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You sneeze, you lose: The impact of pollen exposure on cognitive performance during high-stakes high school exams

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You sneeze, you lose

The impact of pollen exposure on cognitive performance during high-stakes high school exams

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Abstract

Pollen is known to cause allergic reactions in approximately 20% of the population. These reactions have significant detrimental effects on sleep, concentration, and cognitive performance. Coincidentally, in many countries the local proliferation of pollen is concentrated in the spring when students take high-stakes exams. Despite these observations, the effect of pollen allergies on school performance has so far received nearly no attention from economists. Using administrative data on Norwegian high school students merged with daily pollen counts, this paper examines the effect of exposure to pollen spores on exam outcomes. I take advantage of the fact that students take several exams in a variety of subjects on different dates, but at the same location, to implement a student fixed effects model. In all specifications increased pollen proliferation on the exam date is found to significantly reduce cognitive performance measured by examination grade. On average, a one standard deviation increase in the ambient pollen level at the mean leads to a 2.5% of a standard deviation decrease in test scores for the average student, with potentially larger effects for allergic students. Supporting the reduced form estimates, the effect is somewhat more pronounced in subsamples with higher prevalence rates of hay fever. Additionally, I find that an increase in the ambient pollen level across exams reduces the probability that a given student graduates on time, and enrolls in higher education. An implication of these findings is that random increases in pollen counts can temporarily reduce cognitive abilities for allergic students who will score worse relative to their peers on high stake exams, and consequently be at a disadvantage when competing for jobs or higher education.

JEL classification: I10, I20, I21

Keywords: High school, test score, graduation, pollen, allergic rhinitis, hay fever.

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1 Introduction

Seasonal allergic rhinitis (SAR), more widely known as hay fever, is a common chronic condition. The prevalence rate varies between countries and regions, with most estimates around 20% for the general population in industrialized countries. SAR is more prevalent among school aged individuals (Skoner, 2001), and is the most common chronic condition in the pediatric population (Jáuregui et al., 2009). The Norwegian Association for The Asthmatic and Allergic estimates that more than 20% of the general population have allergic reactions to pollen, and for school aged children estimates are even higher at about 25-30% (Hansen, Evjenth, & Holt, 2013; Selnes, Nystad, Bolle, & Lund, 2005; Hovland, Riiser, Mowinckel, Carlsen, & Carlsen, 2014). Not only is SAR a relatively common condition, but several studies have also shown that its prevalence appears to be increasing (e.g. Åberg, 1989; Linneberg et al., 2000), raising the need for research into its societal costs. While SAR is commonly considered relatively harmless, the medical literature has established strong negative effects on various measures of cognitive performance and well-being (e.g. P. S. Marshall, O'Hara, & Steinberg, 2000; Kremer, Den Hartog, & Jolles, 2002). Clinical studies have also shown that medicines commonly used to treat the symptoms of SAR can induce similar, or even stronger, negative effects on cognitive functioning.[1] Significant and unavoidable detrimental effects on cognition suggests that students with SAR are at a definite disadvantage when high-stakes tests are taken during pollen season. Combined with high and rising prevalence rates, the timing of high-stakes exams can significantly affect students' long run human capital accumulation by distorting the relative ranking of students.

This paper explores the effect of pollen on cognition by combining rich administrative data from the Norwegian high school system in the years 2008-2011 with daily pollen counts from measurement stations across the country. The data contain information on numerous observable student characteristics in addition to exam grades for each subject and school attended. The location and the date of these exams are merged to data on

[1] Although older generations of antihistamine treatments generally have the strongest side effects, newer generation drug treatments have also been shown to have some negative effects on cognition (e.g. Vuurman, Van Veggel, Uiterwijk, Leutner, & O'Hanlon, 1993; Jáuregui et al., 2009)

pollen counts collected by The Norwegian Pollen Forecast Services. Taking advantage of the resulting panel structure in the data it is possible to implement a student fixed effects model, allowing variation to come from within students over time. The advantage of this approach is that it removes potential unobserved correlation between student performance and pollen exposure, a potential source of bias in previous studies. The main results show that a one standard deviation increase in pollen counts from the mean decreases the average student's score by about 2.5% of a standard deviation. Assuming that non-allergic students are unaffected by pollen proliferation levels, the treatment-on-the-treated effect is likely to be larger. Using estimates for the prevalence rate of SAR from Norwegian 16-year olds, the results suggest that the effect for allergic students is about 10% of a standard deviation. The results imply that random exposure to pollen can have a substantial effect on the exam grade for students with SAR.

Further, I use the available information on student background to explore heterogenous effects. The results found when the effect of pollen proliferation is allowed to depend on student background are consistent with the patterns in the prevalence rates found in the medical literature, lending support to the validity of the reduced form estimations used in this paper. Lastly, I find that being exposed to higher pollen count levels across exams reduces the probability that graduating students enroll in STEM-programs in university, suggesting longer run effects.[2].

The contributions of this paper is twofold. First, this paper estimates the effect of pollen proliferation on cognitive abilities in a non-experimental setting taking into account student sorting across regions with different proliferation levels. The effect on cognition is likely to be transferable to other settings and could potentially affect labor productivity across the economy. Second, the estimations show that random exposure to pollen during examinations reduces test scores for the average student. Affected students are therefore ranked worse relative to unaffected peers, regardless of true ability. As students who apply for university compete on exam scores the enrollment decisions of universities might be sub-optimal. Consequently, random variations in the timing pollen of proliferation can

[2]STEM is an acronym for science, technology, engineering and math.

harm workforce productivity through it's effect on grades and the composition of students enrolled in higher education. It is probably possible to offset this effect somewhat by increasing efforts in diagnosing and optimizing treatment.

The rest of the paper is organized as follows. First, relevant findings of the effect of pollen on cognitive performance as well as related literature is presented in section 2. Section 3 presents the institutional background, while section 4 presents the data and empirical strategy. Main results are presented in section 5, with robustness tests and heterogenous effects are analyzed section 6. Longer-run estimates are presented in section 7. Section 8 summarizes and concludes.

2 Seasonal allergic rhinitis and related literature

2.1 Seasonal allergic rhinitis: Epidemiology and effects on cognition.

Pollen grains are produced as part of plants' reproduction cycle and are spread by wind or insects from plant to plant. The grains are small and are easily inhaled by humans. In a person with seasonal allergic rhinitis (SAR), the immune system will produce anti-bodies, including histamine and cytokines, to fight the perceived threat from the pollen grains. The antibodies will in turn cause an inflammatory state in the airways causing symptoms including itching, sneezing, congested airways, and rhinorrhoea (Greiner, Hellings, Rotiroti, & Scadding, 2012). In addition to the more visible allergic reactions, SAR can also affect cognitive ability and fatigue both indirectly through reduced quality of sleep (Santos, Pratt, Hanks, McCann, & Craig, 2006; Craig, McCann, Gurevich, & Davies, 2004), and directly, as the antibodies have a detrimental effect on cognitive ability themselves (Tashiro et al., 2002; McAfoose & Baune, 2009). Several laboratory studies have confirmed a link between reduced cognitive function and SAR. P. S. Marshall et al. (2000) found that during pollen season clinically diagnosed patients had impaired cognitive functioning compared to tests taken outside the pollen season. Randomizing ragweed pollen exposure on adults with a history of SAR, Wilken, Berkowitz, and Kane (2002) found that allergic individuals who were exposed to pollen performed worse in a number of cognitive measures, including longer response times, reduced working memory, and computation. A similar result was also found by P. Marshall and Colon (1993). While SAR is associated with reduced cognition under certain conditions, it is important to note that treatment of the symptoms has similar effects. Vuurman et al. (1993) found that when exposed to pollen, children with SAR were cognitively outperformed by other children regardless of whether they received medication or not, although newer generations of antihistamines had smaller negative effects than both placebo and older generations. It therefore seems like students with the condition will suffer irrespective of medication use, although optimal usage may dampen effects.

SAR is a very common condition with an estimated 400 million people affected globally (Greiner et al., 2012). The incidence of the condition varies between countries, but is generally higher in industrialized countries.[3] While parts of the variation in prevalence rates between countries can be explained by differences in climatic and demographic factors, lifestyle also play a major role. Comparing the children born in the former East- and West-Germany, Krämer et al. (2010) found that the convergence in lifestyles coincided with a convergence in the prevalence rate of SAR. The fact that lifestyle is so strongly linked to prevalence rates is interesting as it suggests that the condition might be even more common in the future. Whereas the findings in Krämer et al. (2010) suggests that countries approaching a more Westernized life-style will see increased prevalence rates of SAR, other studies have found a positive trend within Western countries as well (Hansen et al., 2013; Linneberg et al., 2000). Though the exact reason for this development is unknown, it is believed to be associated with changes in exposure to various allergens in early life and a general change in lifestyle (e.g., Bråbäck, Hjern, & Rasmussen, 2005; Mutius, 1998). The rising prevalence rate of SAR combined with its effect on cognition makes it a particularly interesting topic to study in an education economics perspective.

