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Allergy Test:
Seasonal Allergens and Performance in School

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ABSTRACT

Allergy Test: Seasonal Allergens and Performance in School[*]

Seasonal pollen allergies affect approximately 1 in 5 school age children. Clinical research has established that these allergies result in large and consistent decrements in cognitive functioning, problem solving ability and speed, focus and energy. However, the impact of seasonal allergies on achievement in schools has received no attention at all from economists. Here, I use data on daily pollen counts merged with school district data to assess whether variation in the airborne pollen that induces seasonal allergies is associated with performance on state reading and math assessments. I find substantial and robust effects: A one standard deviation in ambient pollen levels reduces the percent of 3rd graders passing ELA assessments by between 0.2 and 0.3 standard deviations, and math assessments by between about 0.3 and 0.4 standard deviations. I discuss the empirical limitations as well as policy implications of this reduced-form estimate of pollen levels in a community setting.

NON-TECHNICAL SUMMARY

In this paper I examine the effect of pollen on school children's performance on mandatory tests of 3rd through 8th graders in the United States. We know from clinical studies that allergies limit cognitive ability. This is the first paper to estimate the impact of a widespread and chronic health problem on student achievement, often measured during the height of allergy season.

JEL Classification: I10, I20, I21

Keywords: education, health, air quality

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The effect of airborne allergens on the cognitive functioning of allergy sufferers has been the subject of much attention among medical researchers. Numerous clinical studies identify effects on fatigue, mood, focus, the speed and accuracy of problem solving and reasoning.[1] There is also a substantial body of research on the effects of common treatments for allergens on many of these same outcomes.[2] Indeed, the advantages of newer generation treatments are their more limited side effects.[3] Surprisingly, the impacts of seasonal allergies in community-based settings have received almost no attention from economists.

Economists have done a substantial amount of research linking exposure to air pollution on child health outcomes and development. Airborne allergens are related to this work on pollutants. However, research on air pollution generally examines the longer-term impact of exposure on development (e.g. birth weight) or health outcomes. In the case of airborne allergens, the physiological mechanisms through which exposure affect seasonal allergic rhinitis (SAR) suggest that unlike pollution, any deleterious effects on cognitive functioning are likely to be immediate and perhaps transitory.

In this paper, I examine whether variation in the airborne pollen that induces SAR is associated with poorer performance on reading and math tests given to students in elementary and middle school. I merge data on daily pollen counts at 16 reporting stations around the country to data on test performance on mandatory

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[1] I review this evidence below.

[2] See Bender (2005) for a review of the literature on both allergy symptoms and treatments.

[3] For example, so-called third-generation antihistamines such as Allegra or Claritan are marketed for their fewer side effects impeding daily functioning.

state assessments and student characteristics from school districts within 10 miles of these reporting stations. Students in grades 3 through 8 are tested every year in each of these districts. Math and reading assessments are given during different weeks (and sometimes different months). Further, assessment dates differ by grade in many districts. So the merged data set provides information on the performance of students in a particular grade on a subject test in each district by year, along with measures of ambient pollen levels, as well as characteristics of the school and student body.

Using these combined data, I identify the impact of exposure to allergens on test performance by making use of this variation in testing dates across districts, subjects and grades, along with the fact that the timing and volume of seasonal allergen peaks vary over time and space. This sets up a clear natural experiment whereby we can assess the direct effect of seasonal allergens on performance on state tests. Further, because I know daily pollen counts, as well as the dates on which tests were taken, I am able to estimate contemporaneous as well as leading and (lag effects) of pollen levels on math and reading achievement. Later, I discuss the relevance of this design compared to those involving student-level randomization. Here, it is important to recognize the current design is relevant for understanding aggregate impacts. In school settings, these aggregate measures are widely used, and form the basis of accountability systems in education.

The first task of the paper is to describe the biological mechanisms through which pollen affects SAR and its subsequent symptoms. In doing so, I summarize clinical evidence on the cognitive and affective effects of SAR. I then describe the data and the empirical framework. I follow this with descriptive statistics and graphical analyses of joint variation in ambient pollen and test performance, along with the main empirical results. In the final section, I discuss results and their limitations, and consider their value both for understanding the effect of pollen on community level measures of cognitive performance, as well as for understanding inter-temporal variation in educational assessment systems.

Background:

Seasonal allergic rhinitis (SAR) is the term clinicians use to refer to pollen allergies, often referred to as hay fever.[4] Pollen is comprised of grains produced by plants as part of the reproduction cycle (NIAID, 2012). Many trees and grasses produce large quantities of fine grains and rely on the wind to spread pollen from one plant to another for reproduction. SAR is a reaction induced in the bodies of some people to these pollen grains that are otherwise not harmful to humans (NIAID, 2012). The allergic reaction is due to the combination of immunoglobulins that target allergens with receptor cells releasing chemicals to combat the perceived threat. These chemicals include histamine and cytokines which cause inflammation of tissue and increased secretion of mucus membrane (Janeway et al. 2001). These are the common symptoms of SAR including nasal congestion and watery eyes, and irritated throat.

These chemicals and symptoms can also affect levels of fatigue, cognitive function, and mood. The most obvious mechanism through which an allergic

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[4] While SAR is commonly called hay fever, fever is not a symptom. However, fever can occur due an infection in the sinuses, a common complication of SAR.

response to allergens affects cognitive function is through effects on sleep. A very common problem suffered by allergy sufferers is interrupted sleep and daytime somnolence (Santos et al. (2006)). Cytokines as well as histamines are involved in brain function, affecting cognition, and memory (McAfoose and Baune (2009) and Tashiro et al. (2002)). Additionally, cytokines appear to affect mood, and have been linked to mood disorders, such as major depression (Kronfol and Remick (2000)).

