More Sneezing, Less Crime? Seasonal Allergies, Transitory Costs and the Market for Offenses

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Abstract

The neoclassical economic model of crime envisions crime as a gamble undertaken by a rational individual who is weighing the costs and benefits of offending at the margin. A large literature estimates the sensitivity of crime to policy inputs that shift the cost of offending such as police and prisons. In this paper, we point out that participants in the market for offenses also respond to transitory changes in situational factors and that these are in constant flux. We consider the responsiveness of crime to a pervasive and common health shock which we argue shifts costs and benefits for offenders and victims: seasonal allergies. Leveraging daily variation in city-specific pollen counts, we present novel evidence that violent crime declines in U.S. cities on days in which the local pollen count is unusually high and that these effects are driven by residential violence. While past literature suggests that property crimes have more instrumental motives, require planning, and hence are particularly sensitive to permanent changes in the cost and benefits of crime, we find evidence that violence may be especially sensitive to situational factors.

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1. Introduction

The neoclassical economic model of crime laid out in Becker's seminal contribution to the economics of crime literature envisions crime as a gamble undertaken by a rational individual who is weighing the costs and benefits of offending at the margin.[1] The cost and therefore the supply of offending is understood to be a function of the certainty and severity of criminal sanctions. On the demand side of the market, a victim's "demand" for crime is a function of the marginal costs and benefits of investments in precaution – a category that includes capital investments (e.g., locks or surveillance cameras) as well as changes in routine activities that raise offender search costs (Ehrlich 1996). The supply and demand schedules for crime interact to generate, at equilibrium, a socially optimal quantity of offending.

While a large literature examines the sensitivity of crime to policy inputs that potentially shift costs and benefits and can be readily manipulated by a social planner,[2] this study focuses on the effect of an input that is not directly manipulated by a social planner: transitory fluctuations in pollen. Among the many examples of the studies that focus on changes manipulated by a social planner are literatures that consider the effect of increases in police resources (DiTella and Schargrodsky 2004; Helland and Tabarrok 2004; Evans and Owens 2006; Weisburd 2016; Chalfin and McCrary 2017), gun control laws (Bronar and Lott 1998; Duggan 2001; Donohue, Aneja and Weber 2017) capital punishment regimes (Ehrlich 1973, 1977; Katz, Levitt and Shustorovich 2003; Mocan and Gittings 2003; Donohue and Wolfers 2006) and harsher sanctions (Helland and Tabbarok 2007; Drago and Galbiati 2012; Lee and McCrary 2017). Recent research also examines the effect of policy interventions that address victim behavior by

[1] Discussions of the costs and benefits of offending can be found in early treatises on the subject by Beccaria (1758) and Bentham (1793) and later extensions by Ehrlich (1973), Shavell (1991) and McCrary (2010) among others.
[2] See Chalfin and McCrary (2017) for a review of the deterrence literature in economics.

changing the costs and benefits of private precautions – for example, business improvement districts (Cook and MacDonald 2011), insurance against terrorism risk (Lakdawalla and Zanjani 2005) and the availability of ride sharing apps that make it easier for victims to avoid the risk of street crimes (Dills and Mulholland 2018).

While policy regimes sometimes shift in response to legislation or new technology, they are typically constant, evolving slowly over time or shifting only occasionally. In most cases, an offender (victim) who goes to sleep in the evening faces the same policy regime and thus the same costs and benefits of offending (precaution) when he wakes up the next morning. In this sense, the costs of offending that are shifted by a social planner – or a technological shock – are essentially permanent or long-run costs. In this paper, we point out that participants in the market for offenses face transitory shocks to costs and benefits as well and that these are in constant flux. Examples of the transitory costs and benefits include changes in *situational* factors such as the weather, a potential offender or victim's daily health and well-being and the opportunity cost of alternate daily activities which could be enjoyed in lieu of crime. Given that market participants may be myopic or, at least, only boundedly rational, shifts in situational factors may be particularly relevant in the market for offenses, especially for offenses that do not require planning or do not have instrumental motives, such as violent offenses. Yet, despite the fact that violent crimes drive an outsize share of the social costs, the literature is mostly silent on the extent to which shocks to situational factors shocks explain variation in crime.

There are a number of reasons to think that transitory fluctuations in the environment (or, in the words of Ross and Nesbitt (1991), "the situation") can have surprisingly large effects on human behavior[3]. With respect to crime, previous research in economics, criminology and urban planning indicates that crime is sensitive to a number of situational factors including pollution levels (Herrnstadt et al. 2015, Bondy, Roth and Sager 2018), the availability of ambient light (Welsh and Farrington 2008; Doleac and Sanders 2015; Umbach, Raine and Ridgeway 2017; Chalfin, Hansen, Lerner and Parker 2018) and weather conditions including temperature and rainfall (Cohn 1990; Cohn and Rotton, 1997; Jacob, Lefgren and Moretti 2007; Ranson 2014; Blakeslee and Fishman 2014). A related literature shows that crime can be extraordinarily sensitive to emotional cues and situational factors that affect a potential offender's decision-making. For example, emergency calls for domestic violence increase in response to unexpected football losses (Card and Dahl 2009) and a large literature documents the sensitivity of violence to the availability of and the abuse of alcohol (Kaysen et al. 2007; Angelucci 2008; Carpenter and Dobkin 2015).

In this paper, we consider the responsiveness of crime to transitory fluctuations in the costs and benefits, and therefore the *net cost* of criminal activity that is generated by a pervasive and common health shock: seasonal allergies caused by exposure to environmental pollen. Pollen allergies affect up to 20 percent of the U.S. population, are a leading cause of absenteeism at work and are associated with symptoms that can be extremely debilitating, especially for young adults who are the age group that is at greatest risk to offend (Jauregui et al. 2009; Greiner et al. 2012). Leveraging daily variation in local pollen counts in fifteen U.S. cities, we present novel

[3] This principle can be seen in the eye-opening findings of Stanley Milgram's classic obedience studies and, more recently, in a host of policy-relevant applications that establish the incredible salience of situational "nudges" relative to the more enduring components of an individual's utility function (Bertrand, Mullainathan and Shafir 2007). For example, minor tweaks to a default rule can have dramatic effects on retirement savings (Madrian and Shea 2001; Thaler and Benartzi, 2012), organ donation (Johnson and Goldstein 2003) and the purchase of insurance (Johnson et al. 1993). Likewise, behavioral nudges have been found to reduce theft from public parks (Cialdini et al., 2006), littering (Thaler and Sunstein 2008) and energy usage (Schultz, 2007).

evidence that violent crime declines by approximately 4 percent on days in which the local pollen count is unusually high. While this might sound like a small behavioral response, it is on par with the change in crime that would be expected to accrue from a 10 percent increase in the size of a city's police force (Evans and Owens 2006; Chalfin and McCrary 2017). Interestingly, we do not find evidence of temporal displacement, indicating that market participants are not smoothing out their behavior over time.