In Norway, the prevalence rate of SAR is estimated to be similar to other Western

[3]In addition to a large variation in estimated prevalence across countries, estimates within countries are very uncertain and depends how prevalence is measured. As one might expect self reported numbers are generally much higher than what is clinically documented, but many that are allergic are not themselves aware of it (Greiner et al., 2012). The connection between socio-economic background and SAR is discussed and explored in section 6.

countries, and several studies have placed it at approximately 20% of the total population, with higher numbers for the young (Weinmayr et al., 2008; Bakke, Gulsvik, & Eide, 1990; Selnes et al., 2005). In a particularly relevant study, Hovland et al. (2014) clinically documented SAR in almost 26% of 16 year-olds in Norway. The high prevalence rate makes SAR the most common chronic medical condition in the younger population (Jáuregui et al., 2009), affecting life quality (Mir, Panjabi, & Shah, 2012), sleep patterns (Craig et al., 2004) and cognition in a large share of students. The combined negative effects might have a major effect on the productivity of individuals with SAR. Hellgren, Cervin, Nordling, Bergman, and Cardell (2010) estimate that the societal costs of SAR in Sweden alone are 2.7 billion euros annually, largely due to absenteeism. More relevant for the current study is that it has been estimated that US school children lose around 2 million school days a year due to the various allergic reactions to pollen, including somnolence in the daytime, lack of sleep, and concentration problems (Arrighi, Cook, & Redding, 1996). Considering the potentially large effects on human capital accumulation, the economics literature on the subject is surprisingly small.

2.2 Related literature

In the economic literature there has been substantial work done in estimating the effects of various types pollution on health and cognitive performance. Although most of these studies evaluate long-run impacts of various pollutants, some newer studies focus on more immediate effects.[4] In a recent contribution Lavy, Ebenstein, and Roth (2014) explore how daily variations in ambient air pollution affects high-stakes test scores in Israeli high schools. The authors take advantage of the panel structure arising from students taking multiple exams on various days with different amounts of pollution. Using student fixed effects, they estimate that increasing the ambient concentration of fine particulate matter and carbon monoxide one standard deviation from their daily averages reduces test scores by 2.8% and 2.4% of a standard deviation respectively. While pollen from plants is not

[4] For example by taking advantage of random variation in the levels of sulfur dioxide in Mexico City Hanna and Oliva (2014) find that higher levels are associated with a negative effect labor supply. And using variation in ozone levels J. S. G. Zivin and Neidell (2011) find a negative effect on labor productivity on farm workers.

commonly categorized as a pollutant it still has a negative impact on allergic individuals, and enters the ambient environment in a similar way as air pollutants. Estimating the effect of pollen proliferation on students' exam performance is therefore methodologically and conceptually a related exercise.

To the author's knowledge only two previous studies have explored the effect of pollen and SAR on school performance outside the laboratory setting. Both found significant negative effects on performance. In the UK students take a high stakes exit exam towards the end of secondary education, the General Certificate of Secondary Education. While the actual examination is carried out in the spring and summer, students take practice exams in the preceding winter. Walker et al. (2007) used grade information from these exams merged with data from questionnaires to assess the impact of SAR symptoms on exam performance. The questionnaires were administered on the day of the exam and provided information on subjectively experienced pollen symptoms. Comparing the results from the test exam and the actual exam the authors found that students who experience symptoms of SAR are 40% more likely to fall at least one grade between the exams compared to students without symptoms. Additionally, for students who reported using sedating antihistamines on the day of the exam, the probability of scoring at least one grade lower rose to 70%. While Walker et al. (2007) present new and novel evidence on the effect of SAR on exam outcomes, there are some problems with the identification strategy. The self-reported prevalence of SAR is generally higher than what is confirmed through clinical documentation, which could lead to a biased estimate of the effect. Further, students who expect to perform poorly at an exam might be inclined towards answering yes to questions on symptoms of SAR. Combined, these observations call for further evidence on the effects of pollen exposure on exam performance for students with SAR.

Marcotte (2015) combines US school district data on test scores with data on pollen counts. In a variety of models he finds a robust negative effect of pollen proliferation on average test scores. The main result reported is that a one standard deviation increase in the ambient pollen level decreases the share of 3rd graders passing the ELA assessment by 0.2-0.4 standard deviations, with smaller effects for older students. There are some no-table differences between the current paper and Marcotte (2015). First, this paper takes advantage of rich administrative data on individuals as opposed to school district data. The data contains multiple observations on exam grade for each individual allowing for a student fixed effects approach. Student fixed effects makes it possible to compare cognitive performance for a given student when exposed to different levels of pollen proliferation, netting out other unobserved student characteristics. This is important as student characteristics might be correlated with the exposure to pollen. For example students in cities might be less exposed to pollen and at the same time have parents who are more engaged in compensating measures to dampen the effects of SAR on school outcomes. Second, the students in the data used herein are older, from age 16 and above. Because the prevalence of SAR is known to be smaller in older age groups the effects can not be expected to be the same. Third, this paper moves one step further, and consider longer-run effects measured in graduation probability and the likelihood of enrolling in university. Last, this paper explores the role of weather condition and ambient air pollution variables as controls in combination with pollen proliferation, netting out any direct effect from these potential confounders.

3 Institutional background

The Norwegian school system consists of ten years of compulsory schooling, starting the year students turn six, and an elective high school education. It is not possible to fail a class in mandatory schooling, implying that grade repetition is practically non-existent and nearly all students graduate from mandatory schooling at age 16. In this study all students who do not finish mandatory schooling at the normal age are dropped from the sample. Roughly 95% of students choose to enroll in the elective high school education the fall after graduating from mandatory schooling. High school is tracked and consists of 12 tracks that can be grouped into two broad categories: the academic track and the vocational track. Exams in the vocational track often have a practical part and it is not possible to identify which exams this applies to. For this reason only students in the academic track are included in the analysis. The academic track lasts three years and grants graduating students eligibility to apply to higher education. Of the students choosing to enroll in high school the year they turn 16, roughly 50% opt for an academic track. In the academic track, exams are either oral or written and can be identified as such. For comparability to other studies, and because oral examinations are likely to be influenced by non-academic characteristics of the student, only written exams are used in the analysis.[5] The curriculum is comprehensive and standardized at the national level, with standardized written exams for each cohort.

4 Data and empirical strategy

4.1 Dependent variable

The main dependent variable in the analysis will be the grade awarded on written exams for students enrolled in the academic track. Exams are high-stake for two reasons. First, a passing grade is required in all exams in order to graduate. Second, students compete on GPA, including exam scores, for placement in higher education. Individual grade records are collected from register data made available by Statistics Norway and cover the period 2008 to 2011. The data contains identifiers on the course the grade is awarded in and the exam date for all students and all courses. Exam scores run from 1 as the lowest to 6 as the highest and are distributed in a bell shape-like with 4 as the median grade. In all estimations the exam grades are standardized to a mean of zero and a standard deviation of one by course-exam year. Exams are anonymized and graded class-wise by 2 external sensors that teach the same course at a different high school. Anonymity is especially important in the current setting for at least two reasons. First, SAR is generally not evenly distributed between genders, races, and potentially even social background (e.g., Chen, Krieger, Van Den Eeden, & Quesenberry, 2002).[6] If the grading is influenced by

[5]In the oral examination the class teacher and an external censor are present under the examination. Oral examinations are more likely to be influenced by non-academic characteristics of the student than written exams. Because the symptoms of SAR are highly visible to the censor, including oral exams could bias the estimations if it influences the grade awarded.

[6]The connection between socio-economic background and SAR seems to have weakened dramatically the last decades. Several recent studies find no correlation between the two. This is explored closer in

either of these factors, it could bias the estimates through spurious correlations. Second, if the teacher personally knows the student and if the student has SAR, it could also affect the grade awarded by the teacher as symptoms of SAR often are highly visible to others.

In the data, the number of exams each student takes in high school varies somewhat due to three factors. First, some students in the sample drop out of high school and therefore do not take the required number of exams needed to graduate. Second, the number of exams taken is not the same for all students who graduate due to exemptions and because a minority of students are randomly assigned to take a written exam the first year in high school.[7] Finally, some students retake exams to achieve a passing grade of a higher score. The student fixed effects framework used in this paper requires all students to take at least 2 exams. Students who take only one exam are consequently dropped from the sample. Students who retake exams are identifiable; results from second attempts on any exam are also dropped from the sample. In the final dataset, the majority of students take 2 to 5 exams, with the median student taking 4 exams. This is consistent with the normal number of exams students take in high school.[8]

4.2 Pollen data

Pollen data are provided by The Norwegian Pollen Forecast Services that operates twelve stations with pollen traps located across Norway (H. Ramfjord, 2005). The number of pollen grains collected in each trap is counted and used to estimate the number of grains per cubic meter (g/m^3) in 24-hour intervals for the 6 main types of pollen spores spread in Norway. Of these, only 3 are registered in the period when the exams are held in any of the years used in the analysis.[9] These 3 are grass, birch, and salix (from willow). To reduce attenuation bias only students who live within the same municipality as the stations are

section 6.

[7]Students can apply to be exempt from taking the exam in one of the two written forms of Norwegian if they have a native language that is not Norwegian or have sufficient difficulties reading.

[8]That is: one exam in a randomly picked elective course the second and third year and one exam in each of the two written forms of Norwegian language in the third year. Elective courses are typically science, math, foreign languages, or social sciences. Arts and music are not options, unlike what is the case in the US.

[9]See figure A1 in the appendix for an overview of the pollen seasons in different regions.

included in the sample[10].

Every day the data collected from the stations are analyzed and used to create forecasts for the spread of pollen the next day for all of Norway divided in to twelve regions. These forecasts are available to the public through newspapers, the internet, and other media outlets. Individuals who know that they are allergic are therefore able to adapt medication usage based on the forecasted pollen spread in their region. Although there are twelve municipalities with stations only the 8 will be used in the main analysis. This is because the 4 largest ones are dropped to reduce attenuation bias[11].