While SAR is a chronic condition, the task of estimating its prevalence in the population is difficult because many sufferers do not seek treatment, and a confirmed diagnosis requires a skin test (NIAID, 2012). The estimate from the National Health Interview Survey is that 7.3 percent of Americans have been diagnosed by a physician with hay fever in the 12 months prior to interview. [5] Metzler et al. (2009) estimate the prevalence of SAR in the community at 16 percent, while the Agency for Health Care and Quality estimates that prevalence ranges between 10 and 30 percent. By all accounts, prevalence is higher among children than adults, with some estimates as high as 40 percent. There is also evidence that prevalence is rising (Linneberg et al., 2000).

Perhaps because of its chronicity and generally mild symptoms, SAR has received almost no attention from economists studying the costs and consequences of disease. However, there is a sizeable literature in medicine on the effects of SAR on functioning. Much of this work is based on clinical lab research, comparing subjects with a history of SAR in various settings. For example, Wilken et al. (2002) randomly divided subjects with SAR into a group exposed to pollen and a control

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[5] http://www.cdc.gov/nchs/data/series/sr_10/sr10_256.pdf

group, and found that the exposed subjects scored lower on measures of computation and reasoning ability, and had longer response times and more difficulty with attention. Marshall et al (2000) find similar patterns for subjects with SAR when comparing tests administered during allergy season to those administered when pollen levels were essentially zero. Regardless of the design for establishing the treatment-control comparison, clinical studies overwhelmingly find lower measured cognitive processing abilities and speed among symptomatic SAR subjects (e.g., Bender, 2005; Druce, 2000; Marshall and Colon, 1993; and Fineman, 2002). It also appears that typical medical treatments do not offer much protection from fatigue and decrements in cognitive functioning (Bender, 2005, and Kay 2000).

The only evidence of which I am aware of the effects of SAR on school children in a community setting comes from a case-control study of nearly 2,000 British teenagers. Walker et al (2007) compare students in one region of the UK who had a history of SAR with students with no such history as they sat for the General Certificate of Secondary Education (GCSE) exams, which are important determinants of post-secondary placement. Importantly, practice CGSE exams are administered in winter, and then the actual exams in June, a period of high grass pollen in the region. The authors used a type of difference in difference analysis by comparing practice scores to final exam scores, and find that students with SAR are 40 percent more likely than comparison students to score one grade lower in one of three core subjects of the final than the practice CGSE, and 70 percent more likely to score lower if they reported taking antihistamine treatment at the time of the final exam (Walker et al (2007)).

In sum, the negative effects of SAR on cognitive functioning have been well established in clinical settings, and there is some evidence that seasonal allergens adversely affect performance on high school end-of-course exams. To date, however, there is has been no work done on whether and to what extent variation in environmental allergens have an effect on measures of cognitive problem solving regularly given to students across the country.

Empirical Framework:

To examine the relationship between seasonal allergens and cognitive problem solving on state assessments of math and reading achievement, I compiled a data set from sources of two types. First, I obtained daily pollen counts from January 2003 through October 2012 from the National Allergy Bureau (NAB), of the American Academy of Allergy, Asthma and Immunology. The NAB data provide daily records of total (and constituent) pollen counts at recording stations around the country.[6] The NAB stations report the accumulated number of pollen grains per cubic meter (grains/m^3) of air in a 24-hour period. Pollen counts of this type are the basis of reports on weather news and sites, such as The Weather Channel. In Table 1, I list the location of the weather reporting stations for which NAB data are available.

The second sources were state and school district accountability data systems, websites and staff. The school systems included here are those for which some portion of the district was within 10 miles of the site at which pollen levels were measured. So, for each NAB reporting station, I merge data for at least one

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[6] Some but not all stations report during the winter, with stations in more temperate zones more likely to report 365 days per year.

school district. Many allergen reporting stations are located within geographically large school districts, and only data from one district is relevant. In other cases, reporting stations are matched to two or three proximate districts. One reporting station (Cook County, Illinois) in an area with very small (geographically) districts and is matched to seven school districts. In total, I use data from 48 school districts, so that the average reporting station is matched to 3 school districts.

From each school district, I obtained data on the percent of students who scored at the level of proficient or advanced on state math and English language arts (ELA) assessments, as well as student characteristics such as race and free/reduced price meal (FARM) eligibility, and teacher to student ratio. While districts across the country report the rates at which students are proficient (or advanced) on state assessments as part of the reporting requirements under the NCLB, state assessments differ on their rigor. Indeed, these differences and critiques of low standards (e.g. Peterson and Hess, 2008) have been an impetus for the recent push (and push-back) for states to adopt standards based on the Common Core. Because the rigor of tests varies by state during this period, all models include fixed effects to capture across-state mean differences in proficiency rates.

For each district in the sample, I also obtained information on the dates state assessments were administered. Using these dates, I calculate the mean level of pollen in the atmosphere during the testing period for each grade/subject in a district. I compile these data into a district/grade/subject/year panel measuring test performance, school characteristics and ambient levels of pollen, with records for all students, and for students by race and FARM status.

Using these data, I estimate a series of models of the following type

$$P_{gdt} = a + b_1 Pollen_{gdt} + b_2 X_{dt} + \ \alpha_g + f(d,t) + \epsilon_{gdt}$$

where P_{gdt} measures the proportion of students scoring proficient or advanced on their state assessment in grade g, in district d during year t.[7] $Pollen_{gdt}$ is a measure of pollen in the atmosphere at the time the test was administered. I discuss the measure of pollen in more detail below. X_{dt} measures the year-specific percent of students in the district eligible for free/reduced price meals; the percent of student who are black; the percent of students who are Hispanic; the pupil-teacher ratio; and per-pupil expenditures on instruction. α_g is a grade fixed effect and $f(d,t)$ represents various parameterizations of district/time effects. I estimate models that include district and year fixed effects; district fixed effects and common time trends, and; district fixed effects and district-specific linear trends. All of these models are estimated separately for math and ELA assessments. In all models, standard errors are clustered at the district-grade level.

