Micro-shocks and public safety: Evidence from 911 calls

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Abstract

The 911 system, a vital component of public safety, responds to over 210 million emergency calls each year. We examine the effect of a small, exogenous public health stressor – pollen emissions – on the operation of the 911 call system. We find that a 100% increase in pollen levels – the modal day-over-day variation we observe in our data – results in 9.9 additional 911 calls per day. We further show that elevated pollen levels alter the quality of both emergency and non-emergency response.

Keywords: healthcare; pollen; first responder; environment
JEL codes: H12; I1; J28; Q5

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1 Introduction

The 911 system is a classic example of a public good. 911 call centers are non-excludable and non-rivalrous, and without government intervention, will be under-provided.[1] Moreover, 911 call centers are an essential component of the public safety infrastructure, and a critical gateway to urgent care and crisis intervention services across the United States and other developed countries. The 911 system includes policing, fire, health, and emergency services, among other programs. In 2021, more than 98% of Americans had access to 911 emergency services, and more than 213 million 911 calls were placed (National 911 Program, 2021). Over 90% of 911 calls are connected within ten seconds, as rapid response to emergency situations is imperative.[2] Therefore, even small increases in response time can be consequential for, and alarming to, local residents (Russo-Lennon, 2025; InvestigateTV, 2025; Johnson et al., 2025; Blasius, 2025).

Despite their importance conceptually as public goods and practically for people requiring emergency assistance, 911 call centers have largely been overlooked by economists.[3] This oversight is surprising given the large and historical literature on the healthcare system (see Culyer and Newhouse (2000) and Cebul et al. (2008) as examples) and the criminal legal system (e.g., Benson and Zimmerman (2010) and Chalfin and McCrary (2017) offer reviews of the literature), two systems that provide adjacent – but not fully overlapping – services to the public. Thus, a contribution of our work is to provide one of the first empirical economic analyses of 911 call centers, specifically regarding the importance of common environmental shocks on system operation.

In this study, we explore the implications of small daily shocks placed on emergency services offered by 911 call centers and responders. While the overall staffing of 911 dispatch centers is likely endogenous to community needs and resources, among other factors, the centers do not adjust staffing specifically or resource allocation more generally to unexpected and very short-lived shocks that may increase the number of calls transitorily.[4] Instead, any additional calls may place temporary strain on the 911 system. We examine whether such "micro-shocks" affect 911 call volume and the urgency composition of calls, and the extent to which variation in call volumes is reflected in

[1] We acknowledge that, through congestion, at some points in time – for example, when demand for services is high relative to supply – 911 call centers may be considered rivalrous.

[2] See the How Long Does It Take for Your 911 Call to Be Answered?, accessed 3/4/2025.

[3] Some notable exceptions include studies that examined domestic violence-related calls during the height of the COVID-19 pandemic shutdowns (Miller et al., 2024, 2022; Bullinger et al., 2021; McCrary and Sanga, 2021) and a recent paper that studied a program that diverts nonviolent 911 calls from police to civilian responders (Ba et al., 2025).

[4] Based on personal communications between 911 call center operators and the authors. Full details available on request.

response time and quality, two measures of system performance.

More specifically, our analysis examines the effect of elevated pollen emissions on 911 calls in Seattle, Washington between 2009 and 2024. Pollen provides a rarely exploited opportunity to study how small, routine health shocks affect the operation of emergency response systems. Unlike large-scale disasters or epidemics that occur infrequently and often trigger anticipatory behavioral or policy responses, pollen-driven allergy symptoms are common, recurrent, and largely exogenous to individual decision-making. After accounting for area, time, and other environmental factors, day-to-day fluctuations in pollen levels are arguably random and driven by unpredictable changes in plant reproductive cycles, weather, humidity, and temperature. In our data, pollen levels vary from zero to thousands per cubic meter and double or more on 53.8% of days from one day to the next, providing substantial high-frequency variation to estimate treatment effects. More than 20% of Americans experience allergy symptoms when exposed to pollen, with effects ranging from mild discomfort (e.g., sneezing, congestion, irritated eyes and throat) to reduced cognitive functioning and alertness (Wilken et al., 2002; Marshall et al., 2000; Kremer et al., 2002; Marshall and Colon, 1993), and in some cases increased mortality risk among individuals with chronic or severe respiratory conditions (Larson et al., 2025).[5] While allergy symptoms are typically observed only once they cross a clinical threshold, daily pollen measures allow us to proxy for variation in symptom severity below the medical utilization margin without relying on healthcare data. Moreover, because real-time pollen information is limited and imperfectly observed by the public, elevated pollen days do not induce anticipatory adjustments in 911 staffing or resource allocation, making pollen a near-ideal quasi-experimental micro-shock for examining how routine demand surges affect system performance.[6]

Growing climate-related variability—including precipitation, ambient temperature, and extreme weather events—has direct implications for the operation of 911 call centers and emergency response systems (Intergovernmental Panel on Climate Change, 2021; Ramgopal et al., 2019). Policy responses at the international, national, and local levels increasingly address extreme weather and disaster preparedness, yet routine biological exposures such as pollen remain largely absent from adaptation planning. This omission is notable given documented health impacts of pollen exposure and the potential for cer-

[5]In addition to increased risk of mortality from respiratory causes among older adults and individuals with chronic illnesses, pollen exposure also increases deaths by suicide and fatal accidents (Abramowitz et al., 2025; Akesaka and Shigeoka, 2023; Chalfin et al., 2019; Danagoulian and Deza, 2025).

[6]While some weather apps include information on pollen counts, the source of these measurements is not clear. App-reported pollen levels may be industry-simulated values based on previous counts. The over 100 National Allergy Bureau (NAB)-certified stations provide the only accurate source of pollen emissions in the U.S.

tain mitigation strategies—such as urban greening initiatives—to inadvertently increase airborne pollen concentrations in some settings (Stevanovic et al., 2025). Understanding how pollen conditions influence demand for emergency services therefore contributes to a broader discussion of how public infrastructure adapts to recurring environmental stressors. The mechanisms we document may extend to other public systems, including healthcare, criminal legal, and social service institutions.

To conduct this analysis, we use two unique datasets: (1) 911 call log data from the Seattle Police Department and (2) daily pollen measurements collected by the National Allergy Bureau (NAB). Collection of pollen data is a highly manual process, requiring specialized equipment and a certified technician. In the U.S., there is no national pollen measurement effort, so we rely on volunteer technicians from a NAB member, the Northwest Asthma and Allergy Center in Seattle. We estimate regressions that comprehensively account for seasonality and time, and local climate and weather, to isolate the impact of pollen levels on 911 calls and responses.

We have several findings. First, we show that 911 calls increase on high pollen days, as a 100% increase – the modal day-over-day increase we observe in our sample – in pollen levels results in roughly 10 additional calls, a 0.5% increase relative to the sample mean. Second, we provide evidence of increases in both higher priority and lower priority calls – based on classifications by 911 operators – as pollen levels rise, suggesting that the effect of pollen is not limited to nuisance calls; instead, calls that arguably require urgent deployment of emergency services increase. Third, we document that the estimated effects vary across call types: vice, medical, violent, and disorder calls are more elastic to pollen levels than are property and assistance calls. Again, this finding suggests that pollen does not simply lead to a rise in unnecessary calls; rather, the pollen-related calls likely represent legitimate uses of 911 call center resources.

Finally, we test whether response times and successful dispatching are sensitive to pollen levels. We find that response times increase by 0.07 minutes (0.27%), though the coefficient estimate is noisy. However, conducting quintile analysis by decile of response time, we find significant and meaningful increases for calls with above median response time, which correspond to non-emergent calls.[7] We also find an increase in the number of "missing connection" calls as pollen levels rise; that is, where no emergency responder arrival time is recorded, where dispatch cancels and recalls emergency responders, where emergency responders are not able to locate the incident, and where the call is false.[8]

[7]For example, the average response time excluding calls when the officer initiates the call (and is thus at the scene of the event) among priority 1 (most urgent) calls is nine minutes, while the response time is 32, 63, and 80 minutes for priority 2, 3 and 4 calls, respectively.

[8]Missing connection calls are not necessarily non-emergent calls. About 46% of calls in this category

We confirm the robustness of our findings to study design choices by testing alternative specifications. We conduct a battery of tests to show that our results are stable across sample definition and do not reflect spurious correlations. We provide empirical evidence to support our argument that day-to-day variation in pollen levels is as good as random after accounting for seasonality and time fixed effects.

These findings suggest that in the presence of micro-shocks, the 911 system reprioritizes resources toward the most urgent calls. This reallocation allows the system to maintain high quality response to urgent incidents despite increased demand for resources. At the same time, the reallocation of resources affects the quality of less urgent services in two ways. First, response times increase among lower-priority calls. Second, the incidence of missing connections increases, where lower-priority calls are overrepresented. These less urgent services, such as inter-agency cooperation or patient transport, are often not reflected in the formal evaluation of the 911 system, but are important for individuals in need of these services.

2 Background

2.1 Emergency Response Services

The 911 system was established at the recommendation of the President's Commission on Law Enforcement and Administration of Justice, which convened in 1967 to evaluate the need for a national emergency reporting system. The Federal Communications Commission collaborated with the telephone company AT&T to select the number (i.e., 911) and initiate implementation of the service in 1968. As each state and municipality had to approve the implementation of the service, in 1976 only 28% of Americans could dial that number for assistance; by 1989, 50% of Americans had access to the 911 system; and by 2000, 93% had coverage. At the time of writing, there are over 6,000 911 call centers in the U.S. (National 911 Program, 2025) and people in nearly all areas of the country have the ability to call 911 for emergency services, with exceptions including very rural areas such as remote villages in Alaska. This service is funded through a monthly fee on telephone customers, ranging from 50 cents to $3.00 across the country, and the funds are used exclusively to support the 911 dispatch center, while the emergency services themselves are financed through other means (Washington State Department of Revenue, 2013; U.S. Government Accountability Office, 2013).[9]

are assigned priority 1 or 2, signaling urgency in response.

[9]See the 911 (emergency telephone number) Wikipedia, accessed 3/4/2025.

Emergency 911 dispatch is a critical component in the chain of public safety, serving as the initial bridge between individuals in crisis and the services they require. By rapidly identifying the nature and gravity of each call, 911 dispatch centers can expedite the deployment of police, fire, or medical units, increasing the likelihood of effective interventions when seconds can truly matter. Because outcomes can depend on just a few moments, the time between incident occurrence and arrival of assistance can substantially influence the outcome of incidents and survival rates (Cummins et al., 1991; Blackwell and Kaufman, 2002; Wilde, 2013; Lucchese, 2024).

Despite the importance of the public safety system, concerns exist regarding the financial stability of this system – including 911 call services (Federal Communications Commission, 2021; Pfannenstiel, 2025; Wyoming Department of Transportation (WYDOT), 2025; Brevitz Consulting Services, 2024; Hartsig, 2017). Emergency services are often one of the first budget items to be curtailed when federal, state, and local governments attempt to reduce expenditures (Government Technology, 2024; Council on Criminal Justice, 2025; La, 2025; Moore, 2025). Constrained resources could leave 911 call centers vulnerable to unexpected shifts in demand for services, and the system may have limited slack. Moreover, understanding factors that predict rising call volume – often cited as a determinant of staff retention (IAED and NASNA, 2023) – is imperative given the 911 call operator staff shortages faced in communities across the country. About 25% of 911 centers are currently facing staff shortages, which, in conjunction with high call volumes, can negatively affect the quality of response via increased wait times (Gonzalez et al., 2009). In Seattle – the focus of our study – over half of the city's 911 dispatcher positions were vacant in 2019 (Lewis, 2023; KOMO News Staff, 2021). Call volumes and the types of calls can also contribute to dispatcher stress, exacerbating the already elevated levels of strain faced by emergency responders on a daily basis (Pierce and Lilly, 2012).

911 call centers can also play an important role in connecting civilians to resources beyond emergency services. In our data, more than 33% of calls logged with the Seattle 911 service are not time sensitive but require the response of police and emergency medical services in some capacity. For example, emergency responders may be called for disturbances and disorderly conduct; in the process of response, they may discover a person experiencing a mental health crisis. Such a response would engage not only police, but also emergency medical services (e.g., stabilization and connection to longer-term treatment). Given well-established shortages of mental healthcare providers in the U.S. and associated unmet need (Hoffmann et al., 2023; Meiselbach et al., 2024), emergency services can be an important connection point for people in need of such care (Kang et al., 2023). Furthermore, while calls for assistance may not be time-sensitive, in some

cases they may be the starting points for investigations into intimate partner violence or child maltreatment. Such calls would engage resources for domestic violence victim support or Child Protective Services. In addition, emergency medical services are often used for patient transportation such as upon discharge from hospital to nursing care facilities and home. These incidents constitute non-emergent use of the 911 services which, nonetheless, are an important and essential service to the community.

2.2 Seasonal Pollen

Pollen, released by plants as part of their reproductive cycle, triggers Seasonal Allergic Rhinitis (SAR), which affects up to 20% of the population in industrialized countries (Jauregui et al., 2009; Greiner et al., 2011).[10] In response to pollen exposure, the immune system releases inflammatory mediators (e.g., histamine and cytokines) which results in allergic symptoms such as secretion of mucus, nasal congestion, watery eyes, irritated throat, itching, and sneezing (Janeway et al., 2001; Greiner et al., 2011). These symptoms can, in turn, affect mood as they induce irritability and fatigue, and lower sleep quality (McAfoose and Baune, 2009; Tashiro et al., 2002; Dowlati et al., 2010; Kronfol and Remick, 2000; Santos et al., 2006; Craig et al., 2004).

The connection between pollen and impaired cognitive abilities is not surprising. Whether directly in response to allergy symptoms or through the mechanism of poor sleep quality, pollen exposure has been linked to impairments in working memory, response time, attention span, and cognitive speed (Wilken et al., 2002; Marshall et al., 2000; Kremer et al., 2002; Marshall and Colon, 1993). Moreover, the cognitive impairment associated with pollen exposure is comparable to having a 0.05% blood alcohol content, which is the maximum legal driving limit in many states (Vuurman et al., 2014). While SAR symptoms are easily treated with over-the-counter medications, such as histamine blockers, these treatments, in turn, often have sedative effects, further affecting cognitive functioning (Vuurman et al., 1993, 2014; Jauregui et al., 2009).

There is a small, but growing, economic literature examining the consequences of pollen exposure. Pollen has been shown to reduce testing performance among school-aged children (Marcotte, 2015, 2017; Walker et al., 2007; Bensnes, 2016). Abramowitz et al. (2025) establish an increase in deaths by suicide as pollen levels rise. Some studies document a rise in accidents on high pollen days: Danagoulian and Deza (2025) show a 5.4% increase in fatal traffic accidents while Akesaka and Shigeoka (2023) demonstrate an increase in all-cause accidents in emergency departments. Consistent with the sedative

[10] There are limited data on this condition in less industrialized countries, though prevalence rates are believed to be lower.

symptoms associated with SAR, but diverging to some extent from other pollen studies within the economics literature, Chalfin et al. (2019) document a 4.1% decline in reported violent crime when pollen levels are exceptionally high.

3 Data

In this section, we review the various data sources that we utilize in our analysis. Summary statistics for all key variables are reported in Table A2.

3.1 911 Data

We use 911 calls for service logged with the Seattle Police Department Communications Center from 2009 to 2024. As in other cities, when a 911 call is made in Seattle, the system identifies the caller's location – whether from a landline or mobile phone – and routes the call to the appropriate dispatch center. If police assistance is required, the dispatcher collects detailed information about the incident, such as a description of the situation and the exact location, and enters these details into the Computer-Aided Dispatch (CAD) system.[11] The dispatcher then uses the CAD system to assess and coordinate the necessary emergency response units.[12]

Figures A1 and A2 report trends in total calls in each month of our study period and average monthly counts over the years. Though call volumes clearly cycle through seasons, we note a slight upward trend between 2009 and 2019, and a sharp decline after 2020, likely attributable to the COVID-19 pandemic and recovery period. In robustness checking, we exclude the pandemic period and our results are not appreciably different. Calls are reasonably homogeneous across months of the year, though there is an uptick in calls during the summer. Our regressions include granular time fixed effects that account

[11] For fire emergencies, the call is transferred to the Seattle Fire Alarm Center.

[12] Seattle does not have a non-emergency information phone number (e.g., 311). Instead, the city has a Customer Service Bureau (206-684-CITY [2489]) that is staffed by city service representatives and not emergency personnel. The Customer Service Bureau is open during business hours and is designed to receive calls related to general city services and inquiries, not emergency calls. In recent years, in particular after our study period ends in 2024, Seattle has adopted programs designed to address mental health crises. For example, the Seattle CARE (Community Assisted Response & Engagement) program was implemented in 2023. CARE includes mental healthcare professionals (e.g., social workers) who are deployed alongside police in response to mental health-related 911 calls. Seattle implemented the 988 suicide crisis line in 2024. In 2010, thus overlapping with our study period, the city implemented the Seattle Police Crisis Response Team (CIT) program which pairs mental healthcare professionals with specifically trained police officers to respond to mental health crises. We expect that our granular fixed effects will account for programs such as CIT which impact the city as a whole.

for general time trends and seasonality in 911 call volumes.

We make use of the CAD data related to the 911 call, including the location of the call, the exact date and time the call was initiated, and a brief description of the precipitating event, as well as the arrival time of the police and/or first responders. The data also include a priority code. Calls are assigned, by dispatchers, a priority code ranging from one to nine, with lower numbers indicating greater relative urgency. Calls are prioritized based on the information provided by the caller to ensure that resources are allocated efficiently. Specifically, the priority codes reflect the following official definitions:

- Priority 1: Critical incidents which pose an immediate threat to human life or involve significant bodily harm;
- Priority 2: Active incidents which could escalate; crimes where apprehension or enforcement is still possible; and most service requests from other agencies;
- Priority 3: Incidents that do not meet the criteria of priority 1 or 2 but may require investigation or action by an officer;
- Priority 4: Non-critical service requests such as found property and parking complaints;
- Priority 5-6: Service calls that do not require an immediate in-person police response and indicate that the incident can be addressed through a callback report;
- Priority 7: Traffic stops;
- Priority 8-9: Instances when officers are engaged in non-dispatch activities, such as administrative tasks, meal breaks, or other duties that temporarily render them unavailable for response.

As neither CAD nor the Seattle Police Department provide general groupings for types of calls like the Federal Bureau of Investigation's Uniform Crime Reporting system or the National Incident-Based Reporting System for reported crimes, we leverage the call descriptions to sort calls into broader categories. More specifically, we create the following categories and provide examples:

- Vice: Detoxification, driving under the influence, gambling, liquor violations, narcotics, overdose, and prostitution;
- Disorder: Disturbance, noise, nuisance, demonstrations, lewd conduct, sex offense (non-rape), and sleeper aboard public transport;

- Domestic violence: Assault, child abuse/neglect/abandonment/molestation, fight, threats, and order violation;
- Assistance: Accident without injury, welfare check, assist public, hazard or other blockage, and follow up;
- Medical: Accident injuries, medical response during fire, person down (report and check), death, burns, sick person, and mental health;
- Violent: Assault, rape, fight, robbery, and purse snatching;
- Property: Auto recovery, auto theft, and robbery;
- Traffic: Accident without injuries, traffic violations, car collision with or without injury, and parking violations;
- Other: Administrative duties, assist other agencies, warrant administration, response to alarm, animal control, missing person, and suspicious package/person/stop.