We explore the mechanisms underlying this relationship using detailed microdata from New York City where violent crimes decrease by approximately 7 percent on high pollen days. Stratifying the results by the location of the incident, we show that high pollen counts lead to an especially large decrease in violent crimes which occur inside residential dwellings, crimes which typically involve violence between intimate partners or family members[4]. We examine outdoor activity on high pollen days, as proxied by the public's usage of Citibike, a bicycle rental service, and find suggestive evidence that fewer people are outdoors when pollen counts are high. This implies that the risk of residential violence, which is predominantly domestic assault or family violence, is even more sensitive to transitory health shocks than the previous analysis suggests. We conclude that violence is especially sensitive to shifts in situational factors brought about by a pervasive and credibly exogenous health shock[5]. This research suggests that while property crimes sometimes require planning and hence respond to permanent changes in incentives, violent crimes which typically require less planning may respond more to transitory shocks generated by situational factors.

[4] We separate indoor crimes into residential and non-residential indoor crimes since non-residential indoor crimes require individuals leaving their residence.

[5] These results add some nuance to the extant literature which has argued that property crimes are more rational than violent crimes in the sense that they are more responsive to changes in policy while violent crimes are more impulsive or irrational (Sjoquist 1973; Raphael and Winter-Ember 2001; Clarke and Cornish 2013).

Beyond exploring the sensitivity of violence to situational factors, this research also helps us to understand the long-run implications of global warming on social activity, given the sensitivity of pollen levels to changes in temperature (Shea, 2009; Ziska et al, 2011). While some consequences of global warming such as increases in temperature (Jacob et al, 2007) and increases in pollution levels (Hernstad et al, 2015) appear to result in increased crime, we present evidence that other factors affected by global warming such as increases in pollen levels may lead to a reduction in crime – at least in violent crime. This research thus documents that the increase in pollen levels may partially offset the effect of other climate circumstances on crime.

The remainder of the paper proceeds as follows. Section 2 provides an overview of the symptomology and incidence of seasonal pollen allergies in the United States. Section 3 presents the data used in the study, and discusses our choice of cities and measures of pollen. In Section 4 we discuss our estimation strategy. Section 5 presents results, Section 6 explores robustness and mechanisms and Section 7 concludes.

2. Background

Seasonal allergic rhinitis (SAR) is a highly prevalent and chronic medical condition which is triggered when an individual breathes in something he is allergic to such as dust, animal dander or pollen. SAR affects approximately 400 million people globally – and approximately 20 percent of the population in the developed world – with particularly strong impacts among children and young adults (Jauregui et al. 2009; Greiner et al. 2012).[6]

[6] Pollen allergies are especially prevalent and affect approximately 15%-20% of the general population in industrialized counties; among school-aged children the prevailing estimate is 25%-30% (Hansen, Evjenth and Holt, 2013; Selnes, Nystad, Bolle and Lund, 2005; Hovland, Riiser, Mowinckel , Carlsend and Carlsend, 2014; Meltzer et al. 2012).

SAR affects sensitive individuals by causing their immune systems to produce antibodies (e.g. histamine and cytokines) that cause inflammation of tissue and increased secretion of mucus as a response to pollen grains, which are easily spread by wind and insects as part of a plant's reproductive cycle (NIAID, 2012; Janeway et al, 2001). The most common visible allergic reactions to these antibodies are nasal congestion, watery eyes, irritated throat, itching, sneezing, and rhinorrhea (Greiner et al., 2012). However, SAR also leads to a number of non-visible downstream behavioral health outcomes and has been shown to affect cognitive ability, cause mood changes and fatigue (McAfoose and Baune 2009; Tashiro et al., 2002; Dowlati et al. 2008; Kronfol and Remick, 2000), lead to reduced quality of sleep, interrupted sleep and daytime somnolence (Santos, Pratt, Hanks, McCann and Craig, 2006; Craig, McCann, Guverich and Davies, 2004; Tashiro et al. 2002; McAfoose and Baune, 2009) and can have a deleterious impact on one's overall quality of life (Mir, Panjabi and Shah, 2012).

These symptoms impose costs upon individuals and generate substantial economic losses for society by reducing productivity and cognitive performance. In the medical literature, clinical studies have found that SAR causes impaired cognitive functioning, which is manifested in longer response times and reduced working memory (Marshall, O'Hara and Steinberg, 2000; Kremer, Den Hartog and Jolles, 2002; Wilken, Berkowitz and Kane, 2002; Marshall and Colon, 1993).[7] Social science research suggests that pollen allergies are responsible for a considerable amount of absenteeism at work generating annual productivity losses of approximately $600 per employee (Hellgren, Cervin, Nordling, Bergman and Cardell, 2010; Lamb et al. 2006). Effects

[7] Unlike pollution and other environmental factors, the effects of pollen are not endogenous in the sense that the effects of SAR cannot be fully reversed by taking medicine. Clinical studies find that once an individual is exposed to pollen, he or she will experience lower cognitive functioning whether or not they received medication because medicines that are used to treat SAR induce similar or even stronger effects on cognitive functioning as SAR, and this was the case for older generations of antihistamine treatments as well as the newer generation (Vuurman, Van Veggel, Uitewijk, Leutner and O'Hanlon, 1993; Jauregui et al., 2009)

on children are similar as SAR is thought to be responsible for approximately 2 million lost school days per year (Arrighi, Cook and Redding, 1996) as well as reduced performance on cognitively demanding tests (Walker et al, 2007, Bensnes, 2016). In a particularly influential paper, Marcotte (2015) uses National Allergy Bureau data from 2003 to 2012 combined with data from school districts in United States to test elementary school student performance on math and English language arts assessments, taking advantage of daily variation in local pollen counts. He finds that a one standard deviation in ambient pollen level reduces the percent of 3rd graders passing the tests by 0.2 to 0.4 standard deviations, an effect size which is nearly half as large as the black-white test score gap.[8]

With respect to crime, the literature thus suggests that pollen allergies could change the costs and benefits of offending through a number of different health-related mechanisms. While it is beyond the scope of this paper to pinpoint the physiological mechanisms that are most directly responsible for changes behavior, we note that a large literature in neuroscience and biology supports the idea that sick animals are less social and less aggressive than healthy animals in a variety of settings (Nelson and Chiavegatto 2001, Tonelli et al. 2009), a finding which is consistent with the idea that violent interactions are more costly when an individual is in poor health.

3. Data and Measures

The goal of this research is to understand whether the volume of crime in U.S. cities changes on days in which seasonal allergens are especially pervasive. To conduct the proposed analysis, we combine three distinct datasets. Pollen data are collected by members of the American Academy

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[8] Marcotte (2017) finds a similar result for school readiness among kindergarteners.

of Allergy Asthma and Immunology as part of the National Allergy Bureau (NAB). There are 74 pollen metering stations throughout the United States, with one, or at most two, metering stations per city. Of these, 26 stations gave us permission to use their data. Each station is certified by NAB to take pollen readings, by measuring three different sources of pollen: tree, grass, and weed. The composition of pollen varies by location, with elm, maple, alder, birch, and hickory among the most common tree pollens, and ragweed, mugwort, and plantains being most common weed pollen. Over 83% of total pollen count originates in tree pollen, with weed pollen being the next largest contributor. In the interest of simplicity and reducing measurement errors, we compute a measure of the total pollen count, summing over the three individual types.