Insight into how to model the relationship between pollen and test outcomes can be obtained from the medical and epidemiologic literature on the relationship between levels of atmospheric pollen and symptomatic response. That literature is robust and commonly finds that SAR symptoms or complications rise quickly with pollen count, and then plateau. This type of dose-response pattern is common in studies regardless of how outcomes are measured, including: 1) Doctors visits for

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[7] In three of the states in which sample districts were located, assessment scores were changed or re-scaled the study period: South Carolina, Tennessee, and New York. In these cases I include indicators to pick up mean shifts associated with the re-scaling.

symptoms of SAR; 2) Emergency clinic visits for complications like asthma, or; 3) Sales or consumption of drugs used for treating SAR (Caillaud et al., 2014a). In studies using these measures, pollen counts of less than less than 100 grains/m^3 and as low as 30 grains/m^3 are associated with response, and higher pollen counts do not appear to result in proportionally higher levels of symptomotology (e.g. Erbas et al., 2007; Johnston et al, 2009, and; Caillaud et al, 2014b). This dose-response pattern is reflected in a common metric for reporting pollen levels: the Padgett Pollen Indicator (PPI). The PPI distinguishes between days with low, moderate, high and extreme levels of pollen in the air. The PPI defines days with pollen counts in excess of 15 grains/m^{3}as moderate; counts in excess of 90 grains/m^3 as high; and pollen counts above 1500 grains/m^3 as extreme.

Because of this dose response pattern, I include measures of pollen in log form. On its own, the log transformation is consistent with the clinical dose-response pattern, since it is more sensitive to variation at the bottom of the distribution. Figure 1 further makes clear the advantage of the log transformation. The figure displays the distribution of pollen counts during testing periods, which is highly skewed.[8] In addition to continuous measures of pollen count, I also estimate models using the PPI to measure variation in pollen levels.

To begin to understand how changes in the levels of pollen in the atmosphere and might affect performance on state assessments, in Table 3 I present descriptive statistics on pollen levels at NAB sites during test dates at proximate school

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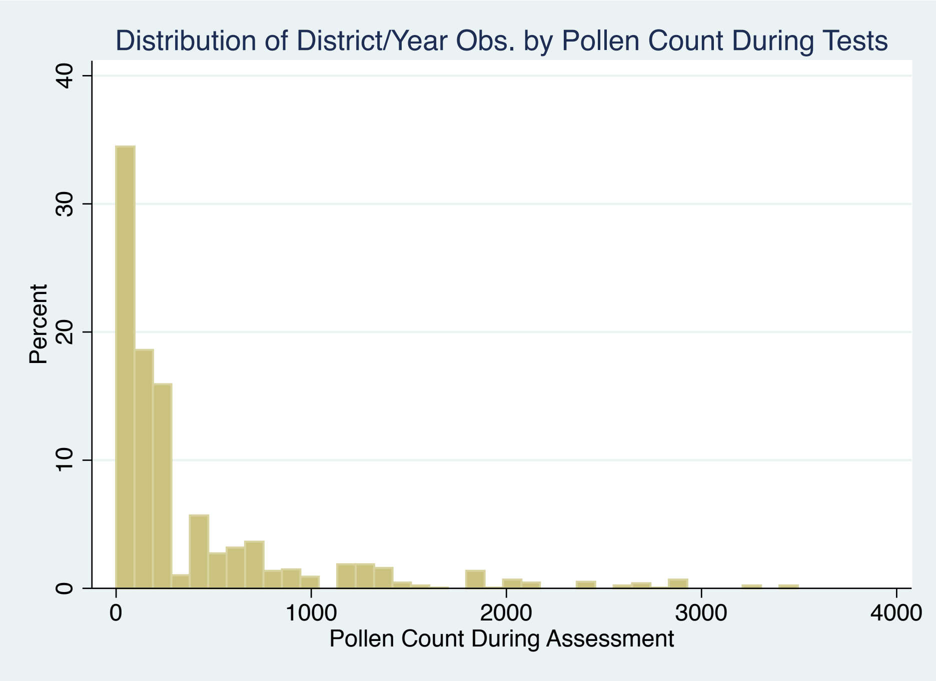
[8] The empirical results are not sensitive to the decision to measure pollen counts in log form. Nonetheless, goodness-of-fit tests confirm the superiority of the use of logs.

districts. In addition to the mean level of pollen during test dates observed over the panel, this includes the standard deviation and extreme values. It is clear that mean levels of pollen vary from site to site. More interesting, though, is the substantial within-site variation. Several sites administer tests when the pollen level is very low (<15) in some years, and extremely high in others. It is this sort of within district variation in pollen levels that I exploit in the models below.

Figure 1



Results:

In order to provide context for the analyses to follow, first consider descriptive statistics for the districts under study here. In Table 2, I present summary statistics of proficiency rates and demographic and economic characteristics of the analytic sample. Two features of the sample are worth noting.

First, the districts included are generally urban or suburban. This is reflected in the proportion of students of color, as well as rates of FARM eligibility. Second, there is substantial heterogeneity within the study sample, with wide variation on proficiency rates as well as student characteristics.

As an initial way to assess the correlation between levels of pollen in the atmosphere and proficiency rates on state assessments, consider the scatterplot and fit of the relationship between the two in Figure 2. Each data point in the plot represents a combination of the proficiency rate and pollen levels for students in a district/year for 3rd graders in math, net of district (and group) fixed effects, and district trends. Both visual analysis and the linear trend indicate that years when students score below expectations for a district, given the district's trend (i.e. below 0 on the y-axis), tend to be years when students in those district are exposed to higher levels of pollen than typical in the district (i.e. above 0 on the x-axis).[9]
An alternative way to assess the joint variation in atmospheric pollen and test performance is to plot mean proficiency rates and allergen levels within a district over time, net of district means and trends. Figure 3 displays time series of mean proficiency rates of 3rd graders in math in all school districts (measured on the left axis) and pollen levels (measured on the right axis). The two time series do appear to move in opposite directions from year to year. For example, the two years with the highest test scores over district averages and trends (2009 and 2011) are also the years with the lowest levels of atmospheric pollen. It is also clear, however, that any inverse relationship between the two time series is certainly not perfect.

