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POLLUTING PUBLIC FUNDS:
THE EFFECT OF ENVIRONMENTAL REGULATION ON MUNICIPAL BONDS.

Akshaya Jha
Stephen A. Karolyi
Nicholas Z. Muller

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ABSTRACT

We present three findings on the effects of environmental regulation on the municipal bond market. First, yields increase (decrease) after a new standard is proposed (finalized), consistent with the resolution of regulatory uncertainty. Second, around annual compliance announcements, yields fall for counties that remain in compliance but increase for newly noncompliant counties. Third, yields are substantially higher for bonds from counties just above the pollution threshold relative to counties just below the threshold. Our findings suggest that increases in regulatory stringency or uncertainty over future environmental policy increase the cost of municipal debt raised to fund critical infrastructure.

Akshaya Jha
Carnegie Mellon University
Hamburg Hall Office 2218
4800 Forbes Avenue
Pittsburgh, PA 15232
Website: http://www.akshayajha.com
akshayaj@andrew.cmu.edu

Stephen A. Karolyi
Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213
sakarolyi@gmail.com

Nicholas Z. Muller
Department of Engineering, and Public Policy
Tepper School of Business
Carnegie Mellon University
4215 Tepper Quad
5000 Forbes Avenue
Pittsburgh, PA 15213
and NBER
nicholas.muller74@gmail.com

1 Introduction

There is a growing literature demonstrating that financial markets internalize climate risk (Bakkensen and Barrage, 2017; Gibson, Mullins and Hill, 2017; Barrage and Furst, 2019; Painter, 2019; Baker et al., 2018*a*; Goldsmith-Pinkham et al., 2019; Baldauf, Garlappi and Yannelis, 2020; Giglio, Kelly and Stroebel, 2020). However, there is very little work on how environmental policy impacts financial markets. We fill this gap by examining whether local air pollution policy affects the municipal bond market in the United States.

We focus on the municipal bond market for several reasons. First, the U.S. municipal bond market is quite large. State and local governments had over 3 trillion dollars in debt outstanding as of the third quarter of 2017 (Driessen, 2018). Second, securities issued in this market fund critical infrastructure such as schools, roads, and hospitals.[1] Implications of environmental policies in this market may thus have far reaching social consequences. Third, unlike corporate bonds, issuers of municipal bonds are tied to a specific geographic location. This allows us to assess how municipal bond yields respond to both spatial and temporal variation in the stringency of environmental policy. Fourth, our work may provide insights to investors in municipal bonds. Systematic differences in yields for bonds issued in locations subject to varying degrees of regulatory stringency potentially suggest trading or investment opportunities.

In terms of environmental policy, we concentrate on the Clean Air Act (CAA). The CAA is one of the most significant federal interventions into markets in the postwar period (Greenstone, 2002*b*). In 2010, the annual pollution control expenditures required to comply with the CAA were roughly 3 billion dollars; the annual benefits of the CAA are over 200 billion dollars (EPA, 1999).[2] The National Ambient Air Quality Standards (NAAQS) are a central component of the CAA. Through the NAAQS, the federal United States Environmental Protection Agency (USEPA) sets maximum allowable ambient concentrations of local air pollutants. Establishing the NAAQS occurs in two phases. First, the USEPA announces a proposed rule. Then following a period for public comment, the final NAAQS is announced. Counties with pollution levels above the final NAAQS in a given year are deemed to be in nonattainment. While the federal USEPA sets the

[1] State and local governments accounted for nearly 75% of public infrastructure spending in the United States in 2004.

[2] Both dollar magnitudes are in 2019 USD.

NAAQS, state and local governments are responsible for establishing plans to ensure compliance with the standards. Often, NAAQS compliance mandates that polluting firms within local jurisdictions take costly actions to reduce emissions levels.

We hypothesize that the NAAQS impact the price and yields of municipal bonds traded in the secondary market in two ways. First, since corporate profits and labor income comprise an important source of the municipal tax base, and because such revenue services municipal debt, investors perceive counties out of attainment with the NAAQS as being more likely to default on their bonds. Consequently, investors require a higher return in order to hold bonds issued in noncompliant counties. Second, the proposed rule announcement increases uncertainty over bond default risk while the declaration of the final standard resolves uncertainty. Canonical models of investor behavior predict that increased uncertainty corresponds to increases in the returns required to hold the bond (Markowitz (1952); Sharpe (1994)).

To test these hypotheses, we collect secondary market data on municipal bonds from the Electronic Municipal Market Access (EMMA) database. This database is managed by the Municipal Securities Rulemaking Board. These data comprise the universe of secondary market trades in the U.S. municipal bond market. The data include more than 140 million trades from 2005-2019. For each bond trade, this database includes information on the yield, the security identifier, and a description of the security.[3] We link municipal bonds to counties using the security description, keeping only trades associated with bonds that can be linked to one county.

Though there are specific NAAQS for each of several local air pollutants, we focus on ground-level ozone for the following reasons. First, a large body of prior research indicates that the bulk of the benefits from the CAA stem from reductions in premature mortality due to decreased exposure to two pollutants: fine particulate matter and ozone (EPA, 1999, 2010; Muller, Mendelsohn and Nordhaus, 2011). Second, there is only one NAAQS for ozone while there are multiple different standards governing fine particulate matter. The existence of more than one standard may obfuscate the effect of changes in any one NAAQS on financial markets. Third, progress in reducing ambient levels of ozone over the sample period has been more limited than for other local pollutants such

[3]Specifically, we observe "yield-to-worst", which is the expected return from holding a bond until maturity given its current price, coupon payments, and face value for options embedded in the bond contract.

as fine particulate matter. As a result, the number of counties out of compliance with the ozone standard is far higher than the number of counties out of compliance with the standards associated with any other pollutant. Finally, the standard for ozone was revised twice during our sample period.

This study employs three empirical strategies to explore the link between environmental policy and municipal bond markets. We utilize an event study framework to compare yields before and after the announcement of a new ozone standard. The proposed rule announcement signals to stakeholders that a regulatory change is imminent, without clearly conveying how stringent the new standard will ultimately be. Intuitively, we find that the announcement of a proposed rule increases yields by about 2% ($p < 0.01$) in the two weeks after the announcement relative to the two weeks before the announcement. This provides evidence that investors must be compensated with additional returns in order to take on the additional risk associated with impending changes in environmental regulation. In contrast, we find that yields fall by 0.3%, ($p < 0.01$) on average after the announcement of the *final* standard. The announcement of the final rule resolves the uncertainty induced by the rule-making process. We also detect a significant uptick in the likelihood that bonds are traded just after the proposed and final rule announcements. These findings indicate that the announcement of a new NAAQS pollutant standard provides important information to municipal bond market investors.

We also estimate an event study model that focuses on the annual announcements of county-level design values. The USEPA, which calculates the design values, uses these air quality summary statistics to determine each county's compliance with the NAAQS in each year. On average, after the new design values are announced, we find a 0.6% reduction in yields ($p < 0.01$) for securities issued in counties that were in compliance under both the old and new design values. This effect reflects the resolution of residual uncertainty regarding whether the county will remain in compliance. However, relative to these consistently compliant counties, securities issued in counties that move from attainment to nonattainment experience a 1.4% increase in yields ($p < 0.01$). This incremental effect reflects the increase in perceived default risk associated with the county being noncompliant.

A novel feature of this setting is that investors can observe the monitored daily pollution levels used to construct the annual design values. This means that attentive bond market investors may be able to anticipate compliance status, particularly in the weeks leading up to the announcement of the design values. We find that yields for bonds issued in newly non-compliant counties start rising relative to yields for bonds issued in consistently compliant counties up to two weeks before the design value announcement. This suggests that investors trade in anticipation of a potential change in compliance status. As further evidence that compliance status is an important component of municipal bond traders' strategies, we find significant increases in the average likelihood that a bond is traded in the two weeks after the announcements of new design values.

Finally, we implement a sharp regression discontinuity (RD) design that compares yields on securities issues in counties with design values just above versus just below the current ozone standard. Our preferred specification controls for a local quadratic function in the difference between design values and the standard and we pick the optimal bandwidth using the method described in Calonico, Cattaneo and Titiunik (2014). Our results indicate that counties just out of compliance with the relevant standard for ozone face a 30% increase in bond yields ($p < 0.05$) relative to counties just in compliance with the standard. The average yield in our sample is 2.1%, so our RD estimate amounts to a change of about 65 bps. This suggests that a noncompliant county must offer substantially higher yields in order to entice investors to hold their bonds. This increases the municipality's cost of raising public funds, potentially impacting the level of investment in local public goods such as hospitals or schools.

State and local government officials know the current NAAQS and they often manage the collection of local ambient monitoring data. It is therefore possible that officials may try to manipulate measured ambient pollution levels to comply with the NAAQS. Importantly, we fail to reject the null hypothesis that counties are unable to manipulate their ozone levels to be just below the standard (Cattaneo, Jansson and Ma, 2019). This test serves as an important check of the assumption required of RD designs that there are no unobserved differences across counties just below versus just above the relevant cut-off.

Our analysis contributes to prior work studying the economic costs of environmental regulation. In particular, a previous literature documents that stricter environmental regulation adversely impacts employment, capital investment, and output across a variety of different sectors in the United States, including oil refineries, pulp and paper mills, and steel mills (Gray and Shadbegian (1998); Shadbegian and Gray (2005); Gray et al. (2014)) as well as the manufacturing sector more broadly (Greenstone (2002*a*); List et al. (2003)). Earlier work demonstrates that environmental policy impacts firm location decisions as well (Bartik (1985); McConnell and Schwab (1990); Levinson (1996)). Combined, this prior research supports our hypothesis that environmental regulations impose a variety of different costs on polluting firms. This in turn may impact municipal tax revenue streams. To our knowledge, we provide the first empirical evidence that environmental policy affects municipal bond yields, and thus, the cost of raising funds for essential local public goods provision such as hospitals, schools, and roads.

This paper also contributes to a small but growing literature linking environmental outcomes to financial markets (Giglio, Kelly and Stroebel (2020)). To date, the majority of this literature has focused on the impacts of climate change. For example, previous work has demonstrated that housing prices are impacted by beliefs over flood risk (Bakkensen and Barrage (2017); Gibson, Mullins and Hill (2017)) and climate change (Baldauf, Garlappi and Yannelis (2020); Barrage and Furst (2019)). In a recent paper, Jerch, Kahn and Lin (2020) demonstrate that hurricanes adversely affect municipal finance systems, noting that climate change increases both the likelihood and intensity of hurricanes. Most closely related to our work, Painter (2019) demonstrates that counties that are likely to be impacted by climate change are forced to increase the yield they offer when issuing municipal bonds.[4] In contrast to this literature, we focus on the impact of environmental regulation rather than changes to the environment. The results from this paper can inform policymakers of the increased cost of public funds associated with both existing air quality regulations and proposed regulations aimed at reducing greenhouse gas emissions.

This paper proceeds as follows. Section 2 describes our data and provides further details on air quality regulations in the United States. Section 3 presents the event study and RD frameworks while Section 4 reports the results. Finally, we conclude and discuss the policy implications of our findings in Section 5.

[4] Also related to our analysis, Baker et al. (2018*b*) provides empirical evidence that people are willing to pay a premium for "green" bonds whose proceeds are used for environmentally sensitive purposes.

2 Background and Data

This section describes the primary sources of data used in the paper as well as background information on municipal bonds, air pollution, and air quality regulations in the United States. Summary statistics are relegated to Appendix Table A.1.

