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

Authors:
Joelle Abramowitz, Institute for Social Research, University of Michigan
Shooshan Danagoulian, Department of Economics, Wayne State University
Owen Fleming, Department of Economics, Wayne State University

Corresponding author:
Shooshan Danagoulian
Department of Economics
Faculty/Administration Building 2095
Wayne State University
Detroit, MI 48202
fr4523@wayne.edu

Abstract:

Suicide rates increased 37% in the US from 2000 to 2018; while structural factors are extensively studied, short-term triggers remain less understood. We examine the impact of small exogenous shocks – allergies triggered by seasonal pollen – on suicides. Pollen allergies diminish cognitive function and disrupt sleep—predictors of suicidality. Combining three datasets across 34 localities in the United States from 2006 to 2017, we identify the effect of pollen on suicides and, also, mental health care from daily variation in each. We find that a modest rise in pollen results in up to 1.7% more suicides, with the majority effect stemming from suicides by firearm. We also estimate a parallel 3.5% increase in mental health emergency visits. We provide evidence that the effect is linked to allergy symptoms 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.

Keywords: mental health, environmental health, seasonal allergies, health care utilization

JEL Codes: I10, I18, Q53, Q54

* The authors would like to thank Basil Isaac and Sara Zobl for excellent research assistance; Steven Stack, David Molitor, Hitoshi Shigeoka, Kosali Simon, Claudia Persico, Corey White, Martin Anderson, Amanda Cook Chase Eck, Kelli Marquardt, Christoph Kronenberg, Edward Norton, Dave Marcotte, Catherine Maclean for suggestions and advice; seminar participants at Indiana University, University of Pittsburgh, University of Kansas, University of Michigan, George Mason University, American University, SEA 2023 and ASHEcon 2022. This research was funded by Wayne State 2021-22 University Research Grant and Wayne State Office of Vice President of Research 2023 Grants Boost. Owen Fleming gratefully acknowledges support from the NIH 1 P50 MD017351-01 grant.

INTRODUCTION

More than 47,000 individuals died by suicide and more than 312,000 received care in the emergency department (ED) for self-harm injuries in 2018, part of a decade-long upward 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 for mental health services in the previous year (National Institute of Mental Health 2022). While the 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 shocks trigger these behaviors. 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, but not completed, suicides, Simon et al. (2001) reported that a quarter of attempts happened within 5 minutes of the decision being made. This highlights the importance of ephemeral shocks in triggering suicide: However, 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 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 episodes requiring emergency care and, potentially, suicidality. We test this hypothesis by examining the impact of seasonal allergies caused by exposure to pollen on the incidence of suicide, as well as 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. While itchy eyes, runny nose, and a cough seem like minor symptoms, 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 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, in some cases, declines in the 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 deaths and mental health episodes.

To understand how a small environmental shock affects suicide, we evaluate the impact of seasonal pollen on suicide using datasets of daily pollen measurements from many metropolitan localities and daily counts of suicides by county. We use 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 1.73% rise in the probability of suicide for every 10 particles per cubic meter (pcm) increase in pollen at low levels, and a 0.45% rise in probability of suicide for every 10 pcm at high levels of pollen. This implies that suicides are more sensitive to pollen at low to medium levels of pollen, with the incremental effect tapering off at high pollen levels. Consistent with other studies, the effects we estimate are present primarily among suicides by White individuals and those between the ages of 19 and 35.

We explore whether the effect of pollen on suicide works through mental health by evaluating the impact of pollen on visits to the emergency department (ED) for behavioral and mental health conditions. We use a daily aggregation of claims at the zip-code level for visits related to mental and behavioral conditions from large commercial and Medicare Advantage health plans. We find that ED visits have a 3.5% rise for every 10 pcm increase in pollen at the lowest levels with the effects moderating or even disappearing as pollen levels rise. Using Google Trends data of searches, we show evidence that allergies and poor sleep quality are likely mechanisms of the impact of pollen on mental health and suicidality.

This study makes five 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 suicide imposes a great social burden, suicidal ideation, suicide attempts, self-harm, and other mental health episodes occur much more frequently. Furthermore, focus on the precursors and risk of 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 the connection between poor mental health, including suicidal ideation, and history of allergies in relation to pollen (Messias et al. 2010, Qin et al. 2011). Our study shifts the focus away from the terminal event of suicide toward episodes of mental distress.

Third, this study uses data from 34 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 allowing us to take advantage of variation in place-based predictors of suicidality.

Fourth, this study uses robust methodology to evaluate a plausibly causal effect between a small health shock and suicidality. While pollution exposure is endogenous to individual activity and choices, changes in pollen levels vary in a manner that is plausibly exogenously. High-quality and high-frequency pollen, suicide, and health care utilization data allows us to overcome the challenges faced by most existing studies in this area which adjust for demographic characteristics, weather, and calendar weeks; none include sufficiently granular fixed effects to absorb unobserved time- and location-specific seasonal variation. We employ granular time and location fixed effects to account for unobserved factors which may contribute to both pollen and suicidality.

Furthermore, our study contributes to the literature in environmental economics by highlighting an overlooked cost of climate change. Most estimates project 1.3% decrease in GDP resulting from 2.5C increase in temperatures (Tol, 2018). Our analysis provides evidence of

a secondary mechanism of climate change on the economy. In view of these mechanisms, this study allows for avenues of adaptation to the effects of climate change through investments in allergy testing and mental health.

The next section describes the impact of pollen on human health and behavior, provides an overview of known social and economic predictors of suicide, and summarizes the literature on air quality and suicidality. Section 2 presents a theoretical framework establishing a possible linkage between environmental stressors and suicide. Section 3 describes the data, and section 4 describes the identification strategy. The results are presented in section 5, followed by a discussion and conclusion in section 6.

1. BACKGROUND

Pollen is a natural byproduct of the reproductive cycle of plants. As such, it peaks as plants flower in the late spring and early summer, as seen in Figure 2. There is a second, 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 to 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).

1.1 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 pollen exposure, SAR causes the immune system to produce antibodies such as histamine and cytokines that trigger inflammation of tissue and secretion of mucus. This results in typical allergy symptoms such as 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 evidence of increased accidents and injuries on high pollen days in Japan. Danagoulian and Deza (2024) show a 5.8% increase in fatal traffic accidents on high pollen days in US. Thus, though its impact on health is minor, literature shows that pollen affects decision making in numerous situations.

1.2 Factors of Suicide

While many factors may push an individual toward suicide, few have been identified and studied extensively. Though pollen and environmental pollution are not the main nor major predictors in suicide trends, they may play a significant role in the impulse which triggers the event.

A large body of literature has identified a number of individual-specific and place-based structural factors contributing to the risk of suicide. Individual factors are summarized by Marcotte and Hansen (2023): (1) poor mental health and depression, which are present in over

half of incidents of suicide; (2) opioid use, which has had a distinctly upward trend; (3) social media and cyberbullying, which is a growing threat to younger generations especially; and (4) bullying and victimization, though the importance of this factor has not grown in recent decades.

Place-based factors can be summarized in six categories: (1) social connectedness, such as domestic and religious integration, residential instability, and social isolation (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; Vardoros et al. 2019); (3) economic structures, such as the proportion of labor force employed in manufacturing, and unionization (Phillips and Nugent 2014); (4) cultural facilitators, such as access to firearms, alcohol consumption, and pain reliever abuse (Rockett et al. 2022; Steelesmith et al. 2019); (5) demographic characteristics, such as ethnic/racial composition as well as the proportion of residents that are male and over 65 and veterans (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 that the individual and place-based risk factors that contribute to the rising level of mental health burden may amplify or minimize the impact of pollen counts on suicidality. For example, presence of a mental health condition and easy access to means of suicide might amplify the impact of pollen on the likelihood of completed suicide.

1.3 Environmental Impact on Mental Health

Little is known about how environmental factors affect our mental health. For example, though environmental factors such as sunlight and rain have long been thought to impact mental

health, research shows that suicides peak in spring and fall, not in winter (Bridges et al. 2005; Woo et al. 2012b). As part of a growing interest to address this gap and understand how environmental factors act as a determinant of mental health, multiple studies have explored the link between the warming climate and mental and cognitive health. Using historical data, 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.

Due to a growing availability of geographically granular data, there is also a growing interest in the relationship between air pollution, another environmental stressor, 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 suicide (Braithwaite et al. 2019; Heo et al. 2021; Liu et al. 2021). In the economics 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.

Though decades of environmental policies are slowing and even reversing pollution, the same is not practicable for pollen emissions. In fact, as a manifestation of climate change, pollen emissions are expected to increase indefinitely, emphasizing the importance of understanding the connection between pollen and health behaviors such as suicide. Most studies examining this link between pollen and suicidality have been limited to associative study designs using locality-collected pollen data in limited geographic areas. Stickley et al. (2017) examined suicides 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 suicide in two localities in Denmark. All of these studies found positive associations between pollen and suicide.

In the United States, at the national level, Messias et al. (2010) associated suicidal ideation with pollen. Postolache et al. (2005) used data from 1995-1998 and found higher pollen levels associated with increased suicides, though these results were not replicable with more recent data (Woo et al. 2012a). A significant limitation in these studies is that they have severely limited external validity; while these studies evaluate effects at 30 to 100 particles per cubic meter, our data shows that pollen levels range from 0 to many thousands of particles per cubic meter. Furthermore, to our knowledge, there are no studies that evaluate the impact of pollen on receipt of mental health care.