The frequency of readings varies from station to station; in most locations measurements are taken several times each week, though readings are suspended during winter months in many stations as pollen counts are considerably lower, or nonexistent, in the winter. The location of the measurement station is determined, in practice, by the location of the AAAI member, sometimes in a central city location, but most frequently in a suburban area. The quality, frequency, and types of pollen vary between cities, but remain consistent across time for each station. The NAB suggests that pollen measurements are valid within a 20-mile radius of each station. However, testing the level and determinants of tree pollen across New York City, Weinberger et al. (2016) found that the percent of tree canopy within 0.5km radial buffer explained 39% of the variation in the level. They went on to conclude that the level and type of pollen is consistent across a larger geographical area, though varying substantially by amount of trees. In our main analysis, we include all stations within 30 miles of the city center and use a binary measure that captures very high exposure to pollen in order to reduce measurement error. To test the sensitivity of results to this choice, we re-estimate results using a "leave one out" sampling approach to show that results are robust to sample construction.

Airborne pollen is collected using a Burkard volumetric spore trap, with exposure periods running 24 hours. Trained counters conduct microscopic analysis of pollen, and counts are expressed in particles per cubic meter of air (Ito et al. 2015, Sheffield et al. 2011). It is not uncommon for a station's pollen count to be zero, especially in the winter but pollen counts can also be quite high – in excess of 40,000. Table 1 summarizes the data and indicates that the mean pollen count is 171.9 ppm (SD = 646.4). Pollen counts are lowest between the months of October and December and are highest in March, April and May. To remain consistent with previous literature and to reduce measurement errors, we use threshold effects of pollen (Ito et al. 2015, Sheffield et al. 2011). Accordingly, our primary measure of pollen intensity is dichotomous and captures the effect of an unusually high pollen count. Following Marcotte (2015, 2017), in our preferred specification, we use 1500 ppm as our threshold for a high pollen day. Table 1 indicates that 2.3% of the city-day cells are defined as days with unusually high pollen counts. However, to demonstrate that the results are not sensitive to this particular threshold, we re-estimate the results using other threshold levels such as whether a city-day observation in the top 90^{th}-99^{th} percentile in that city's distribution and the results remain robust.

We supplement data on pollen counts with data on local weather conditions scraped from the website, *Weather Underground*. The weather conditions include the mean, minimum, and maximum daily temperature, precipitation (in inches), humidity and the lunar phase (the percentage of available moonlight). While all subsequent regression models control for weather conditions, we note that pollen counts are not highly correlated with other weather conditions such as temperature and rainfall. Indeed a regression of the pollen count on the vector of weather variables mentioned above yields an R-squared value of just 0.3%.

In order to test the sensitivity of crime to changes in exposure to environmental allergens, we require daily crime data which are unavailable in the Federal Bureau of Investigation's *Uniform Crime Reports*, the primary national dataset used to measure crimes known to law enforcement in U.S. cities. We therefore obtain incident-level crime data from two different sources. First, we gather data from the National Incident Based Reporting System (NIBRS) for cities with pollen metering which are also located in states that report to NIBRS. The NIBRS is the sole centralized source of crime microdata in the United States and contains information on the type of crime, the incident time and date, the number of victims and details on the perpetrator when available. The NIBRS is therefore a far richer source of national crime data than the ubiquitous Uniform Crime Reports. However, a key disadvantage is that, to date, only thirty-two states consistently report to the NIBRS and states containing large U.S. cities are notoriously underrepresented. Indeed, neither California, Texas, New York, nor Illinois are NIBRS reporting states. We therefore augment NIBRS data with incident-level crime data for cities for which pollen counts and crime microdata are publicly available.[9] For each city, we aggregate the incident-level data to generate daily crime counts which we then match to pollen data.

The choice of cities to be included in this analysis is determined by the availability of pollen and crime data simultaneously. Since the pollen data imposes a constraint on the time-period of study for each city, we have an imbalanced panel from 2007 to 2016. Our analysis includes the following cities: Atlanta (GA), Austin (TX), Baltimore (MD), Bellevue (NE), Colorado Springs

[9] NIBRS cities include: Bellevue (NE), Dayton (OH), Louisville (KY), Knoxville (TN), Colorado Springs (CO), Greenville (SC), Kansas City (MO). The supplemental cities include: Atlanta, Seattle, Detroit, Rochester (NY), Austin, St. Louis, Baltimore and Kansas City.

(CO), Dayton (OH), Detroit (MI), Greenville (SC), Kansas City (MO), Knoxville (TN), Louisville (KY), New York (NY), Seattle (WA), St. Louis (MO), and Twin Falls (MN). Because each city has a different number of pollen readings, we re-weight subsequent regression models so that each city is weighted equally in the analysis regardless of the number of available pollen measurements. Overall, the analysis is based on fifteen cities and 19,752 days with available pollen counts. Referring to Table 1, daily violent crime counts average 53 in our data, though the number varies substantially across cities. Property crimes average 108 per day, with similarly high variability across cities.

4. Econometric Methods

We leverage daily changes in pollen counts to estimate the effect of pollen exposure on crime using the following model:

$$Y_{iymd} = \alpha + \beta Pollen_{iymd} + X_{iymd} + V_{imd} + W_{iym} + \varepsilon_{iymd} \quad (1)$$

In (1), Y_{iymd} is the number of crimes (by type) for city *i* on day, *d*, month, *m*, and year, *y*. $Pollen_{iymd}$ is a dichotomous variable indicating whether the pollen count is "high," and X_{iymd} is a vector of controls for weather which include mean, minimum, and maximum temperature, precipitation, humidity, and lunar phase. V_{imd} are interacted city-month-day of week fixed effects and allows each city to have a different intercept by day of week and month. This allows us to account for the fact that crime varies by day of week and that day of week variation may also be seasonal. W_{iym} are interacted city-month-year fixed effects and account for city-specific time trends. The effect of a high pollen count on crime, β, is thus identified under stringent identifying assumptions.[10] To account for arbitrary serial correlation in the errors, standard errors are clustered at the city-month-year level.[11] To ensure the robustness of our results, we re-estimate (1) using a number of different pollen count thresholds as well as less stringent fixed effects, and also a specification that includes lagged high pollen indicator to account for potential temporal displacement of crime.

Given the differential nature of crimes against persons and property, we separate crime into violent and property crime categories, using the Federal Bureau of Investigation's standard categorization of index crimes. Violent crimes include homicide, forcible rape, robbery and aggravated assault; property crimes include burglary, larceny and motor vehicle theft. In cities that report data on simple (misdemeanor) assaults, we include these in the violent crime category since the distinction between aggravated and simple assaults is subject to departmental discretion and can therefore be blurry.