2.1 Municipal Bonds

The Municipal Securities Rulemaking Board (MSRB), established in 1975, oversees the municipal securities market. Between 2010 and 2016, over 3 trillion dollars of debt was issued in this market (MSRB (2017)). The proceeds from municipal bonds are used by states and local municipalities to fund critical infrastructure such as roads, public education, and healthcare. Indeed, state and local governments accounted for nearly 75% of public infrastructure spending in the United States in 2004.

We collect secondary market data on municipal bonds from the Electronic Municipal Market Access (EMMA) database managed by the MSRB. This database provides information on trade prices and yields for "virtually every municipal security bought and sold".[5] Our data span 2005-2019: 2005 is the first year that municipal bond trades were tracked by the platform. This data-set contains roughly 141 million trades associated with roughly 2.6 million 9-digit CUSIP codes (i.e.: security identifiers).

Our analysis requires linking municipal bonds to the county of issuance. To do this, we use a combination of string matching and manual inspection to match counties to security descriptions. See Appendix Section C.2 for more details. Some bonds are issued by institutions in multiple counties while some bonds are issued by state or federal agencies. Our analysis examines how environmental policy enforced at the county level impacts municipal bonds. As such, we keep only security descriptions linked to a single county. After this sample restriction is imposed, we are still left with over 81 million trades corresponding to roughly 1.9 million 9-digit CUSIP codes and 3,000 counties.

The trade-level data-set includes the price of the bond, the settlement date, the maturity date, the par value to be paid to the bond holder at the maturity date, and "yield to worst". "Yield-to-worst" measures the expected return from holding a bond until

[5] See https://emma.msrb.org/ for more information.

maturity given its current price, coupon payments, and face value for options embedded in the bond contract. Since “yield-to-worst” does not reflect the potential return an investor can receive from trading the bond, this measure is typically seen as a lower bound on the bond’s expected return. Since prices and yields are inversely related, increases in yields are good for investors but bad for issuers. Specifically, if the issuer must provide a higher yield for traders to hold its bond, the issuer faces a higher cost of raising capital.

We calculate the remaining years to maturity for each trade as the difference between the year the bond comes to maturity and the year the trade was made. For ease of exposition, we refer to each CUSIP/remaining years-to-maturity combination as a “bond” for the remainder of the paper. We aggregate the trade-level data-set to the bond/week-of-sample level as follows. First, “final yield” and “final price” are defined to be the yield and price associated with the final trade in the week-of-sample for the bond. For weeks with no trades, the final yield and price are taken from the last week with a trade. We also take the sum over par value of the trades in the week for each bond; weeks without trades for the bond have zero total value for that week. Similarly, we calculate the total number of trades of the bond in a week, with zeros for the weeks with no trades.

2.2 Pollution and Environmental Regulations

The CAA is the overarching legislative framework governing air quality regulations in the United States. The CAA embodies a strong federalist orientation. The federal USEPA is charged with setting air quality standards, but states and counties are responsible for implementing rules and regulations to meet these standards. Specifically, Title I, Section 109, of the CAA established the National Ambient Air Quality Standards (42 U.S.C. §7409 2013). The NAAQS impose pollutant-specific limits on the maximum concentrations of pollution allowed in the county in the year. Primary standards are calibrated to provide protection of human health based on available scientific evidence. The earliest NAAQS were implemented in 1972 (Clay et al., 2020). Periodic review of the scientific basis for the NAAQS, and concomitant updates to the NAAQS, are required under section 7408 of Title I (42 U.S.C. §7408 2013). Our event study framework, discussed below, focuses on announcements of proposed changes to the standards as well as announcements of the final rule.

Each year, the USEPA, together with state and local jurisdictions, make a determination as to whether each county in the United States is in attainment with the NAAQS for each pollutant. The ozone standard during our sample period is the three-year rolling average of the fourth-highest daily ozone value in the year. Attainment determinations rely on daily and hourly readings from monitoring stations across the United States (USEPA (2018)). Specifically, to assess compliance for each pollutant, USEPA calculates an annual summary statistic using monitor readings. This annual county-level summary statistic is a design value. Essentially, counties with design values above the relevant standard are out of attainment with the standard while counties below the standard are in attainment. However, the USEPA has substantial latitude in determining which monitor and hour-of-sample observations are included or excluded when calculating design values for different counties. The USEPA publishes design values for a given year roughly one year after the fact (USEPA (2016)).

As noted above, we focus on ground-level ozone for four reasons. First, prior work finds that the largest benefits from the CAA result from reductions in ozone and fine particulates (EPA, 1999, 2010; Muller, Mendelsohn and Nordhaus, 2011). Second, the NAAQS specifies only one standard for ozone. In contrast, the NAAQS specifies both an annual and a daily standard for fine particulates. It is difficult to identify the impact of changes in any one standard on bond yields in the presence of multiple standards. Third, the majority of counties out of attainment with the NAAQS are in nonattainment due to the ozone standard (see Figure A.1). This is because it has proven costlier to reduce ozone levels relative to fine particulate levels.[6] Finally, the ozone standard was changed twice during our sample period, in 2008 and 2015, allowing us to identify precise effects using an event study specification.

Violations of the NAAQS trigger a joint process between states and the USEPA designed to rectify exceedances. The USEPA posts a list of areas deemed to be in noncompliance with the NAAQS in the Federal Register. Subsequent to such designations, states must submit an implementation plan to USEPA, proposing measures to achieve compliance with the standard. Such measures often involve installation of "reasonably available" pollution control technologies (RACT) at large stationary sources (70 FR 71701, Nov. 29, 2005, as amended at 72 FR 31749, June 8, 2007). Such mandated

[6] Appendix Figure A.2 plots the annual average design values for ozone versus fine particulate from 2000-2019.

investments are costly. In addition, jurisdictions in areas that are out of attainment or have recently achieved attainment must demonstrate that proposed new projects will not exacerbate existing violations or cause new violations. This "conforming projects" requirement most often applies to transportation infrastructure. Ensuring that a proposed transportation project will not adversely affect NAAQS compliance may result in withholding funding and delays in implementation (CRS, 2015). Summarizing, county-level noncompliance with the NAAQS adversely affects economic activity in at least two ways (RACT and transportation conformity).

We argue that there are strong incentives for attainment counties to keep their pollution design values below the threshold. Counties classified as nonattainment cannot simply come back into attainment by bringing pollution design values below the threshold for one year. To be re-classified as "in-attainment", a county must show that "reductions in the area's emissions are permanent and enforceable" (42 U.S.C. §7407 2013). Moreover, the USEPA classifies ozone offenders into bins defined by the severity of the violations. Counties deemed to be more severe offenders have longer to come back into attainment but must impose greater constraints on polluters within their jurisdiction. Nonattainment counties also have strong incentives to consistently maintain pollution levels below the threshold, both to be re-classified as in attainment and to avoid being classified as a more severe offender.

3 Empirical Methods

This section discusses the empirical strategies utilized in the paper. First, we assess the impacts of proposed and final rule announcements on yields using an event study framework (MacKinlay (1997); Eckbo (2008)). This framework is also used to test whether announcements of design values affect yields. Finally, we use a regression discontinuity design to estimate the effect of nonattainment on yields. As discussed in Section 2.1, we aggregate the trade-level data set provided by MSRB to the CUSIP/remaining years-to-maturity/week-of-sample level, noting that we refer to a CUSIP with a given remaining years-to-maturity as a "bond".

Our basic event study specification is:

$$Y_{i,r,c,t} = \alpha_c + \gamma_r + \theta_{E_t} + \beta 1[t > E_t] + \epsilon_{i,r,c,t} \tag{1}$$

where i indexes CUSIP, r indexes remaining years-to-maturity, c indexes county of issuer, and t indexes week-of-sample. In our primary specifications, $\mathrm{Y_{i,r,c,t}}$ denotes the natural log of yields. Event time E_t is the week of the event. An "event" in this setting is always an announcement, either of a new pollutant standard or the design values used to determine attainment status with the NAAQS. The independent variable of interest $1[t > E_t]$ is equal to one if the week-of-sample is after the announcement. This variable captures the impact of the announcement on the outcome variable.

Our primary specifications include fixed effects by county, remaining years-to-maturity, and for each event. We estimate our primary specification using data from the two weeks before and after an event. That being said, we show that our estimates are robust to a host of alternative specifications, such as including CUSIP fixed effects, state-by year fixed effects, or including only observations corresponding to the week before and after an event. In all cases, standard errors are clustered by county.

We consider two additional specifications based on the announcement of annual county-level design values. Recall that a critical determinant of whether a county is designated as nonattainment in a year is if the design value for that year is above the pollution threshold specified by the standard. Based on this, we estimate how yields change with the announcement of new design values separately for counties that fall into the following designations: (1) in nonattainment under the old design values but attainment under the new design values (NA→A), (2) in attainment under the old design values but nonattainment under the new design values (A→NA), and (3) in nonattainment both under the old and new design values (NA→NA). The omitted category is counties that were, and remain in, attainment with the NAAQS (A→A).

We estimate the following specification:

$$\begin{gathered} Y_{i,r,c,t} = \alpha_c + \theta_{E_t} + \gamma_r + \epsilon_{i,r,c,t} \\ + \sum_{\tau=-2}^{2} [\beta_\tau^{\mathrm{NA}\to\mathrm{A}} D_{c,t,\tau}^{\mathrm{NA}\to\mathrm{A}} + \beta_\tau^{\mathrm{A}\to\mathrm{NA}} D_{c,t,\tau}^{\mathrm{A}\to\mathrm{NA}} + \beta_\tau^{\mathrm{NA}\to\mathrm{NA}} D_{c,t,\tau}^{\mathrm{NA}\to\mathrm{NA}}] \\ +1[\mathrm{A} \to \mathrm{NA}]\delta_1 + 1[\mathrm{NA} \to \mathrm{A}]\delta_2 + 1[\mathrm{NA} \to \mathrm{NA}]\delta_3 \end{gathered} \tag{2}$$

where we include fixed effects by county, event, and remaining years-to-maturity. This specification also includes indicators for whether the county in the year switches from attainment to nonattainment, switches from nonattainment to attainment, or remains in nonattainment. Standard errors are clustered by county.

The variables of interest are $D^{\mathrm{NA}\to\mathrm{A}}_{c,t,\tau}$, $D^{\mathrm{A}\to\mathrm{NA}}_{c,t,\tau}$, and $D^{\mathrm{NA}\to\mathrm{NA}}_{c,t,\tau}$. $D^{\mathrm{NA}\to\mathrm{A}}_{c,t,\tau}$ captures the impact of the announcement being τ weeks away for counties that were in nonattainment under the old design values but attainment under the new design values. Similarly, $D^{\mathrm{A}\to\mathrm{NA}}_{c,t,\tau}$ and $D^{\mathrm{NA}\to\mathrm{NA}}_{c,t,\tau}$ capture the effects of being τ weeks away from the event for counties that switch from attainment to nonattainment and remain in nonattainment under both the new and old design values, respectively. Providing further detail, $\tau \equiv t - E_t$ is the difference between the week-of-sample and the event week. We normalize $\beta^{\mathrm{NA}\to\mathrm{A}}_{\tau=-1}$, $\beta^{\mathrm{A}\to\mathrm{NA}}_{\tau=-1}$, and $\beta^{\mathrm{NA}\to\mathrm{NA}}_{\tau=-1}$ to be equal to one. Consequently, $\beta^{\mathrm{A}\to\mathrm{NA}}_{\tau=-2}$, for example, captures the impact of being two weeks before the announcement of the design values relative to one week before the announcement for counties that are in attainment under the old design values but nonattainment under the new design values.