Insofar as the pollen season stands to be extended by a warming climate, our study, like those above, also contributes to the environmental economics literature on the hidden costs of climate change. We quantify the impact of a naturally occurring air contaminant – pollen – on not only suicidality, but also mental health more broadly. Our analysis shows previously understudied secondary costs of climate change in health care and, importantly, offers potential adaptation mechanisms. In addition, given that multiple studies have linked rising global temperatures to poorer mental health, we also contribute to the literature exploring one possible mechanism by which this linkage operates.

2. A THEORETICAL MODEL 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.

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. In this model, we borrow from the Bernheim and Rangel (2004) addiction model, and propose a setting where an agent faces a positive probability of being tipped into a "hot" mode in which they may choose an action such as suicide that departs from their rational preferences. Generally, the agent operates in "cold" mode, optimizing in the presence of mental health stressors and small health shocks such as pollen allergies. In this model framework, as the mental health burden of the individual increases, the probability that pollen allergies may tip the individual into "hot" mode increases. In that sense, the model allows for the possibility that high pollen days may lead to increased utilization of mental health services and, potentially, suicide. See Appendix G for a more detailed exposition of the model.

2.1 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 from the economics literature with the large body of literature on suicidality in other fields. Our model, while still built around a typical utility-maximization problem, proposes a setting where suicide is an irrational choice. This is consistent with literature suggesting that the vast majority of individuals who ideate or attempt suicide do not go on to complete it (Bostwick et al. 2016). This provides evidence in support of both modeling suicide as an instantaneous "hot" mode and the impact of exogenous short-lived shocks on suicide.

3. DATA

We use three main sources of data, aggregating daily information about pollen measurements, utilization of mental and behavioral health care, and suicides at the county level.

3.1 National Allergy Bureau Pollen Data

We use daily pollen measurements from 34 metropolitan localities across the United States (see Figure 1) 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 across the United States. Collection was performed by a designated staff member certified in collection methods by the NAB, and was always carried out on the practice premises. While this process guarantees consistent measurement across time and locality, it restricts measurements to urban or suburban localities.

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. The certified counters then conduct microscopic analysis of the pollen by origin and type, and counts are expressed in terms of particles per cubic meter (pcm) of air (Ito et al. 2015; Sheffield et al. 2011). While some prior studies separate pollen by source: tree, grass, and weeds (Postolache et al. 2005) this study does not 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 volume in our data comes from trees.

Of the more than 80 locations that collected measurements, 34 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. 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.

[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 consider the treatment areas to be the county where the measurement station is located and all adjacent counties. Figure 2 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).

Appendix Figure A1 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).

3.2 National Violent Death Reporting System (NVDRS)

The Centers for Disease Control and Prevention (CDC) compiles the National Violent Death Reporting System (NVDRS) database from multiple sources of reporting. 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] In addition to data from death certificates, the NVDRS compiles information from the coroner/medical examiner, law enforcement, and toxicology reports. Thus, the database includes

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

detailed context for each violent death including, for example, the use of weapons and location. The database also incorporates information about mental health conditions and treatment, relationship problems, drug use, and life stressors. For this project, we obtained all deaths ruled as suicides for individuals aged 10 years and older. We aggregate suicides to daily counts at the county level.

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 throughout the length of the pollen data panel. Combining the NVDRS data with the localities for which we have pollen data, our analysis relies on 187 counties in 21 states.[3]

3.3 Optum's de-identified Clinformatics® Data Mart Database (CDM) (2007-2022) Health Insurance Claims Data

Our third source of data is the newly available and highly granular data that is derived from a database of administrative health claims for members of large commercial and Medicare Advantage health plans, which we will call CDM moving forward. 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. To protect the privacy of beneficiaries, demographic characteristics are limited to age, sex, and zip code of residence. We use diagnostic codes and place of service codes to aggregate claims to

[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.

daily counts of visits by type at the zip-code level. We also identify the demographic composition of these visits, separating the counts by gender and age categories.

3.4 Other Data Sources

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 suicide and mental health, consistent with the literature, we include continuous controls for each minimum, maximum, and average temperature interacted by an indicator of a location and season specific quartile of measurement. In supplemental analyses, we integrate wind data from the North American Regional Reanalysis (NARR) source.

4. EMPIRICAL METHOD

4.1 Identification Challenges

There are numerous challenges that we face in identifying the impact of pollen on suicide. First, pollen and suicide levels are each subject to significant seasonal variation that may be correlated. For example, Figure 3 plots average pollen measurements alongside counts of suicides at the monthly frequency during our study period. As the figure highlights, suicides 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 suicide. To circumvent these confounders, we make use of the highly granular nature of the data and include a set of location by week and month by day fixed effects which allow us to identify the relationship between pollen and suicide by comparing deviations in pollen and suicides from local seasonal trends at the daily frequency. In doing this, we also overcome a potential endogeneity from selective migration in the sense that people may choose where to live based on susceptibility to seasonal allergies.

Even in comparing daily deviations in pollen and suicides from local seasonal trends, a second potential challenge to identification would be the presence an underlying factor which affects changes in both daily pollen levels and daily suicide counts. One such factor could be weather, particularly precipitation and seasonal temperatures, which change daily and are also exogenous to human activity. To account for this, our preferred model specification includes a rich set of 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.

Third, there is a potential for nonlinearity in the relationship between environmental stressors and suicide. To account for this, our preferred specification estimates a separate linear fit for each quartile of pollen measurement. This allows us to approximate a nonparametric fit for the relationship between pollen and the outcome of interest. Fourth, the suicide and the claims data have a mass of zero, as the granularity of county or zip code and date give rise to days with no suicides or visits to the ED from 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.

A final potential challenge to identification highlighted in 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. Nonetheless, we present robustness analyses including controls for wind speed in Appendix L.

4.2 Specification

Taking these challenges into account, we model a Poisson specification of the form:

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

where Y_{it} is the outcome of interest (suicides, mental health visits) for zip code *i* on day *t*. To capture the nonlinear relationship between pollen levels and suicides, we include the interaction of $Pollen_{it}$ with an indicator for the quartile of pollen level I_j. Therefore, the four coefficients β_j capture the slope of the linear fit for each quartile of pollen measurement. 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, over t-2 to t-8. When presenting the results, we sum the contemporaneous and lagged effect of pollen levels for each location-season quartile, $\beta_j + \beta_j^{-1}$, to reflect the cumulative effect of direct exposure and delayed effect on suicide. The set of interactions $Temp_{it} * I_j$ and the indicator $Precip_{it}$ control for weather variables which might confound the impact of pollen on suicide. In all analyses, the pollen measurements have been scaled down by 10 pcm to improve the interpretability of

estimates. Finally, to account for spatial autocorrelation, standard errors, ε_{it}, are clustered at the locality (34 locations) level in all specifications.

The quartile of measurement is defined relative to locality-specific season. Thus, for example, we compare pollen counts in spring (March through May) in Alameda County, California, over the study period 2006-2017, defining quartiles in such manner. Similarly, for summer, fall, and winter months. The choice of this definition of quartile is determined by two considerations. First, pollen emissions differ substantially across seasons and across localities. Examining Figure 2, In Alameda County, California, the timing and intensity of pollen emissions are very different from Erie County. If compared at the same footing, Erie County would contribute to variation in lower quartile of measurement. For residents of Erie County, any deviation from local average, no matter how low, would constitute a larger exposure. Thus, to avoid such comparisons, we define quartiles by locality.

Second, pollen emissions differ not only in quantity but also in composition. Spring pollen is composed mostly of trees, while summer and fall pollen includes ragweed and other grasses. The amount of pollen produced by trees differs substantially from weeds and grasses, however, the effect on human health differs. Despite its relatively low count, ragweed triggers strong allergies. If each quartile included all seasons, pollen counts in summer and fall would contribute variation to lower quartiles, despite their disproportionate effect on health. To avoid this, we define a quartile relative to location and season, ensuring that the ragweed season in a locality is compared to ragweed seasons in the same locality over the years, allowing their variation to contribute to higher quartiles as well.

Our model includes a set of granular location and time fixed effects that absorb variation attributable to location and seasonal trends. As such, 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. The preferred specification includes location by week (34*52) fixed effects, V_{it}, which capture location-specific predictors of suicide, such as economic conditions, connectedness, access to mental health care, access to firearms, and so on, which may change throughout the year. These fixed effects also account for location-specific events, such as seasonal trends in tree blossoming and pollen emissions. The preferred specification also includes month by day (12*31) fixed effects, W_t, to capture which capture monthly patterns, such as holidays and week cycles, which may affect mental health across all locations.

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. In alternative specifications, we explore variations on location and time fixed effects and show that estimates are generally stable.

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. Nonetheless, we present robustness analyses including controls for wind speed in Appendix L.

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.

5. RESULTS

Prior to presenting the adjusted results, we first examine unadjusted trends in pollen and suicides. Table 1 presents average daily pollen measurements by quartile of measurement, and associated suicide counts. As mentioned above, the quartile of pollen levels are location-season specific. We note a number of features of this data: (1) average pollen measurements increase in each quartile, as expected; however, (2) the standard deviations are larger in each quartile, as well, and (3) because each quartile is location and season specific, the 95% confidence interval around each mean overlap. We note that there are about 0.06 suicides per day in each locality, and these counts increase in each quartile.

Figure 4 illustrates the serial correlation in pollen measurements. To evaluate whether pollen rises and declines in cycles, we designate days when pollen levels are in the fourth quartile of measurement as day zero (a high pollen day) and evaluate the average pollen levels in the 7 days before and after that day. The figure 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. This figure shows that pollen measurements are not independent across time and characterized by a slow buildup. 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.