In an auxiliary analysis, we further separate violent and property crimes into residential and non-residential crimes using detailed microdata available in New York City where an unusual amount of relevant data are publicly available. Before separately identifying the effect of pollen on residential versus non-residential crimes, we explore changes in the level of outdoor activity as a potential mechanism through which pollen affects a city's crime rate. We measure outdoor activity using data from New York's Citibike system, a public bicycle rental program rolled out in May 2013 and find that Citibike usage declines on high pollen days. This helps us to better

[10] While individuals may choose whether to live in areas that can potentially be differentially affected by pollen, we assume that few individuals have the ability to sort into or out of a city on high pollen days.
[11] To account for the fact that different cities have different number of observations, we weight the regressions inversely by the number of observations.

understand subsequent analyses of the effect of seasonal allergens on residential versus non-residential crimes.

5. Results

We begin by providing evidence on the existence of a "first stage" relationship between exposure to high pollen counts and the incidence of physical symptoms among the affected population. In order to examine the effects of high pollen counts, we use publicly available Google trends data and test whether individuals are more likely to search for key words that relate to allergic rhinitis on days that have unusually high pollen. We begin the analysis by establishing the relationship between the indicator for unusually high pollen days and Google search results for New York City[12] for the following three sets of search terms: (1) seasonal allergies, (2) Benadryl or Claritin (the two most common seasonal allergy medications), and (3) runny nose, nasal congestion or watery eyes (the most common indicated symptoms of pollen allergies).

In order to generate testable hypotheses, we re-estimate (1) where the dependent variable is an index of Google searches on any given day in New York City. The index compares the number of daily searches to the highest daily search in the year for a given term. Therefore, the day with the highest number of searches of a term in a given year has an index of 100, and the number of searches for all other days in that year are expressed as a share thereof. An index value of 0 indicates no searches for the term on that day. For dependent variables with more than one term, we summed the indices. The independent variable is an indicator for high pollen. We present the estimates in Table 2. We find that searches for "seasonal allergies" and the most common physical symptoms of seasonal allergies (runny nose, nasal congestion, and watery

[12] While the main analysis focuses on all cities, we only explore potential mechanisms in New York City due to data availability.

eyes) increase by approximately 15 and 11 index points, respectively on high pollen days. Likewise, searches for popular over-the-counter allergy medications (Benadryl and Claritin) also increase on high pollen days though the increase is not statistically significant at conventional levels. Taken together with a literature linking high pollen days with sales of over-the-counter (OTC) allergy medication, the available evidence that individuals do suffer symptoms of seasonal allergies on high pollen days and provides evidence for physiological channel of the effect on crime.[13]

Main Results

Table 3 presents estimates of the effect of pollen exposure on violent crimes (Panel A) and property crimes (Panel B). Each column is a separate specification using the sample of all available cities. The dependent variable in each specification is the daily count of crimes in a given city-day and the treatment variable is an indicator for pollen count greater than 1500 ppm in a given city-day cell. The first column uses a specification with the interacted fixed effects only. The second column additionally controls for weather conditions including average, minimum, and maximum temperature, and lunar phase, in addition to an indicator for rainfall greater or equal to an inch. As expected, the effect is somewhat sensitive to the inclusion of weather conditions as these conditions are weakly correlated with pollen counts but are highly correlated with the outcome variable. Finally, the third column additionally controls for a lagged indicator for high pollen in order to account for potential temporal displacement of crimes to adjacent days. In each column, we report the coefficient, its standard error as well as the

[13] Sheffield et al. (2011) compared sales of over-the-counter allergy medication on days where pollen levels peaked, finding 28.7% excess sales at a 2 days lag during the 2003-2008 period in New York City. Repeating the same analysis over 2002-2012, Ito et al. 2015 find a cumulative ratio of medication sales between the 0-to-98th percentile pollen increase of 1.9 for same day sales.

magnitude of the effect as a percentage change, relative to the mean of the dependent variable. The specification in the second column that includes fixed effects and weather controls is our preferred specification as it turns out that controlling for the lag of pollen is unimportant empirically.

The effect of pollen on violent crime in Panel A of Table 3 is consistently negative in all three specifications. While controlling for weather conditions affects the magnitude of the coefficient, the estimates are very similar across columns (2) and (3) indicating that accounting for potential temporal spillovers does not change the magnitude of the treatment effect. We find that violent crimes decline by approximately 4% on high pollen days. Perhaps surprisingly, environmental allergens are nearly as important to the crime production function as rainfall which has been studied to a far greater extent.[14] Effects on property crimes reported in Panel B of Table 3 are considerably smaller and are not statistically significant at conventional levels of significance.

Taken together the evidence suggests that violent crimes are more sensitive to exposure to environmental pollen than property crimes. Interestingly, the same pattern does not hold for high rainfall which has a very similar effect (5.8% versus 4.8%) for violent and property crimes. To the extent that high rainfall is a proxy for changes in crime that are due to weather-induced shocks to routine activities rather than health shocks, the contrast between pollen and rainfall effects is revealing and suggests that environmental allergens do not affect behavior purely through mechanical changes in criminal opportunities and therefore that there are important behavioral channels to consider.

5. Robustness of Results and Mechanisms

[14] By comparison, violent crimes decline by approximately 5.8% on days that experience at least one inch of rainfall.

While there is no reason to believe that high pollen counts, which are a natural phenomenon, are endogenous with respect to crime, in order to further scrutinize the main results, we conduct a series of robustness checks to ensure that results are not driven by choices made in constructing and analyzing the data.

Pollen Threshold

Following the literature, in our main analysis, we defined high pollen as days with pollen count of 1500 ppm or greater. Since pollen counts of 1500 ppm or greater occur just 2.3% of the observations in our sample, it stands to reason that estimates might be sensitive to the precise choice of a cutoff. We thus re-estimate (1) using a range of different thresholds to generate an indicator for pollen count – in particular, using thresholds ranging from the 90^{th} to the 99^{th} percentile of city-specific pollen counts. Results of this exercise are reported in Figure 1. Naturally, the magnitude of the effects are attenuated at lower thresholds (i.e., the 90^{th} percentile) than at higher thresholds (i.e., the 97^{th} percentile). Likewise, estimates become less precise at very high thresholds (i.e., the 99^{th} percentile). However, the direction of the effect as well its economic significance remains consistent with results presented in Table 3, regardless of the threshold used. For instance, violent crime declines by approximately 3% on days when pollen level is higher than 95^{th} percentile of observed days as seen in Appendix Figure 3.

Sample Composition

In order to establish that our results are not being driven by any city in particular, we perform a robustness check in which we re-estimate (1) excluding each of the cities in our sample, one at the time and present the estimated coefficients in Figure 2. The city indicated on the horizontal axis the one that is excluded from the estimates. Estimated coefficient magnitudes are remarkably consistent and are not driven by a single outlier city.

Placebo Test

While reverse causality between crime and pollen counts is difficult to imagine, it is always possible that pollen counts could be correlated with a third unmodeled factor that is itself related to crime. Since daily variation in the presence of environmental allergens is the result of a natural and not a social process and since we condition on a very granular set of fixed effects, we believe the existence of unmodeled confounders is unlikely. Nevertheless, to test for a spurious correlation in the data between pollen counts and crime, we conduct a placebo test limiting the sample to measurements taken in October through March in all the cities, months when pollen measurements are not taken in most cities as plants are dormant. Randomly assigning high pollen indicators during this period, we re-estimate the specification in Table 3 for violent and property crime and report these placebo estimates in Table 6, which shows an effect that, as expected, is statistically indistinguishable from zero.