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[9] The coefficient on the linear fit is -1.81, with a standard error of 0.406.

Figure 2

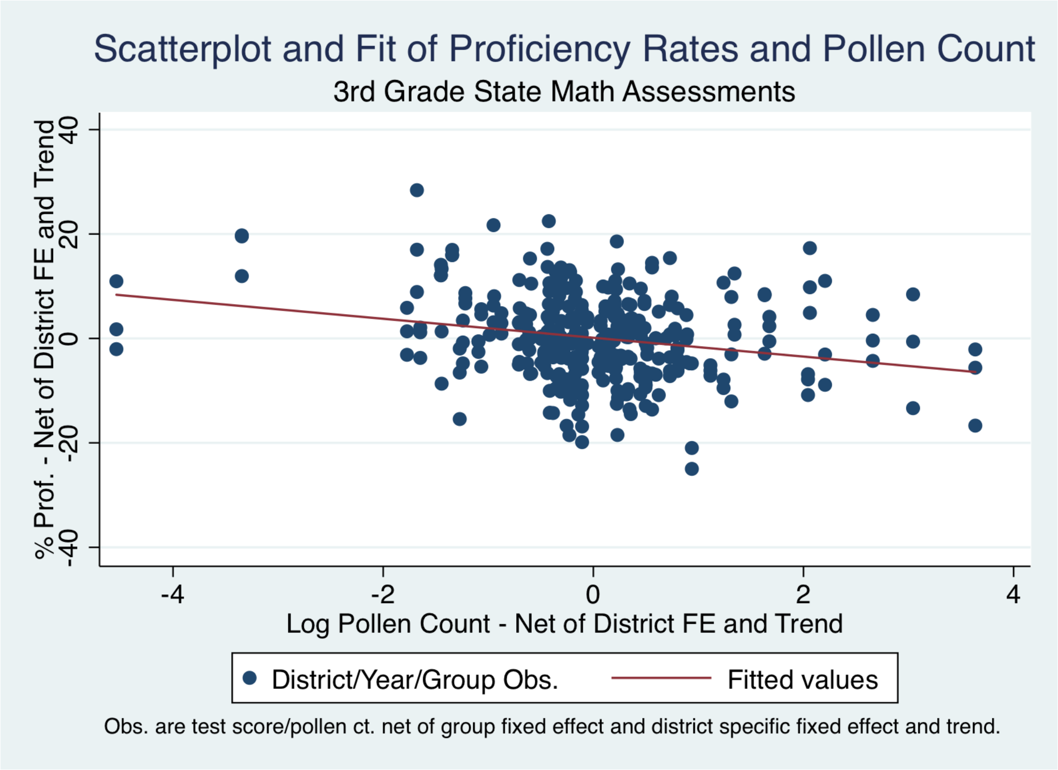
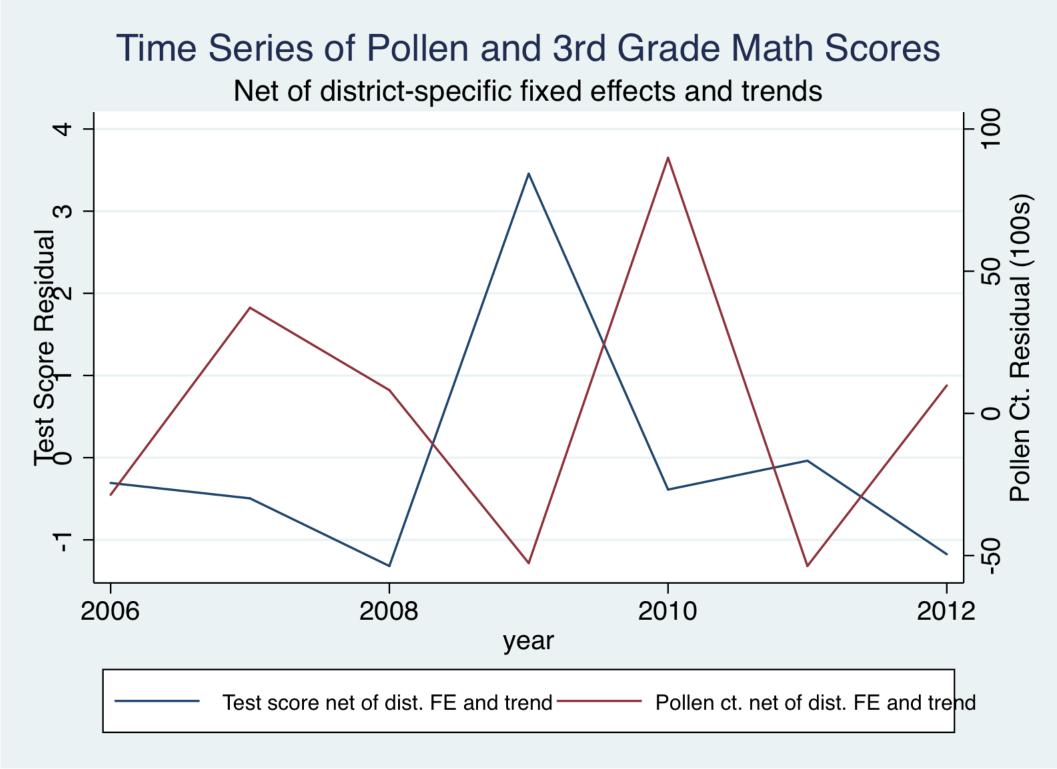