The design value event study explores the effect on yields of newly revealed information about compliance status. We use regression discontinuity (RD) to directly assess the impact of nonattainment on yields. The intuition underlying the RD estimate is simple. Being classified as nonattainment triggers costly actions to reduce pollution levels within their boundaries. Having a design value above the NAAQS is a critical factor affecting compliance status. Thus, counties have a strong incentive to keep pollution levels below the threshold.

Based on this, one concern with the RD approach is that counties just above the threshold might try to manipulate their monitored pollution levels in order to be right below the threshold. Using a density break test (Cattaneo, Jansson and Ma, 2019), we fail to reject the null hypothesis that counties are unable to manipulate their pollution levels in order to be right below the threshold specified by the standard (the relevant p-value is p= 0.829). Appendix Figure A.3 presents graphical evidence consistent with the assertion that there's no break in density around the cut-off.

We estimate the following RD specification:

$$Y_{i,c,m,t} = \alpha + \beta 1[R_{c,t} > 0] + f(R_{c,t}) + \epsilon_{i,c,m,t} \tag{3}$$

where $R_{c,t}$ is the difference between the design value calculated for ozone in county c and the ozone standard, associated with bond issue i that has remaining years-to-maturity r in week-of-sample t (i.e.: $R_{c,t} \equiv \text{Design Value}_{c,t} - \text{NAAQS}_t$). In RD parlance, $R_{c,t}$ is the running variable. Our primary specifications control for local quadratic polynomials in the running variable using Epanechnikov kernel functions (i.e.: $f(R_{c,t})$). The optimal bandwidth is chosen using the common coverage error rate method (Calonico, Cattaneo and Titiunik, 2014).[7] We estimate the primary specification using data from the two weeks before and after the announcement of design values in each year. We consider a host of sensitivity analyses, including residualizing the outcome variable by different sets of fixed effects before estimating the RD specification, considering only data from the week before and after the announcement of design values, and controlling for local cubic polynomials rather than local quadratic polynomials in the running variable. Finally, we cluster standard errors by county.

4 Empirical Results

This section is split into four subsections. We present the estimated impacts on yields of the announcements of the proposed and final ozone standards in the first and second subsections respectively. The third subsection discusses the results from the event study regressions focusing on the annual announcements of the design values. In the final subsection, we estimate the effect of being out of attainment with the ozone standard on yields using the regression discontinuity design.

4.1 Proposed Rule Announcements and Bond Yields

Table 1 reports estimates from the event study regressions focusing on the announcement of proposed rule changes to the ozone NAAQS. The central result is that yields increase in the two weeks following the announcement of the proposed rule changes. The increases are small but precisely estimated.

The specification considered in Column (1) includes fixed effects for the county associated with the issuer, year of the announcement, and remaining years to maturity.

[7]Observations are included in an RD specification if the absolute difference between the design value for that observation and the cut-off is less than the bandwidth.

Table 1: Estimated Impact of the Announcement of the Proposed Ozone Rule on Yields

Dependent Variable: Log Final Yield	(1)	(2)	(3)	(4)
Post	0.019***	0.008***	0.018***	0.019***
	(0.002)	(0.001)	(0.002)	(0.002)
Bandwidth (Weeks)	2	2	2	1
County FE	Yes	No	Yes	Yes
CUSIP FE	No	Yes	No	No
State-by-Event-Year FE	No	No	Yes	No
Event Year FE	Yes	Yes	No	Yes
Remaining Yrs-to-Maturity FE	Yes	Yes	Yes	Yes
R^2	0.537	0.917	0.541	0.530
Mean of Dep. Var.	1.144	1.168	1.144	1.163
Number of Obs.	499,469	470,032	499,469	291,635
Number of Bonds	136,730	107,293	136,730	113,925

Notes: This table presents the impact of the announcement of a proposed new standard for ozone on yields. The unit of observation underlying the regressions in this table is CUSIP/remaining years-to-maturity/week-of-sample. We hereafter refer to a CUSIP/remaining years-to-maturity combination as a "bond". Standard errors, reported in parentheses, are clustered by county for all specifications. The dependent variable considered in all columns is the log of final yields. We calculate final yields as the yield recorded for the last trade of the bond in the week. We use the final yield from the prior week for weeks in which the bond is not traded. The independent variable of interest, "Post", is an indicator variable that is equal to one only if the week-of-sample is on or after the week that a proposed new standard was announced. We consider the two weeks before and after the relevant announcement for all columns except Column 4; in Column 4, we consider only the week before and after the announcement. All of the regressions listed in this table include fixed effects for remaining years to maturity. The regressions presented in Columns 1 and 4 additionally include county fixed effects and announcement year fixed effects, the regression listed in Column 2 additionally includes CUSIP fixed effects and announcement year fixed effects, and the regression considered in Column 3 additionally includes county fixed effects and state by announcement year fixed effects.

The results from this specification suggest that yields increase by about 6 basis points ($p < 0.01$)[8]. As a point of reference, average yields in our sample were roughly 300 basis points. The estimated impact of the announcement is similar if we include state-by-announcement year fixed effects instead of announcement year fixed effects or narrow the window of observations considered to one week around the event (see Columns 3 and 4 of Table 1.

However, inclusion of CUSIP fixed effects diminishes this effect by about one-half, as shown in Column (2). This specification only utilizes empirical variation generated by repeated trades of the same bond within the two week window before and after the proposed rule was announced. Consequently, bonds traded only once in the window

[8] exp(1.144) x 0.019 = 0.06 or 6 basis points.

would be part of the identifying variation used for the effect estimated in Columns (1), (3) and (4) but not (2). The fact that the estimated effect is twice as large when using county fixed effects rather than CUSIP fixed effects suggests a change in the composition of bonds traded before versus after the announcement.

To explore this hypothesis, Appendix Table B.1 presents models that estimate the impact of the announcement of the proposed rule on the likelihood of a trade and counts of trades. The top panel of this table reports the results from a linear probability model. The outcome variable is coded 0/1 denoting whether (1) or not (0) each bond is traded in a given week. The bottom panel of Table B.1 employs Poisson regression to assess whether the count of trades changes before and after the proposed rule announcement event. Standard errors are clustered by county. In addition, we consider the same sets of fixed effects and event windows as utilized in Columns 1-4 of Table 1.

These models show that trading activity increased after the proposed rule announcement. Specifically, the top panel of Appendix Table B.1 reports that, on average, one-third of all bonds trade in a week. In the week following the proposed rule announcement, the likelihood of bonds being traded increases by between 5 and 9 percentage points. The bottom panel of Appendix Table B.1 demonstrates that, on average, bonds trade just over once per week, implying that some bonds trade numerous times within a week. After the proposed rule announcement, the count of trades increases by between 10 and 15 percent.

The estimated increase in yields and trading activity after the announcement of the proposed rule suggests an infusion of uncertainty into municipal bond markets. The proposed rule change does not resolve uncertainty regarding the eventual standard. Nor does it clearly convey what costly compliance measures will be necessary to meet the final standard. Rather, the proposed rule demonstrates to market participants that some regulatory change is imminent without specifying with certainty what the final rule will be. Consequently, investors must be compensated with higher returns in order to bear the added uncertainty resulting from the proposed rule being announcement.

4.2 Final Rule Announcements and Bond Yields

Table 2 reports the results from the event study models focusing on the announcement of the final rule change to the ozone NAAQS. Unlike the proposed rule event studies, Table 2 demonstrates that yields fall following the announcement. The estimated effects are small, about 0.7 basis points ($p < 0.10$) in Columns (1), (3), and (4). The specification considered in Column 1 includes fixed effects for county of issuer, year of the announcement, and remaining years to maturity on the bonds. The estimated reduction in yields after the announcement increases from 0.7 basis points to 2.6 basis points ($p < 0.01$) if we include CUSIP fixed effects instead of county fixed effects (see Column 2). Inclusion of CUSIP fixed effects limits the identifying variation to trades of the same bond before and after the final rule is announced. Consequently, as noted above, the difference in the estimated effect when including CUSIP fixed effects versus county fixed effects suggests that the composition of bonds traded before versus after the announcement plays an important role.

This reduction in yields suggests that the announcement of the final rule resolves policy uncertainty. As discussed above, the proposed rule communicates to market participants that a regulatory change is imminent without specifying exactly what the change will be. The results presented in the previous section suggest that investors require a higher return due to the resulting increase in uncertainty. The final rule, which necessarily follows the proposed rule chronologically, removes the veil of uncertainty caused by the proposal. With the final rule known, firms and local regulators can move forward with plans for compliance. Uncertainty over future default risk falls. Investors are thus willing to take a lower return to hold the bond.

What theory predicts regarding how the announcement of the final rule impacts trading activity is less clear. On the one hand, investors' expectations over future default risk could become more uniform, leading to less trades after the announcement. On the other hand, the final rule provides information on the future compliance status of different counties. An information shock would be expected to increase trading activity. To explore these seemingly rival hypotheses, Appendix Table B.2 presents estimates of the changes in the likelihood of trade and counts of trades following the announcement of the final rule. The top panel of this table reports the results from a linear probability model while we employ a Poisson regression for the bottom panel. The top panel of

Table 2: Impact of Announcement of Final Ozone Rule on Yields

Dependent Variable: Log Final Yield				
	(1)	(2)	(3)	(4)
Post	-0.003***	-0.010***	-0.003***	-0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
Bandwidth (Weeks)	2	2	2	1
County FE	Yes	No	Yes	Yes
CUSIP FE	No	Yes	No	No
State-by-Event-Year FE	No	No	Yes	No
Event Year FE	Yes	Yes	No	Yes
Remaining Yrs-to-Maturity FE	Yes	Yes	Yes	Yes
R^2	0.535	0.933	0.540	0.536
Mean of Dep. Var.	0.863	0.864	0.863	0.860
Number of Obs.	616,373	595,837	616,373	371,186
Number of Bonds	145,719	125,183	145,719	132,797

Notes: This table presents the impact of the announcement of the finalized ozone standard on yields. The unit of observation for the regressions in this table is CUSIP/remaining years-to-maturity/week-of-sample. We hereafter refer to a CUSIP/remaining years-to-maturity combination as a "bond". Standard errors, reported in parentheses, are clustered by county for all specifications. The dependent variable considered in all columns is the log of final yields. We calculate final yields as the yield recorded for the last trade of the bond in the week. We use the final yield from the prior week for weeks in which the bond is not traded. The independent variable of interest, "Post", is an indicator variable that is equal to one only if the week-of-sample is on or after the week that a new standard was announced. We consider the two weeks before and after the relevant announcement for all columns except Column 4; in Column 4, we consider only the week before and after the announcement. All of the regressions listed in this table include fixed effects for remaining years to maturity. The regressions presented in Columns 1 and 4 additionally include county fixed effects and announcement year fixed effects, the regression listed in Column 2 additionally includes CUSIP fixed effects and announcement year fixed effects, and the regression considered in Column 3 additionally includes county fixed effects and state by announcement year fixed effects.

Appendix Table B.2 reports that the likelihood of bonds being traded increases by under one percentage point after the announcement. Conversely, the bottom panel of Appendix Table B.2 demonstrates that the count of trades decreases by between 5 and 20 percent after the final rule announcement. These results suggest that a greater variety of bonds are traded at least once after the announcement. This implies that the announcement provides information on future default risk. However, each particular bond is traded less frequently after the announcement. This may occur because the announcement resolves uncertainty and reduces differences in expectations across investors.