Appendix Table A1 shows additional examples of call descriptions in each group.

These categories allow us to gain an intuitive sense of the composition of calls by priority. In Figure 1, we show a heatmap of the proportion of each call type in each priority rating. The figure shows that most medical (70.8%) and domestic violence (57.3%) calls tend to be the highest priority requiring immediate response due to possible bodily harm or death. On the other hand, calls reporting violence tend to be priority 2 calls (56.8%) requiring immediate police assistance in resolving the situation or apprehending the perpetrator. Vice, disorder, assistance, and property/financial calls, while including a substantial proportion of priority 2 calls, mostly do not require an immediate response (priority 3, vice 54.3%, disorder 53.4%, and assistance 62.2%). Traffic incidents almost never require an immediate response and, often, no follow up (priority 7, 36.3%). The category "other" captures miscellaneous calls which most often are neither urgent (priority 3, 20.9%) nor require follow up (priority 7, 42.8%).

The call log is not restricted to those initiated by civilians dialing 911. Instead, the log includes calls by a civilian or a police officer while on patrol. A civilian can initiate a call by calling 911, or using non-emergency phone numbers, texting, or walking into a police station. For calls initiated by dialing 911, the response time includes the duration in seconds from the moment the call rings to the time first responders arrive on scene.

This duration includes the ringdown time,[13] dispatch response time,[14] and arrival of first responder on scene. Though we would like to gain insight into each of these three components, the CAD data include only the sum. In many cases, 911 calls are initiated by police officers who report and respond to incidents while on patrol. These calls have response time recorded as zero.

911 calls vary substantially throughout the week and during the day. In Figure **??**, we present the average number of calls by day of the week in panel (a) and throughout the day in panel (b). Call volume is related to daily activities. For example, weekday volumes are larger than Saturday and Sunday volumes. Fridays have the largest number of calls, suggesting that evening social events may be important contributors to call volumes. Looking deeper into the distribution of calls over times of day, we find variation in volume in daytime and nighttime. We separate the call volumes by the dispatch shifts: day or first shift (7am-3pm), swing or second shift (3pm-11pm), and graveyard or third shift (11pm-7am). The figure shows that the day and swing shifts experience the largest call volumes, and the day shift experiences a rise in calls, peaking at 12 noon.

3.2 Pollen Data

We obtain daily pollen measurements from the NAB as part of a special initiative by the American Academy of Asthma, Allergy, and Immunology (AAAAI). NAB collects pollen measurements in more than 80 localities across the continental U.S., relying on AAAAI member volunteers for data collection. We contacted stations individually and 41 stations granted us use of their data.[15] We select Seattle for our study as this city provides detailed 911 call data that are consistently available for the number of years that overlap with pollen data. In Seattle, pollen data are collected by an allergy clinic located in the north of the city, situated in a commercial area, flanked by an interstate

[13] Ringdown time is the number of seconds the call is ringing prior to dispatch response. The National Emergency Number Association (NENA) requires that 90% of calls be answered in 15 seconds, and 95% of calls be answered in 20 seconds. No calls go unanswered unless the caller disconnects.

[14] There is substantial variation in the average call duration. Holguín-De La Cruz (2022) cites NENA reports of average one to two minutes and longer for more complex calls. Using California data, Rosenberg et al. (2015) estimates an average response time of 60-120 seconds, which has also been reported by Chicago Office of Emergency Management (OEMC) in an internal audit. Medical emergencies, such as cardiac arrest, can require a longer call time prior to arrival of emergency services, resulting in three to five minute calls (Wang et al., 2012).

[15] At the time we obtained the data, NAB did not have a formal application process and, in addition to a request issued by NAB to stations to permit use of their data, NAB allowed one of the authors to contact individual stations with the request. Since that request, NAB has revised the application process, where NAB notifies all stations of a pending request to access the data, allowing all stations an objection time period. Furthermore, the current application process requires payment for data.

to the west and residential neighborhoods on the other sides.[16]

Pollen measurement is a manual, labor-intensive process. Pollen particles are collected using a Burkard volumetric spore trap, which is left exposed over a 24-hour period. Then, trained technicians evaluate the trap under a microscope, identifying pollen granules by type from trees, grasses, and weeds and counting these to be expressed in particles per cubic meter (pcm) (Ito et al., 2015; Sheffield et al., 2011). For consistent data collection, NAB mandates the type of measurement device and tools used for data collection, and provides training and certification for technicians, giving us confidence in the quality of the data. While the collection process identifies pollen by type, we use the total count, with some robustness checks breaking the total up by tree and grass/weed.

Despite being the only source of pollen tracked over time and using consistent and high-quality methods, the NAB data have limitations. First, pollen measurements are not taken every day, and we use all available dates – if there is no pollen collected, we do not include that day in the analysis (i.e., we do not impute pollen values for missing days). Measurements are not made each day for two reasons: (1) the collection is a volunteer effort as part of an asthma and allergy practice operating during business hours; and (2) Seattle is located in the northern latitudes where many plant species are dormant in winter months, thus pollen collection is limited to non-winter months (i.e., April through October). Notably, the daily pollen level does not influence the likelihood that a pollen measurement is taken; for example, pollen is not more likely to be collected when levels are expected to be high than when levels are predicted to be low.

Second, pollen granules are visible to the naked eye, and, therefore, may be included as part of pollution measurements in particulate matter ten micrometers (PM10) counts. During rain and high humidity, pollen granules may rupture, resulting in smaller and lighter pieces; these pieces may be included in pollution measurements of particulate matter 2.5 micrometers (PM2.5) and rise in the atmosphere allowing additional spread of pollen on wind and clouds. Thus, in all analyses, we include weather indicators (i.e., wind, temperature, and precipitation), and, in robustness checks, we examine the relationship between pollution and pollen. Overall, we find that our results are not sensitive to the manner in which we control for weather or pollution, suggesting that we are able to isolate the impact of pollen on 911 call volumes from these other factors.

[16]We are grateful to Northwest Asthma and Allergy Center in Seattle for collecting the data and making them available to us.

3.3 Weather, Wind, and Pollution Data

We obtain weather, wind, and pollution data from three sources. First, the PRISM Climate Group (2026) provides standardized weather data across U.S. counties. We use maximum temperature and precipitation, though in robustness checks we include a wider range of weather controls.

Second, the North American Regional Reanalysis (NARR) center collects and aggregates wind data for the U.S. (Mesinger et al., 2006; National Centers for Environmental Prediction (NCEP), 2004). We obtain wind speed and direction (u- and v-components) at daily frequency. We categorize wind direction into four 90-degree bins for analysis. In all analyses, we include wind speed and direction, while robustness checks include a more comprehensive set of wind interactions.

Third, the Environmental Protection Agency is the source of pollution data used in this study. We collect daily measurements of the air quality index (AQI) (U.S. Environmental Protection Agency, 2026a) and PM2.5 levels (U.S. Environmental Protection Agency, 2026b). AQI is an index based on five major air pollutants: ozone, particulate matter (PM2.5 and PM10), carbon monoxide, sulfur dioxide, and nitrogen dioxide. Since pollen count can be included in either PM10 or PM2.5, the use of AQI and PM2.5 separately allows us to assess interactions between these variables.

4 Estimation Method

Our identification of the causal effect of pollen on 911 calls stems from the exogenous relationship between daily pollen emissions and human activity. Average pollen emissions are determined by natural vegetation growth and the choice of trees and grasses which are planted by municipalities. Individuals who choose to live in Seattle likely select their place of residence based on, among many other factors, the average interaction of their health with the natural environment, including allergies due to pollen emissions. Thus, we might expect residential sorting on the basis of average emissions, but people are not likely to change their residence based on day-to-day variation in pollen emissions.

The estimation method we choose identifies the effect of pollen relative to the prevailing levels in each season. We identify the effect of pollen on 911 calls by taking advantage of the unexpected daily variation in pollen emissions in Seattle relative to the expected average levels. We argue, based on earlier work (Chalfin et al., 2019; Danagoulian and Deza, 2025; Abramowitz et al., 2025), that daily pollen levels, after conditioning on time fixed effects and other factors (e.g., weather), are as good as random, and thus allow us

to recover causal estimates. More specifically, we do not rely on assumptions of parallel trends in 911 calls for days with different levels of pollen exposure for identification, as is standard in the application of difference-in-differences methods.

We estimate ordinary least squares (OLS) regressions of 911 calls relative to the city-wide pollen counts using the following specification:

$$Y_{dmy} = \alpha + \beta Pollen_{dmy} + W_{dmy}\gamma + \nu_{dm} + \kappa_{my} + \epsilon_{dmy} \tag{1}$$

where Y_{dmy} is 911 calls on day, d, month, m, and year, y, expressed as total count and as rate per 10,000 residents. We use an extensive set of weather controls (W_{dmy}) to ensure that the observed effects are not attributable to temperature (maximum) and precipitation. We also integrate wind speed and direction as controls. In robustness checks, we incorporate wind speed and direction, and pollution in interactive terms to evaluate potential compounding effects with pollen, and our results are not appreciably different.

$Pollen_{dmy}$ is the level of pollen counts on the same day, transformed into natural logarithm plus one to attenuate the impact of outlier measurements.[17] This choice is motivated by two considerations. First, pollen measurements have a few outliers; the mean pollen level in our data is 191, while the median is 54, and the standard deviation of daily measurements is 496. A log transformation allows us to temper the impact of outlier observations and the coefficient estimates reveal the effect of a 100% increase in daily pollen levels. As the mean and standard deviation show, pollen levels vary substantially day to day. More specifically, we calculate that pollen counts double or more on at least 53.8% of the days in our panel, suggesting that a 100% increase in pollen levels is a reasonable change to consider. Second, prior literature has shown that the effect of pollen is nonlinear over the range of pollen values – see, for example, Abramowitz et al. (2025) and Akesaka and Shigeoka (2023). The logarithmic transformation allows us to model this nonlinearity with attenuated effects at high levels.

Nonetheless, our findings are not dependent on this choice of transformation and, instead, are robust to the use of several alternative specifications. In all analyses, we show results of a linear specification, keeping in mind that these specifications do not capture nonlinearities in pollen effects. In the linear specifications, we winsorize daily pollen counts at the 95th percentile, top-coding any higher values to that threshold to limit the influence of outlier measurement days; zero-pollen days and the full sample

[17] Note, we perform this transformation on a predictor variable, not an outcome variable. Thus, our results are not subject to bias, raised in recent econometric work (Chen and Roth, 2024; Mullahy and Norton, 2024), associated with adding one to an outcome variable and then taking the logarithm.

are retained. This top-coding is applied only to the level of pollen, not to the log transformation, which already attenuates the effect of large values. In robustness checks, we also present estimates of quadratic (both log and levels) and quartile specifications. While magnitudes differ with units of treatment, the qualitative effects are the same across these specifications.

We acknowledge that our pollen variable may be subject to measurement error. As the readings used to construct the measure are obtained from a single monitoring station, absent an additional station's readings that could serve as an instrument, we are unable to apply canonical instrumental variables correction methods – see, for example, Bound et al. (2001); Chalfin and McCrary (2018)[18]. Given that we consider pollen on a given day to be as good as random, such measurement error is likely to attenuate our coefficient estimates toward zero (Bound et al., 2001), and thus our findings may represent lower bounds on the true effects. Moreover, since our reading from a single monitor captures an area-level measure and individual exposure likely varies in areas around the monitor site, we may also suffer from Berkson-type error (Berkson, 1950), which may reduce the precision of our coefficient estimates. Nonetheless, we address the measurement error concern by presenting results instrumenting for total pollen using grass/weed pollen, showing similar results.

Granular time fixed effects allow us to identify pollen impacts from deviations, and include day-of-week-by-month, month-by-year, and month-by-day. The day-of-week-by-month fixed effects account for fluctuations in 911 calls between week and weekend days, while day-by-month fixed effects remove daily pollen averages throughout the season. Day-by-month fixed effects also remove variation in 911 calls attributable to holidays. Finally, month-by-year fixed effects remove time trends in both 911 call volumes and pollen counts. In robustness checks, we use alternative sets of fixed effects to assess the sensitivity of our coefficient estimates and find that our results are stable. In our main analyses, we report unadjusted standard errors, but we show in robustness checking that our results are not appreciably different if we take different approaches to inference (e.g., clustering standard errors at the day level).

[18] Chalfin and McCrary (2018) document the extent to which measurement error in police count data affects the literature on the effect of police on crime. They address this by instrumenting one measure of police counts with another, since both available datasets suffer from measurement error that biases coefficients downward when used alone. Following their intuition, we instrument total pollen with measures of grass and weed pollen when available and show that our results remain consistent.

5 Results

5.1 Descriptive Analysis of 911 Calls and Pollen Levels

Before proceeding to our causal analysis of the effects of pollen levels on 911 calls, we first descriptively examine differences in the type of calls that occur on (1) high and (2) low pollen days. We define high pollen days as those days at or above the median pollen level. Low pollen days include those days below the median pollen level. Results from this descriptive analysis are reported in Table A3.

In terms of 911 calls, total calls are lower on high pollen (1,789) vs. low pollen (1,847) days. Stratifying the sample by call initiator shows that officer-initiated calls are lower on high pollen days (514) than on low pollen days (546), and person-initiated calls are similarly lower on high pollen days (1,212) than on low pollen days (1,239). Calls of various priority levels are relatively similar across the two groups of days. Mean priority level is slightly lower on high pollen days, indicating greater urgency of calls – 3.15 on low and 3.07 on high pollen days. However, some specific categories do display notable differences across high and low pollen days, namely, priority levels 1, 2, and 3 calls.

5.2 The Number of 911 Calls

In Table 1 we present coefficients estimated using equation (1). Each column and each panel presents a unique specification. Column (1) presents coefficient estimates with fixed effects but without any weather controls, while columns (2) and (3) add weather and wind controls, respectively, to the regression. The specification in column (3) is our preferred specification because the weather and wind controls remove variation attributable to confounding between these metrics and pollen emissions, and the full set of fixed effects removes seasonal variation in 911 call volumes. Panels A and C present results in terms of the total number of 911 calls (log and level) received on the same day. Panels B and D normalize the number of calls by the population of Seattle, expressing calls as the rate per 10,000 people for both log and level of pollen measurement.

The baseline specification in column (1) shows that a 100% increase in pollen levels results in 18.68 additional 911 calls, or 0.09 additional calls per 10,000 population.[19] The effect size is arguably modest, constituting a 1.03% increase relative to the mean number of calls when pollen levels rise by 100%. Moreover, as we add weather controls, the estimated effect declines in size, with 9.9 additional 911 calls or 0.05 additional calls

[19]The average change in pollen from one day to the next observed day is 125%. The corresponding difference in pollen units ranges between zero and 4,102 pcm, with a mean of 124 pcm.

per 10,000 residents (column 3), constituting a 0.5% increase relative to the mean. We delve into the magnitude and composition of the additional calls below.

In Panels C and D, we estimate the same specifications using pollen levels to test the sensitivity of our estimates to log transformation. The estimates remain consistent with the preferred log transformation. A 100 pcm increase in pollen results in 3.2 additional calls or 0.01 additional calls per 10,000 population.

5.3 External Validity

The choice of Seattle for our study is guided by availability of pollen and 911 call data. While the city has a unique climate and socioeconomic composition, the results can potentially be extended to other cities in the U.S. To evaluate the external validity further, we draw a comparison between Seattle and other cities in Table 2.

We compare Seattle to the District of Columbia, Minneapolis, Baltimore, and San José along demographic indicators, 911 call volume, and pollen levels. These cities are selected for their similarity in size and coastal proximity, as marine air-mass influence has been shown to be associated with lower airborne pollen levels relative to inland locations (de Weger et al., 2021; Camacho et al., 2015; Negral et al., 2021).

Seattle is similar in population size to the District of Columbia, but Seattle has a greater city geographic footprint which makes Seattle more comparable to Minneapolis and Baltimore in terms of population density. All cities are fairly similar in terms of age composition, but not racial and ethnic distribution. Seattle has a lower proportion of residents who are Black (6.6%) compared to all other cities, save San José (2.9%). On the other hand, San José has a very high proportion of residents who are Hispanic (31%), contrary to Seattle (8.2%) as well as the other cities. Median income (poverty rate) of households in Seattle ranges between those of the District of Columbia and San José, but is substantially higher (lower) than those of Baltimore and Minneapolis.

The 911 call data situates Seattle closer to Minneapolis, which has roughly 630,000 calls per year or about 1,400 calls per 1,000 residents, than to other cities considered here. The District of Columbia has more than twice the number of calls in total volume and per capita, while San José has fewer than half the number of calls, and about one third of the calls per capita. A limitation of this comparison is that 911 call volume reporting differs between the cities, as some report exclusively those calls originating through 911, while others include police reports and/or fire calls. See the notes to Table 2 for a detailed description of data sources and methods.

The funding of 911 services is similar across the five cities: the staffing and operation

of the dispatch centers are funded through local municipal funds, and a dedicated 911 tax or fee is assessed at the city or state level to pay for the technology and access to the public safety answering points (PSAP). Seattle relies on E-911 excise tax revenue to support the regional 911 system and PSAP-related costs.[20] Washington, D.C. operates a dedicated 911 fund to primarily defray the costs of technology.[21] Minneapolis, Baltimore, and San José rely on state-wide 911 special revenue funds which pay for technology and access, while staffing and operations remain funded from city or county budgets.

While Seattle has one of the highest tree canopy coverage rates among large cities,[22] pollen emissions in some cities exceed those experienced in Seattle. Both average and maximum daily pollen counts are higher in Minneapolis than in Seattle. However, Seattle has pollen levels and maxima that are substantially higher than those of the District of Columbia, Baltimore, and San José.

In sum, Seattle is a large metropolitan area that shares common characteristics with other cities of similar size. Further, Seattle is not an outlier in any of the demographic, 911 call, or pollen emission dimensions that we consider. Thus, while findings based on Seattle may not be informative for all cities, these findings may be useful for a range of U.S. cities that share similar characteristics.

5.3.1 Composition of Calls

Pollen exposure and associated allergies may affect the marginal caller's willingness to report an incident to 911. Thus, the observed increase in calls may reflect the changing willingness to report rather than the underlying occurrence of events. We can assume that "marginal" calls, on average, would be less urgent and, consequently, may reflect a misallocation of scarce emergency response resources.[23]

To explore this possibility, we next test for the priority composition of calls by estimating the main specification separately at each priority level. We report the separate coefficient estimates visually in Figure 3, where each point represents the percent change in the number of calls relative to the sample mean resulting from a 100% rise in pollen levels, and the horizontal lines represent the associated 95% confidence intervals similarly converted to percent changes. We present results in percentages since the number

[20] See https://www.utc.wa.gov/regulated-industries/utilities/telecommunications/e-911-taxes-and-other-funds-including-susf. Accessed 2/21/2026.