Figure 3



Multivariate Results

To better assess whether any relationship exists between ambient pollen levels and performance on state assessments, I turn next to the results of the multivariate models discussed above. In Table 3 I present the results from three separate sets of regressions, each using different strategies to control for underlying changes in test scores over time. All models are estimated in linear-log form, because of the highly skewed distribution of ambient pollen levels during testing periods. In Model 1 (columns 1 and 2), I present results for ELA and math, respectively, in models with common year fixed effects. In columns 3 and 4, rather than time shifters, I include a common linear trend, and in columns 5 and 6 are the results from models using district specific linear trends. The first two models are robust to unmeasured changes in cohort quality or environmental factors that affect all students, either as mean shifters or in linear form. The last model is robust to unmeasured, linear changes in cohort quality or environment that are specific to each school district. In all models, the first coefficient measures the effect of pollen on the rate at which students in a district pass their state's ELA/math assessment, and the only coefficient of interest for 3rd graders. Below this are interaction terms for additive effects for other grades.

Regardless of how underlying trends are modeled, higher levels of pollen during test windows have a negative effect on the percent of students passing state assessments. These are largest for younger students, since the coefficients on the direct (3rd grade) effects are uniformly negative, and the additive effects for 4th and 5th grades are typically negative. Across all models, the effects for students in grades 4 through 7 are statistically indistinguishable from those of 3rd graders in ELA. For math, however, it appears the relationship between pollen and performance is strongest for students in lower grades. Overall, while the negative effects of pollen on test performance are concentrated on students in the lowest grades, effects are qualitatively similar for both subjects and across grades.

To make sense of the magnitude of the estimates, a 100 percent increase in pollen levels is associated with a decline in 3rd graders passing state assessments by between 1.1 and 1.3 percent for ELA and between 1.8 to 2.2 percent for math. To help interpret these estimates, recall that 100 percent increase in pollen levels (at the mean) is smaller than one standard deviation. Scaling this up slightly, a one standard deviation in ambient pollen levels reduces the percent of 3rd graders passing ELA assessments by between 0.2 and 0.3 standard deviations, and math assessments by between about 0.3 and 0.4 standard deviations. These are sizeable effects compared to other changes in education settings often discussed, such as changes in class size or teacher quality. However, they are a bit smaller than effect sizes on memory, problem solving speed and reasoning measured in clinical settings, which range from 0.30 to 0.65 (Wilken et al. (2002)).

In Table 4, I present results of the Model 1 estimated for two important subgroups of students: black students and economically disadvantaged students, as proxied by FARM eligibility. I present results for these two subgroups because they are important in educational accountability, and because disadvantaged groups are less likely to receive diagnosis and treatment for many health conditions, so could represent groups for which policy levers to improve access to care may be especially beneficial. For both groups, the patterns observed in Table 3 for all students generally persist. The deleterious effects of ambient pollen are seen especially in math, and they seem to be less severe in 8th grade. Importantly, however, the point estimates for these subgroups in math are larger (in absolute value) than those observed for all students in Table 3.

Specification Checks

While the results suggest high levels of pollen reduce performance on primary school math and reading exams, they are surely open to questions about functional form and model specification. The results in tables 3 and 4 are from models that restrict the effect of ambient pollen on achievement to be linear in logs. Recall, that research in clinical settings has often found the effects of pollen levels on allergy symptoms, physician visits or drug sales to rise quickly and plateau, and that pollen levels of 30 to 100 grains/m^3 are typically associated with substantial symptom response. To allow for this type of relationship, I estimate models in which the pollen levels are measured using the PPI index of severity. In addition to being widely used, employing the PPI allows for relatively flexible non-linearities in models of test performance.

In the first panel of Table 5 I present results from models in which pollen levels are measured as a series of indicators of the PPI index, where the omitted category is the lowest level of pollen. Because indicator models with multiple measures of pollen interacted with six grades would have too many coefficients of interest, I estimate this models restricting the effects of pollen to be common across grade, and including grade fixed effects.[10] In order to conserve space, I present estimates for Model 3, which includes district-specific linear trends. This is the most flexible and robust specification, providing the clearest pre-post comparison. In any case, as in the previous tables, results are highly similar across specifications. For both the ELA and math exams, the rate at which students pass assessments is lower at any ambient pollen level other than the lowest level ($< 15/m^3$). I estimate that when tested on days with pollen in the moderate rather than low range, about 3.5 percent fewer students pass ELA exams and 4.9 percent fewer pass math exams. Notably, for neither subject do higher levels of pollen (high or extreme) generate lower levels of achievement.

An alternative threat to validity for the findings presented in Tables 3 and 4 is that high levels of ambient pollen could occur during periods of relatively high levels of air pollution, and hence be picking up the effects of low air quality more generally. One reason this might not be a particularly worrisome concern is rooted in the mechanisms through which pollution, rather than pollen affects cognitive performance. The impact of air pollution on child development is mainly thought to operate through irritating lungs, causing respiratory problems, increasing risk of infection, and slowing growth and development in early childhood (Currie (2005)). Unlike the physiologic reactions that link variations in levels of allergens with contemporaneous changes in cognitive functioning, the effects of pollution on cognitive ability are likely to be chronic, and develop over years. Of course, acute

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[10] To the extent that the weak evidence from Tables 3 and 4 are consistent with different effects by grade, this across-grade average may understate effects in lower grades and overstate effects in higher grades.

respiratory response to high levels of pollutants can cause distress in affected children, making performance on math and reading tests a second order concern.

To provide some evidence of the impact of pollutants separate from airborne pollen, I make use of data collected by the U.S. Environmental Protection Agency (EPA) at air pollution monitoring sites throughout the country. The EPA collects data on a variety of pollutants. A frequently used measure is airborne particulate matter, but this includes organic particles including dust and pollen. So, I use data on sulfur dioxide (SO_2), which is generated by fossil fuel combustion in power plants, industrial production and automobiles (EPA, 2014). Unfortunately, the EPA monitoring sites do not overlap with the NAB reporting stations well. In some cases, there are no EPA sites near NAB sites, and in others EPA monitoring data is available for only a few years. In total, I am able to obtain EPA data for about 43 percent of site/years for which pollen data are available.

