Seasonal Allergies and Mental Health: Do Small Health Shocks Affect Suicidality?

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Abstract

Deaths by suicide, a leading cause of death, increased 37% between 2000 and 2018 in the United States. Though structural factors of suicide have been studied extensively, much less is known about its short-term triggers. We examine the impact of small exogenous shocks – allergies triggered by seasonal pollen – on suicides and mental health care. Pollen allergies impair cognitive ability, cause mood changes, and reduce the quality of sleep – all predictors of suicidality. Combining three datasets across 28 localities in the United States from 2006 to 2017, we identify the effect of pollen on suicides and mental health care from daily variation in each, finding that an increase in pollen of 10 particles per cubic meter results in an increase of up to 2.9% in the number of suicides and a 3.5% increase in mental health visits to the emergency department in a county. We provide evidence that this effect operates through disrupted sleep and exhaustion. As climate change extends and intensifies the pollen season, we expect its impact to more than double the number of suicides in the next 80 years. These results point toward the importance of relatively small exogenous shocks on suicidality and mental health care utilization, and the potential for relatively inexpensive and routine health care measures such as allergy testing and treatment to improve mental health.

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1. Introduction

More than 47,000 individuals died by suicide and more than 312,000 received care in the emergency department for self-harm injuries in 2018, part of a decade-long rising trend (CDC, 2021). In addition, in 2020, an estimated 52.9 million adults had a mental illness (21.0% of all adults) and 24.3 million (46.2%) had received treatment from mental health services in the previous year (National Institute of Mental Health 2022). While structural risk factors of suicidal thoughts and behaviors have been studied extensively (Stack 2021), much less is known about the short-term triggers of suicide and mental health episodes (Franklin et al. 2017), and it is unclear to what extent smaller everyday shocks trigger these behaviors and thoughts. The impulse of the moment is an important factor in suicidality (Baca-Garcia et al. 2005; Baca-Garcia et al. 2001; Yen et al. 2004; Zouk et al. 2006). In a study of attempted suicides, Simon et al. (2001) reported that a quarter of these attempts had been made within 5 minutes of the decision's being taken. This highlights the importance of ephemeral shocks in triggering suicide: Vardoros et al. (2019) show a positive relationship between daily economic uncertainty and suicides in England and Wales. The challenge in understanding these short-term factors is the lack of high-frequency data on triggers and outcomes. Furthermore, the events and circumstances which trigger suicidality may be endogenous to an individual's mental health, such as unemployment and relationship break-ups.

We overcome both of these challenges by examining the impact of a small exogenous health shock on mental health and suicide. While physical health is a significant predictor of suicide and poor mental health (Stack 2021), a small shock may exacerbate the mental health burden to a tipping point, triggering suicidality and episodes requiring emergency care. We test this hypothesis by examining the impact of seasonal allergies caused by exposure to pollen on the incidence of suicide and visits to the emergency department (ED) for mental and behavioral health. We use novel, high-frequency data on seasonal pollen measurements, suicide counts, and mental health care utilization across many localities in the United States to evaluate a plausibly causal relationship.

Though a naturally occurring byproduct of plants' reproductive cycles, pollen affects human well-being significantly: itchy eyes, runny nose, and a cough seem like minor symptoms, but these also affect quality of sleep, mood, and cognitive ability. Pollen allergies are the single largest reason for missed workdays in the United States, and are responsible for $4.9 million in estimated losses to employers each year, a higher figure than health conditions such as hypertension, high blood pressure, or coronary heart disease (Lamb et al. 2006). Decades of environmental policy have regulated and mitigated man-made air pollution, resulting in a stabilization and decline in levels of pollutants. Pollen, however, has never been targeted by environmental policy, nor can it be effectively controlled by it. In fact, the pollen season has been increasing in intensity and duration in the past 30 years due to climate change, with plants blooming earlier in the season (Anderegg et al. 2021; D'Amato et al. 2020, Shea et al. 2008; Zhang and Steiner 2022).

At the same time, seasonal allergies can be treated using over-the-counter medications such as antihistamines and decongestants, which are relatively inexpensive, widely available, and safe to use. As mental health conditions and suicidality have gained attention and their incidence has accelerated in recent years, we evaluate the role of a relatively minor and easily treatable health shock in triggering these episodes of care and death.

To understand how a small environmental shock could affect mental health and death by suicide, we evaluate the impact of seasonal pollen on deaths by suicide and visits to the emergency department (ED) for behavioral and mental health conditions, using three datasets: daily pollen measurements from many metropolitan localities, daily counts of suicides by county, and daily aggregations of claims at the zip-code level for ED visits related to mental and behavioral conditions from a large private insurer. We analyze the interaction between pollen and deaths, and pollen and claims for behavioral and mental health ED visits, using a model richly saturated with location and time fixed effects, identifying the plausibly causal relationship from daily deviations from the local seasonal mean. Our analysis finds a 1.7–2.9-percentage point (pp) rise in the probability of death by suicide for every 10 particles per cubic meter (pcm) of pollen at low levels, and a 0.4-pp rise in probability of death for every 10 pcm at higher levels of pollen. ED visits are more sensitive, with a 3.5-pp rise for every 10 pcm of pollen at the lowest levels and effects moderating or even disappearing as pollen levels rise. The effects we estimate vary in intensity by region: while Midwestern states experience increases in suicide and ED visits at the lowest levels of pollen, localities in southern and western states experience effects primarily at mid to higher-than-median levels of pollen measurements. Consistent with other studies, the effects we estimate are present primarily among suicides by Whites, males, and those between the ages of 19 and 35.

This study makes four significant contributions to the literature on suicidality. First, although the structural causes of suicide are well studied, the short-term triggers of suicide are less examined. Our study illustrates the impact of a widespread shock of relatively small magnitude – seasonal allergies – on mental health and suicidality.

Second, while other studies have focused on suicide and suicidal ideation, ours also examines episodes of mental health care. Though deaths by suicide impose a great social burden, suicidal ideation, suicide attempts, self-harm, and other mental health episodes occur much more frequently. Furthermore, focus on precursors and risk of death by suicide allows for policy interventions to improve quality of life and prevent future suicides. The literature examining the relationship between pollen and mental health is extremely limited: only two studies have examined poor mental health including suicidal ideation (Messias et al. 2010) and history of allergies and allergy treatment among victims of suicide (Qin et al. 2011) in relation to pollen. Our study shifts the focus away from the terminal event of suicide toward episodes of mental distress.

Third, this study uses data from 33 metropolitan areas across the United States, allowing us to examine regional differences and draw national conclusions. Data scarcity has limited previous literature on the relationship between pollen and suicide to opportunistic studies in narrowly defined geographic areas (such as Tokyo, Dallas, or Copenhagen), limiting the generalizability of their findings. Though the data used in this study are not nationally representative, they include a large number of metropolitan areas to allow us to take advantage of variation in place-based predictors of suicidality.

Fourth, this study uses high-quality, high-frequency data combined with plausibly causal identification to detect small variations between pollen and mental health care utilization and suicidality. Though most studies adjust for demographic characteristics, weather, and calendar weeks, none include sufficiently granular fixed effects to absorb unobserved time- and location-specific seasonal variation in both pollen and suicide. We employ granular time and location fixed effects to account for unobserved factors which may contribute to both pollen and suicidality.

Fifth, what sets our study apart from the growing literature on environmental impact on mental health is that while pollution exposure is endogenous to individual activity and choices, changes in pollen levels vary in a manner that is plausibly exogenously. This variation allows us to identify the impact of an exogenous but small health shock on mental health and suicide.

The next section describes the impact of pollen on the human body and the mechanisms by which it affects health and behavior, gives an overview of known social and economic predictors of suicide, and summarizes the literature on air quality and suicidality. Section 3 describes the method of identification of the effect, and presents the specification which is estimated. Data are introduced and discussed in Section 4, and results are presented in Section 5. The paper concludes with an in-depth discussion of the results.

2. Background

Pollen is a natural byproduct of the reproductive cycle of plants. As such, it peaks in the late spring and early summer as plants flower, as seen in Figure 3. There is a second, much smaller, peak in early fall (Bridges et al. 2005; Woo et al. 2012b). The timing and intensity of the pollen season is conditioned by weather, and it is expected that it will grow in length and intensity with climate change (Anderegg et al. 2021; D'Amato et al. 2020; Shea et al. 2008; Zhang and Steiner 2022).

Seasonal Allergic Rhinitis and Health

Seasonal allergic rhinitis (SAR), triggered by pollen from trees, grasses, and weeds, affects nearly 400 million people globally, and up to 20% of the US population (Jauregui et al. 2009; Greiner et al. 2011). In response to exposure to pollen, SAR causes the immune system to produce antibodies such as histamine and cytokines, triggering inflammation of tissue and increased secretion of mucus, resulting in nasal congestion, watery eyes, irritated throat, itching, sneezing, and runny nose (NIAID 2012; Janeway et al. 2001; Greiner et al. 2011).

SAR also affects a person's well-being through less-visible behavioral health outcomes: reduced quality of sleep, interrupted sleep, and daytime somnolence (Santos et al. 2006; Craig et al. 2004; Tashiro et al. 2002; McAfoose and Baune, 2009); reduced cognitive ability, mood changes, and fatigue (McAfoose and Baune 2009; Tashiro et al., 2002; Dowlati et al. 2010; Kronfol and Remick, 2000); and longer response times and reduced working memory (Marshall et al. 2000;

Kremer et al. 2002; Wilken et al. 2002; Marshall and Colon 1993). Some of these are known risk factors of suicide (Liu et al. 2020; Wang et al. 2019; Harris et al. 2020).

It is not surprising, therefore, that exposure to pollen has been linked to a number of behavioral outcomes. Chalfin et al. (2019) found a 4% decrease in violent crime on days with very high pollen measurements. Marcotte (2015) and Marcotte (2017) find a decline in English language and math scores among elementary schoolchildren on high pollen days. Akesaka and Shigeoka (2023) find some evidence of increased accidents and injuries on high pollen days in Japan.

Factors of Suicidality

Though popular opinion believes that winter weather is associated with the highest incidence of death by suicide and mental health episodes, research shows that suicides rise sharply in April and May, and peak in August and September (Bridges et al. 2005; Woo et al. 2012b).

Nonetheless, pollen is not the main nor is it a major predictor of suicidality. A large body of literature has identified a number of place-based structural factors contributing to the risk of death by suicide. These are grouped into six categories: (1) social connectedness, such as domestic integration, residential instability, social isolation, and religious integration (Denney et al. 2015; Pendergast et al. 2019; Pescosolido et al. 2020; Recker and Moore 2016; Rockett et al. 2022; Steelesmith et al. 2019); (2) economic factors, such as unemployment, poverty, and indebtedness (Denney et al. 2015; Phillips and Nugent 2014; Recker and Moore 2016; Rockett et al. 2022); (3) economic structures often predictive of suicide, such as the proportion of labor force employed in manufacturing, and unionization (Phillips and Nugent 2014); (4) cultural facilitators of suicide, such as access to firearms, alcohol consumption, pain reliever abuse (Rockett et al. 2022; Steelesmith et al. 2019); (5) demographic characteristics, such as the proportion of residents that are male and over 65 and of veterans, as well as ethnic/racial composition (Pescosolido et al. 2020; Recker and Moore 2016; Rockett et al. 2022); and (6) local medical and legal resources and norms for certifying a death as suicide (Rockett et al. 2022). For a full discussion of these factors, see Stack (2021). We hypothesize, however, that the characteristics of a place can amplify or minimize the impact of pollen counts on suicidality. For example, easy access to means of suicide might amplify the impact of pollen on the likelihood of completed suicide.