4.3 Design Value Announcements and Bond Yields

Table 3 presents the results from the event study models focusing on the USEPA's annual announcements of each county's design value. Counties with design values above the relevant ozone standard are very likely to be out of compliance with the NAAQS. The announcement of the design values may have heterogeneous effects depending on current and implied future compliance status. Consequently, the models include interaction terms between indicators denoting the attainment status based on the current and new design values and the indicator for weeks after the event. Specifically, we include interaction terms between indicators for counties that move from nonattainment-to-attainment (NA $\rightarrow$ A), attainment-to-nonattainment (A $\rightarrow$ NA), and those that began and remain in nonattainment (NA $\rightarrow$ NA) and the "Post" indicator. This implies that the "Post" coefficient estimate reflects changes in yields for counties that are in attainment both under the old and new design values. Finally, each of the attainment status indicators are also included as main effects (without the interaction with the "Post" indicator).

As in Tables 1 and 2, the four columns reflect different combinations of fixed effects and bandwidths. Column (4) uses a one-week bandwidth, whereas Columns (1) through (3) employ a two-week bandwidth. Across these specifications, we observe a small (0.8 to 1.3 basis points) but precisely estimated reduction in yields following the announcement. This reduction is largest in absolute value when controlling for CUSIP fixed effects (1.7 basis points, $p < 0.01$).

Similarly, Table 3 reports negative coefficients for counties that move from nonattainment to attainment (NA$\rightarrow$A). This suggests that yields fall because the new design

Table 3: Impact of Announcement of Ozone Design Values on Yields

	Dependent Variable: Log Final Yields			
	(1)	(2)	(3)	(4)
A $\rightarrow$ NA $\times$ Post	0.014***	0.014***	0.014***	0.009***
	(0.005)	(0.005)	(0.005)	(0.002)
NA $\rightarrow$ A $\times$ Post	-0.003*	-0.004**	-0.003	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)
NA $\rightarrow$ NA $\times$ Post	0.003***	0.003***	0.003**	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)
Post	-0.006***	-0.008***	-0.006***	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
R^2	0.467	0.811	0.479	0.467
Mean of Dep. Var.	0.748	0.749	0.748	0.749
Number of Obs.	5,220,372	5,155,715	5,220,372	3,135,579
Number of Bonds	488,747	424,090	488,747	452,512

Notes: This table presents the impact on final yields of the announcement of the design values used to determine compliance with the National Ambient Air Quality Standards (NAAQS) for ozone. The unit of observation underlying the regressions in this table is CUSIP/remaining years-to-maturity/week-of-sample. We hereafter refer to a CUSIP/remaining years-to-maturity combination as a "bond". Standard errors, reported in parentheses, are clustered by county for all specifications. The dependent variable considered in all columns is the log of final yields. We calculate final yields as the yield recorded for the last trade of the bond in the week. We use the final yield from the prior week for weeks in which the bond was not traded. The independent variable of interest, "Post", is an indicator variable that is equal to one only if the week-of-sample is on or after the week that the design values were announced. We also include three indicators for whether the county was: (1) in nonattainment under the old design values but attainment under the new design values (NA→A), (2) in attainment under the old design values but nonattainment under the new design values (A→NA), or (3) in nonattainment under both the old and new design values (NA→NA); we also include the interactions between these three indicators and the Post indicator. The regressions listed in all columns except Column 4 are based on trades made in the two weeks before and after the relevant announcement; in Column 4, we consider only the week before and after the announcement. The regressions listed in this table all include fixed effects for remaining years to maturity. The regressions presented in Columns 1 and 4 additionally include county fixed effects and announcement year fixed effects, the regression listed in Column 2 additionally includes CUSIP fixed effects and announcement year fixed effects, and the regression considered in Column 3 additionally includes county fixed effects and state by announcement year fixed effects.

values indicate future compliance. The effect size is similar to that for the counties that are always in attainment, though the statistical significance varies across specifications. Again, the estimated reduction in yields is largest in absolute value for the model that controls for CUSIP fixed effects (0.9 basis points, $p < 0.05$). Future attainment does not mean that firms can stop existing compliance actions. Rather, future attainment signals that the compliance plan currently in place is sufficient to reach attainment. The negative effect of the announcement on yields for NA$\rightarrow$A counties thus suggests that investors' concerns that the county will be forced to incur additional compliance costs are mitigated because the new design value suggests such counties will move to attainment status.

In contrast, yields increase by between 0.4-0.6 basis points more on average for counties that remain in noncompliance under both the old and new design values relative to counties that remain in compliance. This increase is statistically significant across specifications. This finding is intuitive. The county will have to take additional steps to bring ozone levels down below the standard. This could manifest at the intensive margin: more effort (and costs) may be required by firms already reducing emissions. Alternatively, it could manifest at the extensive margin: more polluting firms may be required to abate emissions. In either case, it is likely that investors' valuations incorporate the increase in default risk associated with the additional compliance measures required by continued nonattainment, noting that precisely which measures will be taken would not be known by any party at the time of the design value announcement.

Finally, Table 3 indicates that bonds issued in counties that switch from compliance to noncompliance incur a relatively large increase in yields after the announcement. The estimated effect size ranges from 2-3 basis points ($p < 0.01$). The increase is between three to five times greater than the effect on securities issued by counties that are out of compliance under both the old and new design values. This striking result is also intuitive. Absent a history of nonattainment, which firms or facilities are likely to be subject to emission controls, and what techniques such firms will use to abate emissions, are less well known than in counties that were previously in noncompliance. Therefore, investors are less able to predict the impacts of noncompliance on corporate tax revenues, labor income, and municipal debt service. Our results suggest that investors require higher returns to hold bonds issued by A$\rightarrow$NA counties due to this additional uncertainty in future streams of municipal income.

Figure 1 depicts the relative effects on yields of the design value announcements for counties that move from nonattainment to attainment and from attainment to nonattainment; these estimated impacts are relative to counties that are in attainment under both the old and new design values. The figure indicates a slight decrease in yields over the window for the NA→A counties, though these effects are not statistically significant at the 5% level. In contrast, bonds issued in A→NA counties trade at increasingly higher yields after the announcement. Interestingly, Figure 1 shows a pre-trend in yields for securities issued in counties moving into nonattainment. This suggests that market participants anticipate the change in compliance status. This effect is plausible because design values are a function of publicly available air quality monitoring data. It is thus possible to predict whether each county's new design value will be above versus below the standard and trade accordingly.

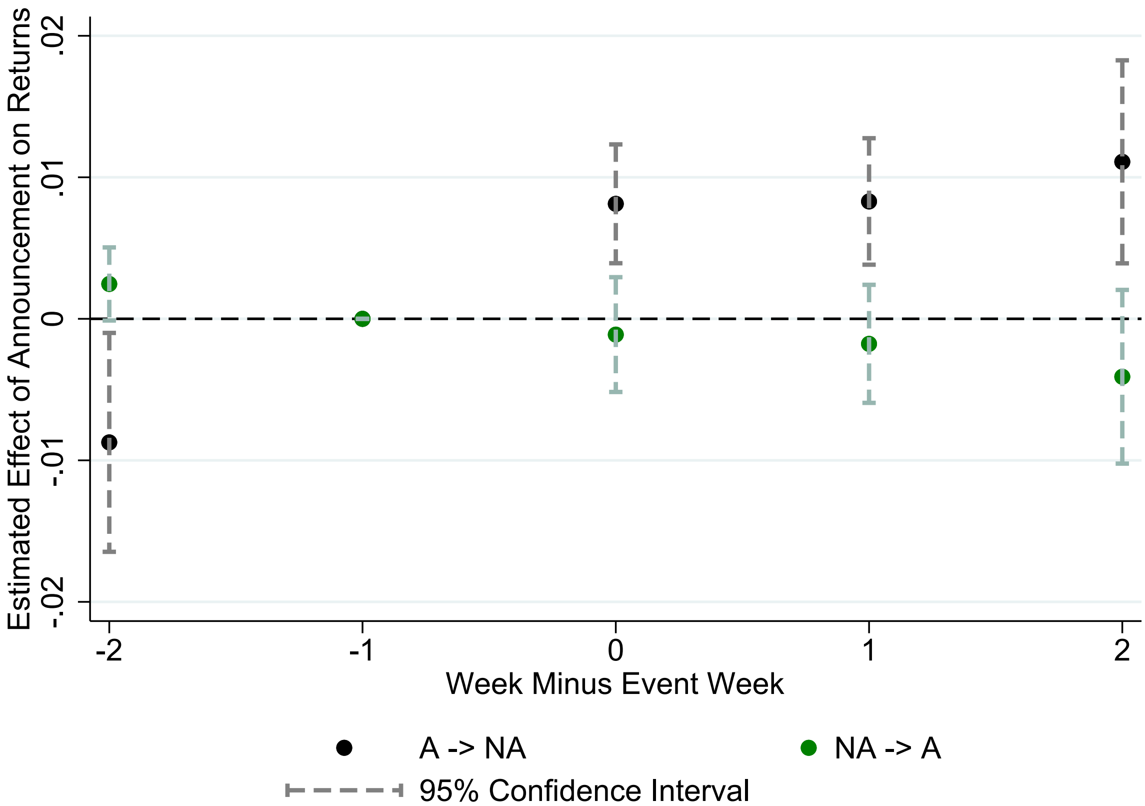
Finally, Appendix Table B.3 presents results pertaining to the incidence and counts of trades in the event study framework specified in Equation (2). The top panel of this table reports the results from a linear probability model while we employ a Poisson regression for the bottom panel. Both panels indicate that trading activity decreases in the week following the announcement of the design values. These results may indicate that investors' expectations over future default risk converge after the announcement, leading to less overall trading of more frequently traded bonds.

4.4 Nonattainment and Bond Yields

The event study specifications discussed in the previous subsections probe the market's response to new information regarding counties' future compliance status. In contrast, the estimates from the RD specifications presented in this subsection reflect the difference in default risk perceived by investors due to being out of compliance with the NAAQS. As discussed in Section 3, we move forward with this regression discontinuity design because of the results from the density break test. We fail to reject the null hypothesis that counties just above the ozone standard are unable to manipulate their pollution levels to reach attainment status.