In the second panel of Table 5, I present results of Model 3 from Table 3, but include the SO_2 air quality index as a control, and an indicator variable that for whether or not SO_2 data are missing for a site/year. So the effect of pollution is estimated off of within site variation in pollution for the years when these data are available. The results in Table 5 indicate that SO_2 pollution levels do affect performance on state reading tests, but not math tests. To better understand the relative effects here, the standard deviation of SO_2 aqi is about 9, so coefficient of SO_2 on reading scales to an effect size of 0.108, which is less than half of the effect size of pollen on performance on reading assessments. Importantly, when I include measures of air pollution, the effects of pollen levels on both math and reading tests are essentially identical to the estimates obtained in Table 3.

Discussion and Conclusions

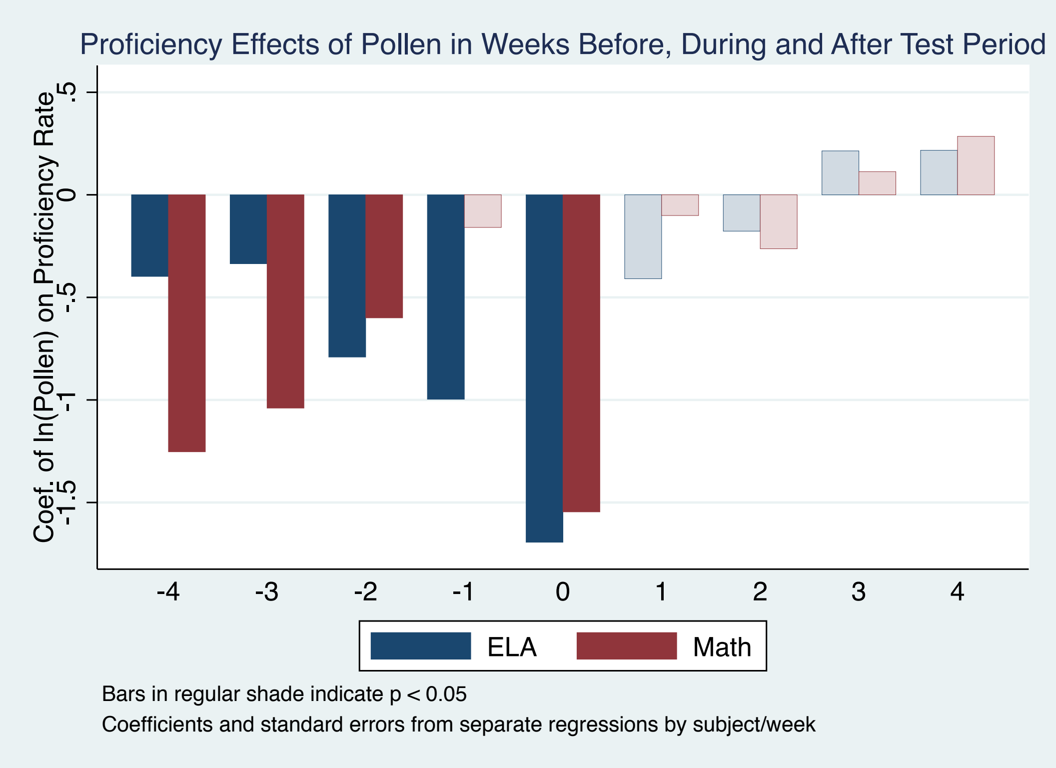
In this paper, I have taken up a straightforward, but important question that has received no attention in the economics literature. Nonetheless, researchers in clinical settings have long understood that the symptoms of seasonal allergic rhinitis affect concentration, problem solving and even mood in ways that impede cognitive functioning. While the evidence from clinical settings is reason to anticipate that natural variations in ambient pollen could affect measures of cognitive performance like state reading and math assessments, there is no way to predict population level impacts without observational data of the type employed here. Of course, the empirical strategy employed here falls short of the randomized control trial design that might be employed by clinical researchers, and the inferences we can draw are subsequently not as strong. The panel models estimated here control for typical measures of student characteristics and school resources, and all inference is drawn from within-district variation and is robust to unmeasured changes in cohort quality or environmental that happen to be coincident with atmospheric pollen.

The threats to inference that remain are variation in inputs or other factors that happen to vary with seasonal pollen and are not measured here. The research design employed here largely rests on the assumption that annual variation in pollen levels during testing periods is as good as random, driven by natural variation that is unrelated to schooling policies. There is no way to put to rest all potential threats to this assumption. But, it is possible to set up a test to assess whether the variation driving the results is due to pollen per se, or something that just happens to be coincidental. This falsification test is to re-estimate models from Table 3, while also including measures of ambient pollen in weeks *before* and/or *after* state tests are administered. Pollen levels in the weeks before tests are administered could affect test performance if symptoms lag pollen levels, but pollen levels after tests are administered should have no affect on outcomes. But, to the extent that inter-temporal variation in pollen is simply correlated with other unmeasured factors that influence test scores, then pollen levels after testing should also be correlated with these omitted factors, leading us to believe in an after-test pollen "effect".

In Figure 4, I present the main coefficients of interest from regressions testing whether there is a before- and/or after-test pollen effect. These coefficient are estimated in separate regression which include controls and specification as in Table 3, including a contemporaneous measure of pollen during the test week(s), as well as pollen in the weeks leading up to the test period, and then after the test period. It is important to control for pollen during the test period, since there is substantial serial correlation in pollen levels. The bars in Figure 5 indicate the magnitude of the coefficient from these regressions on ELA and math proficiency rates: Bars in regular shade indicate statistical significance at the 5% level, while bars in light shade indicate no significant relationship between pollen in a given week and test scores.