Environmental Impact on Mental Health

Recent availability of geographically granular data has allowed for research into the relationship between air pollution and mental health. Multiple meta-analyses have established the association between airborne particulate matter – such as ozone, sulfur dioxide, nitrogen dioxide, and carbon monoxide – and depression, anxiety, and deaths by suicide (Braithwaite et al. 2019; Heo et al. 2021; Liu et al. 2021). In the economic literature, Persico and Marcotte (2022) show a 0.49% increase in daily suicides for each unit increase in daily PM2.5, while Molitor et al. (2023) show an increase in rural suicides following the spread of the smoke plume resulting from the California wildfires.

There is also a growing literature linking the warming climate to a decline in mental and cognitive health. Burke et al. (2018) found a 0.7% rise in suicides in US counties and 2.1% rise in suicides in Mexican municipalities associated with a 1C rise in monthly average temperatures. More recently, Bhalotra et al. (2022) linked fetal exposure to high temperatures to long-term cognitive and economic outcomes in the UK, and Zhang et al. (2024) showed declines in test performance on high-temperature days for school-age children in China.

Though we believe this is the first systematic causal evaluation of the relationship between seasonal pollen and suicidality, a handful of studies in limited geographic settings have established a positive associative relationship. Stickley et al. (2017) examined deaths by suicide in Tokyo; Jeon-Slaughter et al. (2016) examined nonfatal self-directed violence in Dallas, TX; Qin et al. (2011) and Qin et al. (2013) evaluated deaths by suicide in two localities in Denmark. All of these studies found a positive relationship between pollen and deaths by suicide. In the United States, at the national level, Messias et al. (2010) associated suicidal ideation with pollen. Postolache et al. (2005) used 1995–1998 data to find higher pollen levels associated with increased deaths by suicide, though these results could not be replicated by Woo et al. (2012a), who used more recent data. Qin et al. (2011) estimated a higher incidence of allergies and allergy treatment among victims of suicide.

Our study contributes to all three of these bodies of literature as it quantifies the impact of a naturally occurring air contaminant – pollen – on not only suicidality, but also mental health more broadly. It also contributes to the literature exploring one possible mechanism linking rising global temperatures to mental health, as the intensity and duration of the pollen season extends with global warming.

3. Theoretical Models of Suicide

An economic model of suicide was described by Hamermesh and Soss (1974) (henceforth HS), whereby the agent makes a decision in terms of expected lifetime utility. According to the model, the agent maximizes the present value of expected lifetime utility at each age as a function of permanent income. The primary purpose of that model was to match two data trends presented by the authors: a positive relationship between age and suicide, and a negative relationship between income and suicide.

Though HS closely matched the trends they proposed to explain, subsequent work critiqued the irrationality of the model as well as its poor performance in predicting current trends in suicidality. Stack (2021) points out that as rates of suicide rise and fall with the business cycle, economic growth, unemployment, and level of economic development, it is plausible to argue that suicide may contain a rational component, but not entirely so. In recent decades, however, suicidality among younger individuals has increased, undermining the central assumption of the HS model that a monotonically decreasing expected lifetime utility generates suicide trends (Cutler et al. 2001). Furthermore, HS relies on the individual's having perfect information about their future utility – an assumption which is not consistent with the inherent uncertainty around events which might affect the future flow of utility. Cutler et al. (2001) argue that HS's rational-suicide model creates insights into the role of variability and time correlation of happiness, but concede that it does not explain rising youth suicide trends.

In Appendix G we propose an economic model of suicide which conceptualizes the relationship between a minor environmental shock and suicidality. While a small shock, such as a seasonal pollen allergy, might seem like an insignificant factor in an individual's decision to attempt suicide, the conceptual model we propose provides the framework within which such shocks trigger or tip an individual decision-maker from "cold" into "hot" mode, in line with the Bernheim and Rangel (2004) addiction model.

Model Implications

The model generates a testable prediction that for more severe environmental health shocks, there will be a larger number of suicide attempts. This conclusion is consistent with the recent development of an ideation-to-action framework in suicide theory, which stipulates that suicidal ideation and progress from ideation to suicide attempt are distinct phenomena with distinct predictors. In discussing this framework, Klonsky et al. (2016) point out that suicidal ideation progresses to planning when pain exceeds connectedness. The authors note that the ideation-to-action framework is intentionally vague about the nature of pain, allowing for physical suffering to be the motivator of ideation. Therefore, a daily health shock which increases physical suffering may trigger an individual to move from ideation to planning of suicide.

This model allows for reconciliation of the rational expectations framework for utility maximization that is used in economics with the large body of literature on suicidality in other fields. Our model also proposes a setting where suicide is not a rational choice an individual would make in a utility-maximization framework. This is consistent with the literature that suggests that the vast majority of individuals who ideate or attempt suicide do not go on to complete it (Bostwick et al. 2016). That is, what looks like a good choice in a given moment is not a good choice in the next period or the period that follows. This provides evidence in support of both modeling suicide as an instantaneous "hot" mode and the impact of exogenous short-lived shocks on suicide.

4. Data

We use three main sources of data, aggregating daily information about pollen measurements, utilization of mental and behavioral health care, and deaths by suicide at the zip-code level.

National Allergy Bureau Pollen Data

We use newly available daily pollen measurements from 33 stations in 28 metropolitan localities across the United States (see Figure 2) collected between 2006 and 2017, obtained through an exclusive agreement with the American Academy of Allergy, Asthma, and Immunology (AAAI) as part of their National Allergy Bureau (NAB) project. These pollen measurements were collected on a volunteer basis by AAAI-member allergy and immunology practices and institutes across the United States. A designated staff member was certified in collection methods by the NAB, and collection was always carried out on the practice premises, guaranteeing consistent measurement across time and localities. As a result, the measurements used in these analyses are taken in urban or suburban localities, often with a single measurement site for the county area.

Of the more than 70 locations that collected measurements, 33 gave us permission to use their data.[1] As Figure 1 shows, the data include states in every census region, across many climates and population densities. Airborne pollen, as used here, is collected using a Burkard volumetric spore trap, with exposure periods running for 24 hours. The trap collects all airborne pollen, including that which originates from trees, grass, and weeds. Trained counters then conduct microscopic analysis of the pollen, and counts are expressed in terms of particles per cubic meter (pcm) of air (Ito et al. 2015; Sheffield et al. 2011). Pollen counts are often zero in the winter, so many stations, particularly those in northern latitudes, report counts only in spring, summer, and fall months. Postolache et al. (2005) separated pollen by source – tree, grass, and weeds – in their analysis. We do not separate pollen by source because not all stations report counts by type. Nonetheless, we feel that such separation would not impact our estimates significantly, as an average of 83% of the total pollen in our data (where source is reported) comes from trees. Figure 3 summarizes the average pollen measurements (148 pcm) as well as the average daily number of suicides (0.06) at these locations, with substantial variation between locations (New York, NY with the lowest average pollen measurement and Kansas City, MO with the highest).

OptumInsight Health Insurance Claims Data

Our second source of data is the newly available and highly granular data on health insurance claims for individuals insured by UnitedHealthcare, one of the largest private insurers in the United States, provided by OptumInsight. Limited to zip codes of interest, the data allow the identification of the mental health care claims of more than 18 million individuals between 2006 and 2017. Each claim record includes information about the place and date of service, diagnostic and procedure codes, provider information, and payment information. Because of the granular nature of the data, to protect the privacy of beneficiaries, demographic characteristics are limited to age, sex, and zip code of residence. This database is a new and unique resource, as it integrates enrollment records, medical claims, and prescription claims.

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[1] The localities include: Atlanta (GA), Austin (TX), Baltimore (MD), Charlotte (NC), College Station (TX), Colorado Springs (CO), Dayton (OH), Detroit (MI), Draper (UT), Erie (PA), Eugene (OR), Flower Mound (TX), Greenville (SC), Houston (TX), Kansas City (MO), Knoxville (TN), Louisville (KY), Melrose Park (IL), Newcastle (DE), New York (NY), Oklahoma (OK), Olean (NY), Omaha (NE), Onalaska (WI), Pleasanton (CA), Rochester (NY), San Jose (CA), Seattle (WA), Silver Spring (MD), St. Louis (MO), Tulsa (OK), Twin Falls (ID), Waterbury (CT), and York (PA).

We use diagnostic codes and place of service to aggregate claims to the daily zip-code sum of visits by type. We also identify the demographic composition of these visits, by separating counts by gender and age categories. The outcome of interest is the number of visits by date by patient zip code.

The nature of the data presents two significant challenges for identification and estimation. First, as the data include claims from a single insurer, they do not represent the total volume of visits and utilization for the diagnostic codes of interest in these zip codes. As the claims are from private insurance, they are more likely to represent a population that is more affluent. In robustness analyses, we compare the demographic characteristics of the patients in the data to those in the American Community Survey for the zip codes represented in the data in order to quantify the selection inherent in the use of these data.

A second challenge is that the data have a mass of zero, as the granularity of zip code, date, and diagnostic code give rise to days with no visits by those covered by the insurer. To address this challenge, we use a Poisson specification which fits a distribution of nonnegative counts of data with the same first and second moments.

National Violent Death Reporting System (NVDRS)

The Centers for Disease Control and Prevention (CDC) compile this database of violent deaths from multiple sources of reporting. In addition to information from death certificates, the NVDRS compiles information from the coroner/medical examiner, law enforcement, and toxicology reports into a single database describing the context of violent deaths. The database incorporates information about mental health conditions and treatment, relationship problems, drug use, and life stressors. The data also include information about the incidents, including use of weapons and location. The NVDRS defines a violent death as a "death that resulted from the intentional use of physical force or power, threatened or actual, against oneself, another person, or a group or community."[2] For this project, we obtained all deaths ruled as suicides for individuals aged 10 years and older.

Though all states were participating in the NVDRS as of 2022, the database started in 2002 with only six states, and other states joined subsequently. As a result, not all states are present

[2] NVDRS Frequently Asked Questions https://www.cdc.gov/violenceprevention/datasources/nvdrs/faqs.html

throughout the length of the pollen data panel. Our analysis relies on 187 counties in 21 states.[3] As with the claims data, the daily number of deaths by suicide at the county level includes a large number of zeros.

We supplement these data with weather data from PRISM Climate Group, including temperature maxima, minima, and average, and precipitation. To account for the nonlinear impact of weather on mental health, consistent with the literature, we include continuous controls for each minimum, maximum, and average temperature interacted by an indicator of a quartile of measurement. We define the area of pollen exposure as the county where the measurement station is located and all adjacent counties.

5. Empirical Methods

To examine how pollen shocks affect mental health and suicide, we first examine patterns across localities. Figure 3 shows the average pollen count by location for 28 localities in the United States between 2006 and 2017. Though localities vary significantly in timing and magnitude of peaks of pollen counts, all pollen trends show a distinct surge in late spring, and a smaller rise in early fall. For example, Alameda County in California experiences a spike in February and March, while in the colder climate of Erie County in Pennsylvania, pollen counts reach their peak in May and early June. Appendix Figure A1 juxtaposes average pollen measurements against counts of suicides at the monthly frequency during this period. As the figure highlights, deaths by suicide include significant seasonal variation that could be conditioned, among other things, on variation in pollen levels. For example, rising pollen levels coincide with rising temperatures and lengthening daylight hours, both of which may affect mental health and deaths by suicide. At the same time, the decline in pollen during summer months may coincide with locality-specific summer festivities and events which, once again, may affect mental health and deaths by suicide through social channels. To circumvent these confounders, we make use of the highly granular nature of the data to identify the causal relationship between pollen and poor mental health/deaths by suicide by comparing deviations from local seasonal trends at the daily frequency.