5.1 Suicides

Main results

Table 2 presents estimates of equation (1) for the outcome of count of suicides. 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 percent 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. Column (3) 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 2 are consistent across specifications. We note that as the quartile of measurement increases, the magnitude of estimate is smaller and less significant. 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. In the second quartile, a 10-pcm increase in pollen levels increases suicides by up to 1.73%. Suicides increase by 0.45% in the third quartile, a much smaller effect. Finally, we find no statistically significant or economically meaningful impact at the highest quartile of pollen.

While the coefficients appear to attenuate at higher levels of pollen, Table 1 shows that when pollen levels are high, i.e. in the fourth quartile, the variation in pollen levels is much higher. The nonlinear impact of pollen on health suggests that a 10 pcm increase in pollen at low levels does not have the same impact as a similar increase at high levels. In column (4) we scale the coefficient estimate from column (3), showing that a one standard deviation increase in pollen levels is more comparable in magnitude across quartiles. This scaling suggests some form of adaptation, behavioral or physiologic, at high levels of pollen

In column (5) we add an additional lag, showing somewhat larger and more precisely estimated effects. The additional lag contributes marginally to our estimates, motivating the remainder of the analysis to remain with one lag.

We present coefficients β_j and β_j^{-1} separately in Figure 5 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 and 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. 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. Also, in Appendix Table J1, we explore the sensitivity of our estimates to the sample attrition that occurs as more controls are added. When we use the sample from the preferred specification for each less-saturated model, we find effects that are very similar to the main.

Demographic Variation

Figure 6 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 11.8% increase, though the estimates are too noisy for statistical significance. This effect is particularly important given the small number of Hispanic decedents.

Figure 7 shows results by demographic characteristics of suicides (Panels (a) and (c)) by sex (male and female) and age (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 suicides 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.

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).

Heterogeneity in Outcomes

Suicides which use immediately available methods might be more susceptible to the triggering of "hot" mode than those which require more advanced planning. For example, firearms are responsible for 53% of all suicides, and states with the lowest number of firearm laws have more than twice the rate of suicides by firearms than states with more laws. This suggests that pollen allergies may magnify the effect of suicides by firearm. In addition, individuals with underlying mental health conditions might have a higher probability of entering "hot" mode upon pollen exposure, suggesting that pollen exposure might be more detrimental to those with underlying mental health conditions.

To explore these possibilities, Table 3 examines heterogeneity in the effect of pollen on suicides across two dimensions: method of suicide and presence of an underlying mental health condition. We separate methods of suicide into three categories: 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. 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 are separated according to known mental health factors. A feature 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% 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.[4] For each estimate, we report p-values adjusted for multiple inference as suggested by Anderson (2008). These estimates are consistent with our theoretical model that suggests that as mental health deteriorates, the probability of "hot" mode, and hence suicide, being triggered by pollen increases.

5.2 Visits to the ED

Our model predicts that beyond the triggering of suicide for individuals at the margin, rising pollen levels should also increase episodes of mental health care. The results for suicides show that, indeed, pollen levels do have an impact. In this section, we examine the effect of pollen exposure on visits to the ED for any mental health diagnosis. We focus on ED visits because the immediacy of the hypothesized shocks is in days, not weeks, and office visits are less sensitive to such changes due to scheduling constraints.

[4] 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).

Table 4 presents the coefficient estimates for equation (1) for the outcome of count of ED visits with mental and behavioral care diagnostic codes.[5] The unit of analysis is the zip-code-day, and as in the analysis on suicides, 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 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 pollen measurements in the 3rd and 4th quartile. For pollen measurements in the 1st and 2nd quartile, the estimates remain statistically significant at conventional levels and increase in magnitude upon the addition of the fixed effects. In column (2), 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 5 Panel (b), we find that the contemporaneous and lagged coefficients are similar in magnitude and sign and are statistically significant for the first quartile. The coefficients for contemporaneous and lagged effects are reported in full in Appendix Table C1b.

Demographic Variation

Figure 7 shows results by demographic characteristics of 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

[5] The codes are specified in Appendix B.

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.

Absent in the suicide data, we are able to track ED 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. The higher sensitivity of children to pollen is puzzling; on one hand, children have a lower rate of diagnosed seasonal allergies (Zablotsky et al. 2021), so we should not see higher sensitivity among this group; on the other hand, visits to the ED may be initiated by parents who have an allergy induced lower tolerance for behavioral episodes in their child. Youth, young adult, and adult visits are consistent with the baseline estimates. Older adults experience a decline in visits at low levels of pollen.

Heterogeneity of Effect

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 5 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 moderate to high levels of pollen, however, most categories of visits experience an increase.

5.3 Robustness of Estimates

Pollen or Weather?

An alternative explanation for the relationship between pollen and mental health care or suicidality is that pollen partly captures the effect of weather. We examine the role of weather in Appendix E. 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. In Appendix Table E1, we stratify our analysis by the strength of this relationship, finding similar estimates across localities with different strength of the pollen-weather relationship. Additionally, we show in Appendix Table E2 that adding lagged weather controls to our main specification does not change our main coefficient values. These additional analyses suggest that our main results are not capturing the effect of weather.

Furthermore, in Appendix Table K1, we separate the sample by season – spring, summer, and fall – to evince variation in effects. Pollen emission sources differ by season: spring pollen originates mainly in trees, accounting for 83% pollen emissions; summer and fall pollen tend to be grasses and weeds, with ragweed season lasting from August through September. We find some seasonal variation in pollen, with the estimates for spring being most consistent with main findings.

Finally, wind may play a role in the spread of pollen. Though wind direction is not likely to affect the source of emissions as trees, grasses, and weeds do not tend to be spatially concentrated, wind speed may spread pollen granules further away from emission sources. To explore whether variation in wind is affecting our results, we supplement the weather data with the North American Regional Reanalysis (NARR) data[6] and extend our main analysis to include

[6] We supplement the PRISM Climate data with North American Regional Reanalysis (NARR) data on wind speed and direction produced by the National Centers for Environmental Prediction (NCEP). Wind may play an important role in the spread of pollen. Unfortunately, the NARR data includes all of our localities between 2006 and 2011, but

various combinations of wind controls. The estimation results are presented in Appendix Table L1. Our estimates remain consistent with main findings, in magnitude, sign, and statistical significance.

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 combine 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 results in a smaller merged sample. 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,[7] and "very bad" if the levels correspond to the classifications unhealthy for sensitive groups, unhealthy, very unhealthy, or hazardous.[8]

only some of the localities starting in 2012 to 2016. This reduction in sample may be selective and may undermine the power of our estimates, and therefore we leave analyses with wind data as supplemental.

[7] 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.

[8] 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.

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.

Other Robustness Checks

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 D1, 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) includes a linear fit with two lags and a quadratic term for each lag, attempting to capture the nonlinear nature of the data; and column (4) is a log of pollen specification to once-again capture the non-linear nature of the data. These alternative specifications do not show statistically significant estimate at conventional levels. The notable exception is the linear fit of pollen levels with 2 lags and square term. However, we note that, despite lack of statistical significance, the alternative estimates are positive and, if scaled, would represent effects of similar magnitude.

5.4 Mechanisms: Allergies and Sleep

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 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.

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 34) 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.[9] We selected multiple search terms within three broad categories: allergy,[10] exhaustion,[11] and suicidality.[12] We extracted search data for each search term separately and for clusters of terms by category,[13] 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

[9] 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.

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

[11] The search terms included: sleep, sleepy, tired, exhausted.

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

[13] 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.

and weather data, resulting in 50,340 observations, and estimated equation (1) using ordinary least squares specification to account for the continuous nature of the index.

Table 6 presents estimates of the preferred specifications for clusters of terms and combinations of categories. It reports the sum of contemporaneous and lagged coefficients for the interaction of the pollen level with indicators 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 increases in pollen at 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 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 pcm 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.

6. DISCUSSION

Our estimates show economically meaningful changes to both suicides 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. 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 heightened pollen exposure.

Our estimates show that the effect size decreases with rising pollen levels. Figure 8 shows model-predicted daily count of suicides relative to the pollen levels separated by location-season specific ventiles. The figure confirms that the rising pollen levels in the first, second, and third quartiles result in sharply rising suicide counts, while the incremental impact of pollen in the highest quartile is negligible. However, the figure also makes clear that though the marginal effect of pollen at highest levels is negligible, the level of mortality at these levels remains very high. This difference in the marginal effect could be attributable to tolerance as pollen levels rise (also evident when scaling results by standard deviation) or, potentially, to avoidance behavior.

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 suicides 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 suicides 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 suicides; then, on the following day, we would expect to see an increase in ED visits and a larger increase in suicides. If the physiological mechanism dominates the isolation mechanism, we expect equivalent increases on the same and the following day for both ED visits and suicides.

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. Nonetheless, we find some evidence of avoidance behavior in ED visits, as visits decline in the third and fourth quartile of pollen, an effect which is also reflected in the lower marginal impact of pollen on suicide at these high levels. We also find some evidence of avoidance behavior in our analysis of the interaction between pollution and pollen on suicide. Specifically, we find that 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.

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. Jeon-Slaughter et al. (2016) estimated a 56% increase in self-directed violence among female patients in the ED 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. Consistent with these studies, our findings show the largest effects on suicide among White individuals and those in early adulthood.