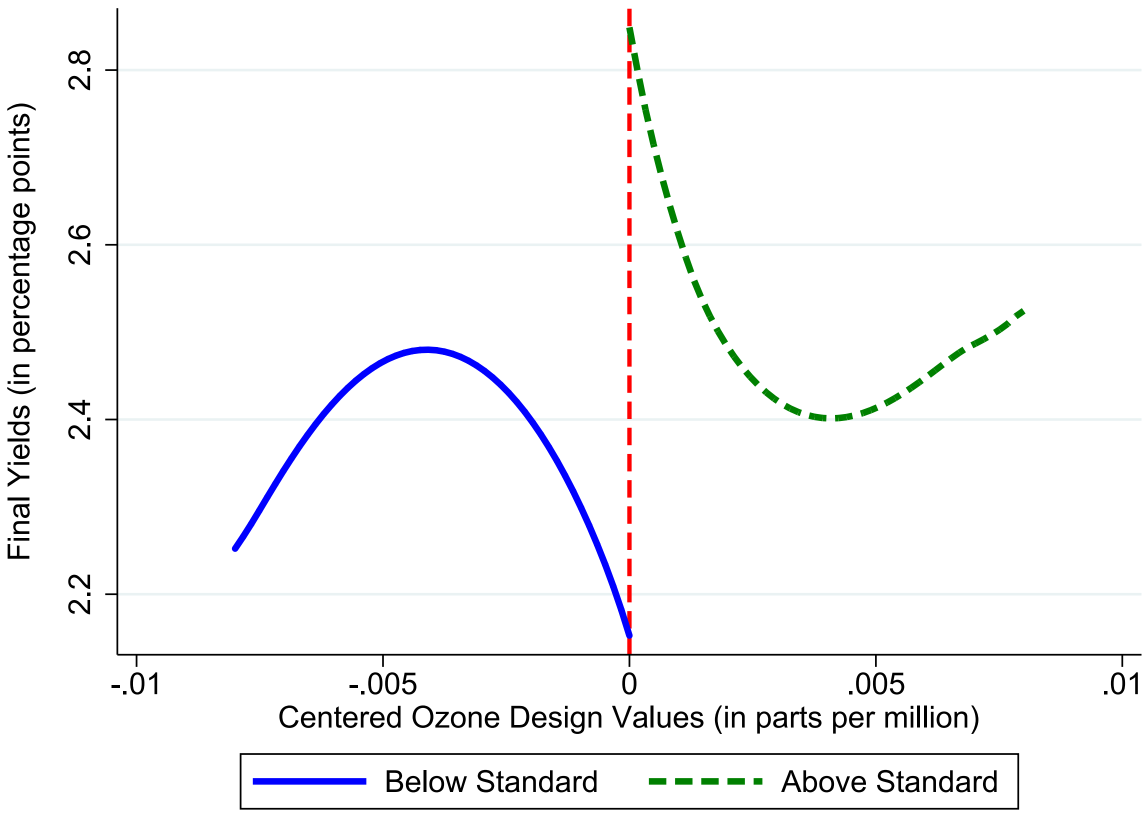
Before presenting estimates from the RD regression, Figure 2 displays local polynomi-

Figure 1: Event Study Impacts of Announcement of Ozone Design Values on Yields



Notes: This figure presents the impact on final yields of the announcement of the design values used to determine compliance with the National Ambient Air Quality Standards (NAAQS) for ozone. The unit of observation underlying the regressions in this table is CUSIP/remaining years-to-maturity/week-of-sample. We hereafter refer to a CUSIP/remaining years-to-maturity combination as a "bond". Standard errors, reported in parentheses, are clustered by county. The dependent variable considered is the log of final yields. We calculate final yields as the yield recorded for the last trade of the bond in the week. We use the final yield from the prior week for weeks in which the bond was not traded. The indicator variable "Post" is equal to one only if the week-of-sample is on or after the week that the design values were announced. We also include three indicators for whether the county was: (1) in nonattainment under the old design values but attainment under the new design values (NA→A), (2) in attainment under the old design values but nonattainment under the new design values (A→NA), and (3) in nonattainment under both the old and new design values (NA→NA); we also include the interactions between these three indicators and the Post indicator. The event study regression focuses only on trades made in the two weeks before and after the relevant announcement. This regression includes county fixed effects, announcement year fixed effects as well as fixed effects for remaining years to maturity.

Figure 2: Municipal Bond Yields Around Ozone Attainment Status Thresholds



Notes: This figure presents local polynomials relating centered design values to final yields (i.e.: LOWESS smoothing) The x-axis plots centered design values: the difference between the design value and the relevant ozone NAAQS. The blue curve is based on a regression of a local quadratic polynomial in centered design values using the Epanechnikov kernel function on final yields for bonds issued in counties with design values below the standard. Similarly, the green curve is based on a regression of a local quadratic polynomial in centered design values using the Epan kernel function on final yields for bonds issued in counties with design values above the standard.

Table 4: Municipal Bond Yields Around the Pollutant Standards

	Dependent Variable: Log Final Yields					
	(1)	(2)	(3)	(4)	(5)	(6)
1[Nonattainment: Ozone]	0.312***	0.303***	0.269***	0.199***	0.304***	0.343***
	(0.104)	(0.099)	(0.071)	(0.076)	(0.103)	(0.101)
Residualize by Years-to-Maturity?	N	Y	Y	N	N	N
Residualize by County?	N	N	Y	N	N	N
Kernel Type	Epan	Epan	Epan	Epan	Epan	Tri
Mean of Dep. Var.	0.740	-0.005	0.009	0.749	0.736	0.739
Optimal Bandwidth	0.008	0.008	0.007	0.004	0.015	0.008
Degree of Polynomial	2	2	2	1	3	2
Effective Number of Obs.	3,209,264	3,209,262	2,936,054	2,344,727	4,152,644	3,123,436
Number of Counties	651	651	616	509	744	651

Notes: This table presents regression discontinuity estimates of average final yields for counties just above versus just below the relevant standard for ozone. The regressions are estimated choosing separate bandwidths in centered pollution design values for observations to the left versus right of the threshold; these bandwidths are chosen optimally based on mean-squared error (MSE) as specified in Calonico, Cattaneo and Titiunik (2014). Standard errors, reported in parentheses, are clustered by county and are bias-corrected as discussed in Calonico, Cattaneo and Titiunik (2014). ***, **, and * correspond to statistical significance at the 1%, 5%, and 10% levels, respectively. The regressions in Columns 1-3 control for local quadratic polynomials in centered design values using Epanechnikov kernel functions. In Column 4, we instead control for local cubic polynomials in the centered design values while we use the triangular kernel function to control for local quadratic polynomials in Column 5. The dependent variable considered in Columns 1, 4, and 5 of this table is the log of final yields. The dependent variable in Column 2 is the residual of a regression of log yields on remaining-year-to-maturity fixed effects, and the dependent variable in Column 3 is the residual of a regression of log yields on year-to-maturity fixed effects and county fixed effects.

als relating centered design values to final yields. The x-axis plots the difference between the design value and the relevant ozone NAAQS. We estimate separate local polynomials relating centered design values and final yields for bonds issued in counties above versus below the standard. Figure 2 presents clear evidence that yields are higher on average for municipalities that exceed the standard.

Table 4 presents the estimates from the RD specification in Equation (3). This table clearly demonstrates that securities issued by counties just above the ozone standard exhibit statistically and economically significantly higher yields than counties just below the standard. The effect size ranges between 40 and 75 basis points ($p < 0.01$). These estimates suggest that securities issued in counties that are out of attainment have significantly higher default risk than comparable securities issued in counties in attainment.

Our primary specification controls for a second order local polynomial in centered design values using the Epanechnikov kernel and includes only observations within 8 parts per billion of the relevant standard (see Column 1).[9] However, the estimates are robust to numerous permutations to the regression model. For example, the estimated effects remain similar if we residualize log final yields before estimating the RD model. Specifically, Columns (2), (3), and (4) consider the residuals from a regression of log final yields on remaining years-to-maturity fixed effects, county fixed effects, and both remaining years to maturity fixed effects and county fixed effects respectively. The estimated effects also remain similar in magnitude if we control for a linear or a cubic local polynomial in the running variable rather than a quadratic local polynomial. (see Columns 4 and 5). Finally, estimating these local polynomials using a triangular kernel rather than the Epanechnikov kernel also has very little effect on the coefficient of interest.

Investors require higher yields for bonds issued in noncompliant counties because polluting firms located in these counties must take costly actions in order to reduce pollution levels. Such actions include reducing output, utilizing inputs that result in less pollution emissions, or investing in pollution abatement technology such as a particulate filter installed in a factory's smokestack. The compliance costs incurred by polluting firms likely implies lower profits and thus less tax revenue for the municipality. Moreover, polluting firms may fire employees, which again would likely have detrimental impacts to municipal budgets. Consequently, investors likely perceive that nonattainment counties have a higher probability of defaulting on their bonds than attainment counties. This likely drives our estimated increase in bond yields for counties just above the threshold relative to those just below the threshold.

5 Conclusions and Policy Implications

This paper examines how the National Ambient Air Quality Standards (NAAQS) affect municipal bond prices and yields from 2005 to 2019. We present three sets of results. First, we use event studies to test whether proposed and final ozone NAAQS rule changes affect yields. The results of this analysis indicate that yields increase in response to the announcement of the proposed rule but decrease after the announcement of the final standard. This suggests that investors require higher returns to be compensated for the uncertainty induced by the announcement of the proposed rule. This uncertainty

[9]Centered design values are simply the design value minus the relevant standard.

is resolved with the announcement of the final rule, lowering the returns necessary for investors to hold the bond.

We also estimate event study regressions focusing on the annual announcements of county-level design values. The announcement results in a decrease in yields for counties in attainment under both the old and new design values. The announcement resolves uncertainty over compliance status for these counties. However, we find a large increase in yields for counties that switch from attainment under the old design values to nonattainment under the new design values relative to counties in attainment under both sets of design values. Yields also increase for counties that are out of compliance under both sets of design values, again relative to the yields for counties in attainment both before and after the announcement. Combined, our findings suggest that investors perceive that municipalities facing nonattainment have a higher default risk.

Finally, we employ regression discontinuity models to directly test whether compliance status affects yields. We find that counties with design values just above the relevant ozone standard incur large (between 40 and 60 basis points) increases in yields relative to counties just below the standard. We attribute this to the increased risk of default associated with the costly measures required to lower pollution levels in order to comply with the ozone standard.

Our results have three primary implications for policy. First, previous studies have likely significantly underestimated the costs associated with the CAA (EPA (1999, 2010)). Specifically, the municipal bond market comprises a large reservoir of capital. Municipalities in, or at risk of, nonattainment are among the largest in the contiguous United States. The costs associated with the large distortion in expected yields we report in a market of this size are likely to be substantial.

Second, a growing body of literature has documented that climate risk has been priced into financial markets (Bakkensen and Barrage, 2017; Gibson, Mullins and Hill, 2017; Barrage and Furst, 2019; Painter, 2019; Baker et al., 2018*a*; Goldsmith-Pinkham et al., 2019; Baldauf, Garlappi and Yannelis, 2020; Giglio, Kelly and Stroebel, 2020). There is currently no federal regulation aimed at mitigating the global pollutants that contribute to climate change. Our results for local air pollution regulations suggest that any cost-benefit analysis of new climate policy must take into account the impacts on financial markets of both extreme weather events and the costs associated with complying the new policy.

Finally, municipal bonds are a vehicle to finance the provision of local public goods. Distortions to municipal bond yields might jeopardize local governments' ability to raise capital. Because of the central role these securities play in funding schools, infrastructure, and health care facilities, the effects of local air pollution regulations on municipal bond yields may have large non-pecuniary impacts operating through the foregone benefits from public good provision. An important extension of our work is studying these knock-on effects. Our results speak to a provocative policy debate regarding the trade-offs inherent to providing local public goods and federal-level environmental regulations.

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A Additional Tables and Figures

This Appendix section presents additional tables and figures. The first subsection pertains to summary statistics while the second subsection focuses on the regression discontinuity framework discussed in Section 3.

A.1 Summary Statistics

Appendix Table A.1 lists the mean, standard deviation, 25th percentile, median, and 75th percentile of the variables relevant to our analysis. The unit of observation for the data-set used to calculate these summary statistics is CUSIP/remaining years-to-maturity/week-of-sample; we refer to each CUSIP/remaining years-to-maturity combination as a "bond". We aggregate the trade-level data provided by the MSRB to the bond/week-of-sample level as discussed in Appendix Section C.1.

