0.022	-0.016
	(0.005)	(0.007)	(0.005)
6. Drop Year 2003	-0.013	-0.020	-0.012
	(0.007)	(0.008)	(0.007)
7. Exclude Dew Point Temperature	-0.016	-0.020	-0.016
	(0.008)	(0.010)	(0.007)
8. Log Medications (Not Costs)	-0.014	-0.022	-0.012
	(0.007)	(0.008)	(0.006)
9. Ages 0-17	-0.003	-0.009	-0.004
	(0.012)	(0.022)	(0.013)
10. Panel of People	-0.009	-0.020	-0.005
	(0.008)	(0.009)	(0.009)
11. Levels (Not Logs)	-10.766	-2.836	-7.948
	(2.548)	(0.800)	(1.914)
12. Purchase-Specific Costs	-0.014	-0.023	-0.012
	(0.006)	(0.007)	(0.006)
13. Copay	-0.015	-0.024	-0.012
	(0.007)	(0.008)	(0.007)

Appendix Table 2. Sensitivity Analysis: Medications (ctd)

	All	Respiratory or Cardiovascular	Non-Respiratory and Non-Cardiovascular
	(1)	(2)	(3)
14. 2000-2007 Firm Panel	-0.011	-0.018	-0.010
	(0.006)	(0.007)	(0.006)
15. Mail Order	-0.016	-0.009	-0.008
	(0.006)	(0.006)	(0.007)
16. Only Counties with Ozone Monitors	-0.016	-0.019	-0.017
	(0.007)	(0.009)	(0.007)
17. Respiratory: Short-Acting Only	---	-0.030	---
	---	(0.017)	---
18. Respiratory: Long-Term Only	---	-0.021	---
	---	(0.010)	---

Notes: The entries in Appendix Table 2 are the coefficient estimates on the Summer*Post*NBP variable from separate DDD regressions using data for 2001-2007. The reported standard errors are clustered at the state-season level. Row 2 takes eight non-NBP states that border the NBP area (Iowa, Georgia, Maine, Missouri, Mississippi, New Hampshire, Vermont, and Wisconsin) and assigns them to the NBP area. Row 3 limits non-NBP states to the half with ozone data which have the smallest Euclidean distance from NBP states, defined from year 2002 mean ozone, NO_x emissions per square mile, medication costs per capita, and temperature. The non-NBP comparison states selected by this criterion are: Arkansas, California, Colorado, Kansas, Nevada, New Mexico, Oklahoma, and Texas. “Log Medications (not costs)” uses counts of medication purchases, rather than cost measures. "Panel of People" uses the much smaller panel of persons who appear in all observations of the MarketScan sample. "Levels (Not Logs)" specifies the response variable in levels rather than logs. "Purchase-Specific Costs" uses the raw reported prices, rather than averaging across national drug codes to deal with outliers as in the main analysis. "Counties with Ozone Data" restricts the analysis to include only counties with ozone monitors satisfying the monitor selection rule. "Copay" measures costs as purchase-level patient expenditures.

Appendix Table 3. Sensitivity Analysis: Hospitalization Costs

	(1)	(2)	(3)	(4)
A: All Hospitalizations				
1. All Hospitalizations	-7.92	-13.57	-12.55	-108.04
	(19.56)	(24.04)	(24.66)	(36.83)
B: Specific Groups of Hospitalizations				
2. Respiratory or Cardiovascular	-6.34	-6.66	-4.70	-38.54
	(7.97)	(8.96)	(8.91)	(15.51)
3. Non-Respiratory and Non-Cardiovascular	-1.58	-6.91	-7.85	-69.50
	(12.90)	(16.90)	(17.98)	(28.68)
County-by-Season FE	x	x	x	x
Summer-by-Year FE	x	x	x	x
State-by-Year FE	x	x		
County-by-Year FE			x	x
Detailed Weather Controls		x	x	x
Only Counties With Ozone Monitors				x
Weighted by Population	x	x	x	x

Notes: The entries in Appendix Table 3 are the coefficient estimates on the Summer*Post*NBP variable from separate DDD regressions using data for 2001-2007. The reported standard errors are clustered at the state-season level.