6.1 Projections

During this panel period, there were more than 470,000 suicides in United States.[14] Assuming an approximate 5% increase in suicides resulting from one standard-deviation increase in pollen, we 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 temperatures increase due to climate change. Akesaka and Shigeoka (2023) estimate that a 1C increase in maximum temperature increases daily pollen by 167.4 pcm. Looking ahead, 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.[15] These two

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

estimates imply an expected increase of 234–736 pcm in daily pollen by 2100. According to our results, this would correspond to a 68–214% increase in pollen-attributable suicides (234/10*0.0291 and 736/10*0.0291) by the end of this century. It should be noted that climate change will increase not only the intensity of the pollen season, but also the duration. Notably, 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. As our back-of-the-envelope calculations do not account for the possible extended duration of the pollen season, they represent a lower bound of the potential increase in pollen-attributable suicides.

6.2 Limitations

While the results presented here are robust, they are based on data with a number of limitations. First, the data on suicides originates from a source which classifies a death as suicide based on coroner or medical examiner report. Such reports can be subject to measurement error (Rockett et al. 2022). Deaths which are attributed to other causes, and particularly, drugs and alcohol, can be misclassified suicides. Furthermore, pollen may affect mortality more broadly, as it increases incidence of accidents. Therefore, a more complete analysis would start from all-cause mortality records, examining all deaths, those attributed to suicides, as well as those with drug or alcohol cause. We intend to perform such analysis in future research.

The claims data is also subject to a number of limitations. Though the data include a multi-payer source, they do not represent the total volume of visits and utilization for the diagnostic codes of interest in these zip codes. In addition, as the claims are derived from a database of administrative health claims for members of large commercial and Medicare Advantage health plans, they are likely to represent a population that is more affluent.

Finally, while we argue that pollen levels are exogenous, they may be affected by activities such as crop planting and harvesting. As previously mentioned, while tree pollen makes up the majority of emissions, grass and weed emissions are limited to summer and fall and, despite lower pollen counts, induce strong allergy symptoms as well. Here, our analysis is limited to urban and metropolitan areas which are likely to have less exposure to agricultural activities and, thus, face more exogenous variation in pollen.

6.3 Policy Implications

We draw two major policy implications from this analysis. First, suicidality and poor mental health are sensitive to relatively small health 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, as it is limited in place and time. 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.

7. CONCLUSIONS

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 a 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.

Bibliography

Akesaka, Mika, and Hitoshi Shigeoka. 2023. "'Invisible killer': Seasonal allergies and accidents." *National Bureau of Economic Research Working Paper Series No. 31593.*

Anderegg, William R. L., John T. Abatzoglou, Leander D. L. Anderegg, Leonard Bielory, Patrick L. Kinney, and Lewis Ziska. 2021. "Anthropogenic climate change is worsening North American pollen seasons." *Proceedings of the National Academy of Sciences* 118 (7): e2013284118. https://doi.org/doi:10.1073/pnas.2013284118.

Anderson, Michael L. 2008. "Multiple Inference and Gender Differences in the Effects of Early Intervention: A Reevaluation of the Abecedarian, Perry Preschool, and Early Training Projects." *Journal of the American Statistical Association* 103 (484): 1481-1495.

Baca-García, Enrique, Carmen Diaz-Sastre, Elena Basurte, Rita Prieto, Antonio Ceverino, Jeronimo Saiz-Ruiz, and Jose de Leon. 2001. "A prospective study of the paradoxical relationship between impulsivity and lethality of suicide attempts." *Journal of Clinical Psychiatry* 62 (7): 560-564.

Baca–Garcia, Enrique, Carmen Diaz–Sastre, Eloy García Resa, Hilario Blasco, Dolores Braquehais Conesa, Maria A. Oquendo, Jeronimo Saiz-Ruiz, and Jose De Leon. 2005. "Suicide attempts and impulsivity." *European Archives of Psychiatry and Clinical Neuroscience* 255 (2): 152-156.

Bernheim, B. Douglas, and Antonio Rangel. 2004. "Addiction and cue-triggered decision processes." *American Economic Review* 94 (5): 1558–1590.

Bhalotra, Sonia, Irma Clots-Figueras, Joseph Flavian Gomes, and Alessio Mitra. 2022. "Fetal temperature exposure on long term cognitive and economic individual outcomes." *Working Paper*.

Bostwick, Michael, Chaitanya Pabbati, Jennifer Geske, and Alastair McKean. 2016. "Suicide attempt as a risk factor for completed suicide: Even more lethal than we knew." *American Journal of Psychiatry* 173 (11): 1094–1100.

Braithwaite, Isobel, Shuo Zhang, James B. Kirkbride, David P. J. Osborn, and Joseph F. Hayes. 2019. "Air pollution (particulate matter) exposure and associations with depression, anxiety, bipolar, psychosis and suicide risk: A systematic review and meta-analysis." *Environmental Health Perspectives* 127 (12): 126002. https://doi.org/10.1289/ehp4595.

Bridges, F. Stephen, Paul S. F. Yip, and Kris C. T. Yang. 2005. "Seasonal changes in suicide in the United States, 1971 to 2000." *Perceptual and Motor Skills* 100 (3_suppl): 920–924.

Centers for Disease Control and Prevention. 2021. "Suicide and self-harm injury." Accessed September 10, 2021. https://www.cdc.gov/nchs/fastats/suicide.htm.

Chalfin, Aaron, Shooshan Danagoulian, and Monica Deza. 2019. "More sneezing, less crime? Health shocks and the market for offenses." *Journal of Health Economics* 68: 102230.

Craig, Timothy J., Jeffrey L. McCann, Faina Gurevich, and Michael J. Davies. 2004. "The correlation between allergic rhinitis and sleep disturbance." *Journal of Allergy and Clinical Immunology* 114 (5 Suppl): S139–145.

Cutler, David M., Edward L. Glaeser, and Karen E. Norberg. 2001. "Explaining the rise in youth suicide." In *Risky Behavior Among Youths: An Economic Analysis*, 219–270. University of Chicago Press.

D'Amato, Gennaro, Herberto Jose Chong-Neto, Olga Patricia Monge Ortega, Carolina Vitale, Ignacio Ansotegui, Nelson Rosario, Tari Haahtela, Carmen Galan, Ruby Pawankar, Margarita Murrieta-Aguttes, Lorenzo Cecchi, Christian Bergmann, Erminia Ridolo,

German Ramon, Sandra Gonzalez Diaz, Maria D'Amato, and Isabella Annesi-Maesano. 2020. "The effects of climate change on respiratory allergy and asthma induced by pollen and mold allergens." *Allergy* 75 (9): 2219–2228.

Danagoulian, Shooshan, and Monica Deza. Driving Under the Influence of Allergies: The Effect of Seasonal Pollen on Traffic Fatalities. *No. w32233. National Bureau of Economic Research*, 2024.

Denney, Justin T, Tim Wadsworth, Richard G Rogers, and Fred C Pampel. 2015. "Suicide in the city: do characteristics of place really influence risk?" *Social Science Quarterly* 96 (2): 313-329.

Deryugina, Tatyana, Garth Heutel, Nolan H. Miller, David Molitor, and Julian Reif. 2019. "The Mortality and Medical Costs of Air Pollution: Evidence from Changes in Wind Direction." *American Economic Review* 109 (12): 4178-4219.

Dowlati, Yekta, Nathan Herrmann, Walter Swardfager, Helena Liu, Lauren Sham, Elyse Reim, and Krista Lanctot. 2010. "A meta-analysis of cytokines and major depression." *Biological Psychiatry* 67 (5): 446–457.

Franklin, Joseph C, Jessica D Ribeiro, Kathryn R Fox, Kate H Bentley, Evan M Kleiman, Xieyining Huang, Katherine M Musacchio, Adam C Jaroszewski, Bernard P Chang, and Matthew K Nock. 2017. "Risk factors for suicidal thoughts and behaviors: A meta-analysis of 50 years of research." *Psychological Bulletin* 143 (2): 187.

Greiner, Alexander N., Peter W. Hellings, Guiseppina Rotiroti, and Glenis K. Scadding. 2011. "Allergic rhinitis." *Lancet* 378 (9809): 2112–2122.

Hamermesh, Daniel S, and Neal M Soss. 1974. "An economic theory of suicide." *Journal of Political Economy* 82 (1): 83-98.

Harris, Lauren M., Xieyining Huang, Kathryn P. Linthicum, Chloe P. Bryen, and Jessica D. Ribeiro. 2020. "Sleep disturbances as risk factors for suicidal thoughts and behaviours: A meta-analysis of longitudinal studies." *Scientific Reports* 10 (1): 13888.

Heo, Seulkee, Whanhee Lee, and Michelle L. Bell. 2021. "Suicide and associations with air pollution and ambient temperature: A systematic review and meta-analysis." *International Journal of Environmental Research and Public Health* 18 (14): 7699.

Ito, Kazuhiko, Kate R. Weinberger, Guy S. Robinson, Perry E. Sheffield, Ramona Lall, Robert Mathes, Zev Ross, Patrick L. Kinney, and Thomas D. Matte. 2015. "The associations between daily spring pollen counts, over-the-counter allergy medication sales, and asthma syndrome emergency department visits in New York City, 2002–2012." *Environmental Health* 14 (1): 71.

Janeway, Charles A., Paul Travers, Mark Walport, and Mark J. Shlomchik 2001. *Immunobiology: The Immune System in Health and Disease*. New York: Garland Science.

Jauregui, Ignacio, Joaquin Mullol, Ignacio Davila, and Marta Ferrer. 2009. "Allergic rhinitis and school performance." *Journal of Investigational Allergology & Clinical Immunology* 19 (1): 32–39.