Mechanisms

Results in Tables 3 indicate that violence is approximately 4% lower on days in which pollen counts are unusually high. However, the source of this relationship remains unclear as there are a number of different stories – some behavioral and some mechanical – that could rationalize this result. In general, it is difficult to identify the mechanisms through which a change in a situational factor, pollen allergies, causes a change in crime because situational factors can change criminal opportunities as well as an offender's taste for crime. However, through an auxiliary analysis of data from New York City, we can at least generate some insight into this black box. In particular, we will be able to address whether the decline in crime is merely an incapacitation effect insofar as fewer individuals leave their homes and therefore are available to be the victim of a street crime. This is not merely an academic concern as research suggests that pollen allergies are a major source of absenteeism at work and missed school days.

There are, in general, two ways in which exposure to seasonal allergies might change a city's crime rate. First, allergens might change crime mechanically by changing the number or nature of interactions between potential victims and potential offenders. For instance, to the extent that allergens prevent individuals from leaving their home, this would be expected to decrease the number of non-residential interactions between potential offenders and potential victims while increasing the number of interactions inside a residence. Depending on the relative risk of each of these respective types of interactions, a city's crime rate could either increase or decrease. On the other hand, exposure to seasonal allergens could induce a behavioral effect, making a given interaction between a potential offender and a potential victim either safer or less safe, depending on the effects that seasonal allergies have on victim or offender behavior.

While we will not be able to explore each of these mechanisms in great detail, we can motivate a test of the hypothesis that the reduction in crime is a purely mechanical effect of pollen exposure using data from New York City. In particular, a testable implication of a purely mechanical effect is that, if seasonal allergies lead to less outdoor activity, then high pollen counts will tend to re-distribute crime from outdoor to residential spaces, with effects on city-level crime driven by reductions in non-residential crimes. We begin by examining whether people are less likely to spend time outdoors on high pollen days. We measure engagement in outside activities through an analysis of data from the city's Citibike program. Citibike is a bicycle rental program operating in New York City, with 750 rental stations across Manhattan, Brooklyn, and Queens.

Bikes are rented for 30 to 45 minute initial periods, with additional 15 minute increments available. Publicly available data includes the number of daily trips as well as vehicle miles traveled, based on the distance between pick-up and drop-off station of the rental. To the extent that outdoor activity declines on high pollen days, we would expect Citibike activity to decrease when pollen counts are high.[15] We regress the log of Citibike number of trips or miles traveled on the high pollen indicator, net of day of week and month-year fixed effects. For the New York City analysis, we use the 95th percentile as our measurement of a high pollen day because the incidence of days with greater than 1500 ppm is very low in New York City during the time period for which data are available. The results of these analyses are presented in Table 4. In Table 4, second and third columns report the effect of a high pollen day on the natural logarithm of Citibike trips and miles traveled, which decline by 5.8% and 19.2%, respectively.[16] Since each of these results is only marginally significant, we also create a Citibike activity index by taking an average of the z-scores of trips and miles traveled. By creating an index we are able to generate a measure of activity that is better measured. We find that Citibike activity declines by approximately 0.13 standard deviations (or 8%) on high pollen days, an effect that is significant at conventional levels of significance.

Taken together with previously reported results on Google searches for symptoms of illness as well as prior research, these results are consistent with the idea that individuals are more likely to remain in their homes on days in which pollen counts are high. What remains to be discussed is whether exposure to seasonal allergens re-distributes crime from non-residential to residential

[15] To the extent that individuals may still leave the house when feeling ill but simply not rent a Citibike, we also examine activity on public transit on high pollen days. We observe a small decline in subway ridership on high pollen days.

[16] Interestingly, a high pollen on the previous day dampens the effect of a high pollen day, with a smaller net decline in ridership (-10%+6.4%=-3.6%).

spaces in New York City. By assessing the degree to which crimes follow the movement of people, we can test the hypothesis that the effect of pollen exposure on crime is purely mechanical as opposed to, at least partially, behavioral.

Residential Versus Non-Residential Crimes

There is reasonable evidence to support the idea that high pollen counts re-allocate people from non-residential to residential locations. In order to get a sense for whether the crime effects we document are purely mechanical, or, at least partially behavioral, we must compare this estimate to an estimate of the differential effect of high pollen counts on residential versus non-residential crimes. Utilizing detailed public crime microdata in New York City, we re-estimate (1) separately for residential and non-residential violent crimes and report the resulting estimates in Table 5. To the extent that the effect of seasonal allergies is purely mechanical, we will expect to see a re-allocation of crimes from the non-residential to the residential realm. Instead, we see something quite different. There is a sizable decrease (4.8%) in residential violence on high pollen days, and no statistically significant change in outdoor violence. Given that there is evidence that more people remain indoors when pollen counts are high, the direction of this result is inconsistent with a purely mechanical effect which would be expected to yield a positive estimate for residential violence. In further support of the idea that the mechanism is at least partially behavioral, we remind the reader that high pollen counts have differential effects on violent and property crimes, which is not true of high precipitation which is equally incapacitating across crime types. We argue that this finding is likewise consistent with the idea that violence is particularly responsive to a health shock and that we are not merely observing an incapacitation effect.

6. Discussion

In this paper, we show that violent crime – but not property crime – is sensitive to a pervasive transitory health shock – seasonal allergies triggered by unusually high pollen counts. The decline in violent crime, four percent on average, is modest in magnitude but is nevertheless important, comparing favorably to costly crime control interventions such as increasing the size of a city's police force by 10 percent (Chalfin and McCrary 2018) or expanding the prison population by 20 percent (Liedka Piehl and Useem 2006). The effect of pollen on violence is also consistent in magnitude with the effects of air pollution (Bondy, Roth, and Sager 2018, Herrnstadt et al. 2015), though the direction of the effect is opposite in that pollen allergies mitigate violent crime while exposure to pollution tends to increase crime.

While the biochemical mechanisms underlying the relationship between pollution and environmental allergens on the one hand – and violence on the other – remain murky, Herrnstadt et al (2015) notes that air pollution may directly affect an individual's brain chemistry by manipulating the level of serotonin, a key neurotransmitter that regulates an individual's mood and behavior. Indeed, a large literature establishes that individuals with reduced serotonin levels are more aggressive and more likely to punish individuals who treat them unfairly (Crockett et al 2013; Siegel and Crockett 2013). While the precise biochemical mechanisms through which seasonal allergies change behavior are likewise unclear, exposure to pollen is not known to have an effect on brain chemistry and thus there is little reason to suggest that behavioral changes that result from high pollen loads are biochemical.

Instead, the primary way in which these allergies affect people may be through the manifestation of the physical symptoms of illness which we argue changes the costs and benefits of offending as well as of victim precaution. Given that the effects we observe are driven by a decline in residential, mostly family, violence, despite the fact that, if anything, there is more residential interaction on high pollen days, this not merely a story about a change in opportunity or routine activities.