For both ELA and math exams, the same pattern emerges between pollen levels leading into, and out of the testing period and student performance. Pollen levels in the weeks leading up to the test window are negatively related to proficiency rates. But, the effect of pollen levels in advance of the test is not as large as the effects of pollen during the period when tests are administered. Further, in no case are pollen levels after the test window related to test performance.

Figure 4



Bars in regular shade indicate $p < 0.05$
Coefficients and standard errors from separate regressions by subject/week

While this falsification test helps provide assurance that the relationship between ambient pollen and test performance observed here is the result of the effects of pollen and thereby SAR on the ability of students to perform on state assessments, there are important limitations of the current study. Most notably, the reduced form approach of the current design cannot tell us about the impact of SAR on the test performance of those affected. Unfortunately, there is simply no community level data available to measure test performance among individuals suffering from SAR compared to those who do not. Diagnosis of SAR requires a skin-prick test that is not possible in any reasonable survey design. In any case, the reduced form strategy employed here is informative about an average treatment effect of atmospheric pollen on test performance. Necessarily, this ATE is likely a poor estimate of effects on individuals. Most students do not suffer from SAR, and elevated levels of ambient pollen likely have little or no effect for them. Indeed, the ATE estimated here is likely comprised of a treatment effect for SAR sufferers, but muted by non-response among those without allergies.

The results of the current paper are relevant for economists studying both health and education. Health economists have made real contributions to the understanding the role that factors like pollution have on child health and development. This paper examines the immediate effects of naturally occurring particulate matter on cognitive functioning. While this relationship has been established in clinical research, the current findings suggest that allergens limit functioning in community settings. This has broader implications than school performance. For example, productivity in the workplace may be affected by exposure to pollen among SAR sufferers who engage in cognitively demanding work.

For economists who study education, the average treatment effects identified here are relevant for understanding whether and how year-to-year changes in test results can be used to measure school or district performance. I estimate that commonly observed variation in ambient pollen levels serve as an important impediment to improvement on state math and reading assessments. The point estimates reported here suggest that proficiency rates for 3rd graders on ELA exams could be 2.5 to 4.5 percent lower if testing occurs during a period of extremely high pollen, compared to typical pollen levels. For math, I estimate the proficiency rates to be 4.5 to 7 percent lower. Effects of this type have direct relevance to understanding the learning or performance effects of a condition that effects a large number of students annually, even as it can be treated at low cost. Further, better understanding the role of extraneous factors like air quality in influencing variation in performance on state assessments is important as administrators continue to refine accountability systems.

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Table 1: Locations of NAB Reporting Stations

Albany, NY
Atlanta, GA
Austin, TX
Baltimore, MD
Chicago, IL
Colorado Springs, CO
Dallas, TX
Dayton, OH
Erie, PA
Greenville, SC
Kansas City, MO
Knoxville, TN
Rochester, NY
San Jose, CA
Seattle, WA
Waco, TX

Table 2 Descriptive Statistics of Analytic Sample

Variable	Mean	Std. Dev.	Minimum	Maximum
Math Prof. Rate	68.13	21.62	2	99
ELA Prof. Rate	70.54	22.39	14.1	99.4
Pollen Ct. During Test	467.7	635.3	0	3,494
Students FARM Eligible (%)	45.55	25.19	0	97.7
Af. Amer. Students (%)	20.29	20.50	0	83.7
Hispanic Students (%)	19.85	18.47	1	68.7
Pupil/Teacher ratio	14.39	2.41	5.9	21.7

n = 1,608

Observations are at the student group/grade level within districts.

Table 3 **Mean Daily Pollen Counts at NAB Sites During State Tests**

Site	Mean	Std. Dev.	Minimum	Maximum
Albany, NY	409.3	818.6	0	2046.6
Atlanta, GA	781.5	512.8	282.4	1307.0
Austin, TX	508.1	326.0	202.7	809.1
Baltimore, MD	69.6	58.5	8.7	166.7
Chicago, IL	8.9	25.4	0	71.7
Colorado Springs, CO	235.7	252.4	0.7	654.3
Dallas, TX	251.5	66.2	183	322.3
Dayton, OH	337.4	195.0	61.5	599.7
Erie, PA	201.9	10.0	190.8	210.4
Greenville, SC	105.8	44.4	64.4	214.0
Kansas City, MO	784.1	979.9	80.9	2860.7
Knoxville, TN	475.5	390.4	233.7	926.0
Rochester, NY	141.0	258.3	0	640.8
San Jose, CA	349.9	423.9	103.9	1383.1
Seattle, WA	127.4	54.5	84.2	207.7
Waco, TX	1140.7	700.9	226.6	2097.7