[21] See https://ouc.dc.gov/page/911-fund. Accessed 2/21/2026.

[22] 28% according to the *Seattle's Canopy Cover* report, https://www.seattle.gov/trees/management/canopy-cover. Accessed 2/21/2026.

[23] For example, frivolous use of 911 services by people who misuse the system to obtain rides to the hospital even when vital signs do not indicate there is an emergency imposes a financial burden as well as diverting resources away from actual emergencies (Kirby, 2025).

of calls differs substantially by priority and, accordingly, so do absolute effect magnitudes captured by the unadjusted coefficient estimates.

We observe increases in all priority levels, though most increases are not statistically significantly different from zero at conventional levels. As anticipated, we estimate a 0.76% increase in priority 3 calls, which require police intervention but are not characterized by urgency of need or time sensitivity. Notably, we also estimate a 0.82% increase in priority 1 calls as pollen levels rise 100%. These are the most urgent 911 calls, which involve physical harm or danger and require immediate response. In the linear model, we estimate a statistically significant increase in priority 1 calls only. We can conclude, therefore, that the additional calls include both low-priority calls for which the probability of reporting is marginal and likely affected by pollen, and urgent calls reflecting a true increase in incidents requiring emergency services.

As each of these priority groups includes different types of calls, we next analyze call categories. We estimate the main specification for each category separately and report the results in Figure 4, again comparing coefficient estimates to the sample mean to account for differences in the frequency of call categories. The coefficient estimates show that pollen particularly increases the number of calls related to vice (2.1%), violence (1.7%), disorder (1.0%), medical emergencies (0.9%), and other (0.5%). These coefficient estimates are consistent with the increase in priority 1 (medical) and 3 (disorder and vice) calls – see Figure 1. This pattern of results is in line with an increase in accidents as pollen levels rise documented in the economics literature (Akesaka and Shigeoka, 2023; Danagoulian and Deza, 2025).

Exposure to pollen, and the desire to avoid such exposure, might change individual daily routines – confining people to home on weekends, when they may have more autonomy over their schedules, for example. To explore additional reporting due to changing routines, we separate the analysis by weekday and weekend. In Figure 5 we show that the magnitudes of the estimated coefficients are greater during the weekdays, with a 0.6-0.7% increase in calls when pollen rises by 100%. Though these magnitudes are not statistically different from weekend levels, these larger effects are consistent with reduced ability to engage in avoidance behaviors during the standard workweek. On the other hand, the smaller estimated effect sizes on weekend days could be attributed to individual choices to remain indoors as pollen levels rise.[24]

Another dimension along which call composition can change is source of reporting. As previously mentioned, calls can be reported by civilians dialing 911 or any police

[24]While we would like to stratify our analysis by whether the call originated indoors or outdoors, this indicator is not available in the data.

department phone numbers, using text messages, or walking into a police station. Police officers, as part of their patrol duties, call in incidents which are logged into the emergency response system. However, the majority of calls in Seattle are reported by civilians (67.4%). Allergies to pollen could slow down first responders, such as officers, disproportionately relative to civilians. In Table 3 we report coefficient estimates stratified by originator of call (i.e., officer or civilian). We show that exposure to pollen increases calls in both categories, and the magnitude of the increase associated with a 100% rise in daily pollen levels is similar. There are 3.6 more calls reported by officers (0.7%) and 5.9 more calls from civilians (0.5%). We separate priority and type of call reporting by officer and civilian in Appendix Figures A3 and A4. We do not find notable differences in either stratification exercise.

5.3.2 Robustness Checks

We next test the robustness of our findings for call volumes to the choice of specification and confounders for which pollen levels may serve as a proxy.

Fixed Effects: The main specification controls for a number of granular time fixed effects to remove weekly, seasonal, and annual trends in pollen and 911 calls. We test the sensitivity of our coefficient estimates to the inclusion of alternative fixed effects in Table 4. Column (1) reports the main coefficient estimates with preferred fixed effects, while columns (2), (3), and (4) use day, day-of-week, week, month, and year fixed effects, alone and in combinations. Estimated magnitudes are quantitatively and qualitatively similar across all specifications. Our preferred specification includes month-by-day fixed effects which, we believe, account for day-to-day variation due to the number of days into the pollen season, such as May 1 being on average 25 days into the pollen season.

Confounding: The estimated effects may be the result of spurious correlation or may reflect another causal factor for which pollen is a proxy. We test for these possibilities by implementing two robustness checks.

First, we include lead and lag pollen controls in our main regression. Specifically, alongside contemporaneous pollen, we control for pollen levels seven and 14 days in the past (lags) and seven and 14 days in the future (leads). In principle, future pollen levels should not affect 911 calls today, implying that the coefficient estimates on the lead variables should be zero. However, pollen can be serially correlated within a week and, thus, pollen levels may rise and persist over this period. To account for this serial correlation, we estimate a regression which includes pollen leads and lags at seven- and 14-day horizons. We show coefficient estimates in Table 5, columns (2), (3), and (4). Not only are the coefficient estimates for pollen leads and lags not statistically distinguishable

from zero at conventional levels, but they are also much smaller in magnitude than the coefficient estimates for contemporaneous pollen levels. The null findings for pollen leads offer suggestive evidence that, as we hypothesize (see Section 1), 911 call center operators do not anticipate future deviations in daily pollen levels and, as a result, do not alter staffing or other resources to absorb the associated (future) increases in call volumes.

Second, we conduct a placebo test, where we iteratively randomize treatment assignment (i.e., pollen levels), and re-estimate the main equation of interest with this placebo treatment 200 times. We fully randomize treatment; that is, we do not apply block randomization methods. Our rationale is that, unlike policies which turn on and then remain in place for an extended period of time, pollen levels (conditional on fixed effects and our included covariates) are random and do not display the history that would be expected with a policy change. Instead, we specifically want to avoid imposing history on pollen variation to mimic real-world pollen exposure. The goal of this exercise is to assess whether the main estimated coefficient is within the plausible range of random occurrence. If our placebo estimates are mostly comparable to the main estimated coefficient, that result would suggest that our findings may be driven by features of the model specification or data, and not a relationship between pollen and 911 calls.[25] Figure 6 shows a (1) scatterplot (panel A) and (2) histogram (panel B) of the 200 placebo coefficient estimates relative to the main estimate. None of the placebo estimates reach the magnitude of the main estimated coefficient. This result allows us to conclude that our findings are unlikely to be driven by any feature of the model or the data other than the relationship between pollen and 911 calls.[26]

These two checks suggest that pollen is not simply serving as a proxy for an unobserved third factor, nor is the effect observed the result of spurious correlation.

Pollen Specification: We chose a natural logarithm for pollen levels as the primary specification to attenuate the effect of outlier measurement days, as well as to model the potential nonlinearity in pollen effects on 911 calls. However, our coefficient estimates are robust to the choice of transformation. In Tables A4 and A5 we introduce alternative specifications with pollen. In Table A4 we include a squared term for pollen levels (in

[25] We use the Stata command *reshuffle* to randomly reassign daily pollen counts across observations. An alternative approach would have been to reshuffle entire weekly pollen sequences. However, weeks do not consistently report all days, making a one-to-one reassignment infeasible.

[26] A concern with our inclusion of granular fixed effects in equation 1 is that these fixed effects may explain much of the variation in 911 call volumes, leaving us limited variation with which to identify pollen effects. Put differently, one may be concerned that multicollinearity is a problem in our analysis. To explore this issue, we estimate an auxiliary regression of pollen levels on the full set of fixed effects that we include in equation 1. The R-squared in this auxiliary regression is 0.81, which implies a variance inflation factor (VIF $= 1/(1 - R^2)$) of 5.3. This value is below the VIF threshold for problematic multicollinearity of ten suggested by Kennedy (2008).

column 2) or an interaction with lagged pollen counts (in column 3). We also report coefficient estimates using a linear measure of pollen counts in the main tables. The main findings remain unchanged, though the coefficient estimate on the interaction with total pollen is negative, suggesting an attenuation in pollen effects at higher levels.

In Table A5 we present results from specifications using pollen quartiles; specifications include indicators for each quartile relative to the first, as well as those with only the fourth quartile indicator relative to all others. The quartiles are defined using two methods: (1) quartiles calculated relative to each season – for example, all observations in spring over all included years; and (2) quartiles calculated relative to the entire sample. In columns (1)-(4) a one period lag of total pollen is included as a control. Relative to the first quartile, there are 19.6 and 23.3 more calls when pollen levels are in the third and fourth quartiles, respectively. When we use global quartiles, as pollen levels rise to the fourth quartile, there are 31.1 more calls each day. When only indicators of the fourth quartile are included, relative to days with lower levels there are between 6.3 and 18.5 more 911 calls.

These coefficient estimates demonstrate that our results are not driven by the use of the natural logarithm specification – instead, they are robust to a range of specifications and, arguably, our preferred specification offers a conservative estimate of pollen impacts on 911 calls. For example, the quartile analysis shows that 25% of days during the pollen season see call volumes increase by up to 31.1 calls.

Calculation of Standard Errors: Though the main analysis does not adjust the standard errors, Table A6 shows the results of alternative assumptions, and thereby corrections, of standard errors. While column (1) reproduces the main standard error estimates, columns (2)-(4) cluster standard errors at various levels; accordingly, while the coefficient estimate stays the same, the standard errors change and, potentially, the statistical significance of the coefficient estimates. While the standard error increases with some forms of clustering, in particular with season-year clustering, the coefficient estimates remain statistically significant at the 1% level.

Alternative Samples: Other robustness checks, in which we explore the sensitivity of our findings to the use of alternative samples, are presented in Table A7. More specifically, we restrict the sample to days when there are non-zero pollen counts, to the spring and summer seasons, and to the period excluding 2020 onward. In each case, the sample is much smaller, resulting in noisier coefficient estimates. We note, however, that the non-zero pollen and spring-summer restrictions do not substantially affect our main findings. Finally, to assess the importance of the COVID-19 pandemic on our findings, as seen in the sharp decline in 911 calls during that period (Figure A1), in column (4)

we report results using the period 2009-2019 only. Findings are very similar to our main coefficient estimates, which suggests that the pandemic does not drive our results.

Pollen Type: Though the total count of pollen particles per cubic meter determines the exposure dose, the source of emissions does affect the body's response to exposure. Allergies are specific to tree, grass, and weed type, and may be more severe for some species. Pollen emissions vary in timing by type of pollen; in particular, deciduous trees emit pollen in spring and early summer; grasses and weeds, notably ragweed, produce pollen in late summer and early fall; non-deciduous trees produce pollen throughout the year, but peak in late fall and early winter in some localities. Tree pollen constitutes the largest count of the total, but weeds, such as ragweed, elicit a stronger allergy response with a smaller volume of emissions. To examine heterogeneity across pollen emissions, we separate pollen volume by tree and grass/weed, presenting results in Appendix Table A8. Relative to the main specification in column (1), we show that the effect is mostly driven by tree emissions, as anticipated. However, the estimated effect of grass/weed pollen is large in magnitude though too noisy for strong conclusions to be drawn.

Wind and Pollution: Wind and pollution may affect the intensity of the exposure to and effect of pollen. Wind can disperse the plume of pollen granules from sources of emission. Pollen granules may interact with pollution. Though pollen granules are too large to be included in PM2.5 levels, they are often a component of PM10. Furthermore, when pollen granules rupture due to rain or humidity, the pieces are sufficiently small to be included in PM2.5 and to travel in the higher atmosphere by wind.

All our analyses control for wind speed and wind direction to account for such sources of daily variation. However, the effect of wind and pollution may be compounding, and our primary specification does not account for this possibility. To examine the potential interaction between pollen, wind, and pollution more fully, we estimate specifications with alternative wind and pollution controls, presented in Table A9. Columns (1) and (2) include wind speed quartile indicators, while columns (3) through (5) additionally include indicators for pollution levels. The estimated impact of pollen on 911 calls does not change meaningfully across these alternative specifications, remaining at 9.9 additional calls when pollen levels rise by 100%.

In Table A10 we include interactions of pollen with wind or pollution. We report the coefficient estimates on the pollen and interaction terms only. We find that the coefficient on pollen remains essentially unchanged and statistically significant at around 9.9 additional calls. These results confirm the robustness of our main finding.

Measurement Error: As pollen counts are collected manually, they may be subject to measurement error. We adopt the classical measurement error framework, under

which such errors are uncorrelated with true pollen levels and attenuate our estimates toward zero, indicating that our main findings represent a lower bound. To mitigate this attenuation, we estimate a two-stage least squares (2SLS) specification, instrumenting for total pollen using grass and weed pollen counts. This approach follows Chalfin and McCrary (2018), who document the extent to which measurement error in police count data affects the literature on the effect of police on crime. They address this by instrumenting one measure of police counts with another, since both available datasets suffer from measurement error that biases coefficients downward when used in isolation. Following their intuition, we instrument total pollen with grass and weed pollen counts when available and show that our results remain consistent

We present these estimation results in Appendix Table A12. The first column presents the first-stage estimates, while columns (2) and (3) present the second-stage IV estimates without and with controls, with pollen in terms of logarithms and levels. In column (1) we show that grass/weed pollen is a strong instrument for total pollen with first-stage F-stats well above conventional levels. In columns (2) and (3) we show that a 100% increase in pollen results in 35.6 additional calls without weather controls and 26.6 additional calls with these controls.

These results are consistent with the classical measurement error framework: the IV estimates exceed our OLS estimates, exactly the pattern expected if measurement error attenuates the OLS coefficients toward zero. We therefore interpret our main estimates as lower bounds on the true effects.

5.4 Service Performance

In this section, we attempt to assess the ways in which the strain placed by the additional calls manifests in service performance indicators. As a first step, we provide context for the magnitude of the deviation of operation from non-pollen season. We define two – admittedly imperfect – proxies for center capacity: (1) differences in daily number of calls in the pollen season relative to average winter days,[27] and (2) the ratio of daily number of calls in the pollen season relative to the highest number of calls, or capacity, on winter days.[28] We estimate equation (1) for these outcomes and present results in Table

[27] For each observation, we compute the difference between the daily number of calls and the average number of calls between November 1st and March 1st (winter season), by day of week. For example, the average number of calls on Sundays (Mondays) between November 1st and March 1st is 1,539 (1,637). Therefore, the difference for any given date that falls on a Sunday (Monday) is the number of daily calls minus 1,539 (1,637). We compute this difference for all observations using the respective average number of calls in the corresponding day of week.

[28] We compute the maximum number of calls for each day of the week between November 1st and March 1st (winter season). For example, the highest number of calls observed on a Sunday (Monday) between

A11. We find that a 100% increase in pollen levels explains 9.9 of the average 141-call difference between the pollen and winter seasons, or 7% of the deviation, in column (1). As the pollen months are characterized by weather and vacations and holidays which may predispose individuals towards activities that lead to a need for emergency services, this effect is arguably a substantial share of the difference. In column (2), we show that as pollen levels rise 100%, dispatch centers operate 0.4 percentage point (0.5%) closer to capacity relative to a sample mean of 0.8.

Next, we analyze the response time for each call as an outcome. As additional 911 calls are placed on higher pollen days, dispatchers may take longer to respond to all calls, resulting in longer ringdown time; this phenomenon may occur mechanically through increased volume or due to the dispatchers being affected by pollen themselves. At the same time, as emergency response personnel are dispatched to more incidents, they will take longer to arrive at any given incident. Table 6 presents coefficient estimates where the outcome variable is the average daily response time. As discussed in Section 3, some calls are logged by police officers reporting on an event in the line of their patrol duties. These calls are predominantly marked with zero response time as the officer is already on the scene. Therefore, we present the outcomes for all calls, but also separated by officer and civilian report. The coefficient estimates show no significant change in response time either for overall, nor separated by officer and civilian. Furthermore, the effect magnitudes are not large. Calls from civilians increase by 0.08 minutes, which constitutes a 0.2% increase on the mean length of 35 minutes.

Daily average times may mask underlying dynamics at the level of the call. As pollen affects the priority composition of the calls received, estimating the effect at the mean of the distribution of response time may hide divergent effects at different points in the distribution. In Figure A5, we show the proportion of calls within each priority group by decile of response time duration. While in the main analysis we use the count of calls per day – a necessary formulation since we do not see the calls which do not occur – the response time can be aggregated to daily averages or disaggregated to individual calls for analysis. The figure shows that priority 1 calls tend to be shorter in duration as seen in their prevalence in lower deciles, while priority 6 calls are longer as seen in the higher deciles.[29] To explore possible heterogeneity, we implement quintile regression

November 1st and March 1st is 2,107 (2,105). The ratio is the number of calls in any given date that falls on a Sunday (Monday) divided by 2,107 (2,105).

[29] For example, the average response time for priority 1 calls (highest priority) is nine minutes, while the average response time is 32, 63, 80, and 74 minutes for priorities 2, 3, 4, and 5, respectively. Priority levels 7 through 9 are combined as these calls are few in number and include traffic and administrative logs which have very short duration times.

(Machado et al., 2011), estimating the effect of pollen at deciles of the response duration distribution. We conduct this analysis at the level of the call placed to 911. Starting with 2,678,592 calls, we retain only those calls with non-zero response time, reducing the analysis sample to 1,459,559 calls.

We present unconditional quantile regression (Firpo et al., 2009) results visually in Figure 7. Because average response times differ substantially across deciles, the figure reports estimated effects as percent changes relative to each decile's mean duration. As pollen levels rise, response times increase for calls with longer baseline response times (deciles seven through nine), are unchanged for calls in the fifth and sixth deciles, and decrease for calls with shorter baseline response times (deciles one through four). Specifically, a 100% increase in pollen levels is associated with response time increases of 0.6%, 0.7%, and 0.7% in deciles seven, eight, and nine, respectively, and decreases of 0.8%, 0.3%, 0.5%, and 0.4% in deciles one, two, three, and four, respectively.

The longer (shorter) response times at higher (lower) deciles are consistent with a strained system reallocating resources: as call volume rises, dispatchers may prioritize high-priority calls while becoming more selective about sending a responder to lower-priority ones. For example, callers with certain medical emergencies may be instructed to transport themselves to the emergency department rather than wait for a response. Rising call volume may also increase miscommunication between caller, dispatcher, and first responder, resulting in false or incomplete reports.