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[3] The states included in NVDRS that overlap with the pollen panel are: California, Colorado, Connecticut, Delaware, Georgia, Illinois, Kentucky, Maryland, Michigan, Missouri, Nebraska, New York, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, South Carolina, Utah, Washington, and Wisconsin.

Specifically, to account for the relatively rare occurrence of deaths by suicide as well as of ED visits for mental health conditions, we model a Poisson specification which includes extensive place and time fixed effects of the form:

$$\log(E(Y_{it}|x)) = \alpha + \sum_{j=1}^{4} \beta_j \, Pollen_{it} * I_j + \sum_{j=1}^{4} \beta_j^{-1} \, Pollen_{it-1} * I_j + \sum_{j=1}^{4} \gamma_j \, Temp_{it} * I_j + \delta \, Precip_{it} + \zeta \, MA \, Pollen_{it} + V_i + W_t + \varepsilon_{it} \quad (2)$$

where Y_{it} is the outcome of interest (mental and behavioral health visits or deaths by suicide) for zip code *i* at time *t*. To capture the nonlinear relationship between pollen levels and mental health, we estimate a separate linear fit for each quartile of measurement, represented by $Pollen_{it}$ interacted with the indicator I_j, and captured by the four coefficients β_j. This linear fit for each quartile of pollen measurement allows us to approximate a nonparametric fit for the relationship between pollen and the outcome of interest. In all analyses, the pollen measurements have been scaled down by 10 pcm to improve the interpretability of estimates.

The autocorrelated nature of pollen data suggests the importance of including not only current but also lagged pollen levels, represented by $Pollen_{it-1}$ and captured by the four coefficients β_j^{-1}, as well as a moving average of measurements for the week before, $MA \, Pollen_{it}$, captured by ζ. When presenting the results, we sum the contemporaneous and lagged effect of pollen levels for each quartile, $\beta_j + \beta_j^{-1}$, to reflect the cumulative effect of direct exposure and delayed care on both deaths by suicide and use of the ED.

Similar to pollen measurements, we capture nonlinearities in the effect of temperature on mental health and suicide by quartile of measurement, captured by the interaction term $Temp_{it} * I_j$. An indicator for precipitation is represented by $Precip_{it}$.

A set of granular location and time fixed effects absorb variation attributable to location and seasonal trends. All specifications include location fixed effects, V_i, which capture location-specific predictors of mental health and suicide, such as economic conditions, connectedness, access to mental health care, access to firearms, and so on. All specifications also include time fixed effects, W_i, to capture national trends during this period, including social, political, and economic events, which are not location specific, but may affect mental health. In our preferred specification, we include location–week fixed effects to account for location-specific events, such as seasonal trends in tree blossoming and pollen release. We also include month–day fixed effects, which capture monthly patterns, such as holidays and week cycles, which may affect mental health across all locations.

To account for spatial autocorrelation, standard errors, ε_{it}, are clustered at the locality level.

Identification

While the empirical method used for analysis does not fit within the canon of causal econometric literature, we believe our estimates are as good as causal. Our estimates constitute an intensity of treatment specification with two-way fixed effects, without a nontreated group as counterfactual. Our preferred specification includes location interacted with week fixed effects to account for location-specific seasonal characteristics which do not change over the years, such as trees blossoming and festivals, as well as seasonal socioeconomic variation. These fixed effects also account for risk factors which change less slowly, but nonetheless are specific to the locality, such as gun ownership. Our preferred specification also includes month interacted with day fixed effects, which accounts for time variation across all locations, such as the rollout of the Affordable Care Act. In alternative specifications, we explore variations on location and time fixed effects and show that estimates are generally stable.

Thus, our estimates are identified from daily deviations in pollen and suicides from location-specific weekly means and national time trends. One potential challenge to identification in this setting would be an underlying factor which affects both changes in pollen levels and changes in suicidality. One such factor could be weather, particularly precipitation and seasonal temperatures, which change daily and are also exogenous to human activity. Our preferred model specification includes weather controls, which should account for some of this unobserved effect. However, to explore this confounder further, we examine the relationship between pollen and weather in Appendix E.

Recent literature on pollution and health uses wind direction to instrument for the level of pollution (Persico and Marcotte, 2022; Deryugina et al. 2019). We do not believe such instrumentation is necessary in this setting. Pollution is generally believed to be endogenous to human activity. Rising pollution levels result from increased economic activity and, thus, confound the impact of pollutants with that of business cycles on health.

Pollen, however, does not have such a relationship with human activity. Though pollen levels may be related to the number of trees and grasses present in a geographic area – which may be the result of a choice by residents of the locality – the change in pollen levels is not associated with economic or noneconomic activity. Pollen is a natural byproduct of the reproductive cycle of plants and is, therefore, governed by seasonal environmental factors.

Over a longer time horizon, individuals may choose where they live based, in part, on their susceptibility to seasonal allergies. Our analysis circumvents this endogeneity by relying on daily variation from local seasonal levels, precluding selective migration.

6. Results

Prior to presenting the adjusted results, we first examine unadjusted trends in pollen and deaths by suicide. Figure 2 characterizes pollen measurements and daily counts of suicides in these counties. Cities with lower-than-average levels of pollen may have less tree-canopy coverage, as in New York, NY or Draper, UT, but still have high daily suicide counts. Cities with higher-than-average daily pollen counts may have more parks and green spaces throughout, as in Kansas City, MO. The identification used in this analysis relies on daily deviations from the average pollen in locality each season. Thus, while there may be an overall elevated level of pollen in a locality, we hypothesize that unusually high pollen days impact mental health and suicidality adversely. We similarly note that though the daily number of suicides varies substantially in a locality, the identification relies on days with deviation from the average number of suicides, rather than an elevated mean.

Figure 3 plots the average weekly pollen count throughout the years of data for each location. The red line shows average levels for all locations, while the blue and black lines show averages for Erie County, PA and Alameda County, CA, respectively. While the seasonal variation is consistent across locations, the timing of the peaks depends on location latitude. To highlight this, Appendix Figure A2 separates these averages by state region, on the same scale. These figures show that even though states in the Northeast and Midwest are in higher latitudes, they experience greater peaks in pollen counts in April and May. States in southern and western latitudes experience medium-to-high levels of pollen for longer periods (February through May).

Figure 4 shows a scatter diagram of monthly average pollen measurements plotted against monthly counts of suicides, separated by census region. Though the average trends move together, these could be conditioned by seasonal and population factors which predict both pollen and suicides. For example, high average levels of pollen in a locality may condition or select for residents who tolerate these levels. Therefore, it is important that the identification relies on unexpected deviations from local seasonal pollen patterns.

Figure 5 illustrates the serial correlation in pollen measurements. In particular, to evaluate whether pollen rises and declines in cycles, we designate days when pollen levels are 1500 pcm and above as day zero (a high pollen day), and evaluate the average pollen levels in the 7 days before and after that day. The figure on the left indicates the average of measurements in the 7 days prior to and following a high pollen day – suggesting that the levels increase gradually and then recede. The figure on the right, however, excludes prior days with pollen levels at or above 1500 pcm. This figure shows no clear increase in pollen measurements in the days before the high-pollen day. These figures allow for insight into two features of pollen measurements in our data. First, pollen measurements are not independent across time, suggesting the presence of serial correlation. Second, however, instead of characterizing a slow buildup, the pollen levels spike and remain high across consecutive days. Accordingly, all analyses will include contemporaneous and lagged effects, as well as a 7-day moving average to account for the previous week's pollen levels.

Suicide Counts

We present estimates of equation (2) in Table 1 for deaths by suicide. Each column presents the estimates for $\beta_j + \beta_j^{-1}$ for each quartile of pollen, and ζ for the 7-day moving average of pollen measurement. Each column in the table is a separate specification which includes the continuous level of pollen interacted with indicators for quartile of measurement. The outcome is the number of suicides in a county-day. The unit of treatment is a 10-pcm increase in the pollen level at each quartile of measurement. As the estimates are from a Poisson specification, the coefficients can be interpreted as the percentage change in the count of suicides resulting from a 10-pcm increase in pollen at each quartile.

Column (1) presents the baseline estimates, without any weather controls or fixed effects, while columns (2) and (3) add location and time fixed effects in various combinations. Column (4) is our preferred specification. It includes weather controls of average, minimum, and maximum daily temperature interacted with the indicator of quartile of measurement, and an indicator of precipitation. This specification also includes location interacted with week fixed effects and month interacted with day fixed effects.

The estimates in Table 1 are consistent across specifications. First, we note that as the quartile of measurement increases, the impact of pollen on suicide is smaller and less significant. That is consistent with our observation that pollen levels tend to rise throughout the week, so that when they reach high levels (i.e., 4^{th} quartile), people have had time to adjust to their impact. At low levels of pollen, we find that a 10-pcm increase in pollen increases suicides by up to 2.9%, though these estimates are not statistically significant at conventional levels. Pollen levels in the second quartile increase suicides by up to 1.7% per 10-pcm increase. In the third quartile, suicides increase by 0.45%, a much smaller effect. Finally, we find no statistically significant or economically meaningful impact at the highest quartile of pollen.

We present coefficients β_j and β_j^{-1} separately in Figure 6 panel (a) to show the individual contribution of same-day and lagged effects in each quartile. Here, the first quartile is notable: while the standard errors are large but preclude statistically significant estimates, we find that the coefficient magnitudes are large and meaningful. In fact, while the impact of same-day pollen is muted, lagged levels of pollen drive the impact, with a 1.9% increase in suicides that is marginally statistically significant at the 10% level. This suggests that at low levels, the impact is greater on the day after, suggesting a delayed-impact mechanism. At other levels of pollen, we do not observe a divergence between same-day and lagged impact.

The coefficients for contemporaneous and lagged effects are reported in full in Appendix Table C1a.

Visits to the ED

Table 2 presents the coefficient estimates for equation (2) for ED visits with mental and behavioral care diagnostic codes.[4] The unit of analysis, here, is zip-code-day, and as in the analysis on deaths by suicide, each column presents a separate specification. Since the geographic units are smaller and the number of states greater than in the NVDRS, we start with a sample of 6,288,628 zip-code-days. We report the summed contemporaneous and lagged coefficient by quartile of measurement, as well as the moving average coefficient. We start by

[4] The codes are specified in Appendix B.

noting positive and statistically significant coefficients for all quartiles of pollen in column (1), but the magnitude of the coefficient declines by each quartile. As location and time fixed effects are added, the magnitude, significance, and even sign changes for high pollen measurements (3rd and 4th quartile) – and at low levels of measurements, the estimates – remain statistically significant at conventional levels and increase in magnitude in column (3). In the preferred specification in column (4), we estimate a 3.5% increase in ED visits associated with a 10-pcm increase in pollen for the first quartile, a 0.26% increase in visits for the second quartile, and a 0.01% decrease for the fourth quartile.

Graphing the coefficients β_j and β_j^{-1} separately in Figure 6 panel (b), we find both the contemporaneous and lagged coefficients similar in magnitude and sign and statistically significant for the first quartile. For the second quartile, the estimate is an order of magnitude smaller, and the lagged effect is not statistically distinguishable from zero. The coefficients for contemporaneous and lagged effects are reported in full in Appendix Table C1b.

Demographic and Regional Variation

The intensity and duration of pollen counts differ across census regions (see Appendix Figure A2). Accordingly, we stratify our estimates by region in Table 3 for deaths by suicide and in Table 4 for ED visits. The estimates in these tables come from our preferred specification, with location by week- and month by day-fixed effects, full weather controls, and the 7-day moving average. At first glance in both tables, we see that the effect of pollen on deaths by suicide and ED visits differs substantially by region. However, the largest and most notable effect for deaths by suicide is in the Midwest (column (3) in Table 3), where an increase of 10 pcm in pollen at low levels results in an up-to 14.6% increase in the number of suicides. In other regions, suicides are much more sensitive to pollen for the second or third quartiles of measurement.