Table 3 Estimates of Ambient Pollen and State Assessment Results

	Model 1				Model 2				Model 3			
	ELA		**Math**		**ELA**		**Math**		**ELA**		**Math**	
Variable	**Coef.** ***SE***	*Sign.**	**Coef.** ***SE***	*Sign.**	**Coef.** ***SE***	*Sign.**	**Coef.** ***SE***	*Sign.**	**Coef.** ***SE***	*Sign.**	**Coef.** ***SE***	*Sign.**
ln(Pollen Count)	-1.242 **		-1.792 ***		-1.138 ***		-1.76 ***		-1.308 ***		-2.23 ***	
	0.546		*0.683*		*0.532*		*0.672*		*0.397*		*0.613*	
ln(Pollen Count) x 4th Grade	-0.303	p=0.005	0.445	p=0.019	-0.31	p=0.006	0.437	p=0.017	-0.289	p=0.001	0.451	p=0.004
	0.297		*0.604*		*0.294*		*0.599*		*0.282*		*0.596*	
ln(Pollen Count) x 5th Grade	-0.422	p=0.002	1.059	p=0.134	-0.471	p=0.002	1.014	p=0.120	-0.398	p<0.001	1.102 **	p=0.006
	0.35		*0.565*		*0.353*		*0.562*		*0.321*		*0.553*	
ln(Pollen Count) x 6th Grade	0.342	p=0.094	1.22 **	p=0.297	0.334	p=0.124	1.204 **	p=0.307	0.35	p=0.013	1.222 **	p=0.031
	0.297		*0.569*		*0.298*		*0.569*		*0.264*		*0.556*	
ln(Pollen Count) x 7th Grade	0.163	p=0.041	1.483 **	p=0.594	0.154	p=0.056	1.468 **	p=0.615	0.163	p=0.003	1.496 **	p=0.144
	0.298		*0.614*		*0.305*		*0.618*		*0.287*		*0.592*	
ln(Pollen Count) x 8th Grade	1.623 ***	p=0.462	1.803 ***	p=0.983	1.573 ***	p=.390	1.755 ***	p=0.993	1.646 ***	p=0.390	1.866 ***	p=0.475
	0.399		*0.676*		*0.391*		*0.672*		*0.401*		*0.672*	
District Fixed Effects?	Yes		Yes		Yes		Yes		Yes		Yes	
Year Fixed Effects?	Yes		Yes		No		No		No		No	
Common Trend?	No		No		Yes		Yes		No		No	
District-Specific Trends?	No		No		No		No		Yes		Yes	
n	1608		1576		1608		1576		1608		1576	
R-squared	0.915		0.862		0.912		0.858		0.938		0.892	

All models control for student demographic and economic characteristics, as described in the text, enrollment and pupil-teacher ratios.
Standard errors (below, in italics) clustered at the district-grade level.
** $p<0.05$
*** $p< 0.01$

* P-value from F-test of joint significance with main effect

Table 4 Estimates of Ambient Pollen and State Assessment Results: by Subgroup

	Black Students						FARM Eligible Students					
	ELA			Math			ELA			Math		
Variable	**Coef.** ***SE***		*Sign.**	**Coef.** ***SE***		*Sign.**	**Coef.** ***SE***		*Sign.**			*Sign.**
Pollen Count	-0.959			-2.615	***		-1.066			-2.597	***	
	0.729			*0.847*			*0.694*			*0.838*		
Pollen Count x 4th Grade	-0.529		p=0.044	0.777		p=0.011	-0.695	**	p=0.01	0.812		p<0.01
	0.358			*0.679*			*0.329*			*0.699*		
Pollen Count x 5th Grade	-0.681	*	p=0.020	1.983	***	p=0.319	-0.769		p=0.006	1.859	***	p=0.212
	0.413			*0.641*			*0.406*			*0.656*		
Pollen Count x 6th Grade	0.379		p=0.423	1.463	**	p=0.091	0.216		p=0.209	1.266	*	p=0.041
	0.33			*0.627*			*0.305*			*0.657*		
Pollen Count x 7th Grade	0.197		p=0.288	1.97	***	p=0.385	0.016		p=0.133	1.592	**	p=0.148
	0.331			*0.687*			*0.357*			*0.701*		
Pollen Count x 8th Grade	1.954	***	p=0.155	2.128	***	p=0.464	1.575	***	p=0.445	1.863	***	p=0.260
	0.461			*0.714*			*0.448*			*0.76*		
District Fixed Effects?	Yes			Yes			Yes			Yes		
Year Fixed Effects?	Yes			Yes			Yes			Yes		
Common Trend?	No			No			No			No		
District-Specific Trends?	No			No			No			No		
n	1204			1171			1309			1282		
R-squared	0.8727			0.828			0.893			0.854		

All models control for student demographic and economic characteristics, as described in the text, enrollment and pupil-teacher ratios.
Standard errors (below, in italics) clustered at the district-grade level.
* p<0.10
** p<0.05
*** p< 0.01

* P-value from F-test of joint significance with main effect

Table 5 Estimates of Ambient Pollen and State Assessment Results: Specification Checks

	Effects for All Grades		Model 3 w/ Controls for Pollution			
	ELA	**Math**	**ELA**		**Math**	
	Coef.	**Coef.**	**Coef.**		**Coef.**	
Variable	***SE***	***SE***	***SE***	*Sign.**	***SE***	*Sign.**
PPI Pollen Level: (Low is reference)						
Moderate	-3.471 **	-4.911 ***	-		-	
	1.515	*1.585*				
High	-2.586 **	-2.686 **	-		-	
	1.075	*1.245*				
Extreme	-2.937 **	-2.428 *	-		-	
	1.29	*1.46*				
Pollen Count	-	-	-1.193 ***		-1.61 ***	
			0.362		*0.547*	
Pollen Count x 4th Grade	-	-	-0.288	p<0.001	0.451	p<0.001
			0.287		*0.575*	
Pollen Count x 5th Grade	-	-	-0.406	p<0.001	1.047	p=0.078
			0.324		*0.535*	
Pollen Count x 6th Grade	-	-	0.352	p=0.01	1.058	p=0.147
			0.267		*0.543*	
Pollen Count x 7th Grade	-	-	0.165	p=0.002	1.332 **	p=0.50
			0.286		*0.579*	
Pollen Count x 8th Grade	-	-	1.639 ***	*p=0.20*	1.659 **	*p=0.91*
			0.408		*0.657*	
Sulfur Dioxide (aqi)	-	-	-0.251 ***		-0.035	
			0.081		*0.084*	
Grade Fixed Effects?	Yes	Yes	Yes		Yes	
District Fixed Effects?	Yes	Yes	Yes		Yes	
Common Trend?	Yes	Yes	No		No	
District-Specific Trends?	Yes	Yes	Yes		Yes	
n	1537	1506	1608		1576	
R-squared	0.9374	0.857	0.938		0.894	

All models control for student demographic and economic characteristics, as described in the text, enrollment and pupil-teacher ratios.
Standard errors (below, in italics) clustered at the district-grade level.
** p<0.05
*** p< 0.01