To explore the possibility that dispatchers become more selective in sending first responders to the scene, we examine the incidence of calls where a first respondent is not likely to have been dispatched, which are calls that have time noted for call receipt but are missing a responder arrival time.[30] Furthermore, we evaluate "missing connections." Missing connections are defined as calls for which we have no evidence of successful event clearance, which we categorize into three groups: (1) canceled calls, defined as "responding units canceled by radio" or "duplicated or canceled by radio;" (2) "false complaint or unfounded;" and (3) "unable to locate incident or complainant" or "no such address or location," though a first responder was dispatched. Missing connections can be a result of an increase in marginal calls, frivolous calls, or poor communication quality between the caller and dispatcher that arises as pollen levels rise. For example, calls where the responder is "unable to locate incident" could be the result of minor incidents that cleared up by the time the first respondents arrived (marginal caller), or

[30] 25% of calls with a missing arrival time are priority 1 or 2 (most urgent and require immediate attention and may be life-threatening) calls, and 70% are priority 3 (less urgent, require investigation, but are not life-threatening).

could be the result of poor communication between the caller and dispatcher, where either party provides or receives an inaccurate description of the location of the incident due to pollen allergies affecting cognitive abilities. Some of these missing connections reflect frivolous use of 911 resources, such as "false complaint." These missing connections are not necessarily less urgent, as priority 1 and 2 calls make up 46.0% of calls in this category, compared to 33.5% in the total sample.[31]

We estimate the main specification using these two measures of response quality – missing arrival time and missing connections – together and separately by type, as the dependent variable. Results are reported in Table 7. Panel A shows our main coefficient estimates for comparison. Panel B shows that calls with missing connections increase by 2.5, an effect size of 1.2% or twice that of the main effect. This result is driven primarily by a 1.9 increase in calls where the first responder is unable to locate the incident, a 1.5% increase, but also a 0.4 increase in canceled calls (0.9% effect). We find no effects for false calls at conventional levels of statistical significance.

Missing arrival time estimates are in Panel C, showing an increase of 1.3 calls, or a 1.2% effect. The disproportionately larger effect magnitude in this category, relative to our main coefficient estimates, informs us that the missing arrival time is not a random occurrence akin to measurement error. Given this evidence, we further investigate the composition of calls with missing arrival time. In Panel D, we focus on the proportion of missing arrival times which are most likely to be the result of intentionally omitted information, rather than misreporting – calls with missing arrival time and missing connection report. These calls constitute 30% of calls with a missing arrival time. In this subsample of calls, a 100% increase in pollen results in 0.5 additional calls or a 1.3% effect.

This analysis implies that – though the 9.9 additional calls due to a 100% increase in pollen are a modest effect relative to the daily volume of calls received by dispatch – this micro-shock leads to a meaningful change in center operations and quality of call response. We show that though the average daily response time is not affected, the shortest calls, which are of the highest priority, and the longest calls, which tend to be lower priority, become even longer. At the same time, we note a decline in response quality as measured by a 1.2% increase in calls missing a logged response time and a 1.2% increase in missing connections. We show evidence that this increase is not random and may be evidence of strain on resources.

[31] 30% of calls with a missing arrival time are considered missing connections. Among missing connections, 77% have a valid arrival time and 23% have a missing arrival time.

6 Discussion and Conclusion

The public safety system plays a critical role in the functioning of society. First responders – including law enforcement officers, firefighters, and emergency medical technicians – all provide assistance in times of crisis. An important link between first responders and people needing assistance is 911 call centers. Dispatchers at 911 call centers direct emergency resources to callers in need of help. Given the serious nature of many 911 calls, timely and accurate response is imperative.

In this study, we use novel data on pollen levels to evaluate changes in 911 calls in response to micro-shocks. Daily pollen levels, and the body's associated natural allergy response, vary randomly and are not driven by changes in human behavior, offering an arguably exogenous micro-shock to study. Moreover, pollen has been linked with accidents, crime, mental health, cognition, and other factors that may influence the likelihood of a 911 call (Abramowitz et al., 2025; Akesaka and Shigeoka, 2023; Chalfin et al., 2019; Danagoulian and Deza, 2025), either by increasing or decreasing the probability of any given call, and the response time of dispatchers and other emergency responders. To study this question, we combine daily pollen levels with calls to Seattle, Washington 911 centers between 2009 and 2024. We carefully control for a wide range of weather variables, and time fixed effects, allowing us to isolate the impact of pollen.

We have several findings. First, we find an increase in call volumes as pollen levels rise: a 100% increase – the modal day-over-day increase that we observe in our data – in pollen levels leads to 9.9 additional calls per day, a 0.5% increase in calls relative to the sample mean.

Second, we find that call volumes experience a change in the composition – as well as volume – as pollen levels rise. A 100% increase in pollen levels results in a 0.8% rise in the highest priority calls, and 0.8% in priority three calls (as described in Section 3, Seattle 911 call centers group incoming calls into nine categories, with one being the highest priority and nine the lowest). This pattern could be the result of either an actual increase in the number of incidents warranting emergency response, or the result of higher pollen levels increasing the propensity to call 911 for any given marginally urgent incident. Additional calls include those related to medical incidents (0.9%), but in even greater proportions, calls more loosely linked to allergy response such as vice (2.2%), violence (1.8%), and disorder (1.0%).

Third, increases in 911 calls originate from both civilians and law enforcement officers. As pollen may affect not only civilian propensity to call 911, but also officers' ability to respond to incidents and dispatches, we interpret the similarity in effect size to indicate

that the change does not stem from officer incapacitation and that it is not likely driven by purely nuisance calls – which we assume are more likely to be reported to 911 services by civilians than by officers.

Fourth, while we observe no change in the daily average call response time – a standard metric tracked by national emergency service professional organizations – when pollen levels rise, we document changes in the operation of call centers responding to elevated demands on the service. No 911 calls go unanswered in Seattle. The National Emergency Number Association (NENA) requires that 90% of calls be answered in 15 seconds, and 95% of calls be answered in 20 seconds, which does not allow a dispatcher discretion in ignoring or not responding to calls that come into the center (NENA, 2020). Though we cannot observe ringdown time, we document that response time increases for the less urgent when pollen levels rise, while response time for high urgency calls decreases reflecting a substitution of resources. This behavioral response manifests in a number of (formally) measured and unmeasured ways.

We show evidence that as pollen levels rise, there is a change in quality of response and reporting. We show a 1.2% increase in calls missing a reported responder arrival time. We also show a 1.2% increase in missing connection calls. These are calls where the responding unit is canceled, where there is a false report, or where responders are unable to locate the incident. This finding suggests a small rise in calls affects the quality of emergency services, and reduces efficiency of response.

Call surges result in another unmeasured cost: emergency responders and transport are diverted away from scheduled discharge transport services from hospitals and nursing facilities.[32] These delays in care due to diversions would not be reflected in 911 dispatch call logs or medical records, but, nonetheless, constitute a cost to society.

These findings are in line with much of the emerging economic literature on the impacts of pollen. Danagoulian and Deza (2025) find a 5.4% increase in fatal traffic accidents as pollen levels rise by 100%, while Akesaka and Shigeoka (2023) find 0.2 more all-cause accidents following a 100% increase in pollen levels. Abramowitz et al. (2025) find that there are 7.4% more deaths by suicide per day when pollen levels increase by 100%.[33] We note that Chalfin et al. (2019), in contrast to the general pattern in the literature, show that domestic violent crimes decline on particularly high pollen days.

To contextualize our findings, the estimated 9.9 additional calls per day implies 1,059

[32]This information is based on authors' conversations with an emergency medical responder – Kristin Kasten, Paramedic and Supervisor at Emergent Health Partners in Ann Arbor, Michigan. Even anticipated events that divert resources, such as concerts and sporting events, leave fewer units to respond to local emergencies (Dornfeld, 2025).

[33]We classify these deaths as medical in our analysis.

added calls per year – which is more than half of the average number of calls received in a day – if we assume pollen levels rise by 100% on at least half of the days during the season.[34] This level of variation is reasonable for Seattle as we observe that day-to-day pollen levels double on 53.8% of the days in our sample. If we assume that each call costs the city of Seattle $800 (Irwin and Pearl, 2020), then these additional calls would increase costs to the city by $847,200 each year. For comparison, the annual budget of the 911 system in Seattle was $28.46 million in 2025. These additional calls represent 3.0% of the total budget – a nontrivial amount. This value is likely an underestimate of the full cost borne by residents of Seattle when pollen levels are high. The additional pollen-related calls result in longer response times for low-urgency calls as 911 dispatchers re-prioritize services, reducing residents' ability to receive assistance for less urgent incidents, which can include lower-priority crime and violence, and healthcare. While we are unable to estimate the costs associated with this delay, they represent a cost borne by victims and community beyond the budget of the emergency response system. Finally, these costs do not account for the increased strain on dispatchers which accumulates day after day. While the micro-shock we study here is the incidence of allergies due to pollen, this disruption is just one of many that regularly, though unpredictably, impact 911 call centers.

While we focus on pollen levels, our findings are potentially informative for a wider range of economically relevant questions. First, we show that the public safety system is vulnerable to arguably small health shocks — a vulnerability that may extend to other disruptions such as influenza or COVID seasons, severe weather, natural disasters (fire, flood, etc.), and other events. Second, our null findings for response time – a key marker of 911 call center performance – highlight that emergency responders aspire to provide the highest quality of care even under strain, but do so by diverting critical resources from non-emergent services. Therefore, policy analyses of public safety systems should explore more than "first-order" outcomes and critically assess the various margins along which systems can respond to strain. These analyses are likely useful for welfare calculations, and assessments of the costs and benefits of public funding.

Third, while a public safety system with the ability to re-prioritize and stretch resources to accommodate surges in need at times of natural disasters is arguably desirable, an optimal system should have sufficient built-in slack to prevent such re-prioritization from being needed to accommodate mild increases in demand. Pollen is not the only

[34] We have data on pollen for months April through October of each year, and these months include 214 days, with about 50% of these experiencing doubling or more of pollen levels. We calculate the number of additional calls per year as follows: 9.9 calls $\times$ 107 days = 1,059 calls.

micro-shock affecting the population of Seattle, as temperature and weather changes, sports events, and other events have been shown to induce behaviors resulting in more 911 calls. Thus, extrapolating from our findings to conclude that there are weekly, if not near-daily, increases in calls attributable to such micro-shocks is reasonable. This burden is a meaningful cost of the public safety system operating under persistent strain. Policymakers and municipal leaders could consider these costs when deciding on budgetary appropriations for emergency services.

Despite the importance of 911 systems – i.e., connecting people to services during times of emergency – there is scant economic research on these systems. Our study represents one of the first efforts to examine factors that may influence the functioning of 911 call centers. We show that exogenous factors can influence demand for emergency services and the provision of these services. Future work could investigate other factors that may affect the performance of 911 call centers – e.g., pollution, natural disasters, funding levels, and so forth – and explore the influence of these centers on economically important outcomes such as crime, health, and property values.

In sum, we document the importance of small health shocks on the public safety system. Our work highlights the impact of these have on public services that provide critical support for the basic functioning of society and the economy overall. As such events become a more common feature of modern life – through changes in disease spread, rising temperatures, and other factors – understanding how emergency services respond to such shocks is crucial.

References

Abramowitz, J., Danagoulian, S., and Fleming, O. (2025). Seasonal allergies and mental health: Do small health shocks affect suicidality? *Journal of Health Economics*, 104:103069.

Akesaka, M. and Shigeoka, H. (2023). "Invisible killer:" Seasonal allergies and accidents. *National Bureau of Economic Research Working Paper Series*, No. 31593.

Ba, B. A., Chen, P., Cheng, T., Eies, M. C., and Holz, J. E. (2025). What is the best response? Examining the impact of police and their alternatives. Technical report, National Bureau of Economic Research.

Bensnes, S. S. (2016). You sneeze, you lose: The impact of pollen exposure on cognitive performance during high-stakes high school exams. *Journal of Health Economics*, 49:1–13.

Benson, B. L. and Zimmerman, P. R., editors (2010). *Handbook on the Economics of Crime*. Edward Elgar Publishing, Cheltenham, UK.

Berkson, J. (1950). Are there two regressions? *Journal of the American Statistical Association*, 45(250):164–180.

Blackwell, T. H. and Kaufman, J. S. (2002). Response time effectiveness: Comparison of response time and survival in an urban emergency medical services system. *Academic Emergency Medicine*, 9(4):288–295.

Blasius, M. (2025). After calling 911: Some Phoenix residents face longer wait for help. Technical report. Investigations desk; Phoenix EMS response times by council district.

Bound, J., Brown, C., and Mathiowetz, N. (2001). Measurement error in survey data. In Heckman, J. J. and Leamer, E., editors, *Handbook of Econometrics*, volume 5, chapter 59, pages 3705–3843. Elsevier.

Brevitz Consulting Services (2024). Audit of the Kansas 911 system. Technical report, Kansas Legislative Division of Post Audit, Topeka, KS. Prepared on behalf of the Legislative Division of Post Audit; testimony to the Senate Committee on Utilities; 149 pp.

Bullinger, L. R., Carr, J. B., and Packham, A. (2021). COVID-19 and crime: Effects of stay-at-home orders on domestic violence. *American Journal of Health Economics*, 7(3):249–280.

Camacho, I., Caeiro, E., Nunes, C., Gaspar, A., and Morais-Almeida, M. (2015). Airborne pollen in Madeira Island: Comparison between urban and rural areas. *Annals of Agricultural and Environmental Medicine*, 22(3):437–442.

Cebul, R. D., Rebitzer, J. B., Taylor, L. J., and Votruba, M. E. (2008). Organizational fragmentation and care quality in the U.S. healthcare system. *Journal of Economic Perspectives*, 22(4):93–113.

Chalfin, A., Danagoulian, S., and Deza, M. (2019). More sneezing, less crime? Health shocks and the market for offenses. *Journal of Health Economics*, 68:102230.

Chalfin, A. and McCrary, J. (2017). Criminal deterrence: A review of the literature. *Journal of Economic Literature*, 55(1):5–48.

Chalfin, A. and McCrary, J. (2018). Are u.s. cities underpoliced? theory and evidence. *The Review of Economics and Statistics*, 100(1):167–186.

Chen, J. and Roth, J. (2024). Logs with zeros? Some problems and solutions. *The Quarterly Journal of Economics*, 139(2):891–936.

Council on Criminal Justice (2025). DOJ funding update: A deeper look at the cuts. Council on Criminal Justice.

Craig, T. J., McCann, J. L., Gurevich, F., and Davies, M. J. (2004). The correlation between allergic rhinitis and sleep disturbance. *Journal of Allergy and Clinical Immunology*, 114(5 Suppl):S139–45.

Culyer, A. J. and Newhouse, J. P., editors (2000). *Handbook of Health Economics*, volume 1. Elsevier, Amsterdam.

Cummins, R. O., Ornato, J. P., Thies, W. H., and Pepe, P. E. (1991). Improving survival from sudden cardiac arrest: The chain of survival concept. A statement for health professionals from the Advanced Cardiac Life Support Subcommittee and the Emergency Cardiac Care Committee, American Heart Association. *Circulation*, 83(5):1832–1847.

Danagoulian, S. and Deza, M. (2025). Driving under the influence of allergies: The effect of seasonal pollen on traffic fatalities. *Journal of Health Economics*, 99:102945.

de Weger, L. A., Pashley, C. H., Åberg, N., et al. (2021). The long-term pollen monitoring network in the benelux: Spatio-temporal trends and implications for allergen exposure. *International Journal of Environmental Research and Public Health*, 18(7):3652.

Dornfeld, A. (2025). On-duty medic and fire units often staff Seattle sporting events and concerts, leaving coverage gaps. Technical report. Published 5:47 p.m. PT.

Dowlati, Y., Herrmann, N., Swardfager, W., Liu, H., Sham, L., Reim, E., and Lanctot, K. (2010). A meta-analysis of cytokines and major depression. *Biological Psychiatry*, 67(5):446–57.

Federal Communications Commission (2021). 911 Fee Diversion; New and Emerging Technologies 911 Improvement Act of 2008. Federal Register, 86 FR 45892 (Aug. 17, 2021). Final rule; PS Docket Nos. 20-291 and 09-14; FCC 21-80; 47 CFR Part 9; FR Doc. 2021-16068.

Firpo, S., Fortin, N. M., and Lemieux, T. (2009). Unconditional quantile regressions. *Econometrica*, 77(3):953–973.

Gonzalez, R. P., Cummings, G. R., Phelan, H. A., Mulekar, M. S., and Rodning, C. B. (2009). Does increased emergency medical services prehospital time affect patient mortality in rural motor vehicle crashes? A statewide analysis. *The American Journal of Surgery*, 197(1):30–34.

Government Technology (2024). Survey suggests difficulties continue for 911 call centers. Council on Criminal Justice.

Greiner, A. N., Hellings, P. W., Rotiroti, G., and Scadding, G. K. (2011). Allergic rhinitis. *The Lancet*, 378(9809):2112–2122.

Hartsig, A. (2017). Calling 911: Funding and technological challenges of county 911 call centers. Technical report, National Association of Counties.

Hoffmann, J. A., Attridge, M. M., Carroll, M. S., Simon, N. J. E., Beck, A. F., and Alpern, E. R. (2023). Association of youth suicides and county-level mental health professional workforce shortages in the United States. *JAMA Pediatrics*, 177(1):71–80.

Holguín-De La Cruz, J. (2022). 911 safety emergency response system call center staffing characterization using stochastic simulation. *International Journal of Engineering Research and Development*, 18(2):21–28.

IAED and NASNA (2023). IAED & NASNA 911 staffing survey report. Technical report, International Academies of Emergency Dispatch (IAED) and National Association of State 911 Administrators (NASNA). Accessed: 2025-02-27.

Intergovernmental Panel on Climate Change (2021). Climate change 2021: The physical science basis. Summary for policymakers.

InvestigateTV (2025). Investigatetv+ weekend: Alarming ambulance delays put patients at risk. Technical report. Updated 2025-03-02.

Irwin, A. and Pearl, B. (2020). The community responder model. Center for American Progress.

Ito, K., Weinberger, K. R., Robinson, G. S., Sheffield, P. E., Lall, R., Mathes, R., Ross, Z., Kinney, P. L., and Matte, T. D. (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, C., Travers, P., and Walport, M. (2001). *Immunobiology: The Immune System in Health and Disease*. Garland Science, New York.

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

Johnson, B., Barron, J., and Tenser, P. (2025). Rising 911 calls, packed ERs stretching EMS system to the breaking point across Massachusetts. Technical report. 5 Investigates; updated 11:31 PM EDT.

Kang, B., van den Berg, J. W., Gopalan, S., and Chatterjee, D. (2023). The association between mental health-related 911 calls and mental health professional shortage areas in New York State. *Community Mental Health Journal*, 59(5):873–882.

Kennedy, P. (2008). *A guide to econometrics*. John Wiley & Sons.

Kirby, B. (2025). Mobile ambulance officials say 911 abuse is causing major strain on emergency services. Technical report.

KOMO News Staff (2021). Staffing crisis impacting response to 911 calls in Seattle. Accessed 2 June 2025.

Kremer, B., den Hartog, H. M., and Jolles, J. (2002). Relationship between allergic rhinitis, disturbed cognitive functions and psychological well-being. *Clinical & Experimental Allergy*, 32(9):1310–5.

Kronfol, Z. and Remick, D. (2000). Cytokines and the brain implications for clinical psychiatry. *The American Journal of Psychiatry*, 157(5):683–94.

La, L. (2025). CA mental health phone line faces steep budget cuts. Cal Matters.

Larson, P., Steiner, A., O'Neill, M., Baptist, A., and Grounlund, C. (2025). Chronic and infectious respiratory mortality and short-term exposures to four types of pollen taxa in older adults. *BMC Public Health*, 25.