These findings deepen our understanding of violent behavior – in particular, the extent to which violence is responsive to situational factors. In this respect, these findings provide a partial test of the nature of violence, in the same vein as Card and Dahl (2009) which finds that family violence increases in the aftermath of an upset football loss. While their findings identify ways in which violence responds to transitory fluctuations in frustration and anger, we identify an alternative way in which violence responds to other situational factors which shift the costs and benefits of offending and precaution: malaise driven by pollen allergies

We pause here to consider what we can and cannot infer from this research. First, it is important to clarify what we mean when we talk about cost shocks imposed by seasonal allergies. We note that seasonal allergies may affect the benefits as well as the costs of offending and precaution. In particular, while a health shock can certainly raise the cost of committing a violent act by increasing the "tax" on physicality, health shocks can also potentially reduce the utility than an offender derives from assaulting a victim. Consider, for example, an offender who commits assaults because of the rush that he feels in physically dominating another person. This offender may experience a reduction in the benefits of offending in the presence of an illness. Seasonal allergies are thus best thought of as a shock to the *net* cost of offending – that is, the costs less the benefits. This analysis then is similar to an analysis of the effect of a shift in the wage on crime – when the legal wage rises (a rise in the cost of crime) or the criminal wage falls (a fall in the benefit of crime), offending is predicted to decline because the net benefits are lower.

A second point that requires some discussion is that seasonal allergies may shift victim behavior in addition to having an effect on an offender's cost and benefit schedules. In the case of residential violence which primarily consists of violence between family members or intimate partners, violence could decline either because the offender's net cost schedule changes or because a potential victim is less active and therefore less likely to provoke a potential offender. While our uncertainty about whether these findings are due to behavioral changes among offenders or victims is an innate limitation of our work, we have one reaction to this line of thinking which may help to clarify the findings in this paper. Specifically, we note that the division between victims and offenders with respect to the perpetration of an assault is sometimes blurry. Consider the case of a fight – police will, in general, arrest the individual who is uninjured or who is thought to be the primary aggressor. However, in some cases, both individuals may have contributed to the violence. What this means is that, to an extent at least, victims and perpetrators may be drawn from the same underlying distribution and therefore that changes in victim and perpetrator behavior may be capturing the same reactions to the same changes in the costs and benefit of violence (Singer 1981; Broidy et al 2006).

A final point that merits discussion is whether the decrease in violent crimes has a longstanding or purely transitory effect on future crime. We can consider three ways in which the health shock caused by high pollen can have effects on days consecutive to high pollen days. For example, a sudden reduction in violent crime on high pollen days could result in higher crime on the days following high pollen days if individuals who are determined to commit a particular crime are incapacitated due to allergies during the high pollen days but commit such crime as soon as they feel better, which would result merely in a temporal displacement of crime. Alternatively, the reduction in violent crime could result in lower crime on the days following high pollen days if there is habit formation, state dependence , or individuals take few days to recover from allergies. Our results do not show evidence of temporal displacement or state dependence.

Third, the reduction in violent crime on high pollen days could result in a purely transitory shock that only affects violence on the days of high pollen with no effect on adjacent pollen days. This last pattern is particularly valuable because it is consistent with the reduction in violent crimes caused by high pollen being ultimately prevented and not merely displaced.

Finally, in addition to helping to better understand how offenders respond to transitory fluctuations in the costs and benefits of crime, our findings also contribute towards developing a more nuanced understanding of the effect of global warming on a broader social outcome-crime. While the previous literature documents that certain climate characteristics that are attributed to global warming – in particular higher temperature and higher pollution levels –increase crime, we note that these effects may be partially offset by the another climate characteristic that is also attributed to global warming: high pollen counts.

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Table 1 Summary of Data Characteristics

	(1) Mean	(2) Std. Dev
Pollen Count	171.86	646.36
High Pollen (1500ppm)	0.023	0.15
Precipitation	0.109	0.32
Rain (greater than 1 inch)	0.146	0.35
Mean Temperature	60.026	15.91
Violent crime (count)	53.605	93.64
Property crime (count)	108	154.19
N	19,818	

Source: National Allergy Bureau, NIBRS and city reports, *Weather Underground*

Table 2 Google searches of terms associated with seasonal allergies.

	"Seasonal Allergies"	"Benadryl" & "Claritin"	"Runny Nose" & "Nasal Congestion" & "Watery Eyes"
	(1) Coeff. Std. Err. Eff. Size	(2) Coeff. Std. Err. Eff. Size	(3) Coeff. Std. Err. Eff. Size
Pollen	15.096*** 3.889 0.993	9.437 5.736 0.159	11.572** 3.461 0.188
Weather	Y	Y	Y
Fixed Effects			
Day of Week	Y	Y	Y
Month * Year	Y	Y	Y
N	563	563	563

** p<0.01, * p<0.05, + p<0.1

Notes: Each column is a separate specification. The dependent variable in each specification is the index of daily Google searches for pollen and allergy related terms in New York City. Treatment variable is an indicator for pollen count of greater than 95^{th} percentile. Other covariates are average, minimum, and maximum temperature, rain, and lunar phase. All specifications include fixed effects for day of week interacted with month, and month interacted with year. Standard errors are clustered at month and year level.

Table 3 Effect of Daily High Pollen on Violent and Property Crime

	(1) Coeff. Std. Err. Eff. Size	(2) Coeff. Std. Err. Eff. Size	(3) Coeff. Std. Err. Eff. Size
Panel A: Violent Crime			
Pollen	-0.317	-0.780*	-0.821*
	(0.359)	(0.368)	(0.386)
	-1.629%	-4.012%	-4.416%
Pollen (L1)			0.213
			(0.494)
			1.146%
Rain		-1.145	-0.438
		(0.581)	(0.593)
		-5.892%	-2.356%
Panel B: Property Crime			
Pollen	-0.87	-1.299	-1.131
	(1.140)	(1.100)	(1.144)
	-1.636%	-2.443%	-2.177%
Pollen (L1)			-0.474
			(0.865)
			-0.911%
Rain		-2.569	-2.943
		(0.769)	(0.851)
		-4.830%	-5.665%
Weather	N	Y	Y
Fixed Effects:			
Day of Week	Y	Y	Y
Month * Year	Y	Y	Y
City	Y	Y	Y
N	19752	19750	16266

** p<0.01, * p<0.05, + p<0.1

The dependent variable in each specification is daily total of violent crime in the city. Treatment variable is an indicator for pollen count of greater than 1500 ppm. Indicator for rainfall of one inch or greater. Other covariates are average, minimum, and maximum temperature, average humidity, and lunar phase. Standard errors are clustered at month-year-city level. City weights are inversely proportional to their number of measured days in the data.