4.3 Other variables

In addition to the grade awarded on written exams, the data contains information on a rich set of student characteristics including gender, immigration status, and parental education and income, as well as dummies for whether parents are working or not. The student fixed effects approach adopted in this paper will not allow these characteristics to enter directly in to the regressions as controls, but will allow for several useful subsample analyses that can lend support to the reduced form identification strategy used. In particular, the prevalence rate of SAR is generally not independent of observable characteristics, but is more common among boys, and tends to correlate with measures of socio-economic background. If the estimated effect of pollen exposure is indeed causal and not spurious, one might expect it to vary along the established variation in prevalence rates from the medical literature. Following the main results a subsample analysis is conducted in section 6.

Further, the data contains information on the teacher-assessed grade for most student-exam observations. While the teacher assessed grade carries some information on students' subject-specific skills, it is well known that it might be biased because teachers can be influenced by non-academic characteristics of students in their grading. This has also been shown to be the case in the Norwegian setting by Falch and Naper (2013) who found

[10] This cause a significant reduction in sample size, but are not driving results as shown in table 3.

[11] The four stations that are dropped cover sparsely populated areas with municipalities larger than 1.000km^2. Dropping these stations are not driving the results as shown in table 3.

that girls were more likely to receive a higher grade from their teacher relative to the exam grade compared to boys in middle school. In itself, bias in the teacher-assessed grade is unproblematic as long as the grade is not influenced by the students' exam performance. However, it is not clear if teachers actually grade students prior to the written exam. Teachers could therefore potentially adjust their grading relative to how students perform on exams. If this is the case, the course grade a student receives could be an outcome variable and hence constitute a so-called "bad control", biasing the estimates (Angrist & Pischke, 2008). Consequently the teacher-assessed grade will not be part of the main estimations, but will be included in alternative specifications.

The data also contain information on the municipality of residence for students the year they graduate from mandatory schooling. This will be the variable that links students to pollen spore counts.[12] Lastly, there are identifiers for the high school students enrolled into the autumn following graduation from mandatory schooling, although not the school's location.

Pollen proliferation is affected by weather in many ways. First, plant growth rates and pollen production is directly affected by climatic conditions in a complex way. The accumulated number of sunshine hours, average temperature and rainfall play major roles. Second, the consequent spread of pollen spores is affected by the same weather variables. Pollen spores spread more effectively when there is more wind, less precipitation and humidity. Also, weather has been found to affect cognitive performance and mood in some settings (e,g, Keller et al., 2005). Additionally J. G. Zivin and Neidell (2014) showed that particularly warm days are associated with a reduction in labor supply and increased leisure consumption. While their findings were strongest for workers in sectors with a high exposure to climatic factors, a similar effect could occur among students. Because weather is known to affect pollen spreads and potentially could affect the test performance of students, it is relevant to control for weather conditions. Weather data is collected on

[12]This measure is not ideal for at least one reason: A handful of students move to other municipalities to attend the high school track they prefer. This problem is mitigated by a combination of two observations. The first observation is that pollen forecast zones largely follow the county borders. The second observation is that nearly all students attend high school in the county in which they lived at age 16. Therefore the pollen forecast matched to individuals will largely be correct as long as individuals do not move into a different county.

the municipality level from stations run by the National Meteorological Institute. Which weather variables are collected in the different municipalities varies with some systematic characteristics. More populated municipalities are more likely to have a weather station and more likely to have reports on a larger number of weather variables. This means that including weather variables as controls effectively alters the sample to only include students living in these areas, as well as reducing the sample size. For this reason weather controls are not included in the main analysis, but are rather used to show that the point estimates remain unaffected when weather variables are controlled for. The weather variables used in the analysis will be air pressure, total daily precipitation, average daily temperature, and average wind speed.

The identification strategy used in this paper relies on variation in the pollen count between tests on different dates for the same student. The main concern with this identification strategy is that other variables that are correlated with both pollen counts and exam scores might be driving the estimated results. Like weather conditions, air pollution might fulfill these criteria. Using a similar identification strategy as applied here, Lavy et al. (2014) recently provided evidence that suggests that ambient levels fine particulate matter ($PM_{2.5}$) and carbon monoxide (CO) on examination days significantly reduced test scores among Israeli students. Additionally earlier contributions have found effects on labor supply and labor productivity from various air pollutants (e.g. Hanna & Oliva, 2014; J. S. G. Zivin & Neidell, 2011). Drawing on these findings it seems natural to include air pollution controls in the estimations. If the estimated effects of pollen exposure are purely driven by excluding air pollution variables, the pollen count should not have any explanatory power once they are included as controls. Air pollution data are provided by The Norwegian institute of air quality research, and the final dataset comprise 22 stations spread over 4 municipalities. The data include measures of nitro-dioxide (NO_2), ozone (O_3), $PM_{2.5}$ and PM_{10}[13]. All of these pollutants are linked to a series of short term health effects, including reduced lung function, worsening of asthma, increased morbidness, higher frequencies of absences, and even death (WHO, 2006). As with the weather

[13] $PM_{2.5}$ and PM_{10} refers to fine particulate matter smaller than 2.5 and 10 microns in width. The pollutants are measured in (μg/m^3).

data, air pollution data is not available for all municipalities with pollen measurement stations, and subject to the similar challenges regarding extrapolation. Including air pollution data will therefore lead to a similar sub-sampling problem as discussed above and consequently will not be included in the main analysis.

Table 1 reports descriptive statistics for exam grade and control variables for the sample as a whole and for relevant subsamples.The total number of exam observations in the final data is 69,021 spread across 25,153 students.

4.4 Empirical strategy

The Norwegian high school system is set up so that students take multiple exams in a handful of subjects. This means that the data has a panel structure where it is possible to observe the test score for each student in several exams taken on different dates, but at the same location. Because the spread of pollen varies between these dates and locations, it is possible to implement a student fixed effects model. The formal representation of this estimation procedure is presented in equation (1).

$$Grade_{sctm} = C + \beta_1 ln(\text{pollen count})_{tm} + \gamma X_{tm} + \sigma S_s + \delta D_c + \tau T_t + u_{sctm} \tag{1}$$

The main dependent variable will be the exam grade for student s in course c at time t in municipality m. X_{tm} is a vector of weather and pollution variables for municipality m as observed at time t. S_s, D_c and T_t are student, course, and date fixed effects respectively. ln(pollencount) is the natural logarithm of the total amount of pollen detected. The pollen count is included in logarithmic rather than linear form to mimic how the immune system in allergic individuals responds to exposure to pollen spores. Several studies have found that sufferers of SAR have an immune response to pollen that increases linearly at first before it plateaus on relatively low levels (e.g., Caillaud et al., 2013; Erbas et al., 2007). Estimations with alternative measurements for pollen are reported in appendix table A1, the general pattern is consistent with a concave response pattern.

Central to the identification of a causal effect of pollen on exam grade is that unobserved characteristics of the students that influence the exam grade are uncorrelated with the exposure to pollen. That is, that there are no time invariant variables left out of the regression that correlate with both pollen exposure and exam grade. Without student fixed effects this might not be true for several reasons. For example, poorer students in rural areas could be exposed to more pollen than richer students in urban ares, because there are fewer plants and less pollen in cities than in rural areas. If this is the case a simple OLS estimation without student fixed effects would overstate the effect of pollen on exam performance because students from weaker backgrounds also tend to achieve lower grades. Alternatively, the effect of pollen on exam performance might be mainly driven by medication use. If well performing students in richer areas are more likely to be diagnosed and receive good treatment, i.e. use medication with fewer side effects, for their allergies the simple OLS estimation could understate the true effect of pollen on exam performance. Other time invariant factors that could bias the estimation includes sorting across schools, certain avoidance behavior and measurement error in assigning measurements of ambient pollen levels to students as pointed out by Lavy et al. (2014).

Another threat to the identification strategy is time variant factors that correlate with both pollen counts and exam performance. The identification strategy used here is only capable of handling this problem to a limited extent by controlling for certain time variant variables. Importantly, all the exams are held within a time period of around one month each year. Students who are assigned to take their exam towards the end of this period are randomly given extra preparation time, which could increase their exam score. At the same time it alters the probability that the exam will be held on a day with detectable amounts of pollen spores. To minimize this problem exam date fixed effects are included in all specifications. While date fixed effects net out time varying conditions that are the same across all regions, local conditions might vary over time as well. Exploring the role of local conditions, a specification controlling for local weather and air pollution is implemented in section 6.

5 Results

Table 2 reports the main results when estimating equation (1). All estimations include student, date and subject fixed effects. In column (1) the estimated coefficient is significant at the 1% level, and suggests that a one standard deviation increase in ambient pollen levels from the mean is associated with a decrease in the exam grade equal to 2.6% of a standard deviation.[14]

The second column in table 2 shows the results when the main model is re-estimated with linear trends for each of the eight pollen forecast zones included in the analysis. Trends are included to reduce bias from any smooth change in the student body, like changes in the prevalence rate, or pollen proliferation within forecast zones due to climatic factors. The trends will also absorb some of the time fixed difference in the levels of pollen proliferation between the zones. Including linear trends raises precision and decrease the treatment effect to about 2.5% of a standard deviation.[15] For the remainder of the paper all specifications will include linear trends for the forecast zones.

A potential threat to causal identification in the model estimated in column (2) is that the difficulty of exams could be positively correlated with pollen proliferation by mere chance. The relative difficulty of each exam varies between students within a course and year depending on their quality and subject specific skills. As a test whether the results are driven by harder exams being held on days with pollen proliferation column (3) shows the results when the model is re-estimated controlling for students' term grade in each subject. Term grade has a very high predictive power of the final exam score, and is therefore a fairly good measure of the expected exam grade in each subject for the individual student. The coefficient of interest remain very similar and statistically undistinguishable from other estimates, although with a somewhat smaller effect in absolute terms.