For ED visits, in Table 4, the effects once again vary by region: in the South, ED visits increase by up to 7.0% for the first and second quartiles for a 10-pcm increase in pollen, but in the West, visits decline by up to 3.4% at low levels of pollen. In the Midwest, however, visits increase by 5.4% for the first quartile of pollen, but decline by 0.4% and 0.3% in the second and third quartiles.

Figure 7 shows effects stratified by the race of the decedent, showing sizable effects for White individuals in the second and third quartiles of pollen levels. While the estimates for Black decedents are not statistically significant, they are similar in magnitude and sign to those of White decedents. Hispanic decedents are more responsive at low levels of pollen, with a fourfold effect compared to White decedents. This effect is particularly important given the small sample size for this population.

Figure 8 shows results by demographic characteristics of suicides (panels (a) and (c)) and ED visits (panels (b) and (d)) by sex (male and female) and age (0–10, 11–18 years; 19–35 years; 35–64 years; 65 and older). We chose these categories because the Consensus Study Report by the National Academies of Sciences, Engineering, and Medicine on *High and Rising Mortality Rates Among Working-Age Adults* noted rising deaths by suicide among working-age adults beginning in the 1990s (National Academies of Sciences, Engineering, and Medicine 2021). The estimates are somewhat surprising. Though decedents of suicide are predominantly male, pollen impacts men and women equally in our sample. Though the effect on women is not statistically significant, the coefficient magnitude is comparable. We also find a similar effect on ED visits for both men and women, showing no evidence of delayed care by men resulting in a higher incidence of suicide.

Stratification by age, however, does show significantly different effects. Though the differences between age groups for suicide are not statistically significant at conventional levels, we find effects comparable to our main specification for all age groups, with the notable exception of midlife. Suicides for individuals aged 36–64 years old do not appear to be sensitive to pollen levels at any quartile. This exception is notable because this group has experienced the sharpest rise in suicides in the past decade (National Academies of Sciences, Engineering, and Medicine 2021). Visits to the ED, shown in panel (d), show a different pattern. Contrary to the suicide data, we are able to track visits for mental health care by children under the age of 10, and it is this group that shows the largest magnitude of increase in visits – almost three times higher rates than the baseline estimate. Youth, young adult, and midlife visits are consistent with the baseline estimates. Older adults experience a decline in visits at low levels of pollen.

Heterogeneity in Outcomes

While the outcomes of suicide and ED visits for mental health have been defined as broadly as possible to encompass as many incidents as might be sensitive to pollen, there may be substantial heterogeneity in its impact.

Suicides which use immediately available methods may be more susceptible to the triggering of "hot" mode than those which require more advanced planning. Guns are responsible for 53% of all deaths by suicide. States with the lowest number of firearm laws have more than twice the rate of suicides by firearms than states with more laws, which suggests that pollen allergies may magnify the effect of suicides by guns.

Table 5 examines deaths by suicide across two dimensions: method of suicide and presence of an underlying mental health condition. Among the methods, we examine three: firearms, drugs/medication, and other. In column (1) we find a significant increase in suicides by firearms when pollen is in the second and third quartiles. On the other hand, suicides by drugs or medication (column (2)) and other methods (column (3)) are not similarly sensitive to pollen levels. To the extent that we believe that suicides involving firearms require less premeditation than those involving drugs or medication, then these results confirm that pollen has a greater effect on less premeditated events.

In columns (4)–(7), suicides were separated according to known mental health factors. An advantage of NVDRS is that it provides information from law enforcement investigations, allowing the researcher insight into witness reports around the event. We use four indicators present in these reports: (a) victim had been identified as having mental health problems at the time of their death; (b) victim was perceived by self or others to be depressed; (c) victim had been in treatment for mental health at the time of their death; (d) victim had a history of having been treated for mental health illness at some point. Column (4) restricts the sample to suicides which do not involve any of these mental health indicators, showing a large and significant effect for the second quartile of pollen measurement (3.15-pp increase in likelihood of suicide). Columns (5)–(7) combine the different report types, but the estimates are consistent across all specifications: significant and large effects in the first, third, and fourth quarters of pollen measurements.[5] These estimates are consistent with our theoretical model that suggests that as stress increases or mental health deteriorates, the probability of "hot" mode, and hence suicide, being triggered by pollen increases.

[5] Column (5), Known MH Indicator, includes reports (a), (b), (c), (d); column (6), MH Condition or Treatment, includes reports (a), (c), (d); column (7), MH Treatment, includes reports (c) and (d).

Though we defined ED visits as any insurance claim for mental health care occurring on the premises of the ED, this category includes a variety of mental and behavioral diagnostic codes. In Table 6 we separate these counts into smaller, clinically meaningful categories, including anxiety, history of mental health conditions, mood disorders, personality disorders, schizophrenia, and attempted suicide. We first notice that there is significant heterogeneity by category; at low levels of pollen, patients with a history of mental health conditions are more likely to avoid the ED, while patients with a diagnosis of anxiety or mood disorders are more likely to seek care. At higher levels of pollen, however, visits increase across all categories of care.

We conclude that pollen has a heterogeneous impact on suicides and ED visits. Individuals with a history of mental health conditions may engage in more avoidance behaviors at low levels of pollen. Similarly, suicides by gun are sensitive to pollen, while other methods do not appear to have the same sensitivity.

Pollen or Weather?

An alternative explanation for the relationship between pollen and mental health care and suicidality is that pollen partly captures the effect of weather. We examine the role of weather in Appendix D. As part of the analysis, we evaluate the relationship between pollen and weather in our data, finding a weak correlation which does not vary substantively between sites. Therefore, while we do stratify our analysis by the strength of this relationship, we do not believe that sites with a higher correlation are more prone to reflect the effect of weather on suicides. We confirm this finding by adding lagged weather controls to our main specification, finding no change in our main coefficient values.

Pollen and Pollution

Pollen and pollution may act in tandem in terms of their effects on mental health. Since pollen particles are included in measurements of PM2.5 levels, and PM2.5 has been shown to have an adverse effect on suicidality (Persico and Marcotte, 2022), one might expect the interaction between these environmental inclusions to have a double impact on mental health. To explore this more fully, we merge suicide and pollen data with daily air-quality index (AQI) measurements provided by the National Oceanic and Atmospheric Administration (NOAA) climate data. Not every locality-year has daily AQI measurements, which meant a smaller subsample was created that we compared to our main results. To evaluate the impact of pollution, we create indicators for pollution levels we deem "bad" and "very bad." This categorization is based on the Environmental Protection Agency (EPA) classification of AQI for healthy and sensitive populations. We categorize pollution as "bad" if the levels correspond to the classification of a moderate level of concern,[6] and "very bad" if the levels correspond to the classifications unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous.[7]

In Appendix Table H1, columns (1) and (2) replicate the main specification using this smaller sample. The coefficient estimates are very similar to the full sample, with large positive effects in the second and third quartiles of pollen measurements. In columns (3) and (4) we add the interaction for "bad" and "very bad" pollution levels. The estimates show that pollution and pollen interact strongly in the first quartile, but have no effect in the second and third quartiles of pollen measurements. At very high pollen levels pollution acts as a protectant, reversing the impact of pollen, creating the null effect we observe in the main specification.

Mechanisms: Allergies and Sleep

The theoretical model presented in Section 3 proposes that at each level of mental health, there exist a range of health shocks which may trigger "hot" mode and result in suicide. This proposition describes a mechanism which connects pollen levels resulting in allergic responses affecting general well-being and sleep. These, in turn, compound mental health conditions and, potentially, trigger the irrational response of suicide.

While the results presented in the previous section link pollen to suicides and mental health visits, they do not provide evidence that the mechanism is, indeed, operating through an impact on health. For example, the effect could be operating through a disruption of supply of mental health care services, rather than a direct impact on individual health.

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[6] AQI 51–100. Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution. Occurs at a rate of about 40% in our data.

[7] AQI 101–301 and higher. Unhealthy for sensitive groups: members of sensitive groups may experience health effects, while the general public is less likely to be affected. Unhealthy: Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects. Very unhealthy: health alert; the risk of adverse effects on health is increased for everyone. Hazardous: health warning of emergency conditions; everyone is more likely to be affected. Unhealthy, very unhealthy, and hazardous occur on fewer than 4% of the days recorded in our data.

To test the mechanism empirically, we use Google Trends daily-search-intensity data for 2006 to 2017. Google Trends indexes the volume of searches for a given term or a cluster of terms relative to its highest volume within a specified time period and locality. For example, if searches in the New York City metropolitan area peak on June 7 in a specific year, then June 7 is assigned an index of 100 and all other days during the year are indexed relative to the volume of that day. We identified 28 (of 33) localities, which were aggregated by Google Trends. Localities are defined akin to commuting zones, incorporating counties. Thus, while our data include close to 4,300 zip codes or 187 counties, they are represented in 28 localities in Google Trends. We scraped daily search volumes for the time period of interest.[8] We selected multiple search terms within three broad categories: allergy,[9] exhaustion,[10] and suicidality.[11] We extracted search data for each search term separately and for clusters of terms by category,[12] as well as clusters of terms combining categories. The clustering of terms and combination of categories were motivated by the relatively low volume and variability of a single search term in many localities, especially in the early years of our panel. We merged search volume with pollen and weather data, resulting in 50,340 observations, and estimated equation (2).

Table 7 presents estimates of the preferred specifications for clusters of terms and combinations of categories. It reports the sum of contemporaneous and lagged coefficients for each quartile of pollen. In the first column, the outcome is the index for the cluster of terms for allergy symptom searches. The estimates show a significant positive relationship between high pollen levels (3rd and 4th quartile) and searches for these terms. A 10-pcm increase in the pollen level yields a 0.0035–0.0166 increase in relative index of searches around that time. In column (2), searches for exhaustion show no statistically significant changes, though we note that the coefficients are

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[8] Google Trends allows up to 10 months of daily search indices. When the time period exceeds 10 months, Google Trends automatically reverts to weekly search aggregation. Since our analysis relies on daily variations in pollen, we extracted 10-month periods and combined them together by using overlapping periods to scale search volumes in separate segments. The index is set to zero below a threshold search volume for privacy reasons. Therefore, and especially in the early panel years, the index has a high frequency of 0 values.

[9] Search terms included: Benadryl, Antihistamine, Zyrtec, Claritin, Allegra, decongestant, allergy, congestion, runny nose, itchy eyes.

[10] The search terms included: Sleep, sleepy, tired, exhausted.

[11] The search terms included: Feeling, feel, depression, depressed, suicide, suicidal, kill myself, killing myself.

[12] We define a cluster as, for example, searches for sleep OR sleepy OR tired OR exhausted, thus summing the search volumes for each individual term.

consistently positive for higher levels of pollen. Similarly, we find no statistically significant effects for depressive symptoms.

When we combine the categories of clusters of terms, the estimates are better powered to detect a statistically significant effect. In column (4), allergy symptom terms are combined with exhaustion terms, yielding positive and statistically significant effects at all but the lowest pollen levels. Here, we see that a 10 ppm increase in pollen levels results in a 0.0057–0.0638 increase in the index of searches for any of these terms. In column (5), we repeat the exercise for allergy symptoms and depressive thoughts, finding a similarly strong positive relationship, with results showing a 0.0046–0.0513 increase in searches. These results allow us to conclude that the hypothesized mechanism of pollen operating through allergies and poor sleep is a plausible predictor of suicidality. We find that rising pollen levels do result in more general symptoms of allergies and exhaustion. The results in column (5) also provide evidence supporting the mechanism of pollen allergies, rather than weather or other factors which may be concurrent with high pollen levels, on suicidality.