Jeon-Slaughter, Haekyung, Cynthia A. Claassen, David A. Khan, Perry Mihalakos, Kevin B. Lee, and E. Sherwood Brown. 2016. "Temporal association between nonfatal self-directed violence and tree and grass pollen counts." *The Journal of Clinical Psychiatry* 77 (9): 1160-1167.

Klonsky, David, Alexis May, and Boaz Saffer. 2016. "Suicide, suicide attempts, and suicidal ideation." *Annual Review of Clinical Psychology* 12 (1): 307–330.

Kremer, Bernd, H. M. Den Hartog, and J. Jolles. 2002. "Relationship between allergic rhinitis, disturbed cognitive functions and psychological well-being." *Clinical and Experimental Allergy* 32 (9): 1310–1315.

Kronfol, Ziad, and Daniel Remick. 2000. "Cytokines and the brain implications for clinical psychiatry." *The American Journal of Psychiatry* 157 (5): 683–694.

Lamb, Charles, Paul Ratner, Clarion Johnson, Ambarish Ambegaonkar et al. 2006. "Economic impact of workplace productivity losses due to allergic rhinitis compared with select medical conditions in the United States from an employer perspective." *Current Medical Research and Opinion* 22 (6): 1203–1210.

Li, Mengyao, Susana Ferreira, and Travis A. Smith. 2020. "Temperature and self-reported mental health in the United States." *PLOS ONE* 15 (3): e0230316.

Liu, Qisijing, Wanzhou Wang, Xuelin Gu, Furong Deng, Xueqin Wang, Hualiang Lin, Xinbiao Guo, and Shaowei Wu. 2021. "Association between particulate matter air pollution and risk of depression and suicide: a systematic review and meta-analysis." *Environmental Science and Pollution Research Int* 28 (8): 9029–9049.

Liu, Robert T., Stephanie. J. Steele, Jessica L. Hamilton, Quyen B. P. Do, Kayla Furbish, Taylor A. Burke, Ashley P. Martinez, and Nimesha Gerlus. 2020. "Sleep and suicide: A systematic review and meta-analysis of longitudinal studies." *Clinical Psychology Review* 81: 101895.

Marcotte, Dave E. 2015. "Allergy test: Seasonal allergens and performance in school." *Journal*

of Health Economics 40: 132–140.

Marcotte, Dave E. 2017. "Something in the air? Air quality and children's educational outcomes." *Economics of Education Review* 56: 141–151.

Marshall, Paul S., and E. A. Colon. 1993. "Effects of allergy season on mood and cognitive function." *Annals of Allergy* 71 (3): 251-8.

Marshall, Paul S., Christine O'Hara, and Paul Steinberg. 2000. "Effects of seasonal allergic rhinitis on selected cognitive abilities." *Annals of Allergy, Asthma and Immunology* 84 (4): 403–410.

McAfoose, Jordan, and B. T. Baune. 2009. "Evidence for a cytokine model of cognitive function." *Neuroscience & Biobehavioral Reviews* 33 (3): 355–366.

Meltzer, Eli O., Michael S. Blaiss, Robert M. Naclerio, Stuart W. Stoloff, M. Jennifer Derebery, Harold S. Nelson, John M. Boyle, and Mark A. Wingertzahn. 2012. "Burden of allergic rhinitis: Allergies in America, Latin America, and Asia-Pacific adult surveys." *Allergy and Asthma Proceedings* vol. 33, no. 5, pp. S113-S141.

Messias, Erick., D. E. Clarke, and R. D. Goodwin. 2010. "Seasonal allergies and suicidality: Results from the National Comorbidity Survey replication." *Acta Psychiatrica Scandinavica* 122 (2): 139–142.

Molitor, David, Jamie T Mullins, and Corey White. 2023. "Air pollution and suicide in rural and urban America: Evidence from wildfire smoke." *Proceedings of the National Academy of Sciences* 120 (38): e2221621120.

National Academies of Sciences, Engineering, and Medicine. 2021. *High and Rising Mortality Rates Among Working-Age Adults.* (Washington, DC) https://doi.org/10.17226/25976.

National Institute of Mental Health. 2022. "Statistics: Mental illness." Available at: https://www.nimh.nih.gov/health/statistics/mental-illness.

NIAID (National Institute of Allergy and Infectious Diseases). 2012. "Pollen allergy." Accessed 12/31/2014.

Pendergast, Philip M, Tim Wadsworth, and Charis E Kubrin. 2019. "Suicide in happy places: Is there really a paradox?" *Journal of Happiness Studies* 20: 81-99.

Persico, Claudia, and Dave Marcotte. 2022. "Air quality and suicide." *IZA Discussion Paper* No. 15087, no. 90,000.

Pescosolido, Bernice A, Byungkyu Lee, and Karen Kafadar. 2020. "Cross-level sociodemographic homogeneity alters individual risk for completed suicide." *Proceedings of the National Academy of Sciences* 117 (42): 26170-26175.

Phillips, Julie A, and Colleen N Nugent. 2014. "Suicide and the Great Recession of 2007–2009: The role of economic factors in the 50 US states." *Social Science & Medicine* 116: 22-31.

Postolache, Teodor T., J. W. Stiller, R. Herrell, M. A. Goldstein, S. S. Shreeram, R. Zebrak, C. M. Thrower, J. Volkov, M. J. No, I. Volkov, K. J. Rohan, J. Redditt, M. Parmar, F. Mohyuddin, C. Olsen, M. Moca, L. H. Tonelli, K. Merikangas, and H. D. Komarow. 2005. "Tree pollen peaks are associated with increased nonviolent suicide in women." In *Molecular Psychiatry* 10: 232–235.

PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu, data created 4 Feb 2014, accessed July 20, 2022.

Qin, Ping, Berit L. Waltoft, Preven. B. Mortensen, and Teodor. T. Postolache. 2013. "Suicide risk in relation to air pollen counts: A study based on data from Danish registers." *BMJ*

Open 3 (5).

Qin, Ping., Preven. B. Mortensen, Berit. L. Waltoft, and Teodor. T. Postolache. 2011. "Allergy is associated with suicide completion with a possible mediating role of mood disorder – A population-based study." *Allergy* 66 (5): 658–664.

Recker, Nicholas L, and Matthew D Moore. 2016. "Durkheim, social capital, and suicide rates across US counties." *Health Sociology Review* 25 (1): 78-91.

Rockett, Ian RH, Haomiao Jia, Bina Ali, Aniruddha Banerjee, Hilary S Connery, Kurt B Nolte, Ted Miller, Franklin MM White, Bernard D DiGregorio, and G Luke Larkin. 2022. "Association of state social and environmental factors with rates of self-injury mortality and suicide in the United States." *JAMA Network Open* 5 (2): e2146591-e2146591.

Santos, Carah B., Ellen L. Pratt, Chris Hanks, Jeffery McCann, and Timothy J. Craig. 2006. "Allergic rhinitis and its effect on sleep, fatigue, and daytime somnolence." *Annals of Allergy, Asthma & Immunology* 97 (5): 579–587.

Shea, Katherine M., Robert T. Truckner, Richard W. Weber, and David B. Peden. "Climate change and allergic disease." *Journal of Allergy and Clinical Immunology* 122, no. 3 (2008): 443-453.

Sheffield, Perry E., Kate R. Weinberger, Kazuhiko Ito, Thomas D. Matte, Robert W. Mathes, Guy S. Robinson, and Patrick L. Kinney. 2011. "The association of tree pollen concentration peaks and allergy medication sales in New York City: 2003–2008." *ISRN Allergy* vol. 2011: 1-7.

Simon, Thomas R, Alan C Swann, Kenneth E Powell, Lloyd B Potter, Marcie-jo Kresnow, and Patrick W O'Carroll. 2001. "Characteristics of impulsive suicide attempts and attempters." *Suicide and Life-Threatening Behavior* 32 (Supplement to Issue 1): 49-59.

Stack, Steven. 2021. "Contributing factors to suicide: Political, social, cultural and economic." *Preventive Medicine* 152: 106498.

Steelesmith, Danielle L, Cynthia A Fontanella, John V Campo, Jeffrey A Bridge, Keith L Warren, and Elisabeth D Root. 2019. "Contextual factors associated with county-level suicide rates in the United States, 1999 to 2016." *JAMA Network Open* 2 (9): e1910936-e1910936.

Stickley, Andrew, Chris Fook Sheng Ng, Shoko Konishi, Ai Koyanagi, and Chiho Watanabe. 2017. "Airborne pollen and suicide mortality in Tokyo, 2001–2011." *Environmental Research* 155: 134–140.

Tashiro, Manabu, Hideki Mochizuki, Kentaro Iwabuchi, Yumiko Sakurada, Masatoshi Itoh, Takehiko Watanabe, and Kazuhiko Yanai. 2002. "Roles of histamine in regulation of arousal and cognition: Functional neuroimaging of histamine H1 receptors in human brain." *Life Sciences* 72 (4–5): 409–414.

Vandoros, Sotiris, Mauricio Avendano, and Ichiro Kawachi. 2019. "The association between economic uncertainty and suicide in the short-run." *Social Science & Medicine* 220: 403–410.

Wang, Xiaofen, Sixiang Cheng, and Huilan Xu. 2019. "Systematic review and meta-analysis of the relationship between sleep disorders and suicidal behaviour in patients with depression." *BMC Psychiatry* 19 (1): 303.

Wilken, Jeffrey A., Robert Berkowitz, and Robert Kane. "Decrements in vigilance and cognitive functioning associated with ragweed-induced allergic rhinitis." *Annals of Allergy, Asthma & Immunology* 89, no. 4 (2002): 372-380.