Pollen triggers an allergic reaction within minutes after entering individuals with SAR, with effects generally not lasting more than 4 to 8 hours (Skoner, 2001). Assuming the estimated results reported above are causal, one would therefore expect the pollen counts

[14] $-.0247 * ln((19.97 + 37.06)/19.97) \approx -.026$
[15] $-.0239 * ln((19.97 + 37.06)/19.97) \approx -.025$

on days before and after the examination day to not have any explanatory power when included alongside the measurement from the actual examination day. Finding an effect of pollen on the days around the exam would suggest that the estimates are biased due to some unobserved variables. In column (4) the pollen levels from the tree days preceding and following the exam are included as controls. Reassuringly, the point estimate for the effect of pollen levels on the exam day is very similar and does not change significantly. Additionally, explanatory power is unchanged.

While the estimated effect is very precise for the average student, it's likely that the estimated effect is driven purely by students with an allergic reaction to pollen. Students without allergies are likely to not be affected at all, or only to a marginal extent through disturbances during the exam caused by students with allergies. Using the estimated prevalence rate of SAR in Norway it is possible to make a reasonable prediction of the effect of pollen on allergic students. The share of students with allergic reactions to pollen is estimated to 10-30% of the population. Assuming that pollen proliferation has no effect on students without allergies, the true effect on students with allergies is between 3 and 10 times bigger than the coefficient estimate. As an example, assume that the true prevalence rate in Norwegian teenagers is equal to 25.6% as found by Hovland et al. (2014).[16] Then the estimated effect for students with allergies rise roughly four times to about 10% of a standard deviation. The lower the true prevalence rate is, the greater the effect of pollen proliferation on allergy sufferers will be. This result should, however, be interpreted with caution as it relies on the assumption that allergic students have the same grade distribution as non-allergic students, which will not be the case if students with SAR suffer from cumulative effects.

[16]For otherwise healthy individuals. In subsamples of students with comorbidities such as asthma the prevalence rate is be higher yet.

6 Robustness

6.1 Sample selection

The first series of robustness checks are related to the sample selection. A potential concern with the results in table 2 is related to the selection of exams and students included in the sample. The exam results available for this study are limited to the years 2008-2011 and are linked to students who enrolled in high school the years 2003-2009. Because the normalized progression in the academic track is 3 years, this means that parts of the sample consists of students who are delayed, and parts of students who have not taken the mandatory exit exams. The first column in table 3 is same as column 5 in table 2 and is included for reference. Columns 2 and 3 in table 3 implement two alternative sample requirements to avoid results being driven by the inclusion of these students and to make the students in the sample more comparable.

First, in column (2), only students from the cohorts 2005-2008 are included in the sample. This excludes the most delayed students, as well as the youngest students who have not had the time to complete high school in the normal time. Second, in column (3), only students who graduate after the normal 3 years are included. This excludes all students with any delay in their progression through high school. Neither of these restrictions alters the main results significantly.

One measurement station, at Lillehammer, was not operational until 2010. Consequently there are no data on pollen counts for the area on exam dates before 2010. In theory, the estimated effects of pollen could be affected by this asymmetry in available data. To address this concern column (4) reports results when all observations from this municipality are excluded from the sample. The estimated effect is not significantly altered by this sample requirement.

In order to reduce attenuation bias in absence of detailed information on where schools are located, the main sample used in this study drops all students living in municipalities without pollen measurement stations and students living in municipalities larger than 1000km^2. These restrictions reduce the sample drastically, as well as altering its composition to be more urban. As the sample composition is changed one might be worried that the estimated effect of pollen proliferation does not hold for the full sample, and is merely a peculiarity of the subsample. In order to mitigate this concern column (4) report results when all students, regardless of geographical location, are included in the sample. Attenuation bias leads to a somewhat smaller effect, but the estimate remains highly significant.

6.2 Contemporaneous air pollution and weather

As previously discussed, the main concern with the identification strategy applied in this paper is that other variables that are correlated with both pollen counts and test scores might be driving the estimated results. To mitigate this concern this section provides estimation results when a battery of measurements of local weather conditions and air pollution are included as controls. If the results reported above are purely driven by excluding weather and air pollution variables, the pollen count should not have any explanatory power once they are included as controls. Air pollution is controlled for by including dummies for days when the levels are higher than the critical threshold as defined by The World Health Organization. NO_2, for which there is no defined threshold, is entered linearly. Results are reported in table 4. Columns (1)-(4) report results for specifications analogue to columns (1)-(4) in table 2 for the subsample for which weather and air pollution data is available. Column (5) controls for average windspeed, average temperature, atmospheric pressure, and total precipitation. Column (6) report results when air pollution controls are included. Reassuringly, while the effect is slightly stronger for this subsample, introducing weather and pollution controls has no effect of the point estimate. The results in table 4 confirm that pollen has an effect separate from that of weather and air pollution, and increase the credibility of the identification strategy.

6.3 Placebo test

To further challenge the credibility of the identification strategy this section presents results of a placebo test using pollen counts from other days than the actual examination day. The placebo test is performed in the following way. For each student-exam observation I find the corresponding pollen count for each day 7 days ahead of, and 7 days after the exam date. I then re-estimate the model replacing the observed pollen level on the examination day with these leads and lags. In total I therefore estimate an additional 14 regressions with pollen levels taken from the same station, but different dates. Admittedly, this is not a perfect placebo test due to the high and strong serial correlation of pollen proliferation, but still a useful approach to assess the strength of the identification strategy.[17] Assuming the estimated results reported above are causal, one would expect the pollen counts on days before and after the examination day to have a fairly limited explanatory power relative to the measurements from the actual examination day. Estimates with confidence bands from the placebo regressions are plotted in figure 1. Regardless of which day is used as the placebo, the coefficients are all smaller than what is estimated for the actual pollen counts from the exam day, and also all are indistinguishable from 0. Overall the absence of a consistent effect of the lead and lag values of the pollen counts is reassuring as it is less likely that pure coincidence or factors other than the measured variation in pollen counts are driving the results.

6.4 Heterogeneity

This section is devoted to exploring heterogeneous effects on students depending on various observable characteristics. There are two main motivating factors for this. First, from a policy perspective it is of interest to identify which, if any, subgroups of students are more likely to be affected. Second, some studies find that the prevalence of SAR is correlated with certain observable characteristics. As all estimations provided in this study are

[17] The correlation coefficient between the pollen count on the exam day and the day before the exam day is .66 and is significant at the 1% level. A correlation table between the pollen counts on the exam day and up to five days before the exam is provided in table A5.

in reduced form, variations in prevalence rates provide a framework for exploring the likelihood of SAR being the treatment channel: If pollen exposure has a negative impact on grades via allergic reactions, one will expect the treatment effect to be more negative among students with observable characteristics correlated with the prevalence of SAR. Otherwise, finding a weaker impact on students that are more likely to have the condition, will reduce the credibility of SAR as the treatment channel.

Historically, SAR has been associated with affluence, but this connection has weakened over time. Looking at Swedish conscripts between 1952 and 1977, Bråbäck et al. (2005) found a convergence in the prevalence of SAR across groups with various socio-economic backgrounds though SAR remained more common among conscripts from stronger backgrounds. The authors theorize that the convergence could be a result of converging living standards, and consequently exposure to risk factors for developing SAR.[18] While the study is limited to Sweden, Norway went through a similar development in the same period, making it likely that the same evolution of prevalence rates occurred there. Though prevalence rates are converging, studies generally still tend to find that socio-economic status is positively correlated with the likelihood of having SAR. In a large study, using more 170 000 insurance records, (Chen et al., 2002) found a strong positive relationship between the SAR and social background. However, some studies find contradicting results. For example, Almqvist, Pershagen, and Wickman (2005) found that Swedish children were actually more likely to be allergic if they had a relatively weak socio-economic background. Considering the convergence in prevalence rates and the lack of consensus in the literature, it is not possible to a priori make justified assumptions about any heterogeneous effects in socio-economic background. To explore the possibility of heterogeneous effects in the current setting the baseline model will be re-estimated allowing for heterogeneity in the treatment effect depending on parental income and education.

In addition to looking at role of socio-economic background, it is also possible to divide the sample by gender. This is a useful exercise as SAR is more common among boys than girls. The gender gap diminishes during puberty and generally vanish later in

[18] See also Butland et al. (1997)

life, with some studies finding higher prevalence rates among adult women (Skoner, 2001; Chen et al., 2002). Importantly, a recent study found that among Norwegian 16 year olds boys were 50% more likely to have SAR (29.3% vs 21.7%) (Hovland et al., 2014). Due to the age composition of the sample it is likely that the prevalence rate of SAR is higher among boys also in the current data.[19].

Columns (1)-(4) in table 4 reports results when the sample is divided by socio-economic background. Starting in column (1) and (2) a separate treatment effect is estimated for students whose parents have a relatively high or low income. Parental income is defined as the average pensionable income for both parents in the years 2002-2003 and is provided by the tax authorities.[20] High income is defined as the average parental income being above the sample median. In column (3) and (4) the sample is divided by parental education level. High parental education is defined as at least one parent having a degree equal to a bachelor's degree or higher. Low parental education is defined as the highest education achieved by any parent to be equal to a high school diploma or less. Both when comparing across income and education groups, students from a stronger background are slightly more affected. These estimates are in line with the traditional finding that a strong socio-economic background is associated with higher prevalence rates of SAR. Note, however, that the difference is not significant and might be attributable to differences in pollen exposure or medication use across the groups.