Table 4 Effect of High Pollen on Outdoor Activities

	Index	**Citibike**	
		ln(Trips)	ln(Miles)
	Coeff.	Coeff.	Coeff.
	Std. Err.	Std. Err.	Std. Err.
Pollen	-0.1091*	-0.0307	-0.1549
	(0.0424)	(0.0238)	(0.0996)
Weather	Y	Y	Y
Pollen (L1)	N	N	N
Fixed Effects			
Day of Week	Y	Y	Y
Month * Year	Y	Y	Y
N	438	438	438

** p<0.01, * p<0.05, + p<0.1

Notes: The first column includes the results for an index of human activity. The treatment variable for all specifications is an indicator for pollen count of greater than 95th percentile. The second and third columns include the results for Citibike rentals. The dependent variables are log of total number of completed trips in 24 hours and log of total number of miles by midnight of the day, respectively. Other covariates are average, minimum, and maximum temperature, average humidity, precipitation, and lunar phase. All specifications include fixed effects for day of week, month and year. Standard errors are clustered at month and year level.

Table 5 Effect of High Pollen on Outdoor and Indoor Violent Crime

	Indoor Coeff. Std. Err. Eff. Size	**Outdoor** Coeff. Std. Err. Eff. Size
Pollen	-4.8258** (1.4406) -0.0480	4.2823+ (2.4504) 0.0330
Weather	Y	Y
Pollen (L1)	N	N
Fixed Effects		
Day of Week	Y	Y
Month * Year	Y	Y
N	438	438

** p<0.01, * p<0.05, + p<0.1

Notes: Each column is a separate specification: indoor residential and outdoor violent crime count. The treatment variable for all specifications is an indicator for pollen count of greater than 95th percentile. Other covariates are average, minimum, and maximum temperature, average humidity, precipitation, and lunar phase. All specifications include fixed effects for day of week, month and year. Standard errors are clustered at month and year level.

Table 6 Placebo test for effect of high pollen on violent and property crime.

	(1) **Violent** Coeff. Std. Err. Eff. Size	(3) **Property** Coeff. Std. Err. Eff. Size
Pollen	-0.164 (0.140) -0.015	-0.192 (0.362) -0.006
Rain	Y	Y
Weather	Y	Y
Fixed Effects:		
Day of Week	Y	Y
Month * Year	Y	Y
City	Y	Y
N	15,820	15,820

** p<0.01, * p<0.05, + p<0.1

The dependent variable in each specification is daily total of violent crime in the city. Treatment variable is a random assignment of high pollen greater than 95th percentile. Other covariates are indicator for rainfall of one inch or greater, average, minimum, and maximum temperature, average humidity, and lunar phase. Standard errors are clustered at month-year-city level. City weights are inversely proportional to their number of measured days in the data.

Figure 1 Threshold sensitivity of coefficient of effect of high pollen on violent crime.

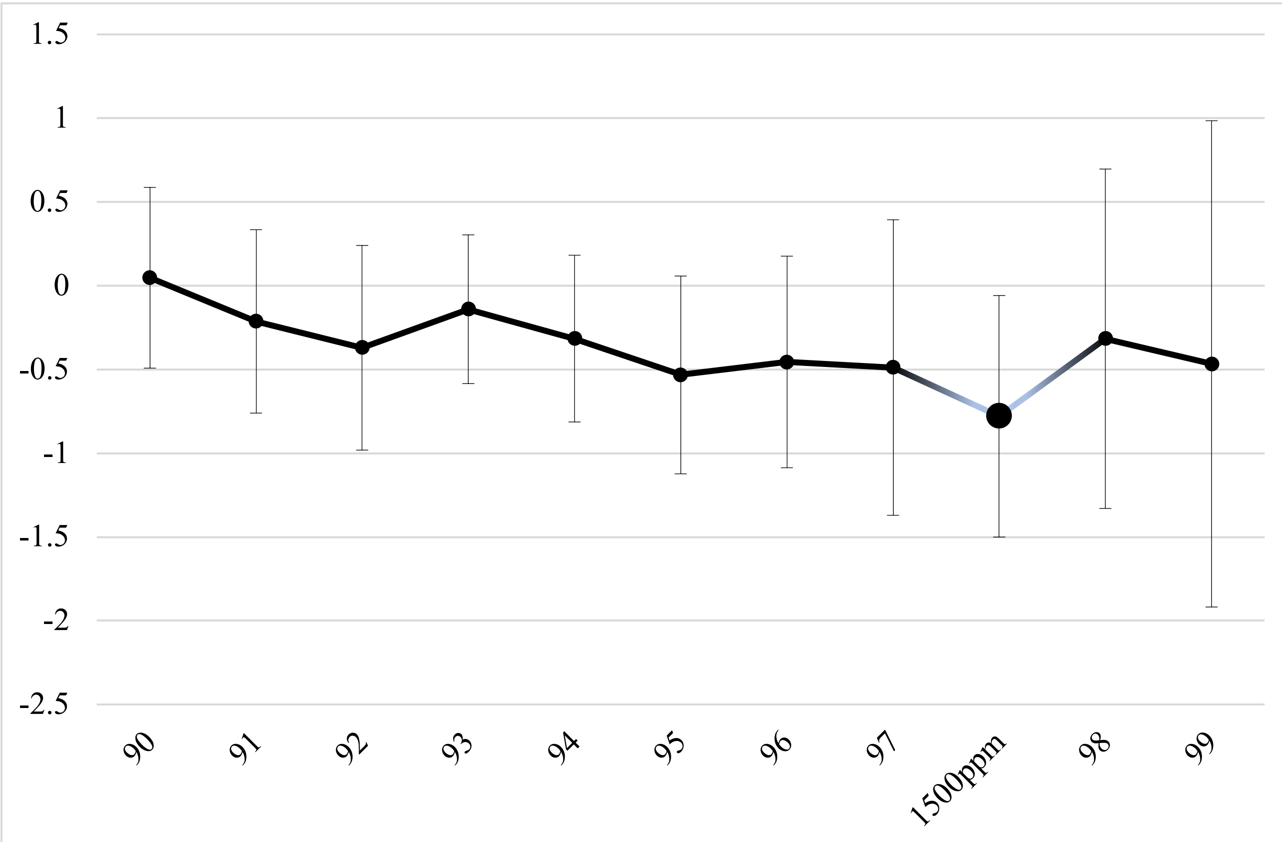
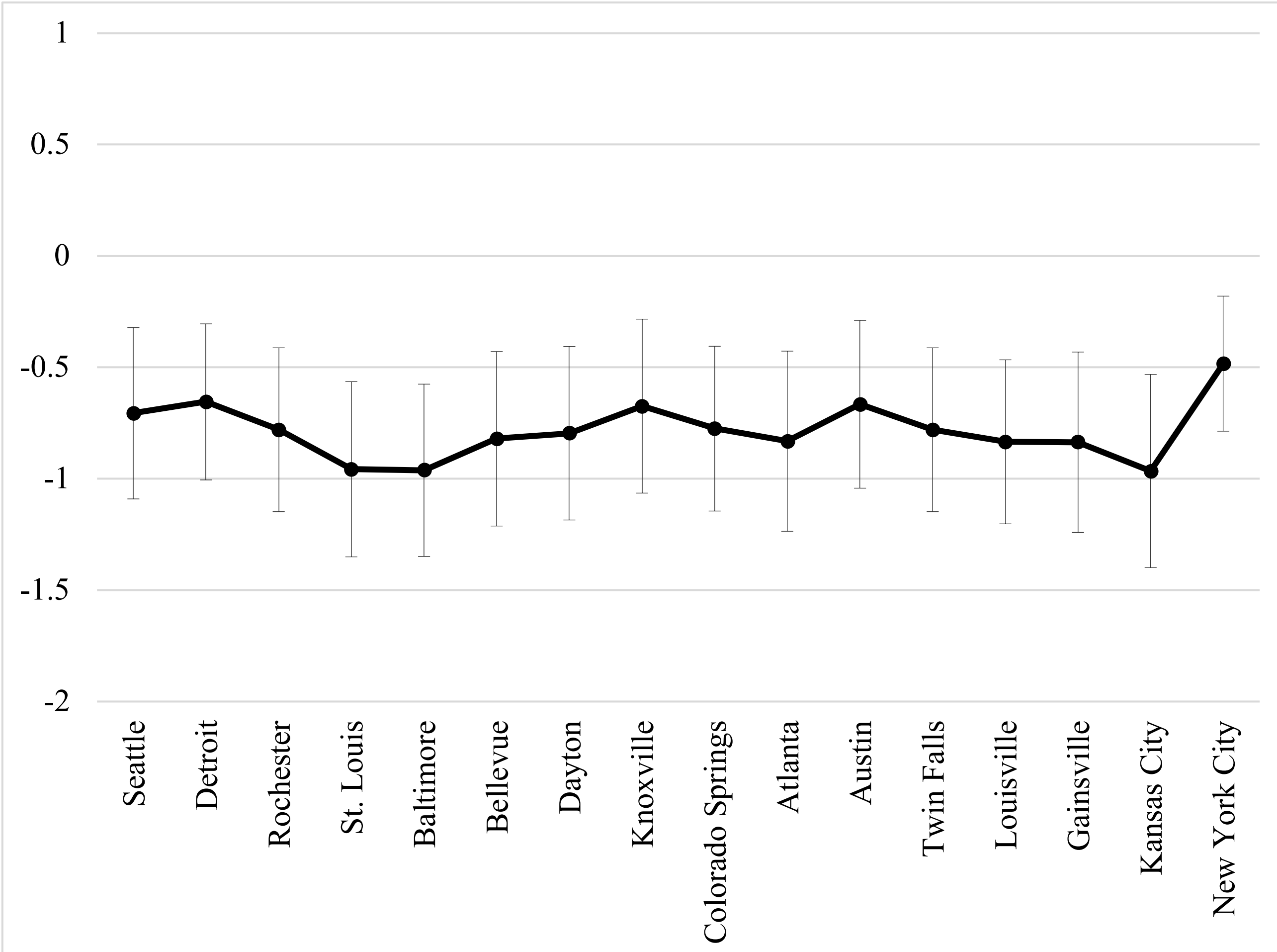