Woo, Jong-Min, Olaoluwa Okusaga, and Teodore. T. Postolache. 2012b. "Seasonality of suicidal behavior." International Journal of Environmental Research and Public Health 9 (2): 531–547.

Woo, Jong-Min, R. D. Gibbons, C. A. Rogers, P. Qin, J. B. Kim, D. W. Roberts, E. S. Noh, J. J. Mann, and Teodore. T. Postolache. 2012a. "Pollen counts and suicide rates. Association not replicated." *Acta Psychiatrica Scandinavica* 125 (2): 168–175.

Yen, Shirley, M Tracie Shea, Charles A Sanislow, Carlos M Grilo, Andrew E Skodol, John G Gunderson, Thomas H McGlashan, Mary C Zanarini, and Leslie C Morey. 2004. "Borderline personality disorder criteria associated with prospectively observed suicidal behavior." *American Journal of Psychiatry* 161 (7): 1296-1298.

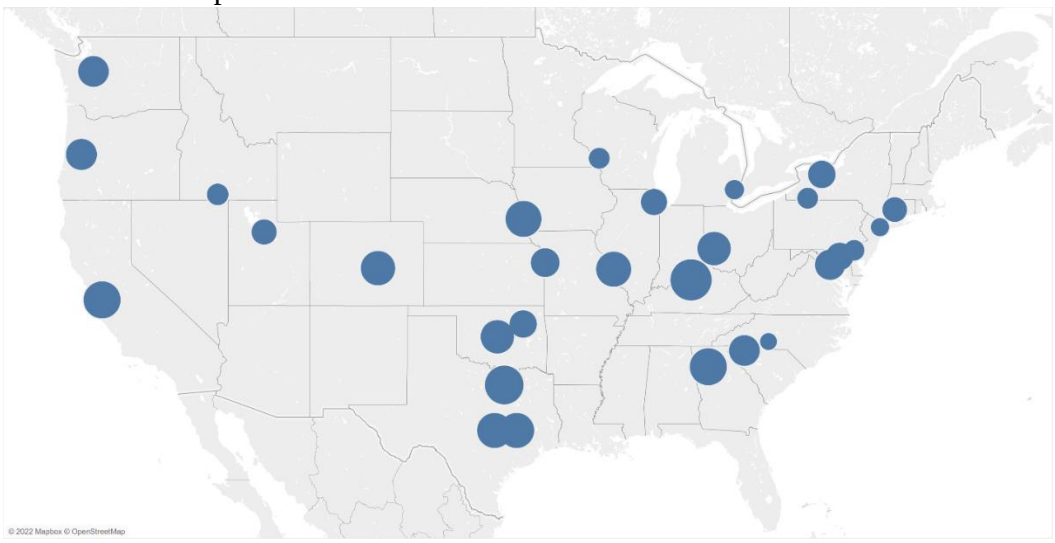
Zablotsky B, Black LI, Akinbami LJ. Diagnosed allergic conditions in children aged 0–17 years: United States, 2021. *NCHS Data Brief, no 459*. Hyattsville, MD: National Center for Health Statistics. 2023.

Zhang, Xin, Xi Chen, and Xiaobo Zhang. 2024. "Temperature and low-stakes cognitive performance." *Journal of the Association of Environmental and Resource Economists* 11 (1): 75-96.

Zhang, Yingxiao, and Allison L. Steiner. 2022. "Projected climate-driven changes in pollen emission season length and magnitude over the continental United States." *Nature Communications* 13 (1): 1234.

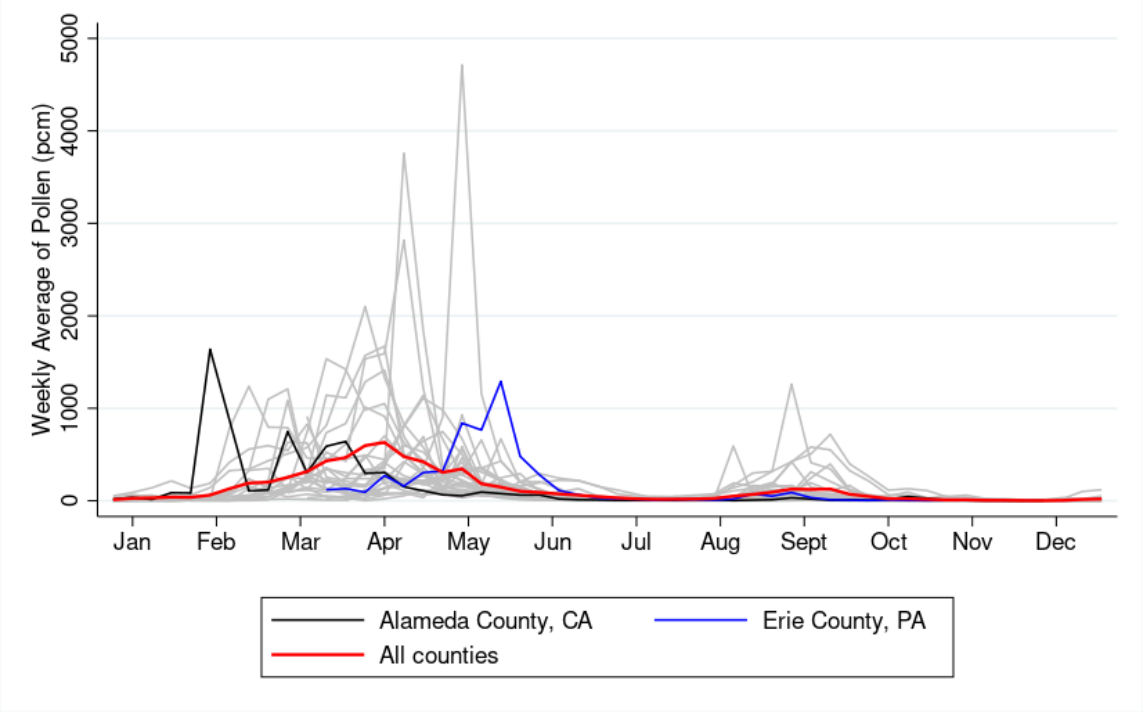
Zouk, Hana, Michel Tousignant, Monique Seguin, Alain Lesage, and Gustavo Turecki. 2006. "Characterization of impulsivity in suicide completers: clinical, behavioral and psychosocial dimensions." *Journal of Affective Disorders* 92 (2-3): 195-204.

Figure 1: Localities of pollen data



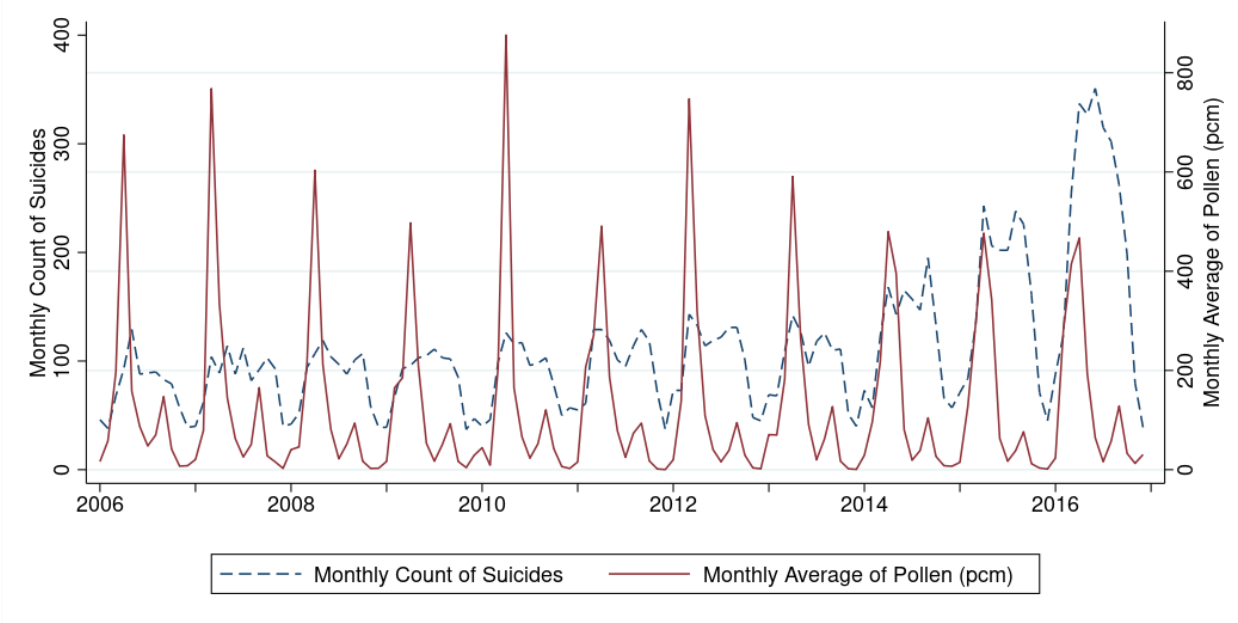
Source: NAB 2006–2017. Each circle represents a pollen measurement station which has shared data. The size of the circle represents the number of observations available for that location. The number of observations is a function of length of panel for that location and the frequency of measurement.