The sample is divided by gender in columns (5) and (6). Exposure to pollen on the exam day is estimated to have approximately twice the effect on boys compared to girls. The difference is not statistically significant, but the direction is in line with the higher prevalence rate of SAR among boys (Hovland et al., 2014). This suggests that the gender gap in the prevalence rate of SAR in teenagers might translate into a real gender specific disadvantage during tests. Additionally, because SAR is likely increase the frequency of absences (e.g. McMenamin, 1994), boys might accumulate an additional long term disadvantage over time, which in turn might explain some of the observed gender

[19]All students in the sample enroll at age 16 and normally graduates 3 years later, so most of the sample is within this age bin although some students are older.

[20]The years 2002-2003 are chosen because it is measured before the students in the sample enrolled in high school and family income could potentially affect the enrollment decision.

differences in general schooling outcomes.

In summary, the subsample analysis show some tendencies that students from certain backgrounds responds stronger to exposure to pollen during exams, but the data does not allow precise enough estimates for a strict distinction to be made. Overall, students with a stronger socio-economic background and boys seem more affected than other students.

7 Accumulated effects

This section takes the findings presented so far one step further and asks: Assuming that the results reported so far are causal, are students affected in the long run? To answer this general question I use four specific measures of academic progression: graduating on time, graduating with no more than a two-year lag, enrolling into university, and enrolling in a STEM[21] program. There are at least two reasons to expect a negative impact on academic progression. First, students are required to pass all exams to be able to graduate high school. Some allergic students might fail these exams due to random variation in ambient pollen levels and therefore not graduate. Second, students compete for placement in higher education based on the average of their GPA and exam grade. A reduced exam score resulting from exposure to pollen could therefore effectively bar some students from enrolling in higher education or certain programs with high requirements.[22]

The longer run outcomes are observed only once for each student, so the student fixed effects strategy employed so far is not feasible. Instead, I sum the total pollen count across all exams for each student, and collapse the data on the student level. This approach will to some degree be more vulnerable to bias due to potential correlation between student ability and pollen exposure, but is the best viable approach. Before proceeding to longer run estimates, table 6 presents the estimated effect of pollen exposure on exam grades when student fixed effects are replaced with school fixed effects and controls for student characteristics are included.[23] To strengthen the identification in the absence of student

[21]Science, technology, engineering, math

[22]A typical student have around 20 course grades and 4 exam grades.

[23]In addition to reported variables each regression also includes course, and date fixed effects, dummies

fixed effect columns (2)-(4) include cohort-by-school fixed effects. With the exceptions described the table is analogue to table 2. When cohort-by-school fixed effects are not included the estimated effect is insignificant, but remains negative. Including cohort-by-school fixed effects strengthens estimates somewhat and increase precision, compared to the student fixed effects the results remain small in absolute terms. The overall decrease in the magnitude of effects is likely attributable to unobserved student characteristics correlated to exposure to pollen on the exam day and exam performance. As student fixed effects are removed in the long run specifications, it is reassuring that the estimates remain significant even when a less strict model is applied.

The first two columns in table 7 show the effect of total pollen exposure on the average exam grade. Full results are reported in appendix table A7. The effect is only significant for students who graduated, but statistically the point estimates in column (1) and (2) are not distinguishable. Increasing the exposure to pollen across all exams by one standard deviation is estimated to reduce the average exam score by 3.2% of a standard deviation. Columns (3) and (4) show results when the outcome is graduating on time and with no more than a 2-year lag. It is not possible to trace any direct effect of pollen exposure on graduation probabilities as both specifications give insignificant estimates very close to zero. In column (5) the outcomes is whether a graduated student has enrolled in university by 2011 or 2012.[24] While there is a small negative and insignificant effect on the probability of enrolling in college, the students who suffer from SAR might still sort into programs with lower entry requirements, such as STEM programs. In column (6) the outcome variable is whether graduated students are enrolled in a STEM program by 2011 or 2012. The point estimate suggest that a one standard deviation increase in the total ambient pollen levels across all exams reduces the probability that a graduating student enrolls into a STEM program by .7%-points. Though some of these estimates are significant at conventional levels they must be interpreted with caution as it is not possible to rule out student sorting in the absence of student fixed effects.

for the number of exams the student take. Full results are reported in the appendix table A6.

[24] Data on university enrollment is only available for these two years.

8 Concluding remarks

This paper has explored the correlation between exposure to pollen and cognitive performance, and is the first to do so in a student fixed effects framework. By merging administrative data from Norwegian high schools on exams taken in 2008-2011 to data on pollen proliferation, I find a consistent negative effect of exposure to pollen on exam grades. On average, students' test scores are reduced by around 2.5% of a standard deviation when pollen levels increase by one standard deviation from the mean. As around 1 in 4 students in the sample have SAR, the estimate is likely to only show the lower bound of the effect. Assuming that allergy is uncorrelated with student ability the effect could be as high as 10% of a standard deviation. Further, I show that the short-run effect is likely to have long run implications by affecting student sorting into higher education.

Despite the reassuring results from the various robustness checks, there are some caveats in interpreting the results. First, the identification strategy is reduced form making it impossible to rule out all competing explanations for the observed effects. The absence of data on student health, in particular allergies, makes it hard to determine with certainty that the estimates are resulting from allergic reactions. Second, this paper uses a student fixed effects approach and is therefore using within student variation in pollen exposure. Any cumulative effects of SAR on school performance are therefore not included. Previous estimates suggest that sufferers of seasonal allergies are more frequently absent from school in addition to temporarily lowered cognitive ability during pollen season. Over time these effects can add up to even stronger negative effects than what has been shown in this paper. Though these factors calls for caution in interpreting the results, this paper provides new evidence of the negative effects pollen exposure on cognitive performance in a real school setting.

An implication of the findings presented here is that students with allergies might suffer a temporary reduction in cognitive abilities if exposed to pollen. Insofar the exposure is on the same day as high-stakes exams students with allergies might score relatively worse than their peers due to random variations in pollen proliferation. In turn this can affect placement in higher education and work with effects on workforce productivity. To some extent it might be possible to mediate the size of this negative effect by implementing various measures aimed at reducing the number of undiagnosed students, or shifting students towards less sedating medication.

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Tables

Table 1: Descriptive statistics by subgroups

	All	Boys	Girls	Low GPA	High GPA
Course grade, 1-6	3.87	3.70	4.03	3.00	4.59
	(0.97)	(0.99)	(0.92)	(0.58)	(0.54)
Exam grade, 1-6	3.33	3.21	3.43	2.66	3.89
	(0.98)	(1.00)	(0.96)	(0.73)	(0.79)
Number of exams taken by student	3.28	3.30	3.26	3.24	3.31
	(0.76)	(0.77)	(0.75)	(0.78)	(0.74)
Highest educational level achieved by any parent					
Mandatory	0.10	0.10	0.11	0.14	0.07
	(0.31)	(0.30)	(0.31)	(0.35)	(0.26)
High school	0.26	0.24	0.28	0.32	0.21
	(0.44)	(0.43)	(0.45)	(0.47)	(0.41)
Bachelor degree	0.37	0.38	0.37	0.35	0.39
	(0.48)	(0.48)	(0.48)	(0.48)	(0.49)
Masters degree or PhD	0.26	0.29	0.24	0.18	0.33
	(0.44)	(0.45)	(0.43)	(0.39)	(0.47)
First generation immigrant	0.05	0.04	0.05	0.06	0.03
	(0.21)	(0.21)	(0.21)	(0.24)	(0.17)
Second generation immigrant	0.09	0.09	0.09	0.11	0.07
	(0.28)	(0.28)	(0.29)	(0.32)	(0.25)
Both parents working	0.74	0.74	0.73	0.69	0.77
	(0.44)	(0.44)	(0.44)	(0.46)	(0.42)
One parent working	0.22	0.21	0.22	0.24	0.20
	(0.41)	(0.41)	(0.41)	(0.43)	(0.40)
Graduated within 5 years	0.86	0.83	0.89	0.77	0.94
	(0.34)	(0.38)	(0.31)	(0.42)	(0.23)
Mean pollen count on exam day	19.97	20.08	19.87	20.97	19.43
	(37.06)	(37.38)	(36.78)	(38.76)	(36.09)
Mean ln(pollen count exam day)	1.76	1.78	1.75	1.77	1.76
	(1.62)	(1.61)	(1.62)	(1.64)	(1.60)
Pollen on exam day (yes=1)	1.00	1.00	1.00	1.00	1.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Mean temperature in celsius	11.63	11.67	11.59	11.59	11.65
	(2.80)	(2.81)	(2.79)	(2.77)	(2.82)
Precipitiation	1.81	1.76	1.85	1.99	1.71
	(3.95)	(3.86)	(4.03)	(4.25)	(3.77)
Mixing ratio	5.61	5.61	5.60	5.60	5.61
	(1.20)	(1.20)	(1.20)	(1.18)	(1.21)
Average wind speed (m/s)	2.74	2.73	2.75	2.74	2.74
	(1.18)	(1.17)	(1.19)	(1.17)	(1.19)
Average atmos pres (hPa)	1,004.68	1,004.73	1,004.63	1,004.86	1,004.58
	(9.27)	(9.31)	(9.23)	(9.46)	(9.16)
O_3 critical threshold (yes=1)	0.12	0.12	0.12	0.12	0.11
	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
PM_{10} critical threshold (yes=1)	0.15	0.15	0.15	0.14	0.15
	(0.27)	(0.26)	(0.27)	(0.27)	(0.27)
$PM_{2.5}$ critical threshold (yes=1)	0.01	0.01	0.01	0.01	0.01
	(0.09)	(0.08)	(0.09)	(0.09)	(0.09)
24-hour average NO_2	31.93	31.85	31.99	32.41	31.66
	(11.59)	(11.58)	(11.60)	(11.68)	(11.54)
#Observations	69,021	32,757	36,264	24,384	44,637
#Students	25,153	11,850	13,303	11,402	13,751

Table 2. Full results reported in appendix table A2

	(1) Without trends	(2) Forecast zone trends	(3) Course grade	(4) Lags and leads
ln(pollen count)	-0.0247***	-0.0239***	-0.0188*	-0.0206*
	(0.00890)	(0.00896)	(0.00966)	(0.0111)
Observations	69,021	69,021	69,021	69,021
R^2	0.687	0.688	0.708	0.688
Trends	No	Yes	Yes	Yes
# Students	25153	25153	25153	25153
Mean pollen	19.97	19.97	19.97	19.97

Student, date and course fixed effects included in all specifications. Standard errors clustered on high school in parentheses. *** p<0.01, ** p<0.05, *** p<0.1.