Lewis, A. J. (2023). Report on public safety investments. Technical report, Seattle City Council.

Lucchese, E. (2024). How important are delays in treatment for health outcomes? The case of ambulance response time and cardiovascular events. *Health Economics*, 33(4):652–673.

Machado, J. A. F., Parente, P. M. D. C., and Santos Silva, J. M. C. (2011). QREG2: Stata module to perform quantile regression with robust and clustered standard errors. Statistical Software Components S457369, Boston College Department of Economics. Available at: https://ideas.repec.org/c/boc/bocode/s457369.html.

Marcotte, D. E. (2015). Allergy test: Seasonal allergens and performance in school. *Journal of Health Economics*, 40:132–140.

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

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

Marshall, P. S., O'Hara, C., and Steinberg, P. (2000). Effects of seasonal allergic rhinitis on selected cognitive abilities. *Annals of Allergy, Asthma & Immunology*, 84(4):403–10.

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

McCrary, J. and Sanga, S. (2021). The impact of the coronavirus lockdown on domestic violence. *American Law and Economics Review*, 23(1):137–163.

Meiselbach, M. K., Ettman, C. K., Shen, K., Castrucci, B. C., and Galea, S. (2024). Unmet need for mental health care is common across insurance market segments in the United States. *Health Affairs Scholar*, 2(3):qxae032.

Mesinger, F., DiMego, G., Kalnay, E., Mitchell, K., Shafran, P. C., Ebisuzaki, W., Jovic, D., Woollen, J., Rogers, E., Berbery, E. H., et al. (2006). North American regional reanalysis. *Bulletin of the American Meteorological Society*, 87(3):343–360.

Miller, A. R., Segal, C., and Spencer, M. K. (2022). Effects of COVID-19 shutdowns on domestic violence in US cities. *Journal of Urban Economics*, 131:103476.

Miller, A. R., Segal, C., and Spencer, M. K. (2024). Effects of the COVID-19 pandemic on domestic violence in Los Angeles. *Economica*, 91(361):163–187.

Moore, R. (2025). FEMA—and the nation's disaster safety net—gets cut adrift. NRDC.

Mullahy, J. and Norton, E. C. (2024). Why transform y? The pitfalls of transformed regressions with a mass at zero. *Oxford Bulletin of Economics and Statistics*, 86(2):417–447.

National 911 Program (2021). 2021 911 profile database report. Accessed: 2026-01-26.

National 911 Program (2025). Tour a 911 call center or PSAP. Technical report. Last updated August 14, 2023.

National Centers for Environmental Prediction (NCEP) (2004). NCEP North American Regional Reanalysis (NARR). NOAA Physical Sciences Laboratory.

Negral, L., Rodríguez-Rajo, F. J., Jato, V., et al. (2021). Impact of air mass origin on olive pollen concentrations in a coastal Mediterranean enclave. *Environmental Pollution*, 286:117272.

NENA (2020). National emergency number association standard for 9-1-1 call processing (nena-sta-020.1-2020).

Pfannenstiel, K. (2025). With money running out in 2031, watchdog report recommends Idaho Legislature stabilize 911 funding. Idaho Capital Sun.

Pierce, H. and Lilly, M. M. (2012). Duty-related trauma exposure in 911 telecommunicators: Considering the risk for posttraumatic stress. *Journal of Traumatic Stress*, 25(2):211–215.

PRISM Climate Group (2026). PRISM High-Resolution Spatial Climate Data for the Conterminous United States. Oregon State University. Accessed February 20, 2026.

Ramgopal, S., Dunnick, J., Owusu-Ansah, S., and Levy, M. J. (2019). The association of weather conditions with emergency medical services demand. *Prehospital Emergency Care*, 23(1):83–90.

Rosenberg, H., Salvucci, A., Kuehl, A., Clawson, J., and Martin, R. (2015). Characterization of call prioritization time in a medical priority dispatch system. *Annals of Emergency Dispatch & Response*, 3(2):38–40.

Russo-Lennon, B. (2025). Critical condition: Why are NYC ambulance response times getting longer every day? Technical report. NYC Transit.

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

Sheffield, P. E., Weinberger, K. R., Ito, K., Matte, T. D., Mathes, R. W., Robinson, G. S., and Kinney, P. L. (2011). The association of tree pollen concentration peaks and allergy medication sales in New York City: 2003–2008. *International Scholarly Research Notices Allergy*, 2011.

Stevanovic, K., Sinkkonen, A., Pawankar, R., and Zuberbier, T. (2025). Urban greening and pollen allergy: Balancing health and environmental sustainability. *Journal of Allergy and Clinical Immunology: In Practice*, 13(2):275–279.

Tashiro, M., Mochizuki, H., Iwabuchi, K., Sakurada, Y., Itoh, M., Watanabe, T., and Yanai, K. (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.

U.S. Environmental Protection Agency (2026a). Air Quality Index (AQI) Daily Data. EPA AirData Service. Accessed: February 20, 2026.

U.S. Environmental Protection Agency (2026b). Outdoor Air Quality Data: $PM_{2.5}$ Daily Summary Statistics. EPA AirData Service. Accessed: February 20, 2026.

U.S. Government Accountability Office (2013). 911 services: Most states used 911 funds for intended purposes, but FCC could improve its reporting on states' use of funds. Technical Report GAO-13-376, U.S. Government Accountability Office.

Vuurman, E. F., van Veggel, L. M., Uiterwijk, M. M., Leutner, D., and O'Hanlon, J. F. (1993). Seasonal allergic rhinitis and antihistamine effects on children's learning. *Annals of Allergy*, 71(2):121–6.

Vuurman, E. F. P. M., Vuurman, L. L., Lutgens, I., and Kremer, B. (2014). Allergic rhinitis is a risk factor for traffic safety. *Allergy*, 69(7):906–912.

Walker, S., Khan-Wasti, S., Fletcher, M., Cullinan, P., Harris, J., and Sheikh, A. (2007). Seasonal allergic rhinitis is associated with a detrimental effect on examination performance in United Kingdom teenagers: Case-control study. *Journal of Allergy and Clinical Immunology*, 120(2):381–387.

Wang, H., Li, J., and Zhang, Y. (2012). Analyzing the volume and nature of emergency medical calls during extreme weather events. *Social Science & Medicine*, 75(5):1035–1041.

Washington State Department of Revenue (2013). 911 tax. https://dor.wa.gov/taxes-rates/other-taxes/911-tax. Accessed: 2025-08-20.

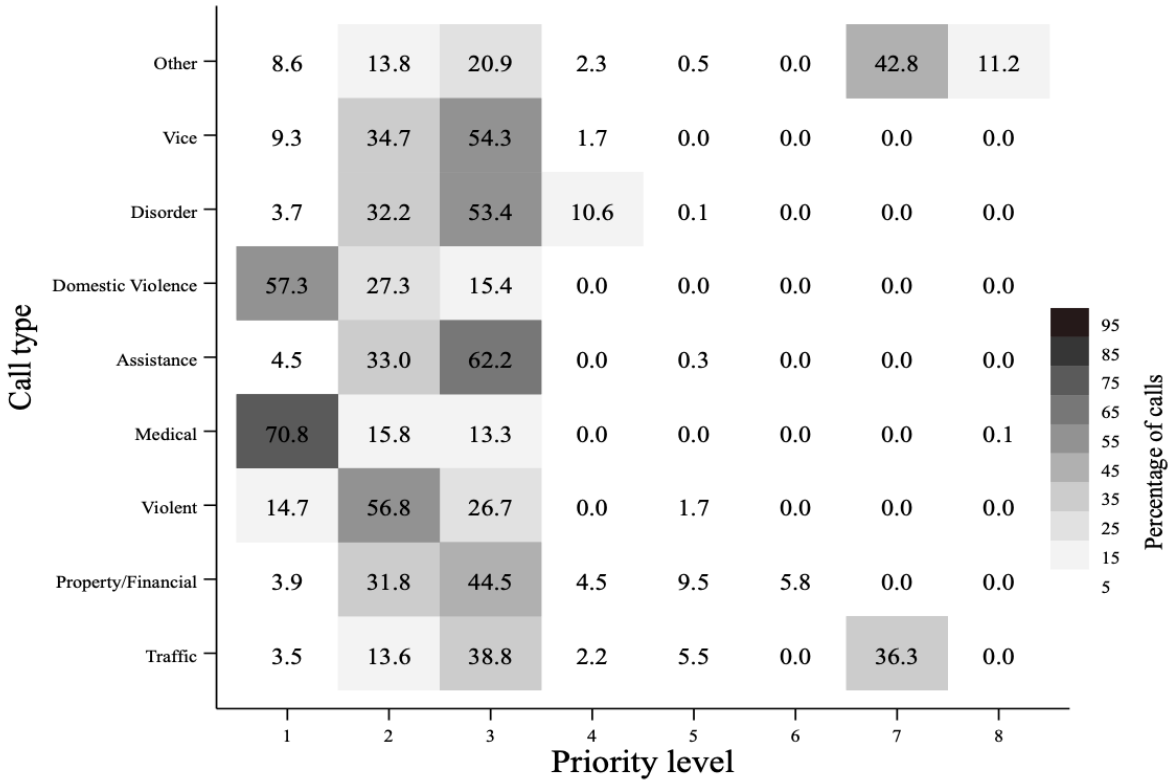
Wilde, E. T. (2013). Do emergency medical system response times matter for health outcomes? *Health Economics*, 22(7):790–806.

Wilken, J. A., Berkowitz, R., and Kane, R. (2002). Decrements in vigilance and cognitive functioning associated with ragweed-induced allergic rhinitis. *Annals of Allergy, Asthma & Immunology*, 89(4):372–80.

Wyoming Department of Transportation (WYDOT) (2025). WYDOT—joint corporations may meeting packet: Summary and recommendations for Next Generation 911 (NG911). Interim Committee Meeting Packet 07-202505089-01, Wyoming Legislature, Joint Corporations, Elections & Political Subdivisions Interim Committee. 25 pp.

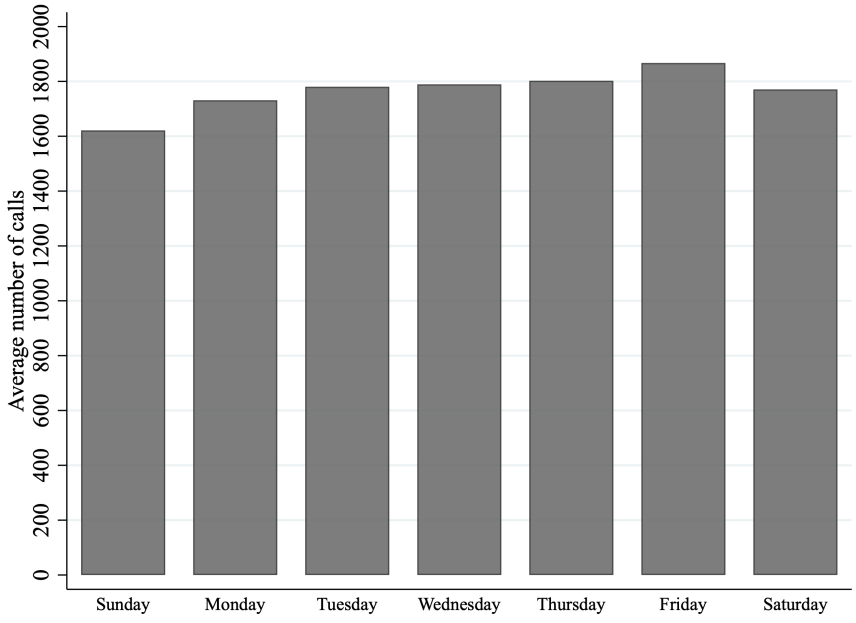
7 Figures and tables

Figure 1: Heatmap of 911 call priority relative to type in Seattle, Washington 2009-2024

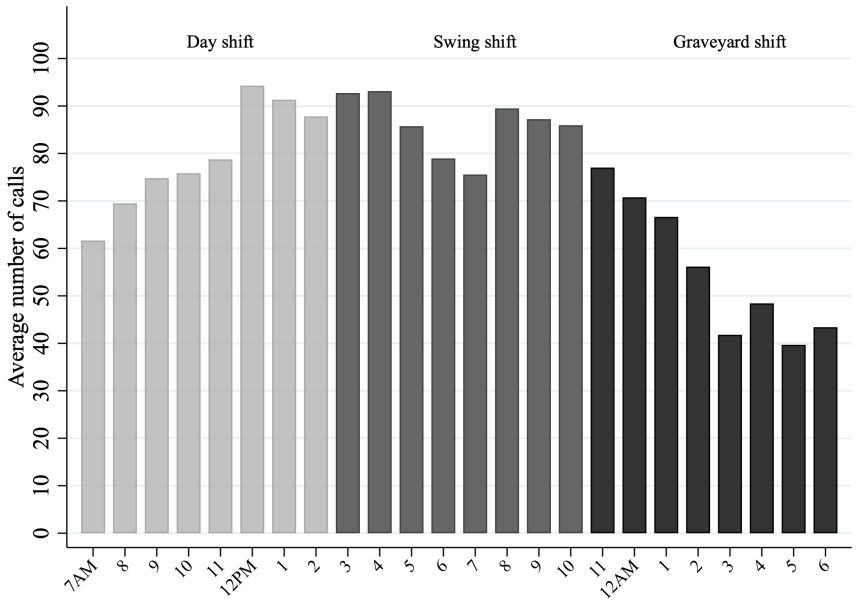


Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This figure shows the distribution of 911 calls by call type and priority level. The percentages represent the proportion of call type in each priority level. Data are unweighted.

Figure 2: 911 Call volume throughout the week and day in Seattle, Washington 2009-2024



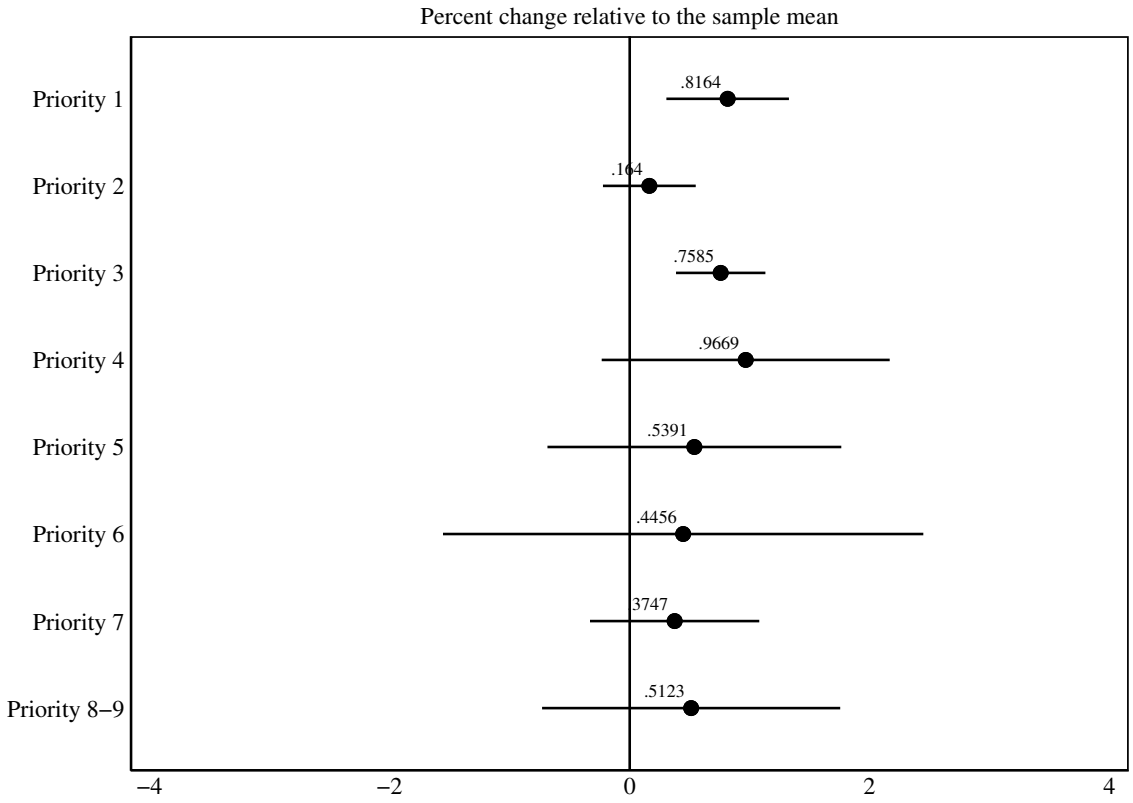
(a) Panel A: Average number of calls by day of week



(b) Panel B: Average number of calls by hour and shift

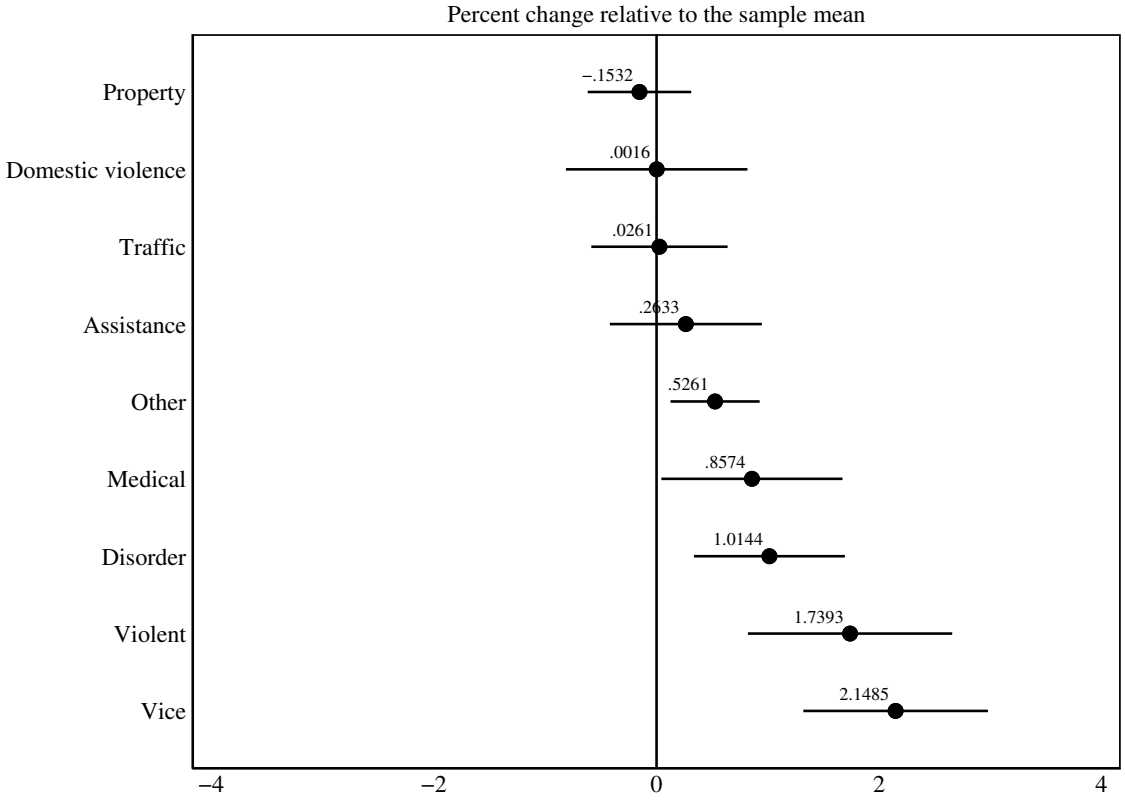
Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This figure shows the average number of 911 calls by (a) day of week and (b) by hour and shift within the day. Data are unweighted.