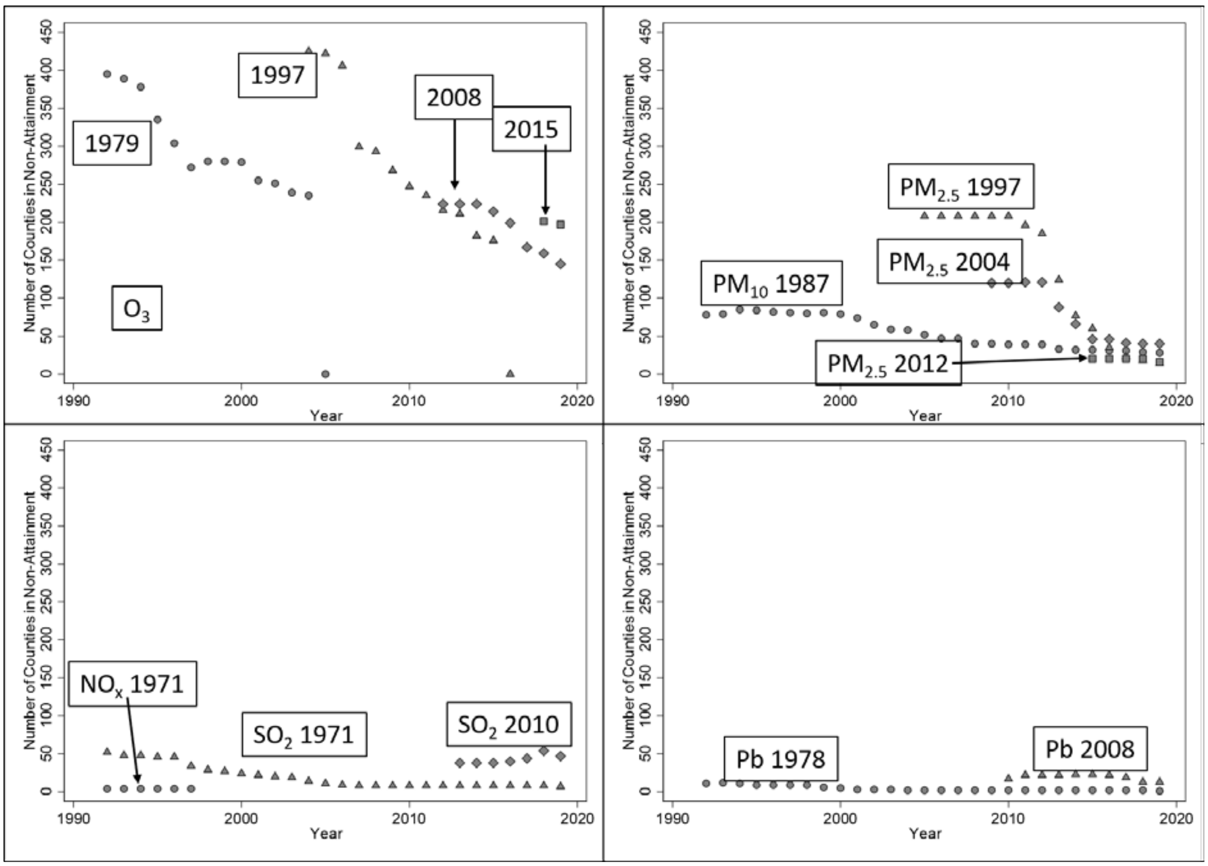
Both the mean and median of final yields is 2.7; this suggests that the yield data are not skewed. In contrast, the median value traded and number of trades in our data-set is equal to zero. This highlights that municipal bonds are traded relatively infrequently.

Appendix Figure A.1 plots the annual number of counties that are out of attainment with each of the pollutant standards associated with the National Ambient Air Quality Standards (NAAQS). The top left panel focuses on the standards for ozone, the top right panel considered the standards for fine particulate matter, the bottom left panel focuses on the standards associated with nitrogen oxide and sulfur dioxide, and the bottom right panel considers the standards for lead.[10] This figure documents that the number of counties out of attainment with the relevant standard for ozone is far higher than the number of counties out of attainment with the standards associated with any of the other pollutants considered as part of the NAAQS. Moreover, the number of counties out of attainment with the ozone standard has not decreased much over time. This highlights that the actions polluting firms must take to reduce ozone levels have far higher cost than actions required to decrease the levels of other pollutants such as fine particulates.

Finally, the left and right panels of Appendix Figure A.2 plot annual summary statistics relevant for compliance with the NAAQS for ozone and fine particulates respectively.

[10] The data underlying this figure are provided by the United States Environmental Protection Agency and are available at: https://www3.epa.gov/airquality/greenbook/downld/phistory.xls.

Figure A.1: Annual Number of Counties Out of Attainment with each Pollutant Standard



Notes: This figure plots the annual number of counties that are out of attainment with each of the pollutant standards associated with the National Ambient Air Quality Standards (NAAQS). The top left panel focuses on the standards for ozone, the top right panel considered the standards for fine particulate matter, the bottom left panel focuses on the standards associated with nitrogen oxide and sulfur dioxide, and the bottom right panel considers the standards for lead. The data underlying this figure are provided by the United States Environmental Protection Agency and are available at: https://www3.epa.gov/airquality/greenbook/downld/phistory.xls.

Table A.1: Summary Statistics

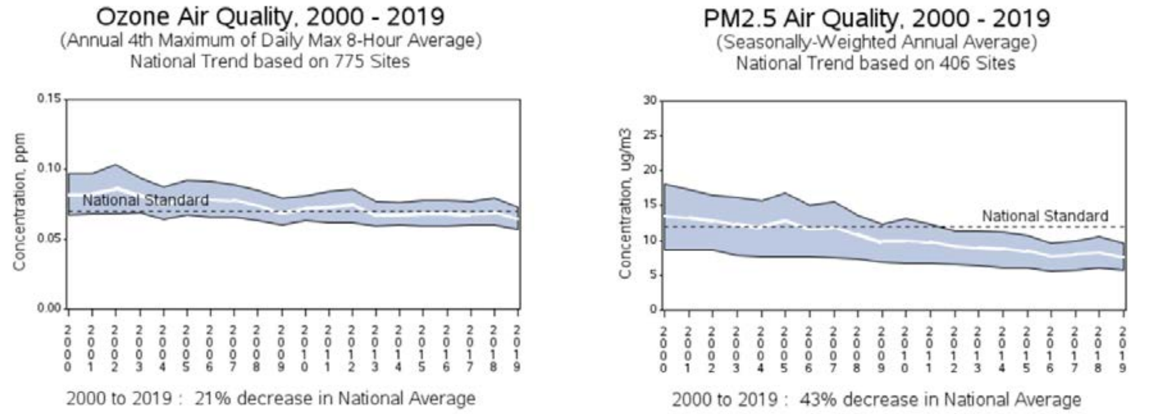
Var.	Mean	SD	P25	P50	P75
Final Yield (%)	2.7	2.7	1.6	2.7	3.8
Final Price (USD)	103.6	11.6	100.4	103.9	108.7
Dollar Value Traded (1000 USD)	338.0	4,771.7	0.0	0.0	20.0
Number of Trades	1.1	4.8	0.0	0.0	1.0

Notes: This table presents summary statistics for the data-set used to estimate the models discussed in Section 3. The unit of observation for the data-set used to calculate these summary statistics is CUSIP/remaining years-to-maturity/week-of-sample; there are 73,315,416 observations in this data-set. We refer to each CUSIP/remaining years-to-maturity combination as a "bond". We keep only trades associated with bonds with security descriptions linked to only one county. We aggregate the trade-level data-set to the bond/week-of-sample level as follows. First, "final yield" and "final price" are defined to be the yield and price associated with the final trade in the week-of-sample for the bond. For weeks with no trades, the final yield and price are taken from the last week with a trade. We also take the sum over par value of the trades in the week for each bond; weeks without trades for the bond have zero total value for that week. Similarly, we calculate the total number of trades of the bond in a week, with zeros for the weeks with no trades.

Focusing on the left panel pertaining to ozone, a county is out of compliance with the NAAQS if the following "design value" is greater than the ozone standard: the annual fourth maximum of the daily maximum of ozone values averaged over any 8-hour period in the day. The blue band plots the middle 80th percentile of this design value over 775 monitoring stations; the white line represents the average design value of the 775 monitors. The current national standard for ozone of 0.07 ppm is plotted as a horizontal dashed line in black. The left panel of Appendix Figure A.2 documents that: (1) average ozone levels have not fell much from 2000 to 2019 and (2) the readings at many monitors across the U.S. would indicate noncompliance with the NAAQS. This suggests that it is especially costly to reduce ozone levels, an assertion that's further evidence by the large number of counties in nonattainment with the ozone standard even as of 2019 (see Appendix Figure A.1).

The right panel of Appendix Figure A.2 plots the seasonally-weighted annual average of fine particulates (i.e.: $PM_{2.5}$) for the 2000-2019 sample period. The blue band consists of the area between the 10th and 90th percentiles of this seasonal average over 406 monitoring stations; the white line represents the national average over the 406 monitors. A county is out of compliance with the current annual standard for fine particulates if the average over three years of their annual average $PM_{2.5}$ levels is larger than 12 micrograms per cubic meter. This 12 micrograms per cubic meter standard is plotted as a horizontal

Figure A.2: Annual Trends in $PM_{2.5}$ and Ozone Levels



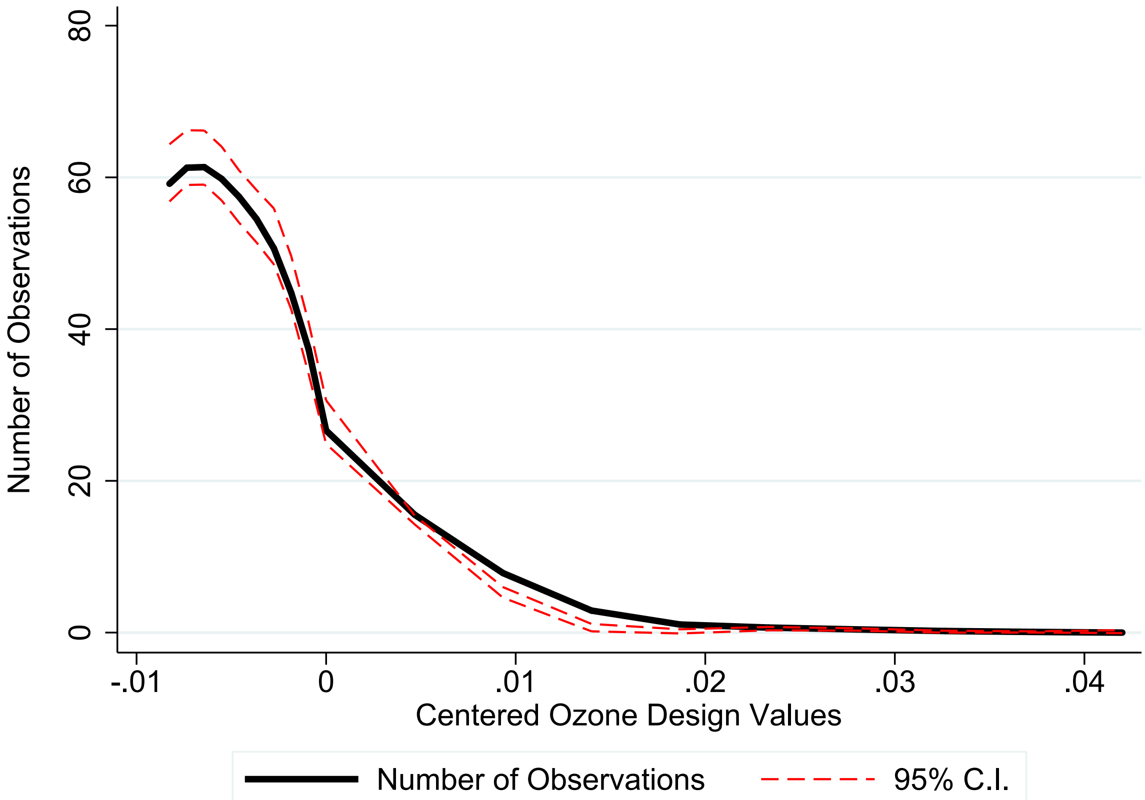
Notes: Focusing on the left panel pertaining to ozone, a county is out of compliance with the NAAQS if the following "design value" is greater than the ozone standard: the annual fourth maximum of the daily maximum of ozone values averaged over any 8-hour period in the day. The blue band consists of the area between the 10th and 90th percentiles of this design value over 775 monitoring stations; the white line represents the national average design value over the 775 monitors. The current national standard for ozone of 0.07 ppm is plotted as a horizontal dashed line in black. The right panel plots the seasonally-weighted annual average of fine particulates (i.e.: $PM_{2.5}$) for the 2000-2019 sample period. The blue band consists of the area between the 10th and 90th percentiles of this seasonal average over 406 monitoring stations; the white line represents the national average over the 406 monitors. A county is out of compliance with the current annual standard for fine particulates if the average over three years of their annual average $PM_{2.5}$ levels is larger than 12 micrograms per cubic meter. Consequently, this 12 micrograms per cubic meter standard is plotted as a horizontal dashed black line. Both panels are taken from the USEPA website: https://www.epa.gov/air-trends/.