Appendix Table 4. Sensitivity Analysis: Mortality

	All	Respiratory or Cardiovascular	Non-Respiratory and Non-Cardiovascular
	(1)	(2)	(3)
1. Baseline Sample	-1.56	-0.50	-1.05
State-Season Clusters	(0.86)	(0.70)	(0.51)
County Clusters	(1.22)	(0.80)	(0.79)
State Clusters	(1.23)	(1.00)	(0.72)
State-Year Clusters	(1.70)	(1.12)	(0.88)
County-Season Clusters	(0.86)	(0.56)	(0.56)
2. Non-NBP Border States Assigned to NBP	-0.87	-0.36	-0.51
	(0.89)	(0.68)	(0.52)
3. Limit to Most Comparable Non-NBP States	-0.63	-0.17	-0.45
	(0.92)	(0.78)	(0.48)
4. Post = 1.0 in Year 2003	-1.01	0.09	-1.10
	(0.81)	(0.67)	(0.48)
5. Post = 0.0 in Year 2003	-1.86	-1.03	-0.83
	(0.85)	(0.66)	(0.48)
6. Drop Year 2003	-1.65	-0.59	-1.05
	(0.87)	(0.69)	(0.54)
7. Logs (Not Levels)	-0.01	-0.01	0.00
	(0.00)	(0.00)	(0.00)
8. Age-Adjustment	-1.39	-0.62	-0.77
	(0.94)	(0.72)	(0.53)
9. Only Counties With Ozone Monitors	-5.71	-2.65	-3.06
	(1.97)	(1.33)	(0.83)

Notes: The entries in Appendix Table 4 are the coefficient estimates on the Summer*Post*NBP variable from separate DDD regressions using data for 1997-2007. The reported standard errors are clustered at the state-season level. Row 2 takes eight non-NBP states that border the NBP area (Iowa, Georgia, Maine, Missouri, Mississippi, New Hampshire, Vermont, and Wisconsin) and assigns them to the NBP area. Row 3 limits non-NBP states to the half with ozone data which have the smallest Euclidean distance from NBP states, defined from year 2002 mean ozone, NO_x emissions per square mile, medication costs per capita, and temperature. The non-NBP comparison states selected by this criterion are: Arkansas, California, Colorado, Kansas, Nevada, New Mexico, Oklahoma, and Texas. "Logs (Not Levels)" specifies the response variable in logs rather than levels. Age-adjustment modifies the response variable to use age-adjusted mortality counts, rather than total deaths per population. Regressions use 1997-2007 data.

Appendix Table 5. Heterogeneity Within NBP Region in NBP Effects

	8-Hour Ozone (1)	All Medication Expenditures (2)	All Mortality (3)
Interaction of NBP*Post*Summer with Dummy for …			
1. Eight Northeastern States Plus Washington, DC	-1.900	0.004	-0.971
	(0.807)	(0.007)	(2.429)
2. County has Below-Median Weekend/Weekday Ozone Ratio in Summer 2002 (VOC-Constrained)	-1.168	0.014	5.526
	(0.790)	(0.010)	(3.985)
3. County has Above-Median Post-2002 Mean Summer Temperature	2.150	-0.005	-0.503
	(1.055)	(0.005)	(1.540)
4. State has Above-Median Child Asthma Rate	0.365	-0.005	-0.320
	(1.485)	(0.011)	(3.850)
5. State has Above-Median Adult+Child Asthma Rate	-1.894	-0.014	0.201
	(1.112)	(0.011)	(3.379)
6. County has Above-Median Post-2002 Medication Expenditure or Mortality Per Capita	-1.679	-0.009	-1.752
	(0.880)	(0.008)	(4.730)
7. County has Above-Median Post-2002 Respir.+Cardio. Medication Expenditure or Mortality per Capita	-0.995	-0.065	-0.899
	(0.919)	(0.063)	(3.328)
8. County has Above-Median Number of Ozone Days ≥60ppb in NBP Summer 2002	-3.332	-0.003	-7.221
	(0.535)	(0.011)	(4.270)
County-by-Season FE	x	x	x
Summer-by-Year FE	x	x	x
County-by-Year FE	x	x	x
Detailed Weather Controls	x	x	x
Data Begin in 2001	x	x	x
Weighted by Population	x	x	x

Notes: The entries in Appendix Table 5 are the coefficient estimates on Summer*Post*NBP*X, where X is the interaction term specified in each row of the table. The reported standard errors are clustered at the state-season level. The regression also controls for Summer*Post*NBP and Summer*Post*X (coefficients not shown), for detailed weather controls, and for county-by-season, county-by-year, and season-by-year fixed effects. Row 1 interacts the main effect with an indicator for being in one of the eight Northeastern states plus Washington D.C. where NBP began in 2003 rather than 2004. Row 3 interacts the main effect with a dummy for a summer having above-median post-2002 season-mean temperature, where the median is calculated separately for each county. Rows 4 and 5 interact the main effect with dummies for a state having above-median 2003 asthma rates. Child asthma rates are only available for 25 states. The adult+child asthma rate is the unweighted mean of the adult and the child rates (or for the 25 states with no data on children, it equals the value for adults). Rows 6 and 7 interact the main effect with a dummy for a county having above-median summer post-2002 medication expenditures or mortality. All data include years 2001-2007.