Figure 2: Seasonal pollen trends across all locations



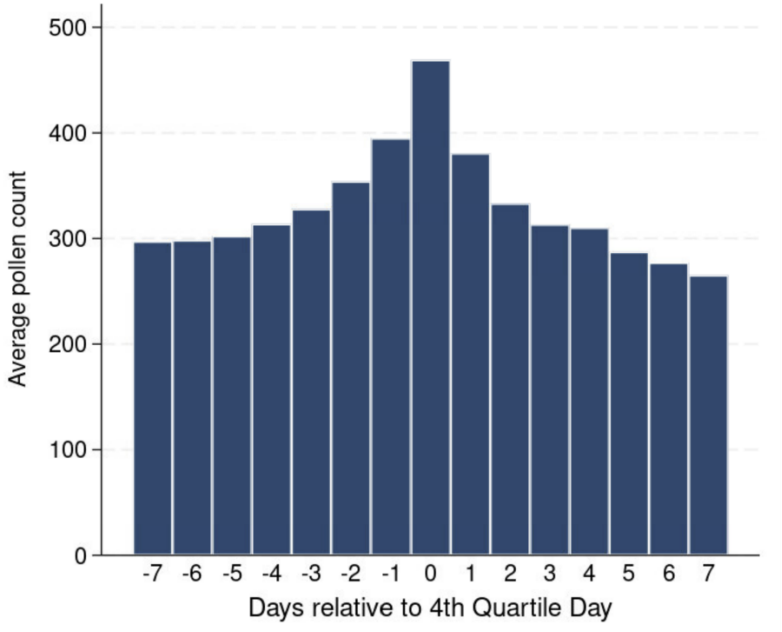
Source: National Allergy Bureau (NAB) 2006–2017

Figure 3: Annual and seasonal trends in suicides and pollen, 2006–2017



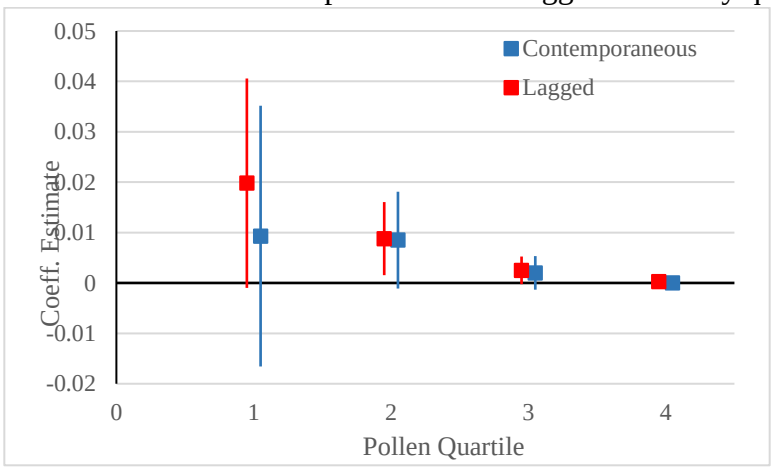
Source: National Violent Death Reporting System (NVDRS), 2006–2017 and National Allergy Bureau (NAB) 2006–2017

Figure 4: Serial correlation in pollen levels

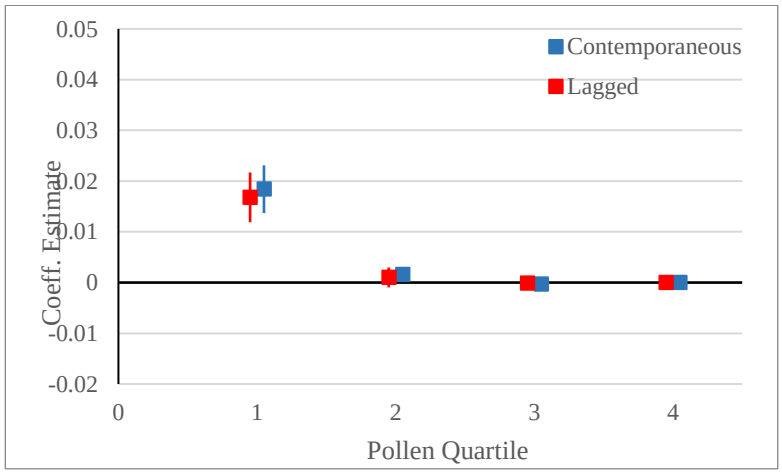


Source: National Allergy Bureau (NAB) 2006–2017

Figure 5: Coefficient estimates for contemporaneous and lagged effects by quartile of pollen



(a) Count of suicides

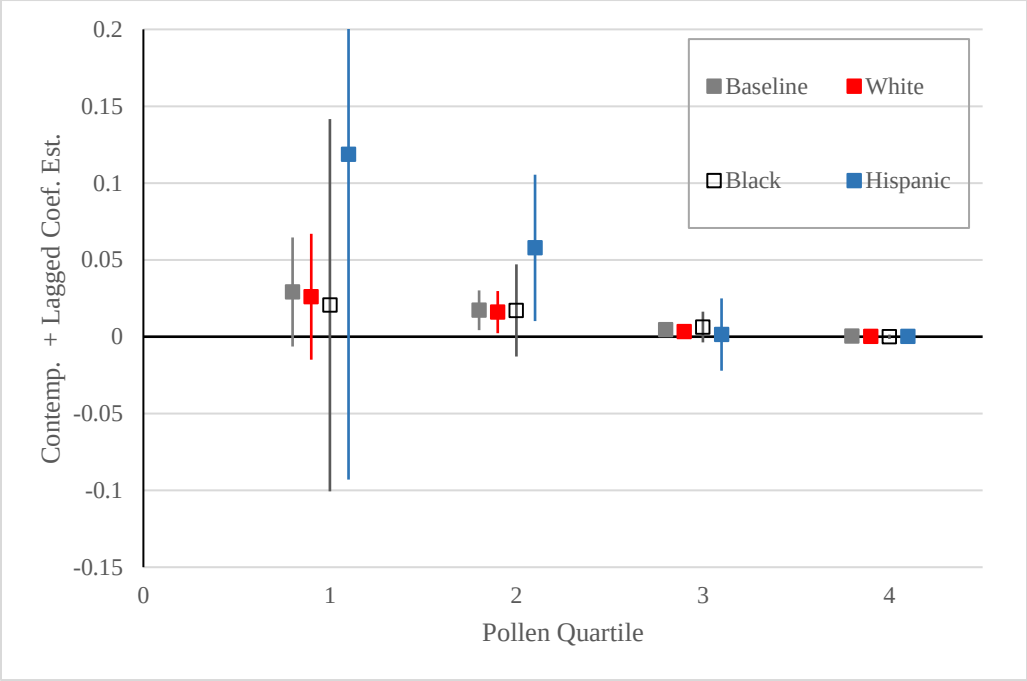


(b) Count of ED visits

Sources: National Allergy Bureau (NAB), National Violent Death Reporting System (NVDRS), CDM, 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 (month*day) and location (locality*week) fixed effects, and weather controls. 95% confidence intervals are indicated by bars around point estimate.

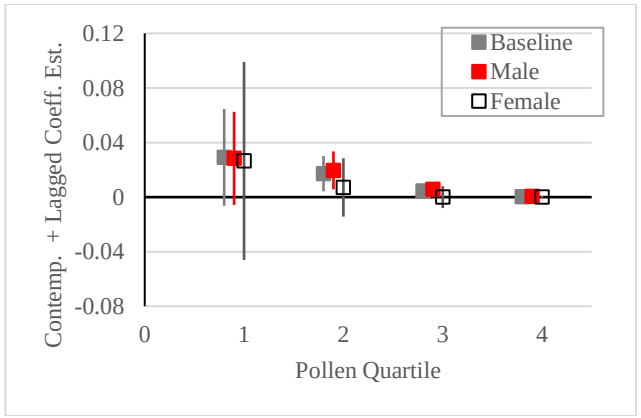
Figure 6: Sum of contemporaneous and lagged estimate for suicides stratified by race



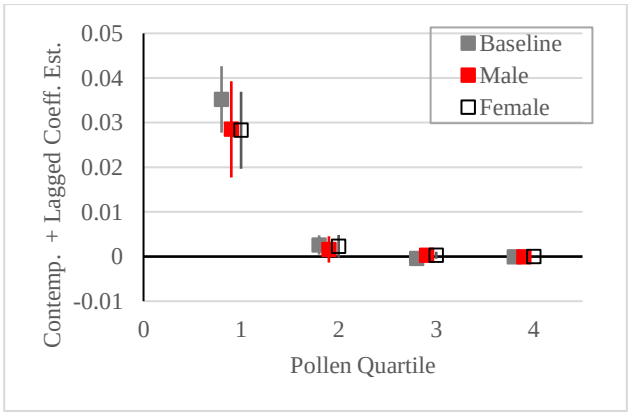
Sources: National Allergy Bureau (NAB), National Violent Death Reporting System (NVDRS), and PRISM Climate Data 2006–2017

Notes: Each color represents a separate specification where the independent variable is the count of suicides per day per locality. Each point is the coefficient estimate for pollen by quartile (indicated on the horizontal axis) for preferred specification (grey), white (red), black (clear), and Hispanic (blue) individuals. All specifications also include a 7-day moving average of the pollen count, time (month*day) and location (locality*week) fixed effects, and weather controls. 95% confidence intervals are indicated by bars around point estimate.