dashed black line. In contrast with the panel for ozone, the right panel documents substantial declines in fine particulate levels over the 2000-2019 sample period. Even the seasonal averages for the 90th percentile monitor are well below the annual standard in 2019. This suggests that the cost associated with reducing fine particulates levels is far lower than the compliance costs associated with ozone. This intuition is borne out by Appendix Figure A.1, which shows a marked decline from 1990-2019 in the number of counties out of compliance with the standards for fine particulates.

A.2 Additional Tables and Figures: RD Specifications

In Table 4, we present estimates from a regression discontinuity framework of the difference in final yields for bonds issued in counties with pollution levels just above versus just below the pollution standard. In order to interpret these estimates as causal, we must assume that counties cannot manipulate their pollution levels to be just below the standard. In support of this assumption, Appendix Figure A.3 plots the density of observations by the distance to ozone attainment status thresholds. The unit of observa-

Figure A.3: Density Break Test: Number of Counties Around Ozone Threshold



Notes: This figure presents the density of observations by the distance to ozone attainment status thresholds. The unit of observation underlying the estimation of this density is county/year, considering only counties associated with bonds in our data-set in the year. The vertical red lines indicate the standard cutoff for attainment status for ozone, the solid black lines represent the local density, and the dashed black lines represent the corresponding 95% confidence interval bounds. The 95% confidence interval is calculated using the plug-in estimator proposed by Cattaneo, Jansson and Ma (2019). We fail to reject the null hypothesis that there's no break in density around the cut-off, with a p-value of 0.829.

tion underlying the estimation of this density is county/year, considering only counties associated with bonds in our data-set in the year. The vertical red lines indicate the standard cutoff for attainment status for ozone, the solid black lines represent the local density, and the dashed black lines represent the corresponding 95% confidence interval bounds. The 95% confidence interval is calculated using the plug-in estimator proposed by Cattaneo, Jansson and Ma (2019). We fail to reject the null hypothesis that there's no break in density around the cut-off, with a p-value of 0.829.

B Impacts on Number of Trades

This Appendix section present estimates of the impact of announcements on the incidence and count of trades. The first subsection present specifications focusing on the announcements of the proposed and final ozone standards. We explore how trading activity responds to the annual announcements of design values in the third subsection.

B.1 Announcement of New Standards

In this subsection, we utilize a very similar framework to one specified in Equation 1 in Section 3. Specifically, we estimate the following event study regression to study the announcements of the proposed change in rule and the final new standard:

$$Y_{i,r,c,t} = \alpha_c + \gamma_r + \theta_{E_t} + \beta 1[t > E_t] + \epsilon_{i,r,c,t}$$

where i indexes CUSIP, r indexes remaining years-to-maturity, c indexes county of issuer, and t indexes week-of-sample. Event time E_t is the week of the event, either the announcement of a proposed or new standard. The independent variable of interest $1[t > E_t]$ is equal to one if the week-of-sample is after the announcement. This variable captures the impact of the announcement on the outcome variable. Standard errors are clustered by county.

We consider two outcome variables. The first is an indicator variable that is equal to one if and only if the bond traded at least once in the week-of-sample. Recall that a "bond" in our terminology denotes a CUSIP/remaining years-maturity combination. The second outcome variable is the count of trades in the week-of-sample. We use ordinary least squares to estimate the specifications based on the indicator of any trade but use Poisson regression to estimate the specifications based on the count of trades.

Appendix Table B.1 presents models that estimate the impact of the announcement of the proposed rule on the likelihood of a trade and counts of trades. The top panel of this table reports the results considering the indicator for any trade as the dependent variable while the bottom panel considers the count of trades. We consider the same sets of fixed effects and event windows as utilized in Columns 1-4 of Table 1. Our primary specification based on a two week window around the event, county fixed effects, remaining years to

Table B.1: Impact of Announcement of Proposed Rule on Trades

Dep. Var: 1[Any Trade in the Week]	(1)	(2)	(3)	(4)
Post	0.083***	0.057***	0.083***	0.069***
	(0.006)	(0.004)	(0.006)	(0.005)
Bandwidth (Weeks)	2	2	2	1
County FE	Yes	No	Yes	Yes
CUSIP FE	No	Yes	No	No
State-by-Event-Year FE	No	No	Yes	No
Event Year FE	Yes	Yes	No	Yes
Remaining Yrs-to-Maturity FE	Yes	Yes	Yes	Yes
R^2	0.204	0.515	0.204	0.233
Mean of Dep. Var.	0.351	0.313	0.351	0.344
Number of Obs.	543,539	513,508	543,539	317,879
Number of Bonds	146,152	116,122	146,152	122,803

Dep. Var: Number of Trades	(1)	(2)	(3)	(4)
Post	0.150***	0.009	0.150***	0.102***
	(0.010)	(0.013)	(0.010)	(0.015)
Bandwidth (Weeks)	2	2	2	1
County FE	Yes	No	Yes	Yes
CUSIP FE	No	Yes	No	No
State-by-Event-Year FE	No	No	Yes	No
Event Year FE	Yes	Yes	No	Yes
Remaining Yrs-to-Maturity FE	Yes	Yes	Yes	Yes
Mean of Dep. Var.	1.293	1.895	1.293	1.258
Number of Obs.	543,484	321,937	543,484	317,801
Number of Bonds	146,141	77,819	146,141	122,777

Notes: This table presents the impact of the announcement of the proposed ozone standard on an indicator for any trade in the week (top panel) and number of trades (bottom panel). The unit of observation underlying the regressions in this table is CUSIP/remaining years-to-maturity/week-of-sample. We hereafter refer to a CUSIP/remaining years-to-maturity combination as a “bond”. Standard errors, reported in parentheses, are clustered by county for all specifications. The dependent variable considered in the top panel is an indicator variable that’s equal to one if and only if the bond was traded in the week; the dependent variable considered in the bottom panel is the number of trades of the bond in the week. The independent variable of interest, “Post”, is an indicator variable that’s equal to one only if the week-of-sample is on or after the week that a new standard was announced. The top panel is based on simple ordinary least squares (OLS) regressions while we utilize Poisson regressions for the bottom panel. The coefficient estimates in the bottom panel should thus be interpreted as the change in the ratio of rates after relative to before the announcement. We consider the two weeks before and after the relevant announcement for all columns except Column 4; in Column 4, we consider only the week before and after the announcement. The regressions listed in this table all include fixed effects for remaining years to maturity. The regressions presented in Columns 1 and 4 of both panels additionally include county fixed effects and announcement year fixed effects, the regression listed in Column 2 additionally includes CUSIP fixed effects and announcement year fixed effects, and the regression considered in Column 3 additionally includes county fixed effects and state by announcement year fixed effects.

maturity fixed effects, and event fixed effects are presented in Column 1 of each panel.

The results demonstrate that trading activity increased after the proposed rule announcement. Specifically, the top panel of Appendix Table B.1 reports that, on average, one-third of all bonds trade in a week. In the week following the proposed rule announcement, the likelihood of bonds being traded increases by between 5 and 9 percentage points. The bottom panel of Appendix Table B.1 demonstrates that, on average, bonds trade just over once per week, implying that some bonds trade numerous times within a week. After the proposed rule announcement, the count of trades increases by between 10 and 15 percent.

The estimates remain similar in magnitude if we include state-by-event fixed effects rather than event fixed effects (see Column 3) or consider a one-week window around the event rather than two-week window (see Column 4). However, the estimated magnitudes are smaller (and statistically insignificant in the bottom panel) if we include CUSIP fixed effects rather than county fixed effects. This suggests that much of increased trading activity is associated with increases in the number of bonds traded rather than more trades of the same bond.

Appendix Table B.2 presents estimates of the changes in the likelihood of trade and counts of trades following the announcement of the final rule. As with Appendix B.1, the top panel of this table reports the results from a linear probability model while we employ a Poisson regression for the bottom panel. The top panel of Appendix Table B.2 reports that the likelihood of bonds being traded increases by under one percentage point after the announcement. Conversely, the bottom panel of Appendix Table B.2 demonstrates that the count of trades decreases by between 5 and 20 percent after the final rule announcement. These results suggest that a greater variety of bonds are traded at least once after the announcement. However, each particular bond is traded less frequently after the announcement. This intuition is confirmed by the fact that the effect size increases in absolute value when we include CUSIP fixed effects rather than county fixed effect (see Column 4 of the bottom panel).