Figure 3: Effect of pollen levels on the number of 911 calls allowing for heterogeneity by call priority in Seattle, Washington 2009-2024



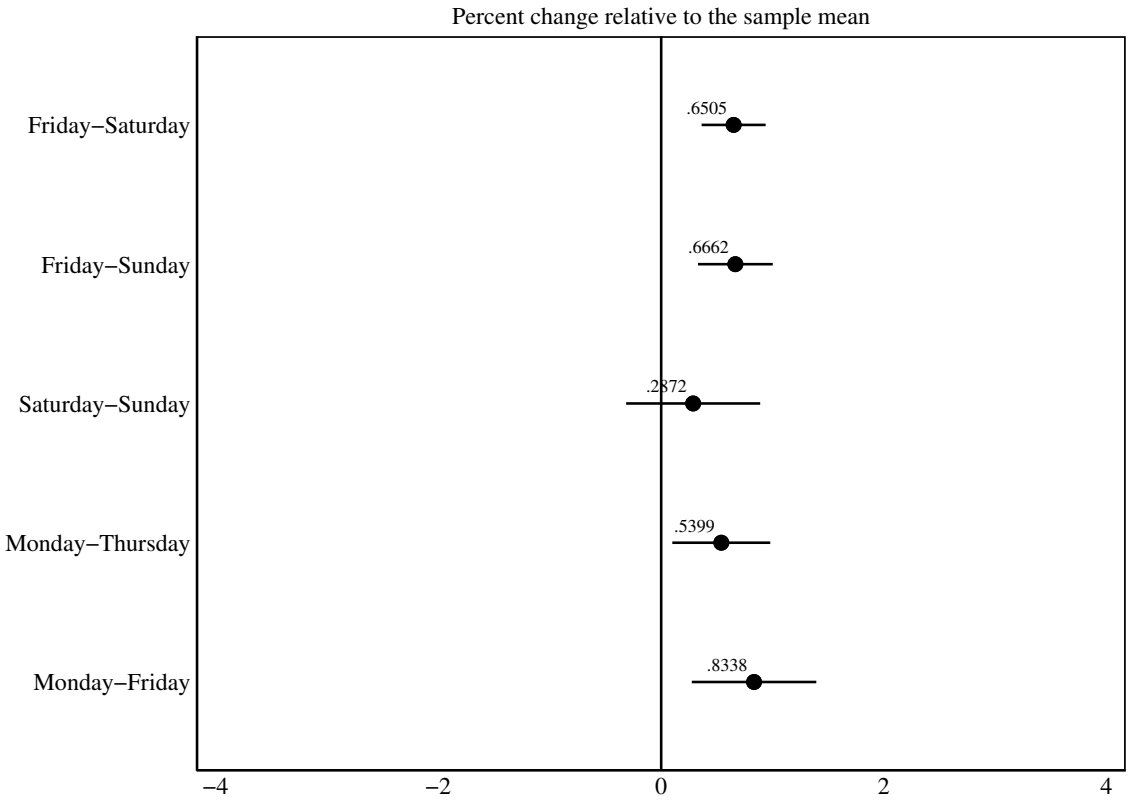
Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This figure reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls. 911 call priority is reported on type on the y-axis. The pollen variable is log-transformed. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects: day-of-week-by-month, month-by-year, and month-by-day fixed effects. Data are unweighted. Regressions estimated with OLS. Coefficient estimates are reported in circles, and 95% confidence intervals are reported with horizontal lines. Coefficient estimates and 95% confidence intervals (X) are converted to the percent change as follows: $X \div sample\,mean \times 100\%$.

Figure 4: Effect of pollen levels on the number of 911 calls allowing for heterogeneity by call type in Seattle, Washington 2009-2024



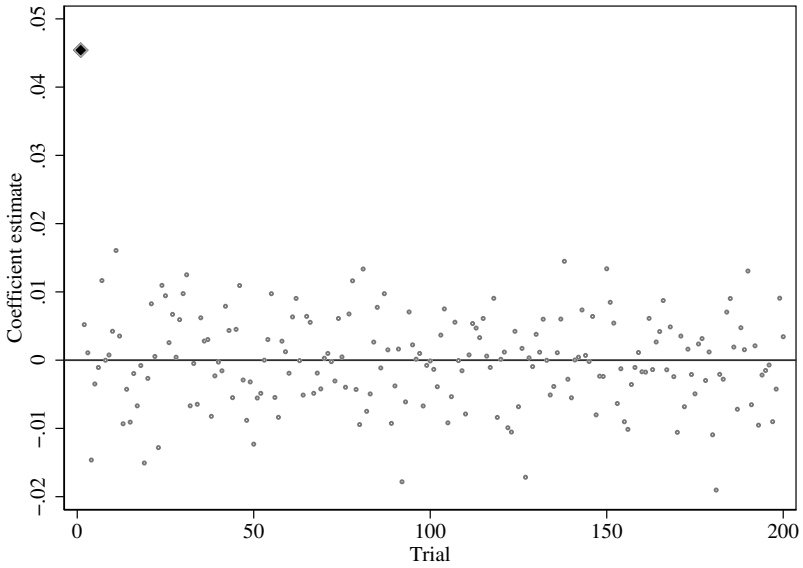
Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This figure reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls. 911 call category is reported on type on the y-axis. The pollen variable is log-transformed. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects: day-of-week-by-month, month-by-year, and month-by-day fixed effects. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Coefficient estimates are reported in circles, and 95% confidence intervals are reported with horizontal lines. Coefficient estimates and 95% confidence intervals (X) are converted to the percent change as follows: $X \div sample\,mean \times 100\%$.

Figure 5: Effect of pollen levels on the number of 911 calls allowing for heterogeneity by day of the week in Seattle, Washington 2009-2024

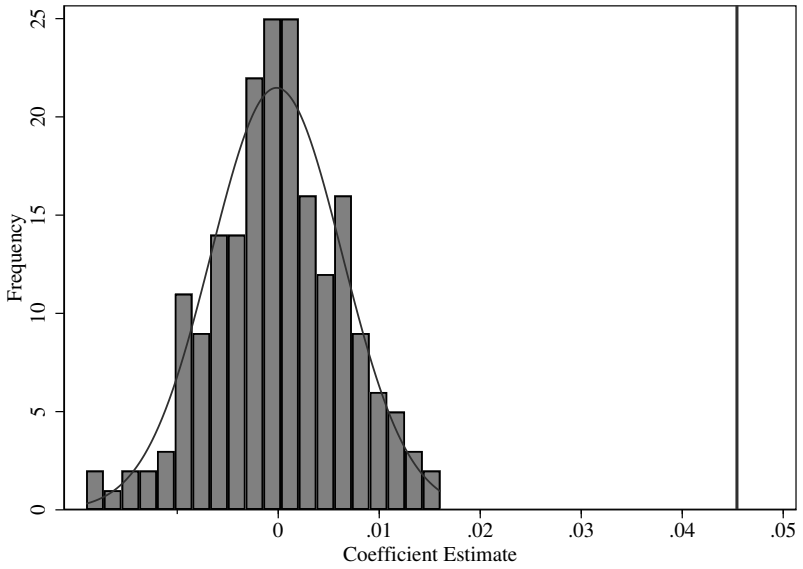


Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This figure reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls. Hour of the day is reported on type on the y-axis. The pollen variable is log-transformed. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects: day-of-week-by-month, month-by-year, and month-by-day fixed effects. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Coefficient estimates are reported in circles, and 95% confidence intervals are reported with horizontal lines. Coefficient estimates and 95% confidence intervals (X) are converted to the percent change as follows: $X \div sample\,mean \times 100\%$.

Figure 6: Effect of pollen levels on the number of 911 calls using randomized inference in Seattle, Washington 2009-2024



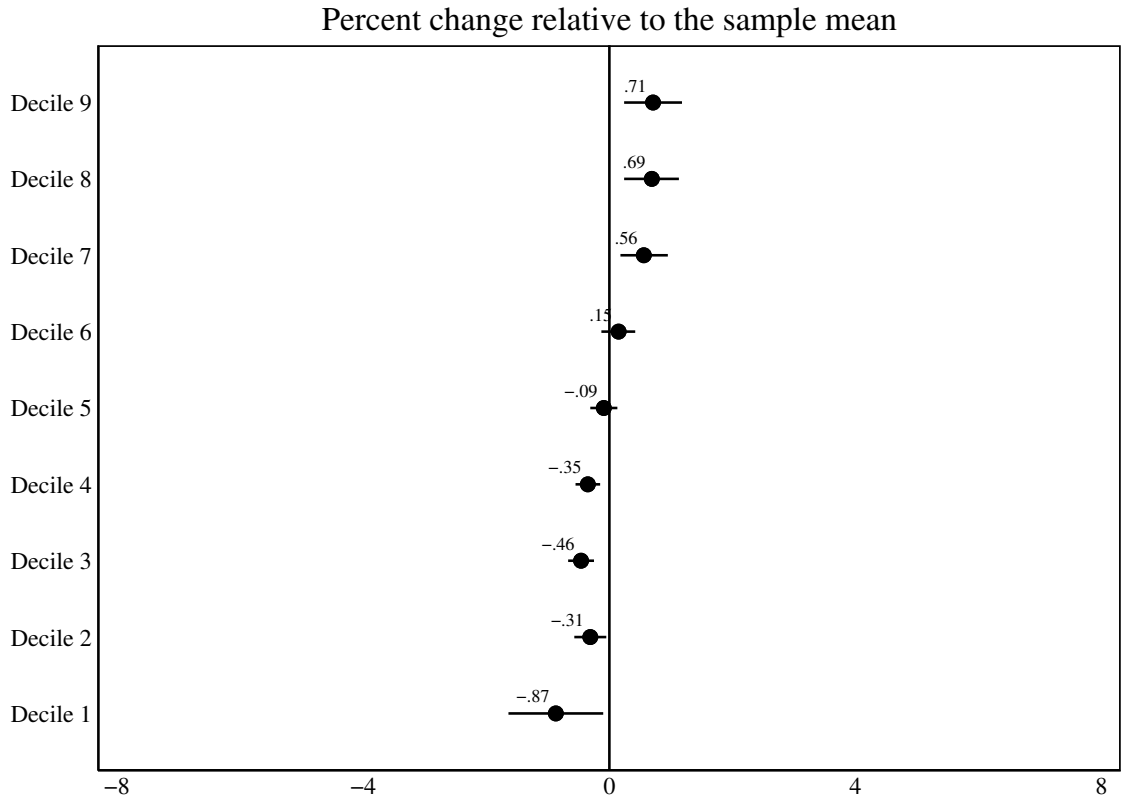
(a) Scatterplot



(b) Histogram

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This figure reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls. In panel (a), the main coefficient estimate is reported with a black diamond and the placebo coefficient estimates are reported with gray circles. In panel (b), the main coefficient estimate is reported with a solid vertical line, the bars reflect the distribution of the placebo estimates. The treatment variable (pollen) is randomly assigned across days. In panel (a), the iteration is reported on the x-asis. The pollen variable is log-transformed. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects: day-of-week-by-month, month-by-year, and month-by-day fixed effects. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS.

Figure 7: Effect of pollen levels on response time allowing for heterogeneity by response time using unconditional quantile regression in Seattle, Washington 2009-2024



Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This figure reports coefficient estimates from regressions of 911 call response time on pollen levels and other controls using unconditional quintile regression. The quintile is reported on the y-axis. The pollen variable is log-transformed. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects: day-of-week-by-month, month-by-year, and month-by-day fixed effects. The unit of observation is a call-day-month-year. Data are unweighted. Regressions estimated with OLS. Coefficient estimates are reported in circles, and 95% confidence intervals are reported with horizontal lines. Coefficient estimates and 95% confidence intervals (X) are converted to the percent change as follows: $X \div sample\,mean \times 100\%$.

Table 1: Effect of pollen (logarithm transformed and levels) on the number of 911 calls in Seattle, Washington 2009-2024

Specification →	(1)	(2)	(3)
		Panel A: Calls	
Pollen (logarithm)	18.68***	10.732***	9.898***
	(2.206)	(2.285)	(2.330)
Mean	1818.6	1818.6	1818.6
Percent change†	1.027	0.590	0.544
		Panel B: Calls per 10,000	
Pollen (logarithm)	0.086***	0.049***	0.045***
	(0.010)	(0.011)	(0.011)
Mean	8.497	8.497	8.497
Percent change†	1.011	0.581	0.534
		Panel C: Calls	
Pollen (level)	0.087***	0.039***	0.032**
	(0.013)	(0.014)	(0.014)
Mean	1817.2	1817.2	1817.2
Percent change†	0.005	0.002	0.002
		Panel D: Calls per 10,000	
Pollen (level)	0.0004***	0.0002***	0.0001**
	(0.0001)	(0.0001)	(0.0001)
Mean	8.494	8.494	8.494
Percent change†	0.005	0.002	0.001
Weather controls††	×	✓	✓
Wind direction	×	×	✓
Fixed effects:			
Day-of-week-by-month	✓	✓	✓
Month-by-year	✓	✓	✓
Month-by-day	✓	✓	✓
Observations	2838	2838	2838

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This table reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls. The pollen variable is log-transformed in Panel A and in levels in Panel B, winsorized at the 95th percentile in the latter. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects: day-of-week-by-month, month-by-year, and month-by-day fixed effects. In Panels A and C the outcome variables are the number of calls per day. In Panels B and D the outcome variables are the number of calls per 10,000 residents per day. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Standard errors are reported in parentheses.
***,**,* = statistically different from zero at the 1%, 5%, 10% level.
†Percent change = coefficient estimate ÷ mean value of the outcome × 100%.
††Weather controls = Minimum temperature, mean temperature, maximum temperature, mean dew point, minimum vapor point, maximum vapor point, precipitation indicator, and wind speed.

Table 2: City demographics, 911 call volumes, and pollen exposure

City →	Seattle, WA	Washington, DC	Minneapolis, MN	Baltimore, MD	San José, CA
Demographics (U.S. Census, 2020-2023)					
Population (April 1, 2020)	737,020	689,545	429,983	585,720	997,368
Population per square mile (2020)	8,791.8	11,280.7	7,962.1	7,235.8	5,684.1
Age 65+ (%)	12.8	12.7	10.8	14.9	14.1
Black alone (%)	6.6	43.3	18.3	60.0	2.9
Hispanic or Latino (%)	8.2	11.6	10.5	7.9	31.0
Median HH income ($2023)	121,984	106,287	80,269	59,623	141,565
Persons in poverty (%)	9.9	14.5	16.4	20.1	7.8
911 calls (annual, 2023)					
Total 911 calls	739,127[a]	1,770,000[b]	630,779[c]	1,669,568[d]	278,608[e]
911 calls per 1,000 residents	1,002.9	2,566.1	1,467.0	2,850.8	279.4
Pollen exposure					
Average pollen	225.7	124.2	428.2	101.0	65.6
Maximum pollen	6,938	2,831	7,676	2,883	1,424

Notes: Rates are computed as annual calls divided by city population and multiplied by 1,000.
[a] FY2022–2023 Seattle CARE Department 9-1-1 Communications Center; includes all calls to 911 and the police emergency telephone number. https://embed.clearimpact.com/Measure/Embed/100717836, accessed 2/21/2026.
[b] 2023 DC Office of Unified Communications (OUC); published headline metric for "911 calls for service." The total is an approximation. https://ouc.dc.gov/page/911-performance-dashboard-beta, accessed 2/21/2026.
[c] 2023 Minneapolis "911 Incidents Reported," incident-based proxy for incoming 911 calls due to public reporting constraints. https://www.minneapolismn.gov/government/government-data/datasource/911-performance-dashboard/, accessed 2/21/2026.
[d] 2023 Open Baltimore "911 Calls for Service:" police calls-for-service only (fire/EMS excluded). https://data.baltimorecity.gov/datasets/baltimore::911-calls-for-service-2023/explore, accessed 2/21/2026.
[e] 2023 San José Open Data "Police Calls for Service:" incident-based proxy for 911 call volume. https://data.sanjoseca.gov/dataset/police-calls-for-service, accessed 2/21/2026.
HH = household; pollen exposure is calculated based on the most recent four-year period available for each location.

Table 3: Effect of pollen levels on the number of 911 calls allowing for heterogeneity by call initiator in Seattle, Washington 2009-2024

Call initiator →	Officer	Civilian
	Panel A: Logarithm of pollen	
Pollen	3.598**	5.919***
	(1.401)	(1.622)
Mean	530.62	1226.1
Percent change†	0.678	0.483
	Panel B: Pollen level	
Pollen	0.013	0.023**
	(0.008)	(0.010)
Mean	530.62	1226.1
Percent change†	0.002	0.002
Weather controls	✓	✓
Wind direction	✓	✓
Fixed effects:		
Day-of-week-by-month	✓	✓
Month-by-year	✓	✓
Month-by-day	✓	✓
Observations	2838	2838

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This table reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls. The pollen variable is log-transformed in Panel A and in levels in Panel B, winsorized at the 95th percentile in the latter. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects as indicated. The outcome variables are the number of calls per day. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Standard errors reported in parentheses.
***,**,* = statistically different from zero at the 1%,5%,10% level.
†Percent change = coefficient estimate ÷ mean value of the outcome × 100%.

Table 4: Effect of pollen levels on the number of 911 calls controlling for alternative fixed effects in Seattle, Washington 2009-2024

Specification →	(1)	(2)	(3)	(4)
		Panel A: Logarithm of pollen		
Pollen	9.898***	11.477***	9.898***	10.371***
	(2.330)	(3.271)	(2.330)	(2.336)
Mean	1818.6	1818.6	1818.6	1818.6
Percent change†	0.544	0.631	0.544	0.570
		Panel B: Pollen level		
Pollen	0.032**	0.075***	0.032**	0.038***
	(0.014)	(0.021)	(0.014)	(0.014)
Mean	1818.6	1818.6	1818.6	1818.6
Percent change†	0.002	0.004	0.002	0.002
Weather controls	✓	✓	✓	✓
Wind direction	✓	✓	✓	✓
Fixed effects:				
Day-of-week-by-month	✓	×	✓	×
Month-by-year	✓	×	✓	✓
Month-by-day	✓	✓	×	×
Week	×	✓	×	×
Year	×	✓	×	×
Day-by-week	×	×	×	✓
Month	×	×	×	✓
Observations	2838	2838	2838	2838

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This table reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls. The pollen variable is log-transformed in Panel A and in levels in Panel B, winsorized at the 95th percentile in the latter. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects as indicated. The outcome variables are the number of calls per day. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Standard errors reported in parentheses.
***,**,* = statistically different from zero at the 1%,5%,10% level.
†Percent change = coefficient estimate ÷ mean value of the outcome × 100%.