Appendix Table 6. Characteristics of the MarketScan Sample

	MarketScan (1)	CPS Jan 2003 (2)	Census 2000 (3)
Employee Classification			
Union	0.24	0.13	---
Non-Union	0.76	0.87	---
Salary	0.60	0.53	---
Hourly	0.40	0.47	---
Employment Status			
Active Full-Time Employee	0.97	0.82	0.42
Active Part-Time Employee	0.03	0.18	0.11
Relation of Patient to Employee			
Employee	0.44	---	---
Spouse	0.23	---	---
Child/Other	0.33	---	---
Industry			
Oil & Gas Extraction, Mining	0.01	0.00	0.00
Manufacturing, Durable Goods	0.27	0.08	0.05
Manufacturing, Nondurable Goods	0.19	0.05	0.03
Transportation, Communications, Utilities	0.33	0.08	0.05
Retail Trade	0.02	0.12	0.07
Finance, Insurance, Real Estate	0.04	0.07	0.04
Services	0.14	0.44	0.28
Sex			
Male	0.48	0.52	0.49
Female	0.52	0.48	0.51
Age			
0-4 Years	0.06	0.00	0.07
5-17 Years	0.20	0.02	0.19
18-64 Years	0.75	0.95	0.62
≥65 Years	0.00	0.03	0.12

Notes: Column (1) describes the main 2001-2007 sample. Current Population Survey (CPS) data restricted to individuals with strictly positive working hours. MarketScan and CPS data include only respondents with one of the indicated values of each attribute, so that shares for each attribute sum to one. For example, data on employment status include only respondents who indicate full-time or part-time work.

Appendix Table 7. Effect of NO_x Emissions and Ambient Ozone Concentrations On Medication Purchases and Mortality: Instrumental Variables Estimates, 2001-2007, by Cause

	Log Medication Costs			Mortality		
	All Counties	Counties with NO_x Emissions	Ozone Monitored Counties	All Counties	Counties with NO_x Emissions	Ozone Monitored Counties
	(1)	(2a)	(2b)	(3)	(4a)	(4b)
A: 2SLS, Respiratory or Cardiovascular						
NOx Emissions	30.68	17.30	---	1.87	1.89	---
	(18.15)	(7.89)	---	(2.49)	(1.64)	---
8-Hour Ozone	---	---	6.60	---	---	1.07
	---	---	(2.58)	---	---	(0.92)
Days ≥65 ppb	---	---	1.80	---	---	0.35
	---	---	(0.70)	---	---	(0.32)
B: 2SLS, Non-Respiratory and Non-Cardiovascular						
NOx Emissions	20.16	11.66	---	2.79	2.83	---
	(13.09)	(5.60)	---	(2.24)	(1.71)	---
8-Hour Ozone	---	---	5.80	---	---	1.09
	---	---	(2.32)	---	---	(0.45)
Days ≥65 ppb	---	---	1.58	---	---	0.36
	---	---	(0.66)	---	---	(0.17)

Notes: In Panel A, the dependent variable includes respiratory or cardiovascular medication costs or mortality; in Panel B, the dependent variable includes all non-respiratory and non-cardiovascular medication costs or mortality. The coefficient estimates in columns (1), (2a), and (2b) are multiplied by 1000 for readability. All estimates are based on the 2001-2007 sample. NO_x emissions are measured in thousand tons per county. All regressions include county*year, season*year, and county*season fixed effects, as well as the detailed weather controls. The regressions are GLS weighted by the square root of the relevant population in a given county-year-season (MarketScan or full population). The endogenous variable is NOx or ozone and the excluded instrument is Summer*Post*NBP interaction (see equation 9). Number of observations is 30,730 for medication regressions including all counties, 7,588 for medication regressions including counties with NO_x emissions, 2,338 for medication regressions including only counties with ozone monitors, 35,546 for mortality regressions including all counties, 7,840 for mortality regressions including counties with NO_x emissions, and 2,352 for mortality regressions only including counties with ozone monitors. The sample is smaller for medications than for mortality due to counties without no medication data or zero expenditures.

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