This combination of results may occur because the announcement resolves uncertainty and reduces differences in expectations across investors. Specifically, on the one hand, the final rule provides information on the future compliance status of different counties. An information shock would be expected to increase trading activity. On the other hand,

Table B.2: Impact of Announcement of Final Rule on Trades

Dep. Var: 1[Any Trade in the Week]	(1)	(2)	(3)	(4)
Post	0.004***	0.004**	0.004***	0.008***
	(0.002)	(0.001)	(0.002)	(0.002)
Bandwidth (Weeks)	2	2	2	1
County FE	Yes	No	Yes	Yes
CUSIP FE	No	Yes	No	No
State-by-Event-Year FE	No	No	Yes	No
Event Year FE	Yes	Yes	No	Yes
Remaining Yrs-to-Maturity FE	Yes	Yes	Yes	Yes
R^2	0.017	0.415	0.017	0.020
Mean of Dep. Var.	0.275	0.251	0.275	0.280
Number of Obs.	669,151	647,949	669,151	402,851
Number of Bonds	156,325	135,123	156,325	142,788

Dep. Var: Number of Trades	(1)	(2)	(3)	(4)
Post	-0.046***	-0.164***	-0.046***	0.002
	(0.018)	(0.018)	(0.018)	(0.021)
Bandwidth (Weeks)	2	2	2	1
County FE	Yes	No	Yes	Yes
CUSIP FE	No	Yes	No	No
State-by-Event-Year FE	No	No	Yes	No
Event Year FE	Yes	Yes	No	Yes
Remaining Yrs-to-Maturity FE	Yes	Yes	Yes	Yes
Mean of Dep. Var.	1.194	1.867	1.194	1.237
Number of Obs.	669,051	391,339	669,051	402,731
Number of Bonds	156,305	84,789	156,305	142,749

Notes: This table presents the impact of the announcement of the finalized ozone standard on an indicator for any trade in the week (top panel) and number of trades (bottom panel). The unit of observation underlying the regressions in this table is CUSIP/remaining years-to-maturity/week-of-sample. We hereafter refer to a CUSIP/remaining years-to-maturity combination as a "bond". Standard errors, reported in parentheses, are clustered by county for all specifications. The dependent variable considered in the top panel is an indicator variable that's equal to one if and only if the bond was traded in the week; the dependent variable considered in the bottom panel is the number of trades of the bond in the week. The independent variable of interest, "Post", is an indicator variable that's equal to one only if the week-of-sample is on or after the week that a new standard was announced. The top panel is based on simple ordinary least squares (OLS) regressions while we utilize Poisson regressions for the bottom panel. The coefficient estimates in the bottom panel should thus be interpreted as the ratio of rates after relative to before the announcement. We consider the two weeks before and after the relevant announcement for all columns except Column 4; in Column 4, we consider only the week before and after the announcement. The regressions listed in this table all include fixed effects for remaining years to maturity. The regressions presented in Columns 1 and 4 of both panels additionally include county fixed effects and announcement year fixed effects, the regression listed in Column 2 additionally includes CUSIP fixed effects and announcement year fixed effects, and the regression considered in Column 3 additionally includes county fixed effects and state by announcement year fixed effects.

investors' expectations over future default risk could become more uniform, leading to less trades after the announcement

B.2 Announcement of Design Values

In this subsection, we utilize a very similar framework to one specified in Equation 2 in Section 3. In particular, we estimate the following regression model to study the impacts of the annual announcements of the design values used to determine compliance with the ozone standard:

$$\begin{aligned} Y_{i,r,c,t} &= \alpha_c + \theta_{E_t} + \gamma_r + \epsilon_{i,r,c,t} \\ &+ \sum_{\tau=-2}^{2} [\beta_\tau^{\text{NA}\to\text{A}} D_{c,t,\tau}^{\text{NA}\to\text{A}} + \beta_\tau^{\text{A}\to\text{NA}} D_{c,t,\tau}^{\text{A}\to\text{NA}} + \beta_\tau^{\text{NA}\to\text{NA}} D_{c,t,\tau}^{\text{NA}\to\text{NA}}] \\ &+ 1[\text{A}\to\text{NA}]\delta_1 + 1[\text{NA}\to\text{A}]\delta_2 + 1[\text{NA}\to\text{NA}]\delta_3 \end{aligned}$$

where we include fixed effects by county, event, and remaining years-to-maturity. This specification also includes indicators for whether the county in the year switches from attainment to nonattainment, switches from nonattainment to attainment, or remains in nonattainment. The independent variables of interest are these variables interacted with indicators denoting event time. For example, $\tau \equiv t - E_t = -2$ denotes observations corresponding to two weeks before an announcement of new design values. Standard errors are clustered by county.

Appendix Table B.3 presents the results pertaining to the incidence and counts of trades in the event study framework specified in Equation (2). The top panel of this table reports the results from a linear probability model while we employ a Poisson regression for the bottom panel. As before, we consider a range of different sets of fixed effects as well as a one-week (rather than two-week) window around the announcement. Across specifications and dependent variables, the results indicate that trading activity decreases in the week following the announcement of the design values. The estimates do not differ across bonds issued in counties that switch attainment status versus remain either in or out of attainment under both the old and new design values. These findings may indicate that investors' expectations over future default risk converge after the announcement, leading to less overall trading of more frequently traded bonds.

Table B.3: Impact of DV Announcement on Trades

	(1)	(2)	(3)	(4)
Dep. Var: 1[Any Trade in the Week]				
A → NA × Post	-0.003	-0.002	-0.003	-0.003
	(0.003)	(0.003)	(0.003)	(0.003)
NA → A × Post	-0.002	-0.004	-0.002	-0.002
	(0.004)	(0.003)	(0.004)	(0.003)
NA → NA × Post	-0.001	-0.001	-0.001	-0.000
	(0.001)	(0.001)	(0.001)	(0.002)
Post	-0.010***	-0.007***	-0.011***	-0.010***
	(0.001)	(0.001)	(0.001)	(0.001)
R^2	0.017	0.217	0.018	0.018
Mean of Dep. Var.	0.226	0.216	0.226	0.224
Number of Obs.	5,464,346	5,397,811	5,464,346	3,282,100
Number of Bonds	504,772	438,237	504,772	467,373
Dep. Var: Number of Trades	(1)	(2)	(3)	(4)
A → NA × Post	0.010	0.008	0.010	-0.002
	(0.024)	(0.025)	(0.024)	(0.020)
NA → A × Post	-0.014	-0.021	-0.014	-0.021
	(0.028)	(0.028)	(0.028)	(0.028)
NA → NA × Post	-0.006	-0.007	-0.005	0.003
	(0.016)	(0.017)	(0.016)	(0.019)
Post	-0.050***	-0.065***	-0.050***	-0.059***
	(0.010)	(0.011)	(0.010)	(0.013)
Mean of Dep. Var.	0.898	1.030	0.898	0.890
Number of Obs.	5,464,281	4,574,425	5,464,281	3,281,965
Number of Bonds	504,764	322,403	504,764	467,346

Notes: This table presents the impact on the indicator variable for any trade in the week and number of trades of the announcement of the design values used to determine compliance with the National Ambient Air Quality Standards (NAAQS) for ozone. The unit of observation underlying the regressions in this table is CUSIP/remaining years-to-maturity/week-of-sample. We hereafter refer to a CUSIP/remaining years-to-maturity combination as a "bond". Standard errors, reported in parentheses, are clustered by county for all specifications. The dependent variable considered in the top panel is an indicator variable that's equal to one if and only if the bond was traded in the week; the dependent variable considered in the bottom panel is the number of trades of the bond in the week. The top panel is based on simple ordinary least squares (OLS) regressions while we utilize Poisson regressions for the bottom panel. The coefficient estimates in the bottom panel should thus be interpreted as the ratio of rates. The independent variable of interest, "Post", is an indicator variable that's equal to one only if the week-of-sample is on or after the week that the design values were announced. We also include three indicators for whether the county was: (1) in nonattainment under the old design values but attainment under the new design values (NA→A), (2) in attainment under the old design values but nonattainment under the new design values (A→NA), and (3) in nonattainment both under the old and new design values (NA→NA); we also include the interactions between each of these three indicators and the Post indicator. The regressions listed in all columns except Column 4 are based on trades made in the two weeks before and after the relevant announcement; in Column 4, we consider only the week before and after the announcement. The regressions listed in this table all include fixed effects for remaining years to maturity. The regressions presented in Columns 1 and 4 additionally include county fixed effects and announcement year fixed effects, the regression listed in Column 2 additionally includes CUSIP fixed effects and announcement year fixed effects, and the regression considered in Column 3 additionally includes county fixed effects and state by announcement year fixed effects.

C Data Appendix

This Appendix Section discusses the data sources and data construction process.

C.1 Municipal Bond Data

We collect secondary market data on municipal bonds from the Electronic Municipal Market Access (EMMA) database managed by the MSRB. This database provides information on trade prices and yields for "virtually every municipal security bought and sold".[11] Our data span 2005-2019, noting that 2005 is the first year that municipal bond trades were tracked by the platform. This data-set contains roughly 141 million trades associated with roughly 2.6 million 9-digit CUSIP codes (i.e.: security identifiers). Our analysis requires us to link municipal bonds to the county of issuance. To do this, we use a combination of string matching and manual inspection to match counties to security descriptions; this matching procedure is discussed in the next subsection. Some bonds are issued by institutions in multiple counties while some bonds are issued by state or federal agencies. Our analysis examines how county-level changes in the stringency of environmental regulation impact municipal bonds associated with the county. For this reason, we keep only security descriptions linked to a single county. After this sample restriction is imposed, we are still left with over 81 million trades corresponding to roughly 1.9 million 9-digit CUSIP codes and 3,000 counties.

The trade-level data-set includes the price of the bond, the settlement date, the maturity date, the par value to be paid to the bond holder at the maturity date, and "yield to worst". "Yield-to-worst" is a construct that adjusts the expected return from holding a bond until maturity given its current price, coupon payments, and face value for options embedded in the bond contract (e.g., the reported yield is the lowest return a bond investor would expect given the set of option terms). This measure of bond expected returns is favored (and reported) by the MSRB, and because it reflect expected bond returns to investors, an increase in yield corresponds to an increase in the cost of capital for the issuer.

We calculate the remaining years to maturity for each trade as the difference between the year of maturity and the year of settlement. For ease of exposition, we refer to each

[11] See for more information.

CUSIP/remaining years-to-maturity combination as a "bond" for the remainder of the paper. We aggregate the trade-level data-set to the bond/week-of-sample level as follows. First, "final yield" and "final price" are defined to be the yield and price associated with the final trade in the week-of-sample for the bond. For weeks with no trades, the final yield and price are taken from the last week with a trade. We also take the sum over par value of the trades in the week for each bond; weeks without trades for the bond have zero total value for that week. Similarly, we calculate the total number of trades of the bond in a week, with zeros for the weeks with no trades.

C.2 Matching Security Descriptions to Counties

We match security descriptions in the bond trade data-set to FIPS county codes using a combination of string matching and manual inspection. The string matching consists of the following steps. First, we obtain the set of unique security descriptions in the trade-level data from 2005-2019. These descriptions often include the county name as part of the string. Consequently, we match a security description to a county if both the state abbreviation and county are listed in the description.[12] The security descriptions often list abbreviations such as "PENN" or "PA" for Pennsylvania; we standardize all references to a state to the default abbreviations used by the United States Postal Service prior to matching. A match is dropped from our final data-set if more than one county name is listed in the security description.

We turn next to matching by school district. The list of school districts in each state can be found at . A security description is matched to a school district only if both the state abbreviation and school district name are included in the description. We drop school districts associated with multiple counties from our final data-set. Finally, we match by city name and state. As before, matches associated with multiple counties are dropped from the final data-set.

We supplement this automated matching process using manual inspection. Specifically, multiple research assistants as well as the authors manually looked for county names, city names, or school districts in the security description and matched to the relevant counties. There are very few cases where the matches generated from the auto-

[12] The list of county names in each state is from

mated procedure differ from the matches due to manual inspection. We thus append the manual inspection matches to those generated using automated matching, again dropping those descriptions matched to multiple counties.

Finally, we merge our matched security descriptions back into the trade-level data-set in order to construct the final CUSIP/remaining years-to-maturity/week-of-sample level data-set used in the analysis.

C.3 Announcement Dates and Design Values

The United States Environmental Protection Agency (USEPA) provides extensive documentation for each of the changes to the ozone standard. This documentation includes the announcement dates for each proposed change to the ozone standard as well as the final rule associated with this proposal. The websites for each of the ozone standards are:

- The 2008 standard: https://www.epa.gov/ground-level-ozone-pollution/2008-national-ambient-air-quality-standards-naaqs-ozone
- The 2015 standard: https://www.epa.gov/naaqs/ozone-o3-air-quality-standards-documents-review-completed-2015

Recall that the USEPA calculates design values for each county in each year. These design values are used to determine compliance with the each of the standards associated with the National Ambient Air Quality Standards (NAAQS). These design values, along with the dates they were announced, can be found at https://www.epa.gov/air-trends/air-quality-design-values.