Table 5: Effect of pollen levels on the number of 911 calls including lead and lags in pollen levels in Seattle, Washington 2009-2024

Specification →	(1)	(2)	(3)	(4)
		Panel A: Logarithm of pollen		
Pollen (current)	9.898***	10.205***	10.390***	10.471***
	(2.330)	(2.337)	(2.349)	(2.352)
Pollen (7-day lead)		0.615		0.863
		(2.200)		(2.212)
Pollen (7-day lag)		-1.696		-1.645
		(2.071)		(2.088)
Pollen (14-day lead)			1.739	1.593
			(2.242)	(2.253)
Pollen (14-day lag)			2.176	2.293
			(2.116)	(2.122)
Mean value of outcome	1818.6	1818.6	1818.6	1818.6
		Panel B: Pollen level		
Pollen (current)	0.032**	0.034**	0.033**	0.034**
	(0.014)	(0.014)	(0.014)	(0.014)
Pollen (7-day lead)		0.621		0.843
		(2.206)		(2.219)
Pollen (7-day lag)		-1.795		-1.776
		(2.087)		(2.105)
Pollen (14-day lead)			1.283	1.130
			(2.246)	(2.256)
Pollen (14-day lag)			2.026	2.146
			(2.122)	(2.128)
Mean value of outcome	1818.6	1818.6	1818.6	1818.6
Weather controls	✓	✓	✓	✓
Wind direction	✓	✓	✓	✓
Fixed effects:				
Day-of-week-by-month	✓	✓	✓	✓
Month-by-year	✓	✓	✓	✓
Month-by-day	✓	✓	✓	✓
Observations	2838	2838	2838	2838

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This table reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls, sample sizes differ across specifications as singletons are excluded. The pollen variable is log-transformed in Panel A and in levels in Panel B, winsorized at the 95th percentile in the latter. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects as indicated. The outcome variables are the number of calls per day. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Standard errors reported in parentheses.
***,**,* = statistically different from zero at the 1%,5%,10% level.

Table 6: Effect of pollen levels on average 911 calls response times in minutes in Seattle, Washington 2009-2024

Sample →	(1) All	(2) Officer	(3) Civilian
		Panel A: Logarithm of pollen	
Pollen	0.069	0.005	0.076
	(0.099)	(0.009)	(0.124)
Mean	25.78	0.074	35.31
Percent change†	0.268	6.622	0.215
		Panel B: Pollen level	
Pollen	0.0003	-0.00001	0.0003
	(0.0006)	(0.0001)	(0.0007)
Mean	25.78	0.074	35.31
Percent change†	0.001	0.0001	0.001
Weather controls	✓	✓	✓
Wind direction	✓	✓	✓
Fixed effects:			
Day-of-week-by-month	✓	✓	✓
Month-by-year	✓	✓	✓
Month-by-day	✓	✓	✓
Observations	2369	2369	2369

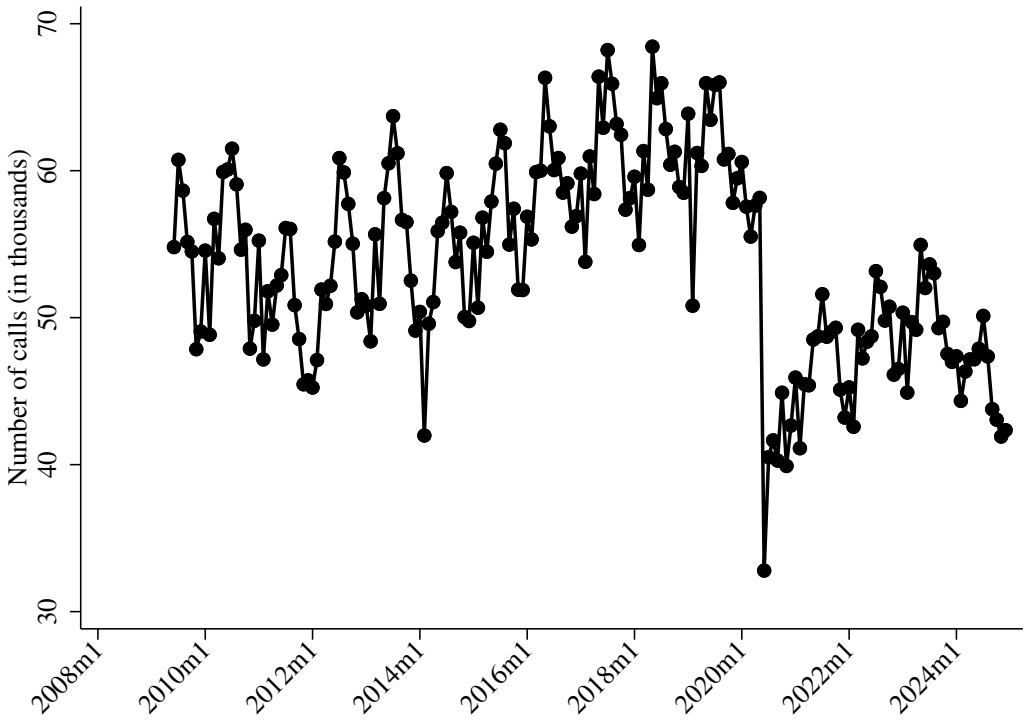
Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This table reports coefficient estimates from regressions of 911 call response times on pollen levels and other controls. The pollen variable is log-transformed in Panel A and in levels in Panel B, winsorized at the 95th percentile in the latter. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects as indicated. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Standard errors reported in parentheses.
***,**,* = statistically different from zero at the 1%,5%,10% level.
†Percent change = coefficient estimate ÷ mean value of the outcome × 100%.

Table 7: Effect of pollen levels on the number of 911 calls with missing arrival time or connections in Seattle, Washington 2009-2024

Outcome ↓	(1) Logarithm	(2) Level
Panel A: All calls	9.898***	0.032**
	(2.330)	(0.014)
Mean	1818.6	1818.6
Percent change†	0.544	0.002
Panel B: Missing connections	2.512***	0.009***
	(0.570)	(0.003)
Mean	217.43	217.43
Percent change†	1.155	0.004
Canceled calls	0.394*	0.001
	(0.232)	(0.001)
Mean	41.87	41.87
Percent change†	0.941	0.003
False calls	0.208	-0.002
	(0.242)	(0.002)
Mean	43.99	43.99
Percent change†	0.473	-0.004
Unable to locate	1.910***	0.009***
	(0.426)	(0.003)
Mean	131.56	131.56
Percent change†	1.452	0.007
Panel C: Missing arrival time	1.347***	0.005**
	(0.354)	(0.002)
Mean	114.66	114.66
Percent change†	1.175	0.004
Panel D: Missing connections &	0.549***	0.002
missing arrival time	(0.204)	(0.001)
Mean	42.51	42.51
Percent change†	1.292	0.004
Weather controls	✓	✓
Wind direction	✓	✓
Fixed effects:		
Day-of-week-by-month	✓	✓
Month-by-year	✓	✓
Month-by-day	✓	✓
Observations	2838	2838

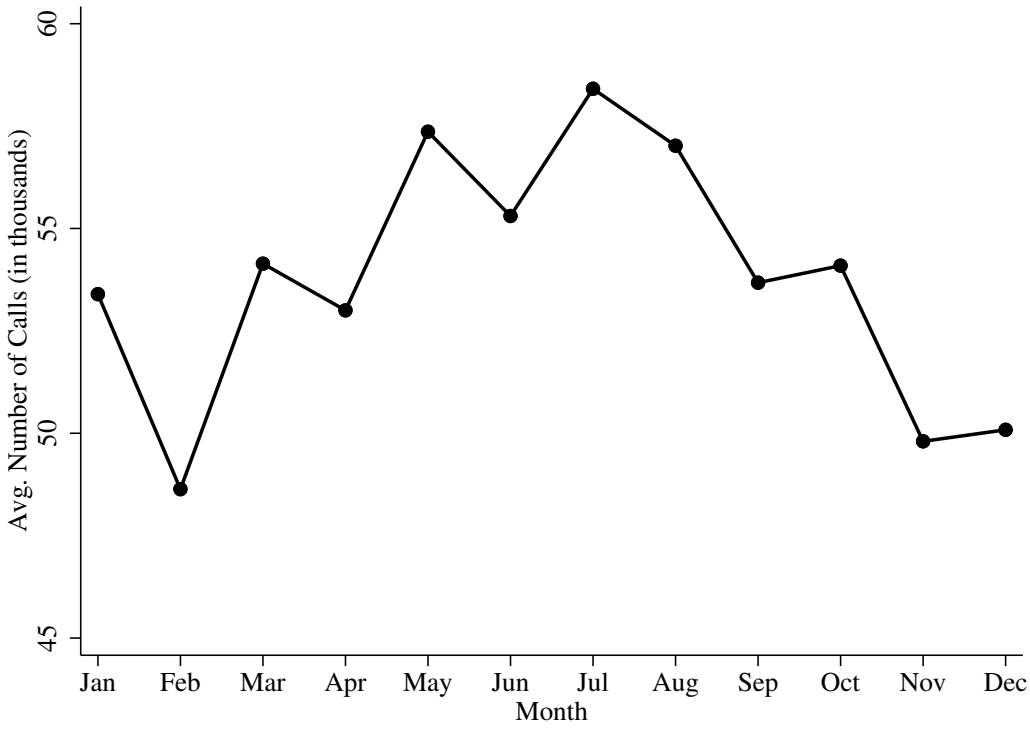
Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This table reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls. The pollen variable is log-transformed in column 1 and in levels in column 2, winsorized at the 95th percentile in the latter. All regressions include weather controls, wind directions, and fixed effects: day-of-week-by-month, month-by-year, and month-by-day fixed effects. The unit of observation is a day-month-year. Data are unweighted. Standard errors are reported in parentheses.
***,**,* = statistically different from zero at the 1%, 5%, 10% level.
†Percent change = coefficient estimate ÷ mean value of the outcome × 100%.

Figure A1: Number of 911 calls by month-year in Seattle, Washington 2009-2024



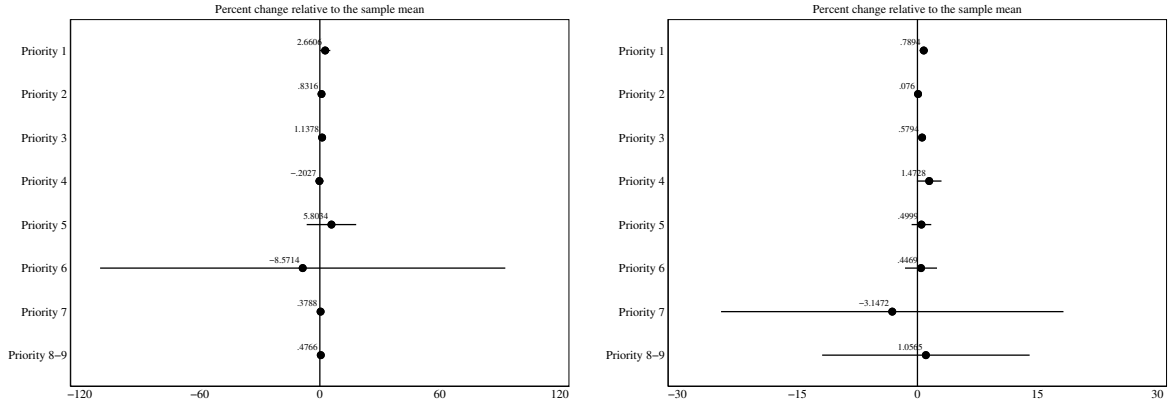
Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This figure shows the number of 911 calls by calls by month and year. The data ranges from June 2009 to December 2024.

Figure A2: Average number of 911 calls by month in Seattle, Washington 2009-2024



Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This figure shows the number of 911 calls by calls by month.

Figure A3: Effect of pollen levels on the number of 911 calls allowing for heterogeneity by call priority in calls initiated by police officers and civilians in Seattle, Washington 2009-2024

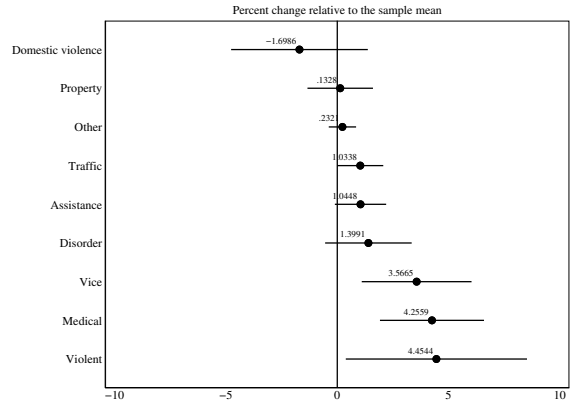


(a) Officer report

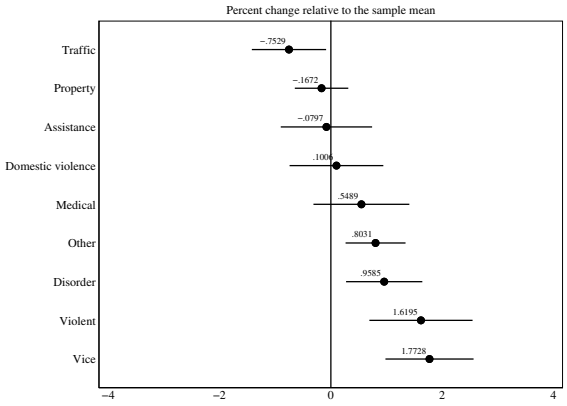
(c) Civilian report

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This figure reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls. 911 call priority is reported on type on the y-axis. The data source is the Seattle Police Department Communications Center. The pollen variable is log-transformed. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and day-of-week-by-month, month-by-year, and month-by-day fixed effects. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Coefficient estimates are reported in circles, and 95% confidence intervals are reported with vertical lines. Coefficient estimates and 95% confidence intervals (X) are converted to the percent change as follows: $X \div sample\,mean \times 100\%$.

Figure A4: Effect of pollen levels on the number of 911 calls allowing for heterogeneity by call type in calls initiated by police officers and civilians in Seattle, Washington 2009-2024



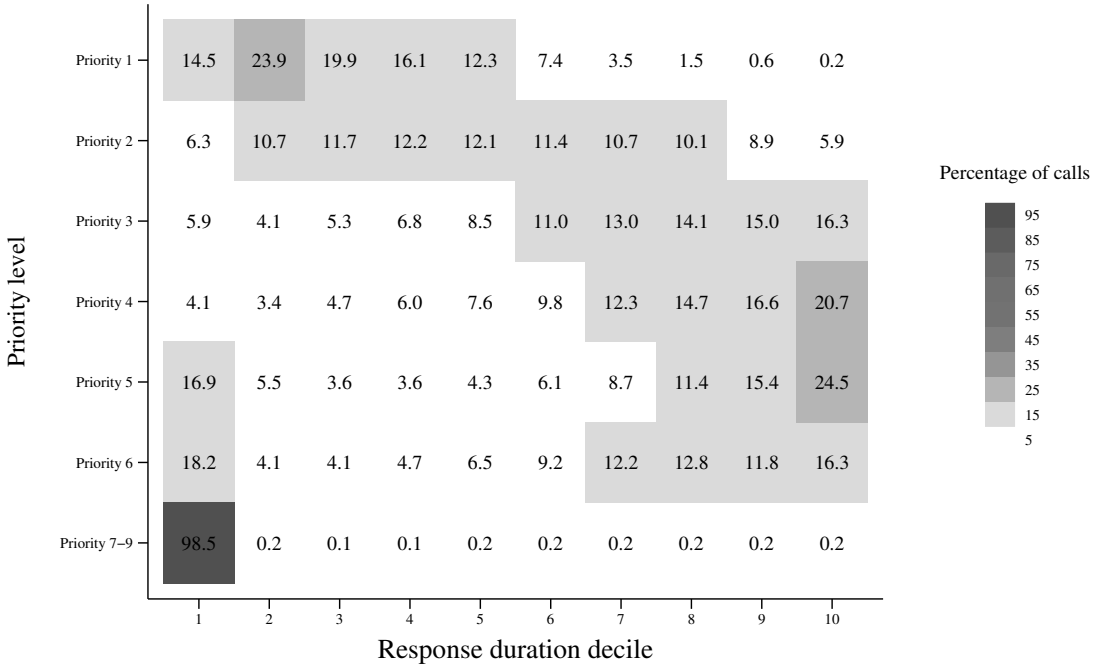
(a) Officer report



(c) Civilian report

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This figure reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls. 911 call priority is reported on type on the y-axis. The data source is the Seattle Police Department Communications Center. The pollen variable is log-transformed. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and day-of-week-by-month, month-by-year, and month-by-day fixed effects. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Coefficient estimates are reported in circles, and 95% confidence intervals are reported with vertical lines. Coefficient estimates and 95% confidence intervals (X) are converted to the percent change as follows: $X \div sample\,mean \times 100\%$.

Figure A5: Response time duration by priority level in Seattle, Washington 2009-2024



Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This figure shows the proportion of call priority categorization by decile of response time. Priority levels 7 through 9 combined into a single category due to small number of calls and preponderance of first decile duration.

Table A1: Categorized service calls in Seattle, Washington 2009-2024: Examples

Call category ↓	Example service calls
Vice	Detoxification, gambling, liquor violation, narcotics found
Disorder	Disturbance, lewd (e.g., exposing), nuisance mischief, panhandling
Domestic violence	Fight in person physical/no weapons, child abuse or neglect, custodial interference, violation of divorce court order
Assistance	Injured person - industrial accident, rescue of person, service welfare check, tree down & obstructing public property
Medical	Accident-unknown injuries, accident-known injuries, burn, sick person, mental crisis complaint, mental person or pickup/transport, person in behavioral/emotional crisis, suicide attempt/suicidal person
Violent	Fight with weapons, person shot, purse snatch, rape
Property & financial	Auto recovery, auto theft, motivated crimes, commercial burglary, residential burglary
Traffic	Hit & run, parking violation, pedestrian violation, traffic blocking roadway
Other	Assisted duty court, elementary school visit, missing adult, prisoner escape

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This table reports example call types for each service category.

Table A2: Characteristics of 911 calls volumes and response time aggregated to day in Seattle, Washington 2009-2024

Sample →	All Days	Days <Median	Days in 1st quartile	Days ≥Median	Days in 4th quartile
Calls	1818.6	1847.3	1843.3	1789.1	1771.3
Officer-initiated call	530.62	546.58	540.08	514.21	505.23
Person-initiated calls	1226.1	1239.4	1242.0	1212.4	1203.2
Mean priority	3.110	3.150	3.150	3.070	3.060
Priority 1	401.88	400.18	400.59	403.63	405.48
Priority 2	495.16	491.91	492.64	498.49	497.94
Priority 3	512.17	529.03	528.70	494.84	485.27
Priority 4	39.39	43.14	42.60	35.55	32.75
Priority 5	32.40	30.82	30.56	34.03	34.15
Priority 6	9.290	10.340	10.070	8.210	7.280
Priority 7	275.76	286.03	280.46	265.19	259.25
Priority 8-9	52.31	55.70	57.55	48.83	48.83
Response time	25.78	25.45	25.65	26.12	26.10
Response time (>0)	35.38	35.20	35.35	35.57	35.47
Observations	2882	1461	765	1421	719

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This table reports mean values. Data are unweighted.