Table 3: Sample checks

	(1)	(2)	(3)	(4)	(5)
		Cohorts	Only students	Dropping	Full
	Baseline	2005-2008	graduating on time	Lillehammer	sample
ln(pollen count)	-0.0239***	-0.0240***	-0.0213**	-0.0244***	-0.0141***
	(0.00896)	(0.00903)	(0.00909)	(0.00916)	(0.00408)
Observations	69,021	67,482	56,536	67,856	266,351
R^2	0.688	0.686	0.647	0.688	0.664
Trends	Yes	Yes	Yes	Yes	Yes
# Students	25153	24339	20193	24784	93435
Mean pollen count	19.97	19.67	19.61	18.78	23.83

Student, date and subject fixed effects included in all specifications. Column (1) is identical to column (2) in table 2. Standard errors clustered on high school in parentheses. *** p<0.01, ** p<0.05, *** p<0.1

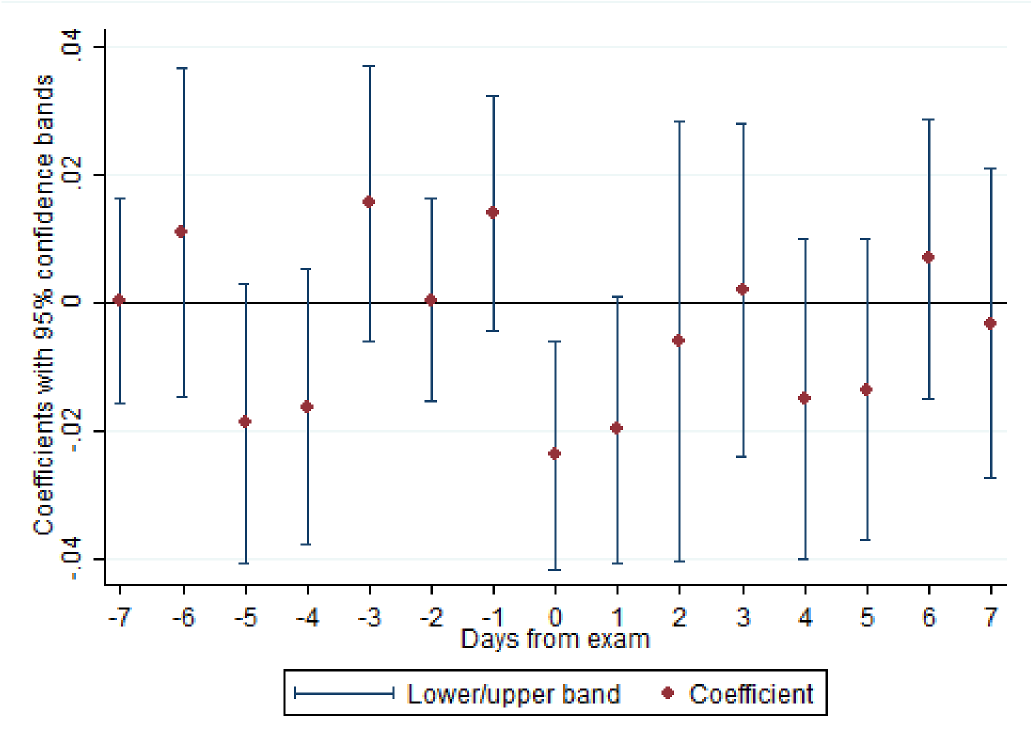


Figure 1: Effect of pollen exposure on days before and after exam. Each estimate represents a separate regression. Controlling for date, student, and course fixed effects and forecast zone trends.. Confidence bands reflect the 95%-confidence interval.

Table 4: Weather and air pollution controls. Full results reported in table A3.

	(1)	(2)	(3)	(4)	(5)	(6)
:	Without trends	Forecast zone trends	Course grade	Lags and leads	Weather controls	Weather and air pollution controls
ln(pollen count)	-0.0323***	-0.0296**	-0.0281**	-0.0287**	-0.0277**	-0.0326***
	(0.0123)	(0.0124)	(0.0131)	(0.0122)	(0.0122)	(0.0119)
Observations	57,658	57,658	57,658	57,658	57,658	57,658
R^2	0.686	0.686	0.707	0.687	0.686	0.686
Trends	No	Yes	Yes	Yes	Yes	Yes
# Students	20585	20585	20585	20585	20585	20585
Mean pollen	21.37	21.37	21.37	21.37	21.37	21.37

Student, date and course fixed effects included in all specifications. Standard errors clustered on high school in parentheses. *** p<0.01, ** p<0.05, *** p<0.1.

Table 5: Sub-sample analysis

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome:	High	Low	High	Low	Girls	Boys
Exam grade	inc.	inc.	educ.	educ.		
ln(pollen count)	-0.0250**	-0.0217*	-0.0235**	-0.0225*	-0.0154	-0.0294***
	(0.0110)	(0.0120)	(0.0108)	(0.0128)	(0.0107)	(0.0108)
t-stat on difference	-0.200		-0.0568		0.922	
Observations	41,752	27,269	44,261	24,760	36,264	32,757
R^2	0.671	0.698	0.668	0.688	0.685	0.692
Trends	Yes	Yes	Yes	Yes	Yes	Yes
# Students	15,073	10,080	16,001	9,152	13,303	11,850

Student, date and subject fixed effects included in all specifications. See notes under table 2. High income is defined as aggregate parental income in the years 2002-2003 to be higher than the median. Low income encompass the rest of the students. High education is defined as at least one parent having a university degree, while low education comprise the rest of the students. High GPA is defined as the average course grades for a student being above the median. Students with an average below the median are defined to have a low GPA. Each regression pair is mutually exclusive and jointly comprise all students included in the baseline specification. Standard errors clustered on high school in parentheses. *** p<0.01, ** p<0.05, *** p<0.1

Table 6: School fixed effects

	(1) Without trends	(2) Forecast zone trends	(3) Course grade	(4) Lags and leads
ln(pollen count)	-0.0104	-0.0219***	-0.0144**	-0.0195**
	(0.00646)	(0.00636)	(0.00729)	(0.00864)
Observations	69,021	69,021	69,021	69,021
R^2	0.173	0.195	0.458	0.195
Interactions	No	Yes	Yes	Yes
# Students	25,153	25,153	25,153	25,153
# Schools	221	221	221	221

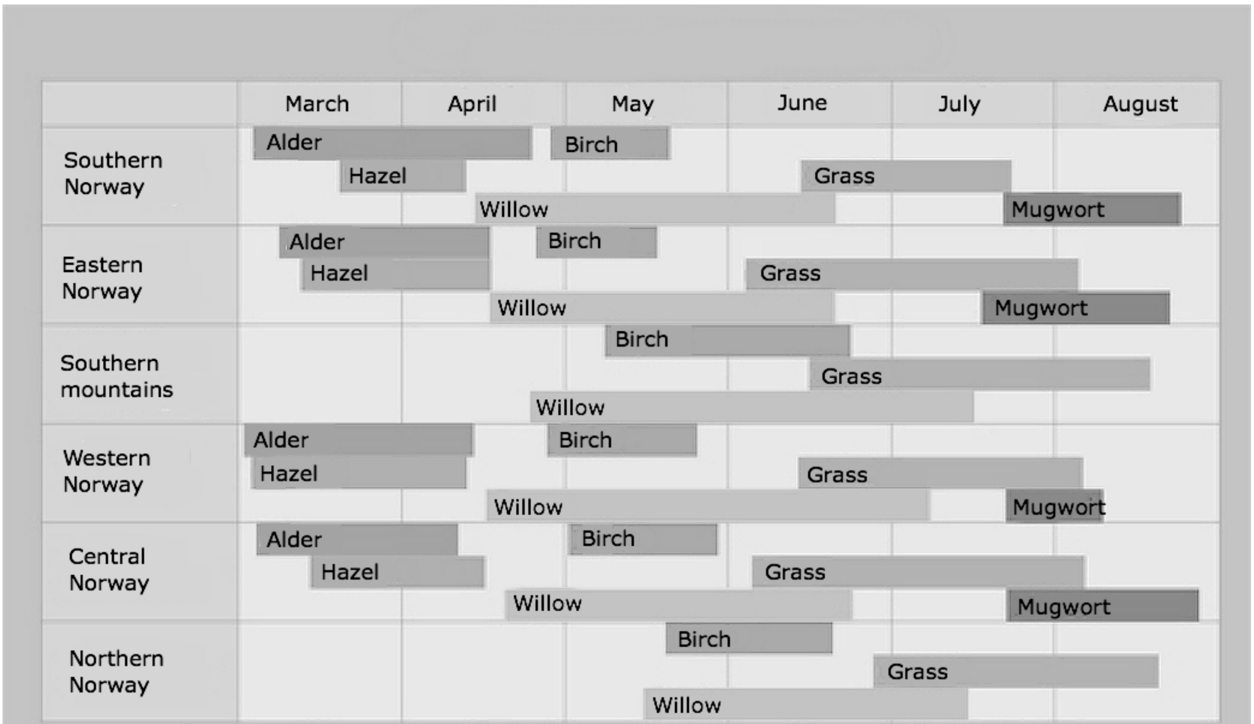
All specifications include: school and cohort fixed effects. Interactions of indicator variables for all school times cohort combinations are included in columns (2)-(4). In addition to the reported variables each specification also includes dummies for the number of exams each student takes and several background characteristics. See appendix for full results. Standard errors clustered on high school in parentheses. *** p<0.01, ** p<0.05, *** p<0.1