Robustness of Estimates

Though the selection of model specification was aimed at best capturing variability in pollen levels, in Appendix D we estimate alternative specifications to gain insight into the role of thresholds, lags, and linearity in the impact of pollen on suicide and ED use. In Appendix Table D1a, we examine the following specifications: column (1) reports threshold effects for very high pollen at 1500 pcm following the method used in Chalfin et al. (2019) and Marcotte (2015); column (2) shows estimates from a linear fit for all levels of pollen with contemporaneous and lagged values; column (3) adds a second-day lag to the linear fit; column (4) includes linear fit with two lags and a quadratic term for each lag, attempting to capture the nonlinear nature of the data. We find no significant or notable effects for the threshold and linear fits, and we find that the quadratic fit has coefficients of the same sign and significance as our preferred specification for deaths by suicide. These specifications suggest that nonlinearities are important to the model fit. Visits to the ED in Appendix Table D1b show a significant and negative impact across all alternative specifications; however, the magnitude is generally very small. One notable exception is the estimate for the threshold effect of 1500 pcm, which shows a 12.8% decline in visits, a significant effect that is both contemporaneous and lagged. Though the sign of this effect is contrary to most of our findings at lower levels of pollen, we note that the impact of a 10-pcm increase in pollen for the top quartile of measurement is negative, though very modest. This allows us to conclude that the impact of pollen on the use of the ED is u-shaped, increasing utilization at low levels, but having an isolating impact at the very high levels as individuals avoid venturing outside.

7. Discussion

Our estimates show economically meaningful changes to both deaths by suicide and use of the ED for mental health care at low-to-medium levels of airborne pollen. Specifically, we find a 1.7–2.9% increase in suicides for each 10-pcm increase in pollen at low-to-medium levels. In fact, our estimates show that as pollen levels increase, the incremental impact of pollen at each quartile is smaller. We also find that the effect operates on the same and following days, equally.

We find a 3.5% increase in ED visits in the first quartile of pollen measurements, and a smaller increase in the second quartile. As with deaths, the effect is in the same direction and of similar magnitude on the same and following day of pollen.

Our estimates show that the effect size decreases with each quartile of pollen measurement. This difference in magnitude could be attributable to increased avoidance behavior, or, potentially, tolerance as pollen levels rise. One possible source of variability in estimate size is mechanical: pollen levels are represented in 10-pcm increments, which may capture variation differently in the quartiles. More specifically, 10 pcm may capture the majority of variation in the first quartile, but only a small fraction of variation in the fourth. To overcome this variation we scale the point estimate by one standard deviation for each quartile in Table 8. One standard-deviation increase in pollen level in each quartile, when scaled by point estimates, has a similar effect on suicide, ranging from a 2.6% increase in the fourth quartile to 8.1% in the second quartile. Visits to the ED, however, do not have a similar effect across quartiles. When scaled, we find a 1.2–5.7% increase in the first two quartiles, but a 0.4–0.8% decrease in the third and fourth quartiles of measurements. This allows us to conclude that high pollen levels may trigger avoidance of visits to the ED, though they do not have a similar effect on suicides.

We also find a significant interaction between pollution and pollen on suicide. Specifically, we find that high pollution amplifies the impact of pollen at low pollen levels; however at high pollen levels, high pollution acts as a protectant, reversing the impact of pollen. As the AQI is communicated more effectively to the public than pollen, this protective effect may be the result of individuals avoiding going outdoors on high pollution days, reversing the possible impact of very high pollen days.

We hypothesize that pollen impacts the risk of suicide through two avenues: first, it may affect mental health through the physiological impact of pollen on sleep, mood, and cognitive ability; second, it may induce individuals to remain isolated at home, reducing their access to and use of mental health care services and other interactions which may be protective of mental health. The physiological mechanism would result in an increase in the use of mental health care services and deaths by suicide on the same and following days as it increases the need for care and triggers fatal self-harm in individuals who are on the margin. The isolation mechanism should have a different effect on the same day to that on the following day. In particular, if avoidance keeps people at home and prevents them from seeking care and interaction, we hypothesize that ED visits would reflect temporal displacement: a decline on the same day, but a rise on the following day. The same would operate for risk of suicide, as some such acts are carried out outdoors. In turn, the reduction in access to care would trigger an increase in deaths by suicide the following day. Thus, if the isolation mechanism were to dominate the physiological mechanism, we would expect to see a same-day decline in ED visits and a modest increase in deaths by suicide; then, on the following day, we would expect to see an increase in ED visits and a larger increase in deaths by suicide. If the physiological mechanism dominates the isolation mechanism, we expect equivalent increases on the same and the following day for both ED visits and deaths by suicide.

Our estimated results show that the effect is of similar magnitude for the same and the following days for both suicides and ED visits. This suggests that though the isolation mechanism may be present, it certainly does not dominate, allowing us to conclude that in these data, pollen impacts mental health through its physiological impact on sleep, mood, and cognitive ability.

The direction of our results is consistent with that of the other literature in the field; however the magnitudes are difficult to compare as the units of observations and study design are not the same across studies. Stickley et al. (2017) found a 50% increase in the odds of same-day suicide for a 30-pcm rise in pollen in Tokyo compared to no pollen for women, but no such effect for men. Qin et al. (2013) estimated a 6.4% increase in the relative risk of suicide for a 30-pcm rise in pollen counts compared to no pollen in Denmark. This estimate is in line with our own 1.7 – 2.9% increase at low levels of pollen for a 10-pcm rise. Postolache et al. (2005) found doubling of unadjusted suicide rates among women in the United States during the pollen period, compared to the pre-pollen period, though this change may be attributable to many other seasonal factors contributing toward suicidality. Examining self-directed violence, Jeon-Slaughter et al. (2016) estimated a 56% increase in female patients with that diagnosis in EDs in the Dallas, TX area when tree pollen counts increased by 1000 pcm, and a further 57% increase the following day. As our analysis shows, nonlinearity in the impact of pollen counts makes it difficult to reconcile Jeon-Slaughter et al.'s findings with those in our study. Contrary to these studies, however, our findings show the largest effects on suicide among Whites, men, and those in early adulthood. We also find that Midwestern states experience the most acute impact from pollen at modest levels.

Projections

Though the magnitudes of estimates are modest, during this panel period there were more than 470,000 deaths by suicide in United States.[13] Assuming an approximate 5% increase in suicides resulting from one standard-deviation increase in pollen leads us to estimate that seasonal allergies may have played a role in up to 2300 deaths per year during that period. Furthermore, the impact of seasonal allergies on mental health and suicidality will accelerate as climate change increases temperatures. Anderegg et al. (2021) estimate that the pollen season has increased in length by 20 days and in intensity by 21% over the past 28 years as a result of higher temperatures. The United States Department of Agriculture (USDA) projects an average increase in temperatures of between 1.4C and 4.4C in the United States by 2100.[14] Relying on Akesaka and Shigeoka's (2023) estimate that a 1C increase in maximum temperature increases daily pollen by 167.4 pcm, we can project an expected increase of 234–736 pcm in daily pollen by 2100. In turn, this would correspond to a 68–214% increase in suicides (234/10*0.0291 and 736/10*0.0291) by the end of this century which could be attributed to rising pollen levels. These back-of-the-envelope calculations focus only on the rising intensity and not the duration of the pollen season and, therefore, present the lower range of such estimates.

[13] CDC WONDER, "About Multiple Cause of Death, 1999–2020," https://wonder.cdc.gov/mcd-icd10.html.
[14] USDA, US Forest Service Climate Change Resource Center, "Expected Effects in the US," https://www.fs.usda.gov/ccrc/education/climate-primer/expected-effects

Policy Implications

We draw two major policy implications from this analysis. First, suicidality and poor mental health are sensitive to relatively small environmental shocks. While physical constraints and reduced access to means have been shown to significantly reduce the incidence of suicide, relatively small shocks may nudge the individual from ideation to planning a suicide.

Second, our research highlights relatively low-intensity and easy-to-implement interventions which can reduce the burden of mental health. If, as we believe, the mechanism of the effect of pollen on suicidality operates through sleep, our research highlights the importance of mitigation of the impact of seasonal pollen. Mitigation can take many forms: here, we highlight a few.

Individuals may not be aware of the presence of their seasonal allergies, nor of their importance and impact on their health. Akesaka and Shigeoka (2023) show little-to-no avoidance behavior in response to pollen levels in Japan, suggesting that while people may feel allergy symptoms, this does not motivate them to engage in avoidance behavior. We think that while allergies are fairly common, testing and treatment are not, as people experience a short period of respiratory symptoms and underestimate the larger impact on their sleep and cognition. Increased awareness of the full impact of seasonal allergies may lead to an increase in avoidance behavior, such as installing air filters in bedrooms, purchasing over-the-counter allergy medication, and masking.

There is also little information and notification available about pollen levels in United States. While weather reports include notifications of high ozone and AQI levels, no similar warning exists for pollen levels. While one can find daily pollen levels for some localities, these measurements are not taken by a single national authority (as are pollution measures for the EPA or pollen measurements in Japan) and are not communicated widely to the public. This lack of information means that even if the public were made aware of the importance of avoidance, there are scant sources of information to identify high pollen days.

8. Conclusion

Suicide claims the lives of more than 47,000 individuals every year, and mental illness affects more than 52 million individuals in United States. While there is general scientific consensus that suicidality is caused by both long- and short-term socioeconomic, demographic, and mental health factors, much less is known about its vulnerability to relatively small short-term shocks.

We provide evidence of the sensitivity of suicide and mental health to seasonal allergies. While pollen cannot be effectively controlled through traditional policy levers, our research highlights the value of relatively small and easy-to-implement medical interventions – allergy testing and treatment – on the rapidly rising levels of mental illness and suicide. This paper focused on pollen measurements in urban areas; future research will extrapolate pollen measurements to rural areas for additional insights into the role of seasonal allergies in areas which have been the hardest hit by the epidemic of suicidality.