Table A3: Call types on high and low pollen days in Seattle, Washington 2009-2024

	All				≤Median				>Median			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Calls	1818.6	253.51	721.00	2580.0	1847.3	248.53	785.00	2580.0	1789.1	255.27	721.00	2517.0
Officer-initiated calls	530.62	164.83	89.00	1147.0	546.58	163.59	91.00	1147.0	514.21	164.56	89.00	949.00
Person-initiated calls	1226.1	153.54	578.00	1717.0	1239.4	154.76	655.00	1717.0	1212.4	151.12	578.00	1674.0
Mean priority	3.110	0.360	2.160	4.130	3.150	0.350	2.230	4.130	3.070	0.360	2.160	4.120
Priority 1	401.88	90.02	151.00	730.00	400.18	89.13	152.00	730.00	403.63	90.93	151.00	694.00
Priority 2	495.16	86.41	248.00	806.00	491.91	83.60	258.00	761.00	498.49	89.12	248.00	806.00
Priority 3	512.17	111.13	126.00	797.00	529.03	104.20	126.00	797.00	494.84	115.33	138.00	767.00
Priority 4	39.39	20.40	2.000	243.00	43.14	21.14	3.000	243.00	35.55	18.85	2.000	175.00
Priority 5	32.40	17.97	0.0001	108.00	30.82	17.80	0.0001	108.00	34.03	18.00	0.0001	103.00
Priority 6	9.290	12.69	0.0001	78.00	10.340	13.08	0.0001	78.00	8.210	12.19	0.0001	68.00
Priority 7	275.76	123.11	17.00	739.00	286.03	125.71	17.00	739.00	265.19	119.51	19.00	623.00
Priority 8	0.0001	0.040	0.0001	1.000	0.0001	0.050	0.0001	1.000	0.0001	0.030	0.0001	1.000
Priority 9	52.31	32.57	1.000	301.00	55.70	33.86	3.000	301.00	48.83	30.81	1.000	182.00
Response time	25.78	11.37	7.080	94.80	25.45	10.780	7.080	88.03	26.12	11.94	8.150	94.80
Response time (>0)	35.38	13.11	13.09	114.28	35.20	12.49	13.09	114.28	35.57	13.71	14.25	109.78
Observations	2882				1461				1421			

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This table reports mean values. Data are unweighted. SD = standard deviation. Min = minimum. Max = maximum.

Table A4: Effect of pollen levels on the number of 911 calls allowing for polynomials in pollen levels in Seattle, Washington 2009-2024

Specification →	(1)	(2)	(3)
		Panel A: Logarithm of pollen	
Pollen	9.898***	10.496***	11.44***
	(2.330)	(2.388)	(2.388)
Pollen squared		0.0001	
		(0.0001)	
Pollen_{-1}			-0.015***
			(0.006)
Mean value of outcome	1818.6	1818.6	1818.6
		Panel B: Pollen level	
Pollen	0.032**	0.035**	0.045***
	(0.014)	(0.015)	(0.015)
Pollen squared		0.0001	
		(0.0001)	
Pollen_{-1} (level)			-0.014**
			(0.006)
Mean value of outcome	1818.6	1818.6	1818.6
Weather controls	✓	✓	✓
Wind direction	✓	✓	✓
Fixed effects:			
Day-of-week-by-month	✓	✓	✓
Month-by-year	✓	✓	✓
Month-by-day	✓	✓	✓
Observations	2838	2838	2837

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This table reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls. The pollen variable is log-transformed in Panel A and in levels in Panel B, winsorized at the 95th percentile in the latter. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects as indicated. The outcome variables are the number of calls per day. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Standard errors are reported in parentheses.
***,**,* = statistically different from zero at the 1%,5%,10% level.

Table A5: Effect of pollen levels on the number of 911 calls using quartiles of the pollen distribution in Seattle, Washington 2009-2024

Specification →	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Seasonal pollen quartiles			
2nd	17.83***					
	(6.803)					
3rd	37.54***					
	(7.605)					
4th	46.79***		18.05***		15.11**	
	(9.010)		(6.711)		(6.615)	
			Panel B: Global pollen quartiles			
2nd		20.49***				
		(7.757)				
3rd		31.40***				
		(8.687)				
4th		50.27***		24.31***		21.05***
		(10.143)		(7.132)		(7.050)
Pollen_{-1}	-0.012**	-0.012**	-0.011**	-0.012**		
	(0.005)	(0.005)	(0.005)	(0.005)		
Mean value of outcome	1818.6	1818.6	1818.6	1818.6	1818.6	1818.6
Weather controls	✓	✓	✓	✓	✓	✓
Wind direction	✓	✓	✓	✓	✓	✓
Fixed effects:						
Day-of-week-by-month	✓	✓	✓	✓	✓	✓
Month-by-year	✓	✓	✓	✓	✓	✓
Month-by-day	✓	✓	✓	✓	✓	✓
Observations	2837	2837	2837	2837	2838	2838

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This table reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls. The pollen variable is transformed into four quartiles; in Panel A, the quartiles are relative to same season; in Panel B, the quartiles are relative to all observations. Coefficient estimates are relative to Q1. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects as indicated. The outcome variables are the number of calls per day. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Standard errors are reported in parentheses.
***,**,* = statistically different from zero at the 1%,5%,10% level.

Table A6: Effect of pollen levels on the number of 911 calls using alternative assumptions about standard errors in Seattle, Washington 2009-2024

Alternative standard errors →	Main	Robust	Season-year	Month-year
		Panel A: Logarithm of pollen		
Pollen	9.898***	9.898***	9.898***	9.898***
	(2.330)	(2.221)	(2.711)	(2.677)
Mean value of outcome	1818.6	1818.6	1818.6	1818.6
Percent change†	0.544	0.544	0.544	0.544
		Panel B: Pollen level		
Pollen	0.032**	0.032**	0.032*	0.032**
	(0.014)	(0.013)	(0.017)	(0.016)
Mean value of outcome	1818.6	1818.6	1818.6	1818.6
Percent change†	0.002	0.002	0.002	0.002
Weather controls	✓	✓	✓	✓
Wind direction	✓	✓	✓	✓
Fixed effects:				
Day-of-week-by-month	✓	✓	✓	✓
Month-by-year	✓	✓	✓	✓
Month-by-day	✓	✓	✓	✓
Observations	2838	2838	2838	2838

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: Column (1) is our preferred standard error estimation (homoskedastic). Column (2) reports robust standard errors. Column (3) reports standard errors clustered at the season-year level. Column (4) reports standard errors clustered at the month-year level. This table reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls, sample sizes differ across specifications as singletons are excluded. The pollen variable is log-transformed in Panel A and in levels in Panel B, winsorized at the 95th percentile in the latter. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects as indicated. The outcome variables are the number of calls per day. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Standard errors reported in parentheses.
***,**,* = statistically different from zero at the 1%,5%,10% level.
†Percent change = coefficient estimate ÷ mean value of the outcome × 100%.

Table A7: Effect of pollen levels on the number of 911 calls restricting to alternative pollen periods in Seattle, Washington 2009-2024

Pollen period →	Main	Pollen > 0	Spring & summer	Exclude 2020+
		Panel A: Logarithm of pollen		
Pollen	9.898***	12.41***	10.335***	9.704***
	(2.330)	(2.607)	(2.733)	(2.300)
Mean value of outcome	1818.6	1817.2	1827.6	1818.6
Percent change†	0.544	0.683	0.566	0.534
		Panel B: Pollen level		
Pollen	0.032**	0.040***	0.036**	0.037***
	(0.014)	(0.014)	(0.015)	(0.014)
Mean value of outcome	1818.6	1817.2	1827.6	1818.6
Percent change†	0.002	0.002	0.002	0.002
Weather controls	✓	✓	✓	✓
Wind direction	✓	✓	✓	✓
Fixed effects:				
Day-of-week-by-month	✓	✓	✓	✓
Month-by-year	✓	✓	✓	✓
Month-by-day	✓	✓	✓	✓
Observations	2838	2706	2397	2633

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This table reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls, sample sizes differ across specifications as singletons are excluded. The pollen variable is log-transformed in Panel A and in levels in Panel B, winsorized at the 95th percentile in the latter. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects as indicated. The outcome variables are the number of calls per day. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Standard errors reported in parentheses.
***,**,* = statistically different from zero at the 1%,5%,10% level.
†Percent change = coefficient estimate ÷ mean value of the outcome × 100%.

Table A8: Effect of pollen levels on the number of 911 calls allowing for heterogeneity by type of pollen in Seattle, Washington 2009-2024

Specification →	(1)	(2)	(3)
		Panel A: Logarithm of pollen	
Total pollen	9.898***		-9.494
	(2.330)		(9.677)
Grass/weed pollen		8.940***	11.12***
		(3.290)	(3.970)
Tree pollen		8.453***	17.19*
		(2.380)	(9.219)
Mean value of outcome	1818.6	1818.6	1818.6
		Panel B: Pollen level	
Total pollen	0.032**		0.042**
	(0.014)		(0.019)
Grass/weed pollen		0.360**	0.322**
		(0.142)	(0.143)
Tree pollen		0.003	-0.008
		(0.005)	(0.007)
Mean value of outcome	1818.6	1818.6	1818.6
Weather controls	✓	✓	✓
Wind direction	✓	✓	✓
Fixed effects:			
Day-of-week-by-month	✓	✓	✓
Month-by-year	✓	✓	✓
Month-by-day	✓	✓	✓
Observations	2838	2816	2816

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: This table reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls. The pollen variable is log-transformed in Panel A and in levels in Panel B, winsorized at the 95th percentile in the latter. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects as indicated. The outcome variables are the number of calls per day. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Standard errors reported in parentheses.
***,**,* = statistically different from zero at the 1%,5%,10% level.

Table A9: Effect of pollen levels on the number of 911 calls alternative approaches to controlling for weather in Seattle, Washington 2009-2024

Specification →	(1)	(2)	(3)	(4)	(5)
			Panel A: Logarithm of pollen		
Pollen	9.898***	9.678***	9.738***	9.945***	9.920***
	(2.330)	(2.329)	(2.375)	(2.373)	(2.332)
Wind direction (91-180)	-14.53	-8.960	-8.296	-8.981	-9.989
	(8.846)	(8.277)	(8.395)	(8.392)	(8.284)
Wind direction (181-270)	-10.38	-5.629	-0.846	-2.839	-5.610
	(8.073)	(5.855)	(6.101)	(5.995)	(5.866)
Wind direction (271-360)	-4.684				
	(8.449)				
Wind speed top quartile		-22.73***			
		(8.614)			
PM2.5 above median			12.60**		
			(5.738)		
PM2.5 top quartile				9.647	
				(6.564)	
Air Quality Index > 101					15.81
					(18.07)
Mean value of outcome	1818.6	1818.6	1818.6	1818.6	1818.6
			Panel B: Pollen level		
Pollen	0.032**	0.032**	0.034**	0.035**	0.033**
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Wind direction (91-180)	-16.64*	-11.02	-10.415	-11.15	-12.15
	(8.940)	(8.277)	(8.391)	(8.388)	(8.284)
Wind direction (181-270)	-12.21	-7.461	-2.459	-4.581	-7.488
	(8.143)	(5.846)	(6.100)	(5.989)	(5.858)
Wind direction (271-360)	-4.639				
	(8.546)				
Wind speed top quartile		-23.79***			
		(8.630)			
PM2.5 above median			13.47**		
			(5.751)		
PM2.5 top quartile				10.732	
				(6.572)	
Air Quality Index > 101					16.80
					(18.14)
Mean value of outcome	1818.6	1818.6	1818.6	1818.6	1818.6
Percent change†	0.002	0.002	0.002	0.002	0.002
Weather controls	✓	✓	✓	✓	✓
Wind direction	✓	✓	✓	✓	✓
Fixed effects:					
Day-of-week-by-month	✓	✓	✓	✓	✓
Month-by-year	✓	✓	✓	✓	✓
Month-by-day	✓	✓	✓	✓	✓
Observations	2838	2838	2760	2760	2837

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: Column (1) is the main specification showing coefficients on wind direction quadrants. Column (2) in addition to main specification, controls for an indicator for wind speed being in the top quartile. Column (3) in addition to main specification, controls for an indicator for PM2.5 being above the median. Column (4) in addition to main specification, controls for an indicator for PM2.5 being in the top quartile. Column (5) in addition to main specification, controls for an indicator for AQI being above 101. This table reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls, sample sizes differ across specifications as singletons are excluded. The pollen variable is log-transformed in Panel A and in levels in Panel B, winsorized at the 95th percentile in the latter. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), and fixed effects as indicated. The outcome variables are the number of calls per day. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Standard errors reported in parentheses. ***,**,* = statistically different from zero at the 1%,5%,10% level.
†Percent change = coefficient estimate ÷ mean value of the outcome × 100%.

Table A10: Effect of pollen levels on the number of 911 calls alternative approaches to controlling for weather in Seattle, Washington 2009-2024

Specification →	(1)	(2)	(3)	(4)
		Panel A: Logarithm of pollen		
Pollen	9.703***	12.56***	10.205***	9.904***
	(3.605)	(2.816)	(2.509)	(2.336)
Pollen (logarithm)				
× Wind speed top quartile	-2.259			
	(1.820)			
× Wind direction (91-180)	0.604			
	(4.418)			
× Wind direction (181-270)	1.413			
	(4.060)			
× Wind direction (271-360)	0.634			
	(4.386)			
× PM2.5>median		-5.375*		
		(2.887)		
× PM2.5>Q4			-0.988	
			(3.085)	
× Air Quality Index>101				1.339
				(10.607)
Mean value of outcome	1818.6	1818.6	1818.6	1818.6
		Panel B: Pollen level		
Pollen	0.008	0.069***	0.047***	0.033**
	(0.021)	(0.019)	(0.016)	(0.014)
Pollen (level)				
× Wind speed top quartile	0.009			
	(0.023)			
× Wind direction (91-180)	0.048*			
	(0.029)			
× Wind direction (181-270)	0.024			
	(0.027)			
× Wind direction (271-360)	0.022			
	(0.032)			
× PM2.5>median		-0.060***		
		(0.021)		
× PM2.5>Q4			-0.036*	
			(0.021)	
× Air Quality Index>101				0.295
				(0.255)
Mean value of outcome	1818.6	1818.6	1818.6	1818.6
Percent change†	0.0004	0.004	0.003	0.002
Weather controls	✓	✓	✓	✓
Wind direction	✓	✓	✓	✓
Fixed effects:				
Day-of-week-by-month	✓	✓	✓	✓
Month-by-year	✓	✓	✓	✓
Month-by-day	✓	✓	✓	✓
Observations	2838	2760	2760	2837

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: Column (1): pollen is interacted with wind speed quartiles (Q2 = quartile 2, Q3 = quartile 3, and Q4 = quartile 4). Column (2): pollen is interacted with an indicator for PM2.5 being above median. Column (3): pollen is interacted with an indicator for PM2.5 being in the top quartile. Column (4): pollen is interacted with an indicator for the Air Quality Index being above 101. Main effects for interaction terms are included in the regression. This table reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls, sample sizes differ across specifications as singletons are excluded. The pollen variable is log-transformed in Panel A and in levels in Panel B, winsorized at the 95th percentile in the latter. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects as indicated. The outcome variables are the number of calls per day. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Standard errors reported in parentheses. ***,**,* = statistically different from zero at the 1%,5%,10% level.
†Percent change = coefficient estimate ÷ mean value of the outcome × 100%.

Table A11: Effect of pollen levels on the number of 911 calls accounting for capacity Seattle, Washington 2009-2024

Outcome →	Call difference	Call ratio
	Panel A: Logarithm of pollen	
Pollen	9.898***	0.004***
	(2.330)	(0.001)
Mean value of outcome	141.20	0.814
Percent change†	7.009	0.516
	Panel B: Pollen level	
Pollen	0.032**	0.0001**
	(0.014)	(0.0001)
Mean value of outcome	140.96	0.814
Percent change†	0.023	0.0001
Weather controls	✓	✓
Wind direction	✓	✓
Fixed effects:		
Day-of-week-by-month	✓	✓
Month-by-year	✓	✓
Month-by-day	✓	✓
Observations	2838	2838

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.
Notes: Call difference = number of calls − winter-season average number of calls on the respective weekday. Call ratio = number of calls / winter-season maximum number of calls on the respective weekday. This table reports coefficient estimates from regressions of 911 call volumes on pollen levels and other controls, sample sizes differ across specifications as singletons are excluded. The pollen variable is log-transformed in Panel A and in levels in Panel B, winsorized at the 95th percentile in the latter. All regressions include weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed), wind directions, and fixed effects as indicated. The outcome variables are the number of calls per day. The unit of observation is a day-month-year. Data are unweighted. Regressions estimated with OLS. Standard errors reported in parentheses. ***,**,* = statistically different from zero at the 1%,5%,10% level.
†Percent change = coefficient estimate ÷ mean value of the outcome × 100%.

Table A12: Effect of pollen levels on the number of 911 calls addressing measurement error with an instrumental variable approach in Seattle, Washington 2009-2024

	(1) First stage	(2) IV	(3) IV controls
		Panel A: Logarithm of pollen	
Grass/weed pollen	0.017***		
	(0.001)		
Pollen		35.67***	26.57**
		(8.507)	(10.53)
First-stage F-stat	181.36		
Pre-treatment mean		1818.6	1818.6
Percent change (%)		1.962	1.461
		Panel B: Pollen level	
Grass/weed pollen	1.416***		
	(0.216)		
Pollen		0.428***	0.421**
		(0.114)	(0.190)
First-stage F-stat	42.94		
Pre-treatment mean		1818.6	1818.6
Percent change (%)		0.024	0.023
Weather controls	×	×	✓
Wind direction	×	×	✓
Fixed effects:			
Day-of-week-by-month	✓	✓	✓
Month-by-year	✓	✓	✓
Month-by-day	✓	✓	✓
Observations	2838	2838	2838

Source: Seattle Police Department Communication Center 911 Data, National Allergy Bureau, 2009-2024.

Notes: Column (1) reports the first-stage regression of pollen on grass/weed pollen. Columns (2) and (3) report IV estimates; column (3) includes the full set of controls.The pollen variable is log-transformed in Panel A and in levels in Panel B, winsorized at the 95th percentile in the latter. All regressions include fixed effects: day-of-week-by-month, month-by-year, and month-by-day fixed effects. Column (3) additionally includes weather controls (mean/min/max temperature, dew point, vapor point, precipitation, and wind speed) and wind directions. The outcome variable is the number of calls per day. The unit of observation is a day-month-year. Data are unweighted. Standard errors reported in parentheses.
***,**,* = statistically different from zero at the 1%, 5%, 10% level.