Table 7: Human capital accumulation

	(1) Average exam score	(2) Average exam score only graduates	(3) Graduating on time	(4) Graduating within 2 years	(5) Enrolling in university	(6) Enrolling in STEM
Total pollen count	-0.000202	-0.000450**	7.51e-05	-9.58e-05	-0.000147	-9.07e-05**
	(0.000191)	(0.000198)	(0.000118)	(9.14e-05)	(0.000109)	(4.42e-05)
Observations	25,153	20,193	25,153	25,153	20,193	20,193
R^2	0.641	0.588	0.334	0.343	0.302	0.053
Trends	Yes	Yes	Yes	Yes	Yes	Yes
# Schools	221	202	221	221	202	202

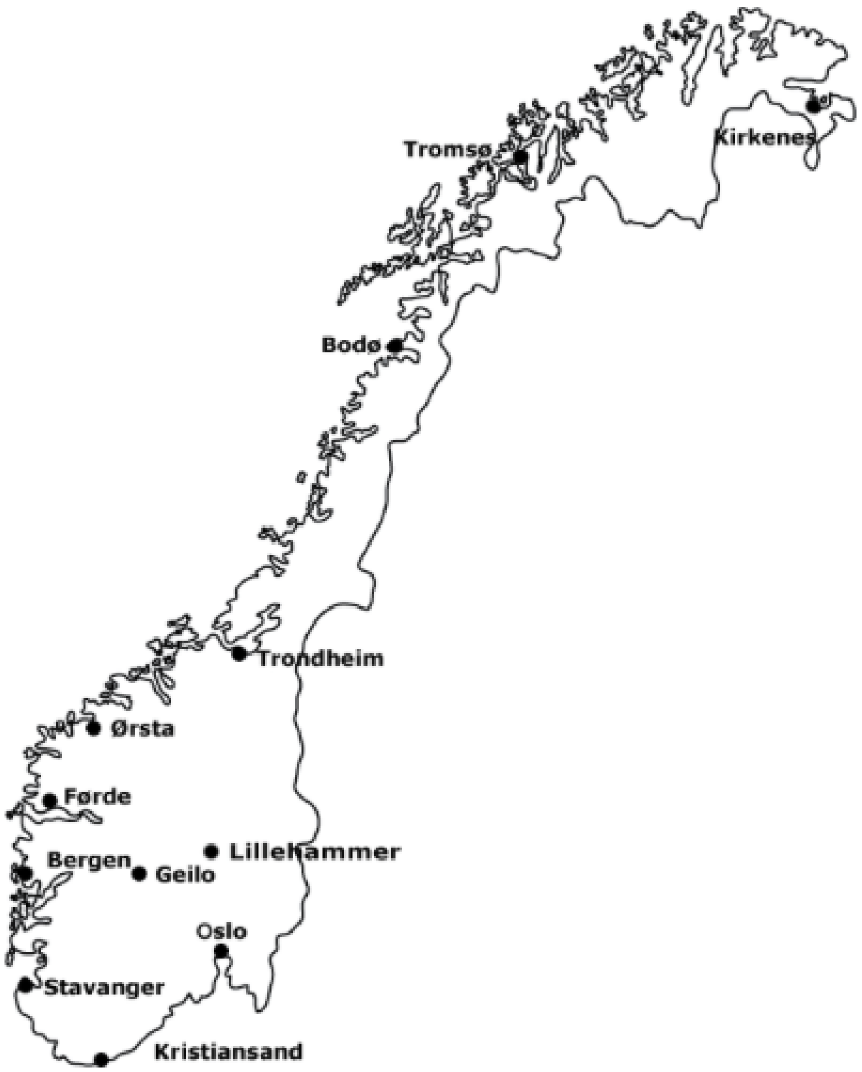
All specifications include: school and cohort fixed effects. Interactions of indicator variables for all school times cohort combinations are included in columns (2)-(4). In addition to the reported variables each specification also includes dummies for the number of exams each student takes, average course grade, and several background characteristics. See appendix for full results. Average total pollen count across all exams is 54.9 with a standard deviation of 72. Standard errors clustered on high school in parentheses. *** p<0.01, ** p<0.05, *** p<0.1

Appendix



Average dates for pollen based on recent seasons. Starting date and duration is subject to considerable variation between years.
Chart from The Norwegian National Pollen Service. Examinations are held between May 14th and June 8th in all years in the data used.

Appendix figure A1: Pollen season by larger region



Appendix figure A2: Pollen measurement stations' locations. The municipalities Geilo, Kirkenes, Tromsø, and Bodø are all more than 1000km^2 and are excluded from the main analysis to decrease attenuation bias.

Appendix table A1: Alternative specifications

	(1) Above median	(2) Thirds	(3) Quartiles	(4) 90th percentile	(5) 95th percentile
Pollen level above median	-0.0160				
	(0.0224)				
Pollen levels in middle third		-0.110***			
		(0.0332)			
Pollen levels in upper third		-0.0726**			
		(0.0344)			
Pollen levels in second quartile			-0.111***		
			(0.0263)		
Pollen levels in third quartile			-0.0819***		
			(0.0278)		
Pollen levels in fourth quartile			-0.121***		
			(0.0401)		
Pollen level 90th centile				0.00168	
				(0.0474)	
Pollen level 95th centile					-0.0243
					(0.0541)
Observations	69,021	69,021	69,021	69,021	69,021
R^2	0.687	0.688	0.688	0.687	0.687
Trends	Yes	Yes	Yes	Yes	Yes
# Students	25152	25152	25152	25152	25152

Student, date and subject fixed effects included in all specifications. Standard errors clustered on high school in parantheses. *** p<0.01, ** p<0.05, *** p<0.1

Appendix Table A2. Full results corresponding to table 2.

	(1) Without trends	(2) Forecast zone trends	(3) Course grade	(4) Lagged pollen
ln(pollen count)	-0.0247***	-0.0239***	-0.0188*	-0.0206*
	(0.00890)	(0.00896)	(0.00966)	(0.0111)
ln(pollen count 1 day earlier)				0.00760
				(0.00861)
ln(pollen count 2 days earlier)				0.000824
				(0.00756)
ln(pollen count 3 days earlier)				0.0142
				(0.00949)
ln(pollen count 1 day after)				-0.00316
				(0.0101)
ln(pollen count 2 days after)				-0.0108
				(0.0127)
ln(pollen count 3 days after)				0.00894
				(0.0119)
Course grade			0.301***	
			(0.0120)	
Observations	69,021	69,021	69,021	69,021
R^2	0.687	0.688	0.708	0.688
Trends	No	Yes	Yes	Yes
# Students	25153	25153	25153	25153
Mean pollen	19.97	19.97	19.97	19.97

Student, date and course fixed effects included in all specifications. Standard errors clustered on high school in parentheses. *** p<0.01, ** p<0.05, *** p<0.1.

Table A3: Have pollution data

	(1) Without trends	(2) Forecast zone trends	(3) Course grade	(4) Lagged pollen	(5) Weather controls	(6) Weather and air pollution controls
ln(pollen count)	-0.0323***	-0.0296**	-0.0281**	-0.0287**	-0.0277**	-0.0326***
	(0.0123)	(0.0124)	(0.0131)	(0.0122)	(0.0122)	(0.0119)
ln(pollen count 1 day earlier)				-0.00526		
				(0.0111)		
ln(pollen count 2 days earlier)				-0.000193		
				(0.00805)		
Course grade			0.302***			
			(0.0134)			
Precipitation					0.00320	0.00310
					(0.00391)	(0.00384)
Temperature					-0.00904	-0.00718
					(0.00818)	(0.00821)
Wind speed					-0.00262	-0.00248
					(0.0186)	(0.0186)
Air pressure					-0.00171	-0.00218
					(0.00664)	(0.00684)
O_3 above threshhold						0.0527
						(0.0569)
PM_{10} above threshhold						-0.126
						(0.221)
NO_2						-0.000903
						(0.00193)
Observations	57,658	57,658	57,658	57,658	57,658	57,658
R^2	0.686	0.686	0.707	0.687	0.686	0.686
Trends	No	Yes	Yes	Yes	Yes	Yes
# Students	20585	20585	20585	20585	20585	20585
Mean pollen	21.37	21.37	21.37	21.37	21.37	21.37

Student, date and course fixed effects included in all specifications. No students take exams both on days with the level of $PM_{2.5}$ being above and below the threshold level, the effect is there not possible to estimate in a student fixed effects framework. Standard errors clustered on high school in parentheses. *** p<0.01, ** p<0.05, *** p<0.1.