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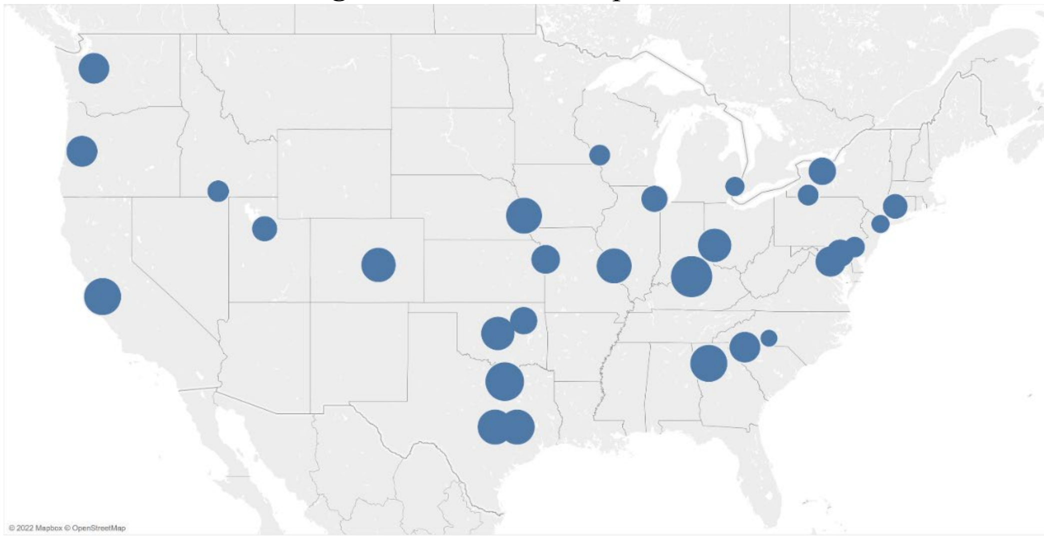
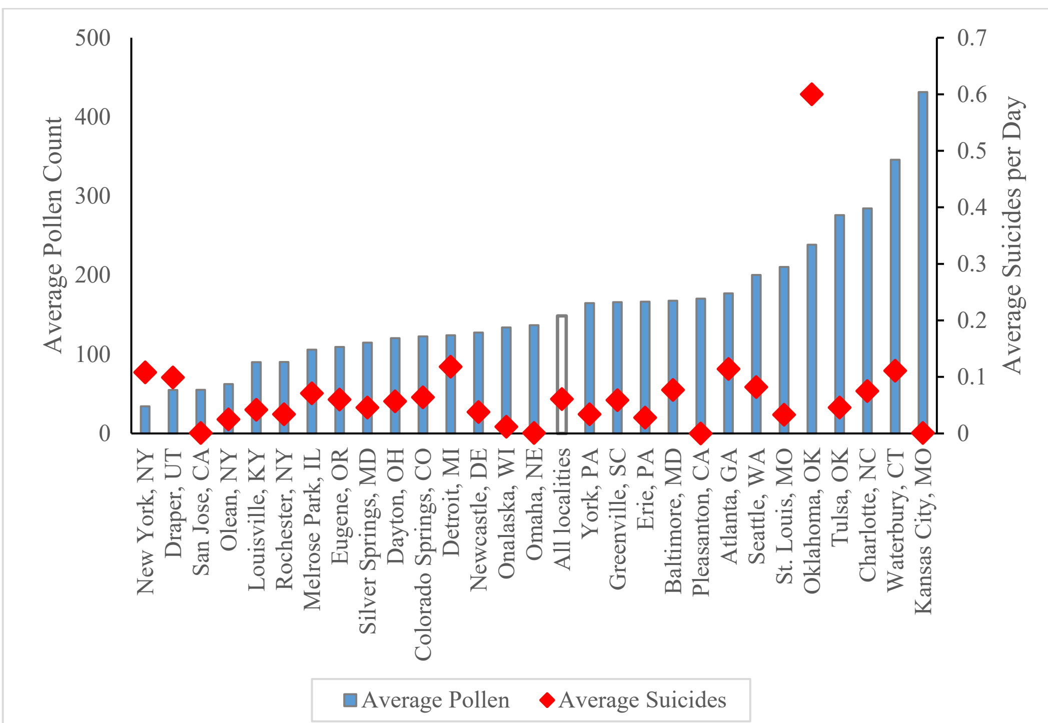
Figure 1: Localities of pollen data



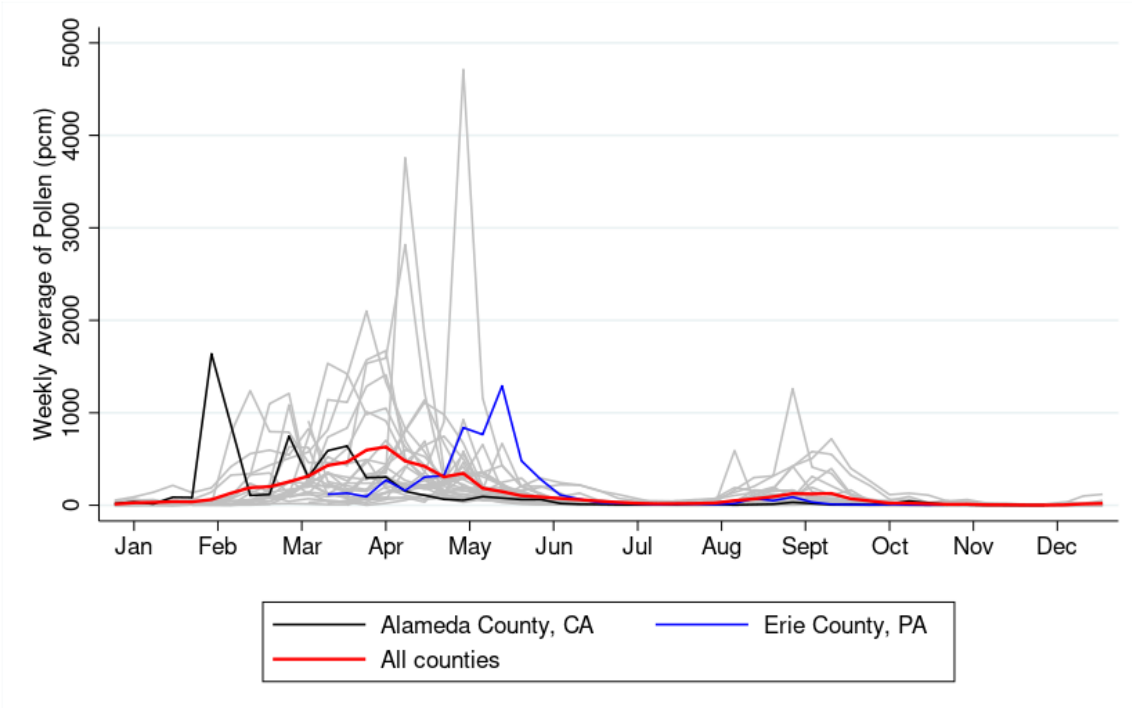
Source: NAB 2006–2017. Each circle represents a pollen measurement station which has shared data. The size of the circle represents the number of observations available for that location. The number of observations is a function of length of panel for that location and the frequency of measurement.

Figure 2: Average pollen counts and suicides by location



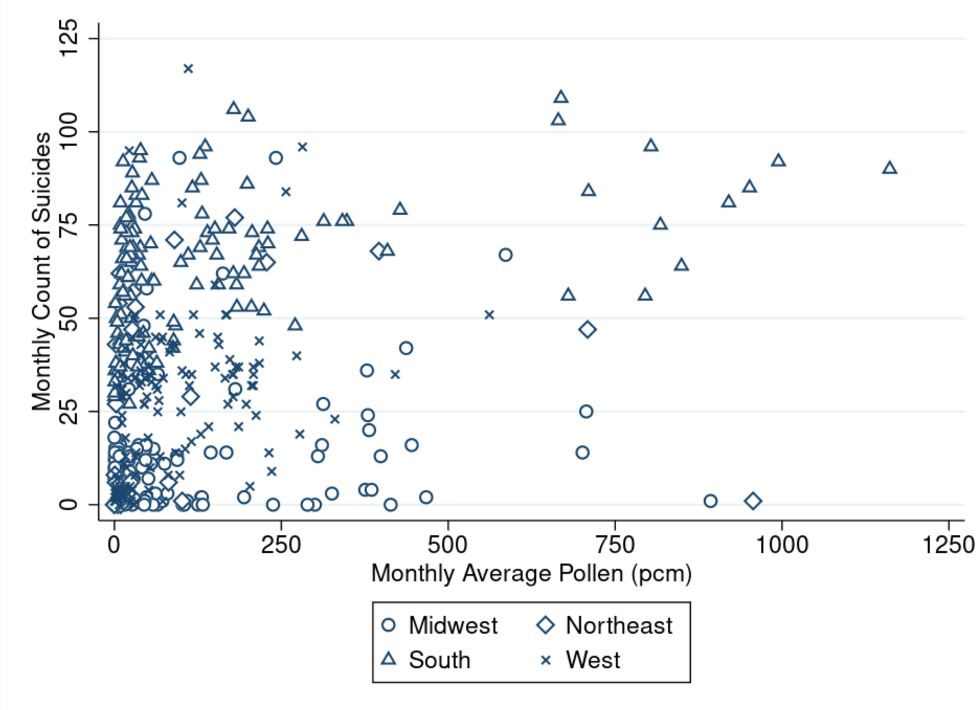
Sources: National Allergy Bureau (NAB) 2006–2017, National Violent Death Reporting System (NVDRS) 2006–2016.

Figure 3: Seasonal pollen trends across all locations



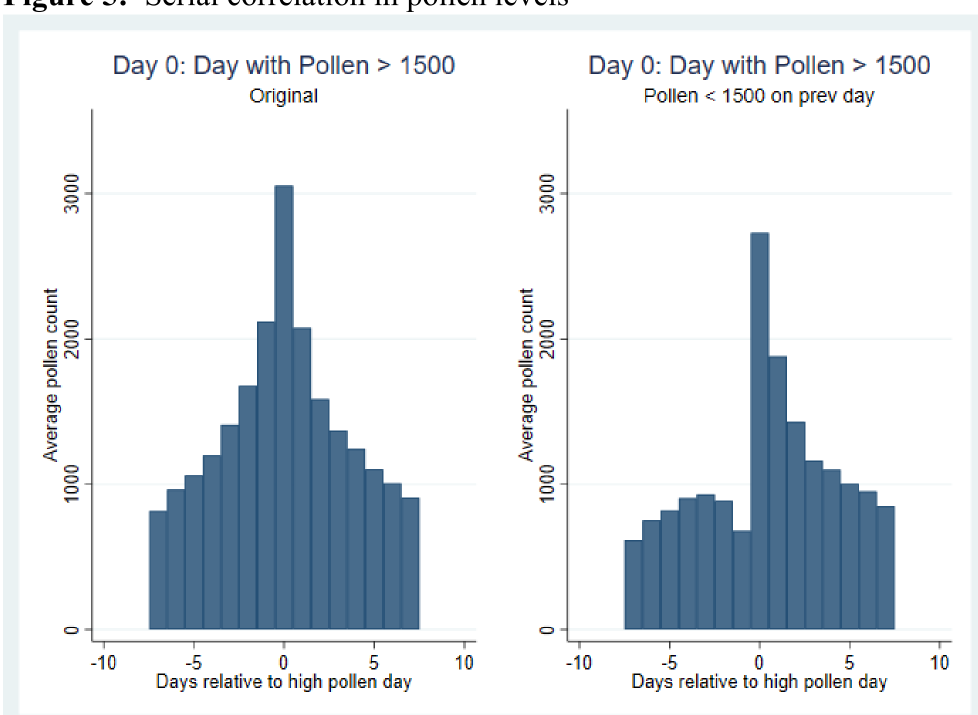
Source: National Allergy Bureau (NAB) 2006–2017

Figure 4: Unadjusted relationship between pollen and monthly count of suicides.