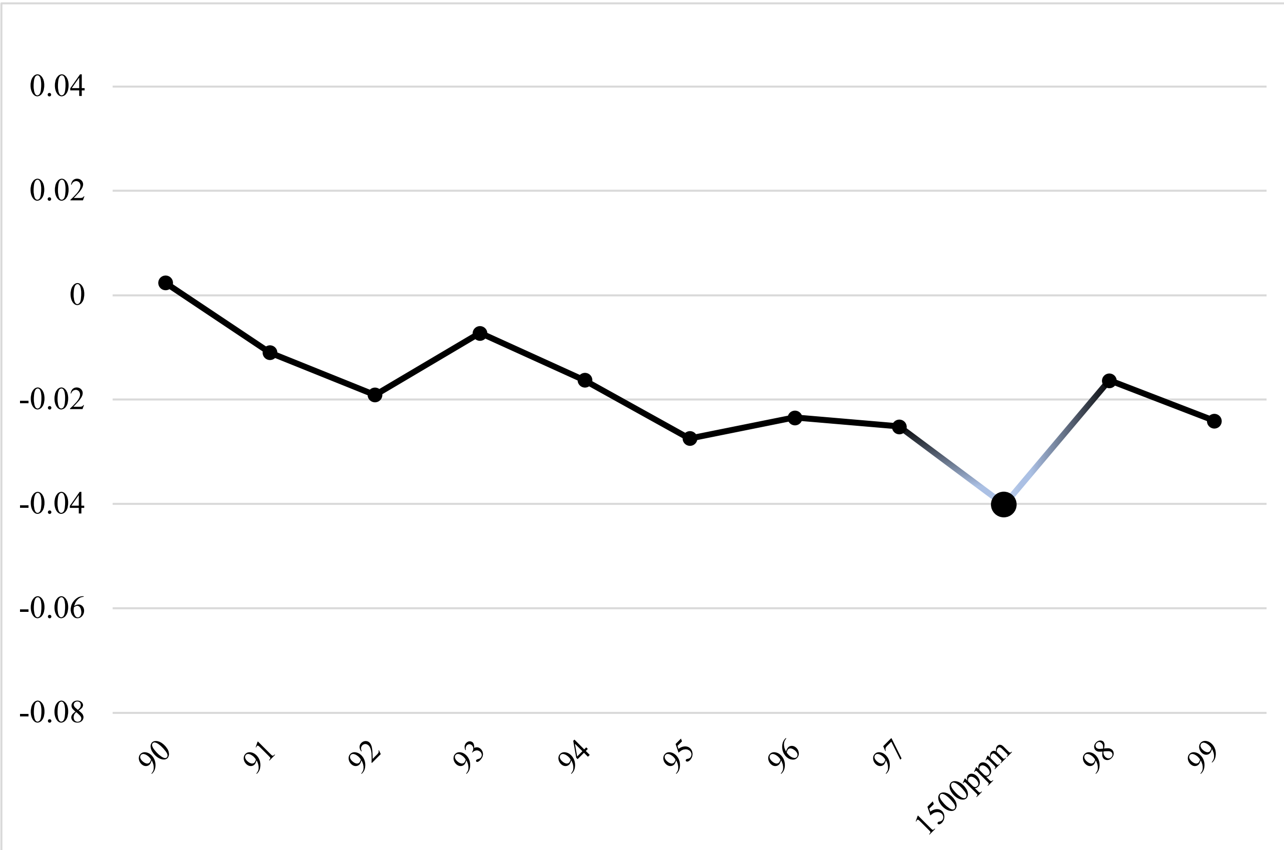
Figure 2 Sensitivity of coefficient estimate to inclusion of cities.



Notes: Each point is the coefficient estimate for effect of high pollen on violent crime in sample, excluding the city noted on the horizontal axis. High pollen is defined as pollen levels above 1500 ppm. Other covariates include greater than inch rain, daily temperature, and lunar phase. All specifications include fixed effects for day of week interacted with month, and month interacted with year. Standard errors are clustered at month and year level. 95% CI is indicated by bars around point estimate.

Appendix

Figure 3 Threshold sensitivity of effect size of high pollen on violent crime.



Notes: Each point is the effect size estimate for effect of high pollen on violent crime with high pollen defined as pollen levels greater than the percentile indicated by the value on the horizontal axis. Other covariates include greater than inch rain, daily temperature, and lunar phase. All specifications include fixed effects for day of week interacted with month, and month interacted with year. Standard errors are clustered at month and year level.