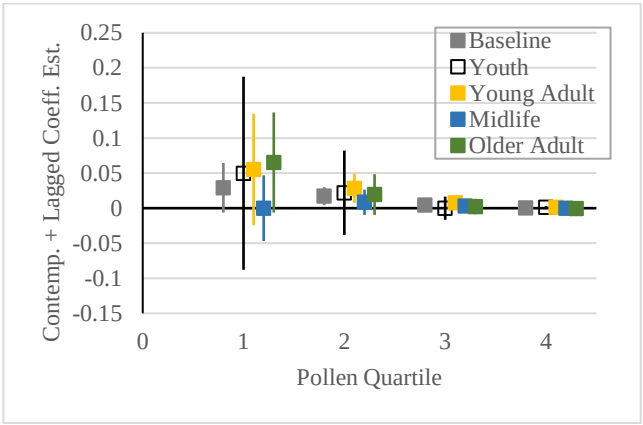
Figure 7: Sum of contemporaneous and lagged estimate for suicides stratified by gender and age



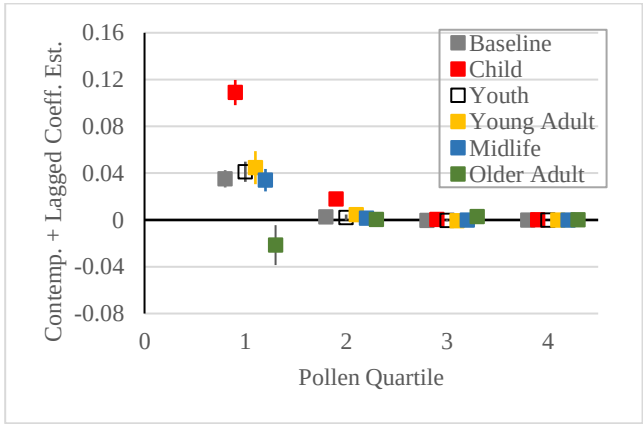
(a) Gender: Suicides



(b) Gender: ED Visits



(c) Age: Suicides

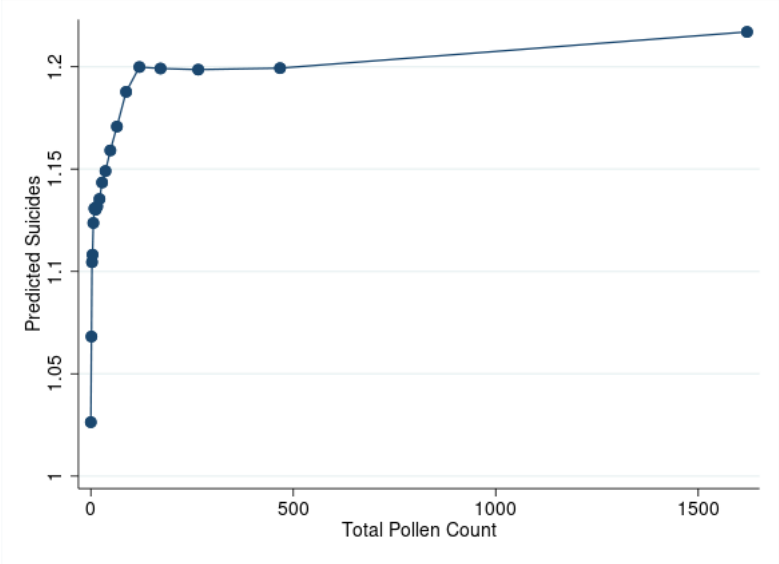


(d) Age: ED Visits

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

Notes: Each color represents a separate specification where the independent variable is the count of suicides per day per locality. Each point is the coefficient estimate for pollen by quartile (indicated on the horizontal axis) for preferred specification (grey), and specifications separated by gender and age as indicated. All specifications also include a 7-day moving average of the pollen count, time (month*day) and location (locality*week) fixed effects, and weather controls. 95% confidence intervals are indicated by bars around point estimate.

Figure 8: Predicted count of suicides by pollen ventiles



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

Notes: Average predicted values of suicide from preferred specification, separated into ventiles of pollen measurement. All specifications also include a 7-day moving average of the pollen count, time (month*day) and location (locality*week) fixed effects, and weather controls. Standard errors clustered at locality level.

Table 1: Average of Pollen and Suicides by Quartile.

Quartile	**Pollen**		**Suicide**	
	Mean	*StdDev*	*Mean*	*StdDev*
1	8.59	16.32	0.0589	0.2599
2	39.03	47.15	0.0640	0.2687
3	102.39	124.94	0.0636	0.2685
4	469.00	877.46	0.0638	0.2725

Table 2: Main specification: Count of suicides

	Suicides (1) $\beta_j + \beta_j^{-1}$	Suicides (2) $\beta_j + \beta_j^{-1}$	Suicides (3) $\beta_j + \beta_j^{-1}$	(4)	Suicides (5) $\beta_j + \beta_j^{-1} + \beta_j^{-2}$
	Coeff/SE	*Coeff/SE*	*Coeff/SE*	*Scaled by StdDev*	*Coeff/SE*
Quartile of Pollen					
1st	-0.0161	0.0247	0.0291	0.0474	0.0404*
	(0.0306)	(0.0181)	(0.0181)		(0.023)
2nd	0.0004	0.0166**	0.0172***	0.0811	0.0231***
	(0.0091)	(0.0066)	(0.0066)		(0.0085)
3rd	-0.0004	0.0047***	0.0045**	0.0562	0.0058***
	(0.0029)	(0.0018)	(0.0018)		(0.0022)
4th	0.0004*	0.0005**	0.0003	0.0263	0.0003
	(0.0002)	(0.0002)	(0.0002)		(0.0003)
MA Pollen	0.0003	0.0005	0.0005		0.0007*
	(0.0004)	(0.0004)	(0.0004)		(0.0004)
No. of Lags	1	1	1		2
Weather Controls			X		X
FE:					
Location*Week		X	X		X
Month*Day		X	X		X
N	235943	205811	146761		146033
No. 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). Column (3) is the preferred specification. Column (4) scales column (3) estimates using $(\beta_j + \beta_j^{-1}) * \frac{StdDev}{10}$. Standard errors (SE) clustered at the locality level. * p<0.1, ** p<0.05, *** p<0.01

Table 3: Estimated effects stratified by method of suicide and presence of an underlying mental health condition

	Suicides (1) Firearm	Suicides (2) Drug or Medication	Suicides (3) Other	Suicides (4) No Known MH Indicator	Suicides (5) Known MH Indicator	Suicides (6) MH Condition or Treatment	Suicides (7) MH Treatment
	Coeff./SE	*Coeff./SE*	*Coeff./SE*	*Coeff./SE*	*Coeff./ SE*	*Coeff./SE*	*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)
p-value	0.473	0.432	0.842	0.679	0.153	0.365	0.485
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)
p-value	0.112	0.754	0.485	0.112	0.558	0.558	0.842
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)
p-value	0.112	0.318	0.679	0.602	0.112	0.112	0.112
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)
p-value	0.365	0.749	0.679	0.842	0.112	0.112	0.112
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	117278	43859	87577	106632	118383	103260	87018
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: In each specification 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. This table reports the sum of contemporaneous and lagged coefficients for continuous measure of pollen count interacted with an indicator of quartile by location-season. All specifications also include a 7-day moving average of pollen, time and location fixed effects as indicated, and weather controls. Standard errors (SE) clustered at locality level. Multiple hypothesis testing q-values reported. * p<0.1, ** p<0.05, *** p<0.01

Table 4: Count of ED visits

	ED Visits (1) $\beta_j + \beta_j^{-1}$ *Coeff/SE*	ED Visits (2) $\beta_j + \beta_j^{-1}$ *Coeff/SE*
Quartile of Pollen		
1st	0.0162**	0.0352***
	(0.0064)	(0.0038)
2nd	0.0024	0.0026**
	(0.0016)	(0.0011)
3rd	0.0009**	-0.0004
	(0.0005)	(0.0004)
4th	0.0001**	-0.0001**
	(0.0000)	(0.0000)
MA Pollen	0.0006***	-0.0002**
	(0.0001)	(0.0001)
Weather Controls		X
FE:		
Location*Week		X
Month*Day		X
N	6288628	4768382
Number of localities	4312	4183

Sources: National Allergy Bureau (NAB), CDM, 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 (SE) clustered at the locality level. * p<0.1, ** p<0.05, *** p<0.01

Table 5: Estimated effects on ED visits stratified by diagnostic category

	ED Visits (1)	ED Visits (2)	ED Visits (3)	ED Visits (4)	ED Visits (5)	ED Visits (6)
	Anxiety	MH History	Mood Disorders	Personality Disorders	Schizophrenia	Attempted Suicide
	Coeff./SE	*Coeff./SE*	*Coeff./SE*	*Coeff./SE*	*Coeff./SE.*	*Coeff./SE.*
Quartile of Pollen						
1st	0.0165***	-0.0327***	0.0516***	0.0485	-0.002	0.0126
	(0.0063)	(0.01)	(0.0049)	(0.0379)	(0.0133)	(0.0324)
2nd	0.0035**	-0.0077***	0.0040***	0.0036	0.0062	-0.0021
	(0.0017)	(0.0029)	(0.0014)	(0.0103)	(0.004)	(0.0095)
3rd	0.0015**	0.0016*	-0.0003	0.0006	0.0033**	0.0056*
	(0.0006)	(0.0008)	(0.0005)	(0.0033)	(0.0013)	(0.0031)
4th	-0.0001	0.0003***	-0.0001	0.0003	0.00001	0.0003
	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0003)
Weather Controls	X	X	X	X	X	X
FE:						
Location*Week (34*52)	X	X	X	X	X	X
Month*Day (12*31)	X	X	X	X	X	X
N	3,243,898	1,796,657	4,519,201	209,860	1,165,055	238,515
Number of zip codes	3,812	3,554	3,956	912	2,910	1,641

Sources: National Allergy Bureau (NAB) 2006-2017, CDM, 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 6: 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 (28*52)	X	X	X	X	X
Month*Day (12*31)	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