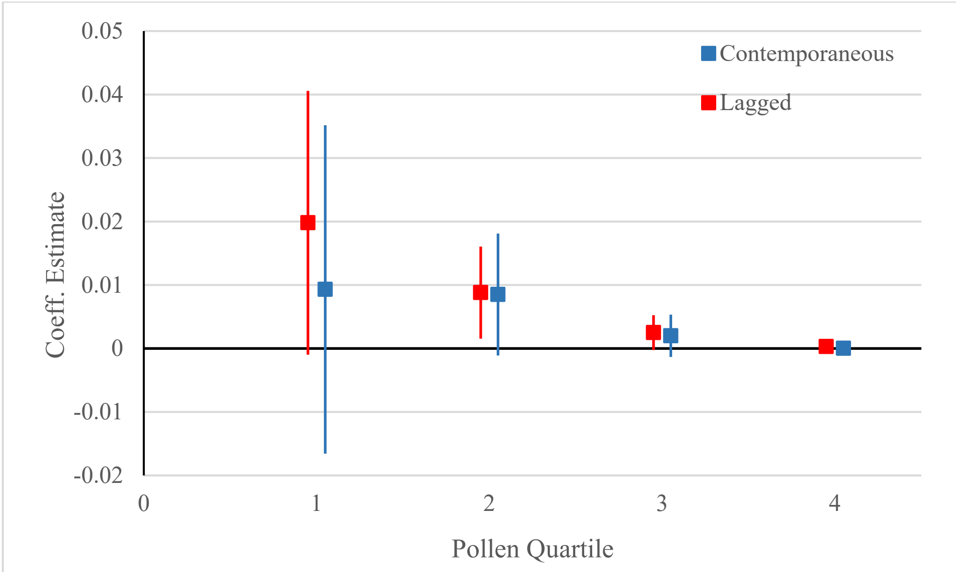
Source: National Violent Death Reporting System (NVDRS), 2006–2017 and National Allergy Bureau (NAB) 2006–2017

Figure 5: Serial correlation in pollen levels

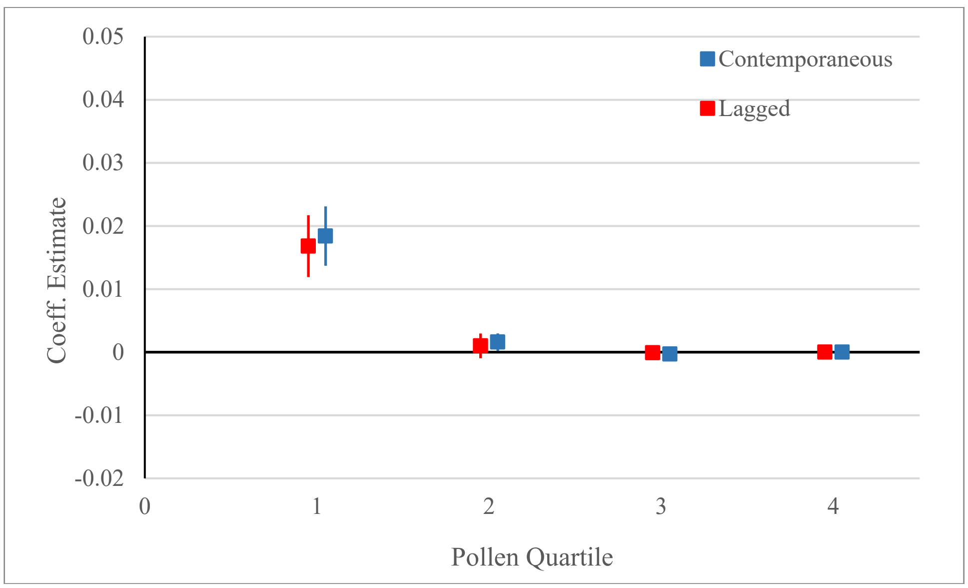


Source: National Allergy Bureau (NAB) 2006–2017

Figure 6: Coefficient estimates for contemporaneous and lagged effects by quartile of pollen



(a) Count of suicides

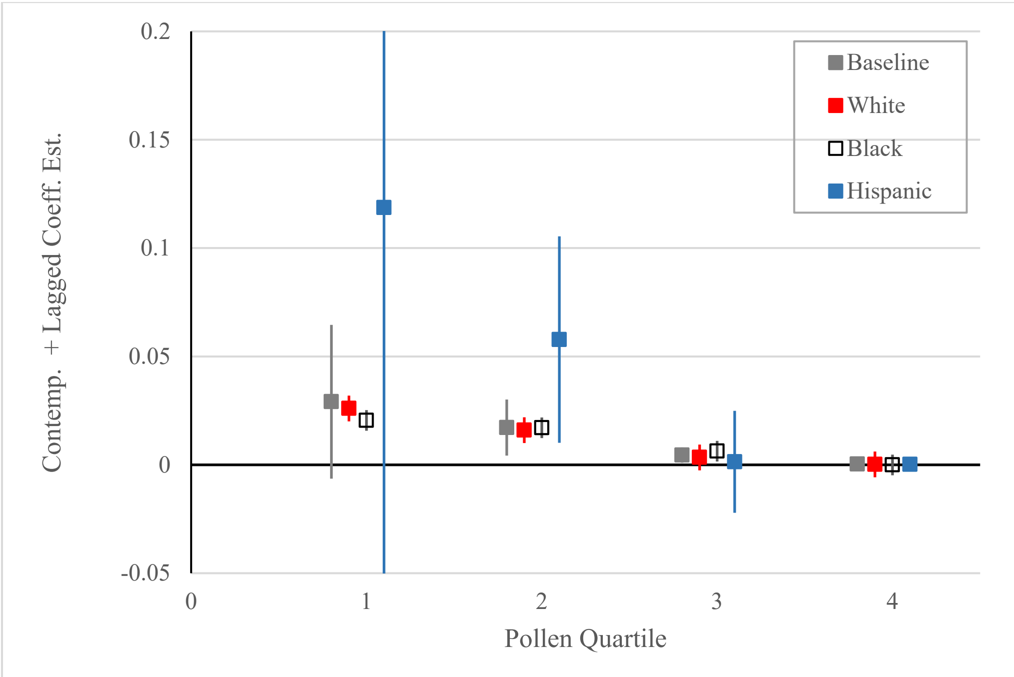


(b) Count of ED visits

Sources: National Allergy Bureau (NAB), National Violent Death Reporting System (NVDRS), OptumInsight Health Insurance Claims Data, PRISM Climate Data 2006–2017

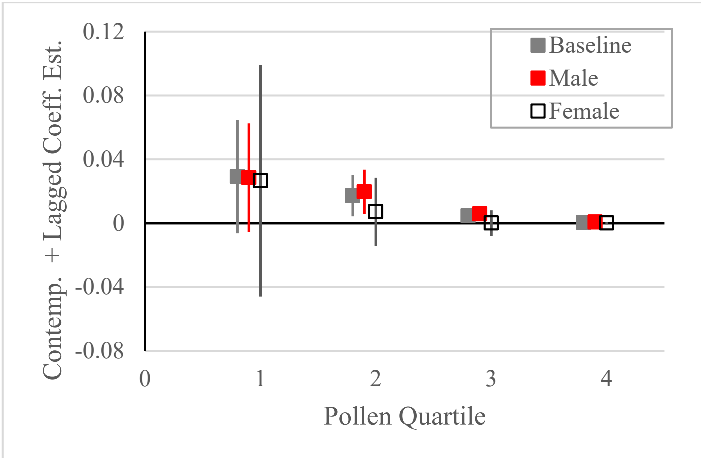
Notes: Each figure represents a separate specification where the independent variable is the count of suicides or ED visits per day per locality. Each point is the coefficient estimate for pollen by quartile (indicated on the horizontal axis) for contemporaneous (blue) and lagged (red) effect. All specifications also include a 7-day moving average of the pollen count, time and location fixed effects, and weather controls. 95% confidence intervals are indicated by bars around point estimate.

Figure 7: Sum of contemporaneous and lagged estimate for suicides stratified by race

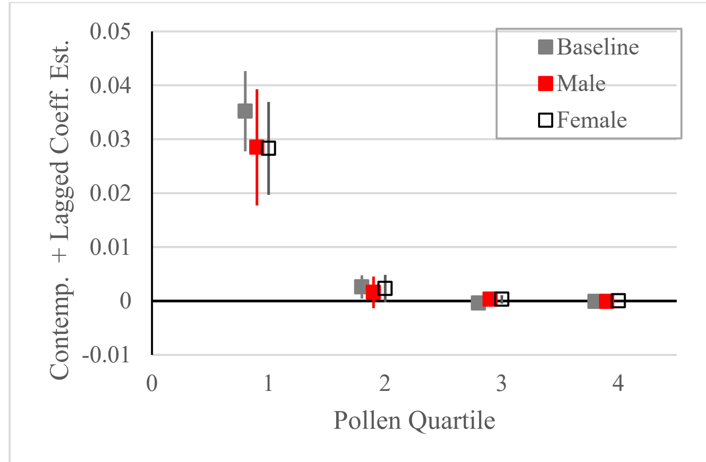


Sources: National Allergy Bureau (NAB), National Violent Death Reporting System (NVDRS), and PRISM Climate Data 2006–2017

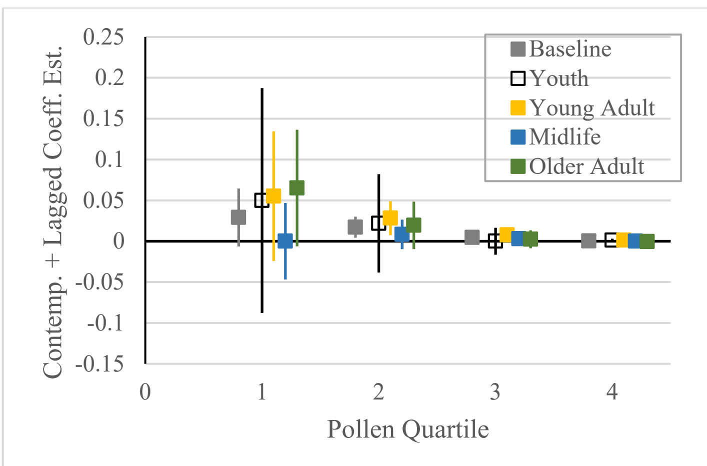
Figure 8: Sum of contemporaneous and lagged estimate for suicides stratified by gender and age.



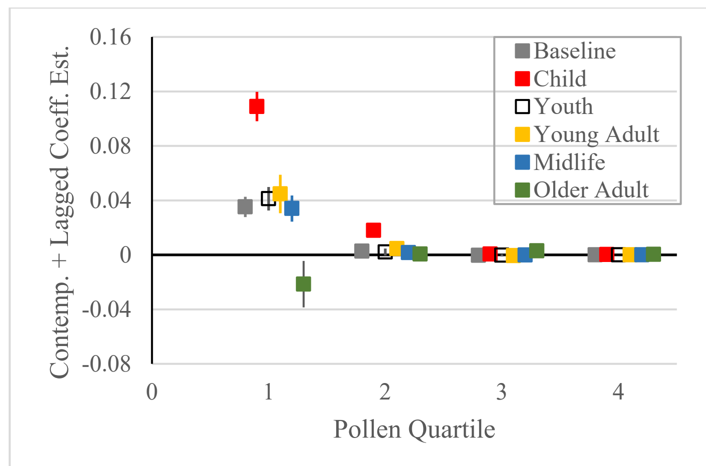
(a) Gender: Suicides



(b) Gender: ED Visits



(c) Age: Suicides



(d) Age: ED Visits

Sources: National Allergy Bureau (NAB), National Violent Death Reporting System (NVDRS), OptumInsight Health Insurance Claims Data, PRISM Climate Data 2006–2017

Table 1: Main specification: Count of suicides

	Suicides	Suicides	Suicides	Suicides
	(1)	(2)	(3)	(4)
	$\beta_j + \beta_j^{-1}$	$\beta_j + \beta_j^{-1}$	$\beta_j + \beta_j^{-1}$	$\beta_j + \beta_j^{-1}$
	Coeff./SE	*Coeff./SE*	*Coeff./SE*	*Coeff./SE*
Quartile of Pollen				
1st	-0.0161	0.0047	0.0247	0.0291
	(0.0306)	(0.0139)	(0.0181)	(0.0181)
2nd	0.0004	0.0095**	0.0166**	0.0172***
	(0.0091)	(0.0041)	(0.0066)	(0.0066)
3rd	-0.0004	0.0023	0.0047***	0.0045**
	(0.0029)	(0.0015)	(0.0018)	(0.0018)
4th	0.0004*	0.0004***	0.0005**	0.0003
	(0.0002)	(0.0001)	(0.0002)	(0.0002)
MA Pollen	0.0003	-0.00003	0.0005	0.0005
	(0.0004)	(0.0003)	(0.0004)	(0.0004)
Weather Controls				X
FE:				
Location		X		
Year		X		
Location*Week			X	X
Month*Day			X	X
N	235,943	205,811	146,761	146,115
Number of Localities	187	147	147	144