Appendix table A4. ln(pollen count) by station.

Stations	Mean	sd	min	max
Bergen	0.47	0.91	-0.51	2.64
Lillehammer	2.88	1.77	0.18	5.80
Ørsta	0.82	1.23	-0.51	3.58
Oslo	2.47	1.30	-0.51	4.98
Førde	0.41	1.12	-0.51	2.80
Stavanger	0.54	1.06	-0.51	3.45
Kristiansand	1.31	1.62	-0.51	4.31
Trondheim	1.68	1.46	-0.51	5.30

Appendix table A6: School fixed effect. Full results

	(1) Without trends	(2) Forecast zone trends	(3) Course grade	(4) Lags and leads
ln(pollen count)	-0.0104	-0.0219***	-0.0144**	-0.0195**
	(0.00646)	(0.00636)	(0.00729)	(0.00864)
ln(pollen count 1 day earlier)				0.00544
				(0.00791)
ln(pollen count 2 days earlier)				0.00494
				(0.00727)
Parents highest educational level is high school	0.0548***	0.0564***	0.0290**	0.0564***
	(0.0192)	(0.0201)	(0.0114)	(0.0201)
Parents highest educational level is bachelor degree	0.226***	0.223***	0.0855***	0.223***
	(0.0199)	(0.0207)	(0.0124)	(0.0207)
Parents highest educational level is master or PhD	0.397***	0.390***	0.141***	0.390***
	(0.0231)	(0.0235)	(0.0123)	(0.0234)
Female	0.198***	0.195***	0.0159**	0.195***
	(0.0130)	(0.0129)	(0.00690)	(0.0129)
First generation immigrant	-0.289***	-0.284***	-0.175***	-0.284***
	(0.0370)	(0.0365)	(0.0211)	(0.0366)
Second generation immigrant	-0.249***	-0.243***	-0.176***	-0.244***
	(0.0340)	(0.0335)	(0.0214)	(0.0334)
Exactly 1 parent working	0.114***	0.100***	0.0306*	0.100***
	(0.0238)	(0.0230)	(0.0175)	(0.0230)
Both parents working	0.160***	0.145***	0.0543***	0.146***
	(0.0269)	(0.0262)	(0.0180)	(0.0262)
Course grade			0.577***	
			(0.00757)	
Observations	69,021	69,021	69,021	69,021
R^2	0.173	0.195	0.458	0.195
Interactions	No	Yes	Yes	Yes
# Students	25,153	25,153	25,153	25,153
# Schools	221	221	221	221

All specifications include: school and cohort fixed effects. Interactions of indicator variables for all school times cohort are included in columns (2)-(4). In addition to the reported variables each specification also includes dummies for the number of exams each student takes and several background characteristics. See appendix for full results. Standard errors clustered on high school in parentheses. *** p<0.01, ** p<0.05, *** p<0.1

Appendix table A5. Serial correlation of pollen measurement.

	Exam day	1 day before	2 days before	3 days before	4 days before	5 days before	6 days before	7 days before
Exam day	1.000							
1 day before	0.655	1.000						
	(0.000)							
2 days before	0.644	0.652	1.000					
	(0.000)	(0.000)						
3 days before	0.626	0.652	0.695	1.000				
	(0.000)	(0.000)	(0.000)					
4 days before	0.449	0.410	0.452	0.647	1.000			
	(0.000)	(0.000)	(0.000)	(0.000)				
5 days before	0.558	0.430	0.551	0.634	0.666	1.000		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)			
6 days before	0.368	0.457	0.370	0.600	0.515	0.710	1.000	
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
7 days before	0.367	0.309	0.202	0.451	0.472	0.534	0.616	1.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	

p-value for test of significance reported in parentheses.

Appendix table A7: Human capital accumulation. Full results

	(1) Average exam score	(2) Average exam score only graduates	(3) Graduating on time	(4) Graduating within 2 years	(5) Enrolling in university	(6) Enrolling in STEM
Total pollen count	-0.000202	-0.000450**	7.51e-05	-9.58e-05	-0.000147	-9.07e-05**
	(0.000191)	(0.000198)	(0.000118)	(9.14e-05)	(0.000109)	(4.42e-05)
GPA	0.706***	0.686***	0.139***	0.114***	0.0994***	-0.00447*
	(0.00972)	(0.0104)	(0.00654)	(0.00609)	(0.00435)	(0.00257)
Parents highest educational level is high school	0.0246**	0.0263	0.0206**	0.0195**	0.0138	-0.00421
	(0.0121)	(0.0163)	(0.00985)	(0.00801)	(0.0119)	(0.00763)
Parents highest educational level is bachelor degree	0.0710***	0.0612***	0.0218**	0.0285***	0.0125	0.00324
	(0.0145)	(0.0168)	(0.00980)	(0.00906)	(0.0118)	(0.00784)
Parents highest educational level is master or PhD	0.118***	0.113***	0.00775	0.0199**	0.00649	0.00677
	(0.0151)	(0.0166)	(0.0111)	(0.00940)	(0.0123)	(0.00922)
Female	-0.0352***	-0.0384***	0.0207***	0.0222***	0.0543***	-0.0599***
	(0.0102)	(0.0113)	(0.00574)	(0.00464)	(0.00521)	(0.00468)
First generation immigrant	-0.172***	-0.143***	-0.0250*	-0.00877	0.160***	0.0482***
	(0.0268)	(0.0328)	(0.0148)	(0.0117)	(0.0171)	(0.0128)
Second generation immigrant	-0.176***	-0.164***	-0.0101	0.00110	0.186***	0.0267***
	(0.0233)	(0.0277)	(0.00971)	(0.00925)	(0.0145)	(0.00982)
Exactly 1 parent working	0.0375*	0.0732***	0.00766	0.00453	0.00221	0.00993
	(0.0202)	(0.0246)	(0.0144)	(0.0134)	(0.0128)	(0.00769)
Both parents working	0.0553***	0.0911***	0.0315**	0.0296**	0.0287**	0.00445
	(0.0203)	(0.0251)	(0.0142)	(0.0129)	(0.0114)	(0.00824)
Observations	25,153	20,193	25,153	25,153	20,193	20,193
R^2	0.641	0.588	0.334	0.343	0.302	0.053
Trends	Yes	Yes	Yes	Yes	Yes	Yes
# Schools	221	202	221	221	202	202

All specifications include: school and cohort fixed effects. Interactions of indicator variables for all school times cohort combinations are included in columns (2)-(4). In addition to the reported variables each specification also includes dummies for the number of exams each student takes, average course grade, and several background characteristics. See appendix for full results. Standard errors clustered on high school in parentheses. *** p<0.01, ** p<0.05, *** p<0.1

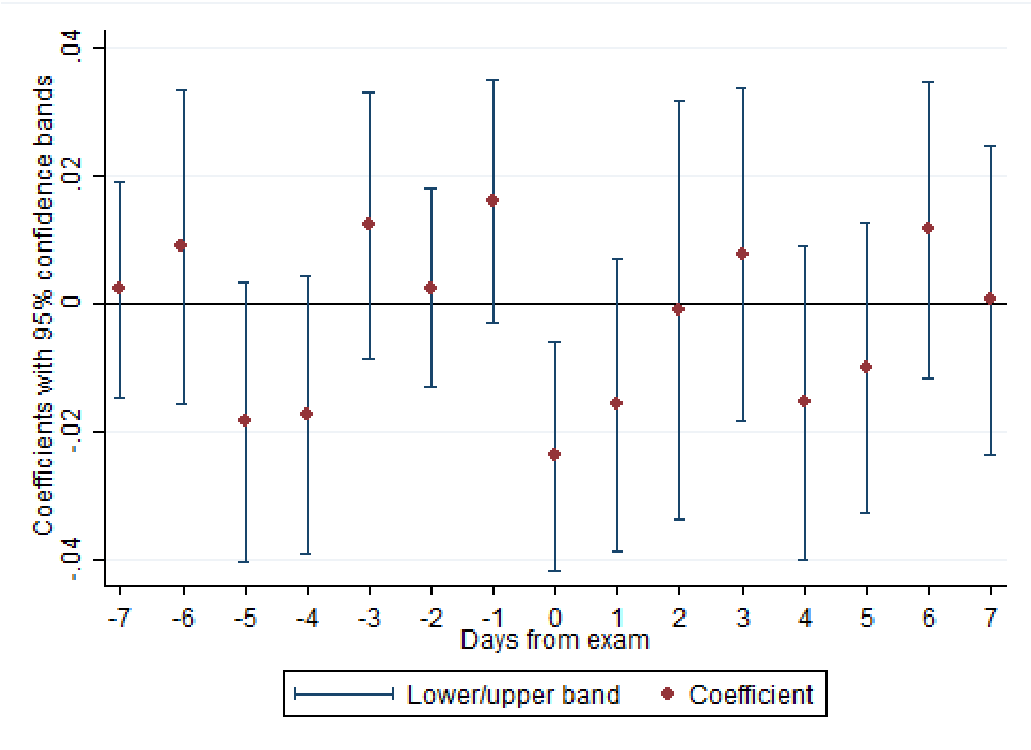


Figure A3: Effect of pollen exposure on days before and after exam. Each estimate represents a separate regression. Controlling for date, student, and course fixed effects and forecast zone trends.. Confidence bands reflect the 95%-confidence interval.