Sources: National Allergy Bureau (NAB), National Violent Death Reporting System (NVDRS), PRISM Climate Data 2006–2017

Notes: Each column represents a separate specification where the independent variable is the count of suicides per day per locality. The treatment variable is a continuous measure of the pollen count interacted with an indicator of quartile by location, and one lag thereof. This table reports the sum of contemporaneous and lagged coefficients. All specifications also include a 7-day moving average of the pollen count (MA Pollen). Each specification adds time and location fixed effects as indicated. Column (4) includes weather (temperature and precipitation). Column (4) is the preferred specification. Standard errors clustered at the locality level. * p<0.1, ** p<0.05, *** p<0.01

Table 2: Main specification: count of ED visits

	ED Visits	ED Visits	ED Visits	ED Visits
	(1)	(2)	(3)	(4)
	$\beta_j + \beta_j^{-1}$	$\beta_j + \beta_j^{-1}$	$\beta_j + \beta_j^{-1}$	$\beta_j + \beta_j^{-1}$
	Coeff./SE	*Coeff./SE*	*Coeff./SE*	*Coeff./SE*
Quartile of Pollen				
1st	0.0162**	0.0131***	0.0378***	0.0352***
	(0.0064)	(0.0025)	(0.0038)	(0.0038)
2nd	0.0024	0.0034***	0.0034***	0.0026**
	(0.0016)	(0.0007)	(0.0011)	(0.0011)
3rd	0.0009**	0.0011***	-0.0003	-0.0004
	(0.0005)	(0.0003)	(0.0004)	(0.0004)
4th	0.0001**	0.000006	-0.0001***	-0.0001**
	(0.00004)	(0.00002)	(0.00003)	(0.00003)
MA Pollen	0.0006***	0.0002***	-0.0002**	-0.0002**
	(0.0001)	(0.0000)	(0.0001)	(0.0001)
Weather Controls				X
FE:				
Location		X		
Year		X		
Location * Week			X	X
Month * Day			X	X
N	6,288,628	6,264,591	4,768,382	4,768,382
Number of Localities	4312	4186	4183	4183

Sources: National Allergy Bureau (NAB), OptumInsight Health Insurance Claims Data , PRISM Climate Data 2006–2017

Notes: Each column represents a separate specification where the independent variable is the count of ED visits per day per locality. The treatment variable is a continuous measure of the pollen count interacted with an indicator of quartile by location, and one lag thereof. This table reports the sum of contemporaneous and lagged coefficients. All specifications also include a 7-day moving average of the pollen count. Each specification adds time and location fixed effects as indicated. Column (4) includes weather (temperature and precipitation). Column (4) is the preferred specification. Standard errors clustered at the locality level.
* p<0.1, ** p<0.05, *** p<0.01

Table 5: Estimated effects stratified by method of suicide and presence of an underlying mental health condition

	Suicides (1) Firearm *Coeff./SE*	Suicides (2) Drug or Medication *Coeff./SE*	Suicides (3) Other *Coeff./SE*	Suicides (4) No Known MH Indicator *Coeff./SE*	Suicides (5) Known MH Indicator *Coeff./ SE*	Suicides (6) MH Condition or Treatment *Coeff./SE*	Suicides (7) MH Treatment *Coeff./SE.*
Quartile of Pollen							
1st	0.0326	0.0684	0.0029	0.017	0.0394**	0.0377	0.0344
	(0.0250)	(0.0497)	(0.0352)	(0.0272)	(0.0201)	(0.0254)	(0.0306)
2nd	0.0235**	-0.0080	0.0131	0.0315***	0.0063	0.0076	0.0026
	(0.0097)	(0.0178)	(0.0116)	(0.0116)	(0.0067)	(0.0083)	(0.0096)
3rd	0.0066**	0.0108	0.0041	0.0023	0.0059**	0.0083***	0.0079**
	(0.0031)	(0.0067)	(0.0041)	(0.0029)	(0.0026)	(0.0031)	(0.0034)
4th	0.0005	0.0002	0.0002	-0.00008	0.0005**	0.0006**	0.0006**
	(0.0034)	(0.0005)	(0.0003)	(0.0004)	(0.0002)	(0.0002)	(0.0003)
MA Pollen	0.0003	0.0006	0.0007	0.0003	0.0006	0.0006	0.0005
	(0.0004)	(0.0012)	(0.0006)	(0.0005)	(0.0005)	(0.0006)	(0.0006)
Weather Controls	X	X	X	X	X	X	X
FE:							
Location*Week	X	X	X	X	X	X	X
Month*Day	X	X	X	X	X	X	X
N	117,278	43,859	87,577	106,632	118,383	103,260	87,018
Number of Localities	138	112	132	136	141	138	136

Sources: National Allergy Bureau (NAB) 2006–2017, National Violent Death Reporting System (NVDRS) 2006–2017, PRISM Climate Data 2006–2017

Notes: Each column represents a specification where the independent variable is the count of suicides by means (gun, drug/medication, other) or by presence of mental health (MH) condition or treatment per day per locality. MH indicator includes known MH condition, witness-reported depression symptoms, and current/ history of MH treatment. Column (6) includes known MH condition, and current/history of MH treatment. Column (7) includes current/ history of MH treatment. The treatment variable is a continuous measure of pollen count interacted with an indicator of quartile by location, and one lag thereof. This table reports the sum of contemporaneous and lagged coefficients. All specifications also include a 7-day moving average of pollen count, time and location fixed effects as indicated, and weather (temperature and precipitation) controls. Standard errors clustered at locality level. * $p<0.1$, ** $p<0.05$, *** $p<0.01$

Table 6: Estimated effects on ED visits stratified by diagnostic category

	ED Visits (1) Anxiety	ED Visits (2) MH History	ED Visits (3) MH Misc.	ED Visits (4) Mood Disorders	ED Visits (5) Personality Disorders	ED Visits (6) Schizophrenia	ED Visits (7) Attempted Suicide
	Coeff./SE	*Coeff./SE*	*Coeff./SE.*	*Coeff./SE*	*Coeff./SE*	*Coeff./SE.*	*Coeff./SE.*
Quartile of Pollen							
1st	0.0165***	-0.0327***	-0.0046	0.0516***	0.0485	-0.002	0.0126
	(0.0063)	(0.01)	(0.0096)	(0.0049)	(0.0379)	(0.0133)	(0.0324)
2nd	0.0035**	-0.0077***	-0.002	0.0040***	0.0036	0.0062	-0.0021
	(0.0017)	(0.0029)	(0.0027)	(0.0014)	(0.0103)	(0.004)	(0.0095)
3rd	0.0015**	0.0016*	-0.0020**	-0.0003	0.0006	0.0033**	0.0056*
	(0.0006)	(0.0008)	(0.001)	(0.0005)	(0.0033)	(0.0013)	(0.0031)
4th	-0.0001	0.0003***	-0.0001	-0.0001	0.0003	0.00001	0.0003
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0003)
MA Pollen	0.00001	0.0007***	-0.0001	-0.0003***	0.0003	0.0004**	0.0007
	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0004)	(0.0002)	(0.0005)
Weather Controls	X	X	X	X	X	X	X
FE:							
Location*Week	X	X	X	X	X	X	X
Month*Day	X	X	X	X	X	X	X
N	3,243,898	1,796,657	1,717,746	4,519,201	209,860	1,165,055	238,515
Number of localities	3,812	3,554	2,631	3,956	912	2,910	1,641

Sources: National Allergy Bureau (NAB) 2006-2017, OptumInsight Health Insurance Claims Data, PRISM Climate Data 2006-2017

Notes: Each column represents a specification where the independent variable is the count of ED visits by type per day per locality. MH History – history of mental health care; MH Misc – miscellaneous mental health visit. The treatment variables are continuous measure of pollen count interacted with an indicator of quartile by location, and one lag thereof. This table reports the sum of contemporaneous and lagged coefficients. All specifications also include a 7-day moving average of pollen count, time and location fixed effects as indicated, and weather (temperature and precipitation) controls. Standard errors clustered at locality level. * p<0.1, ** p<0.05, *** p<0.01

Table 7: Relative volume of Google searches

	(1) Allergy Symptoms	(2) Exhaustion	(3) Depressive Thoughts	(4) Allergy Symptoms & Exhaustion	(5) Allergy Symptoms & Depressive Thoughts
	Coeff./SE	*Coeff./SE*	*Coeff./SE*	*Coeff./SE*	*Coeff./SE*
Quartile of Pollen					
1st	-0.0205	-0.0925	-0.1363	-0.0353	-0.0819
	(0.1488)	(0.1029)	(0.0965)	(0.1545)	(0.0850)
2nd	0.0151	0.0323	0.0141	0.0638**	0.0513*
	(0.0240)	(0.0286)	(0.0357)	(0.0272)	(0.0288)
3rd	0.0166*	0.0088	0.0141	0.0333***	0.0153**
	(0.0097)	(0.0102)	(0.0105)	(0.0108)	(0.0071)
4th	0.0035*	0.0005	-0.00003	0.0057**	0.0046**
	(0.0019)	(0.0013)	(0.0013)	(0.0023)	(0.0017)
Weather Controls	X	X	X	X	X
FE:					
Location*Week	X	X	X	X	X
Month*Day	X	X	X	X	X
N	50,340	50,340	50,340	50,340	50,340
Number of Localities	28	28	28	28	28

Sources: National Allergy Bureau (NAB) 2006–2017, Google Trends 2006–2017, PRISM Climate Data 2006–2017

Notes: Each column represents a separate specification where the independent variable is the Google Trends relative search interest per day per locality. The treatment variable is the level of pollen interacted with a dummy for the quartile of the measurement, and a lag thereof. All specifications also include a 7-day moving average of pollen count, time and location fixed effects as indicated, and weather (temperature and precipitation) controls. "Allergy symptoms" are defined as search interest in any of the following terms: allergy, congestion, runny nose, itchy eyes, feel, feeling. "Exhaustion" is defined as search interest in any of the following terms: sleep, sleepy, tired, exhausted. "Depressive thoughts" is defined as search interest in any of the following terms: feeling, feel, depressed, depression, suicide, suicidal, kill myself, killing myself. Columns (4) and (5) reflect the combination of respective search-term groupings. Standard errors are clustered at the locality level. * $p<0.1$, ** $p<0.05$, *** $p<0.01$

Table 8: Main estimates scaled to one standard deviation at quartile mean

Quartile	**Mean**	**SD**	**Suicides**		**ED Visits**	
			Point Est.	*Std. Dev. Scale*	*Point Est.*	*Std. Dev. Scale*
1	8.59	16.32	0.0291	0.047	0.0352	0.057
2	39.03	47.15	0.0172	0.081	0.0026	0.012
3	102.39	124.94	0.0045	0.056	-0.0004	-0.0049
4	468.99	877.46	0.0003	0.026	-0.0001	-0.0087

Sources: National Allergy Bureau (NAB) 2006–2017, OptumInsight Health Insurance Claims Data, PRISM Climate Data 2006–2017

Notes: Each quartile represents the mean and standard deviation (Std. Dev.) of pollen at each location for each season. The point estimates (Point Est.) are from specification (4) in Tables 1 and 2. The standard deviation scaling is conducted according to following formula: $StdDev\ Scale = \frac{Std.\ Dev. * Point\ Est.}{10}$.