# The Effect of Weather on Crime: An Investigation of Weather and Annual Crime Rates

By

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This paper investigates the effect of temperature and precipitation on murder, rape, homicide, and burglary levels in California from 2000-2010. It uses annual data to smooth out the effects of short-term, stress-inducing weather shocks on crime, and instead focus on how weather plays into rational criminals' expected utility functions. Initial findings show that higher temperatures are associated with fewer robberies and homicides, and more burglaries. However, after adding in economic and demographic controls along with county-specific fixed effects, these results become statistically-insignificant. Precipitation is initially found to only be associated with lower robbery levels, but after adding in controls, this result becomes statistically-insignificant. With controls and county-specific fixed effects, though, this paper finds that higher levels of rain and snow are associated with fewer burglaries. These results may indicate that precipitation levels play into burglars' expected utility functions and stress the importance of controlling for as much demographic, economic, and unobserved heterogeneity as possible.

## 1. Introduction

The costs of crime in America are staggering. A single homicide costs society over $8.9 million; a robbery over $42,000, and a burglary over $6,000 (French, McCollister and Fang, 2010). As stunning as these numbers are, they likely fail to capture the true suffering experienced by victims of crime, many of whom struggle with long-term mental health problems. Roughly 25% of crime victims experience post-traumatic stress disorder, as compared to 9.4% of non-crime victims (Kilpatrick and Acierno, 2003). The fear of crime also has adverse consequences for individuals. Those who report a fear of crime experience lower levels of both mental and physical health (Stafford et al, 2007). With such high costs to both individuals and society, researchers are constantly attempting to find what causes an individual to commit a crime, and how to stop it. Most studies focus on obvious factors, like income, educational attainment, and intelligence. However, some researchers have sought links between crime and other, less-obvious factors, such as weather.

### 1.1 Motivation

Studying the effect of weather on crime holds interest for a few reasons. First, it can help law-enforcement officials allocate resources more efficiently. If crime is more likely to occur in hot temperatures, more police can be put on duty in warmer regions and during periods of warm weather. Secondly, the relationship between crime and weather can be used by policy makers to help create new laws and crime-deterring policies. If more property crime is being committed in warm weather, policy-makers may want to give incentives for residents to watch their house more vigilantly when temperatures are above average. Lastly, examining the mechanisms by which weather affects crime can help researchers better understand the human decision-making process. There are numerous theories that attempt to explain why an individual decides to break the law. Seeing how weather plays into an individual’s decision to commit crime can test aspects of these theories.

The relationship between weather and crime has been investigated extensively in prior literature. Studies have largely found that crime levels tend to increase with temperature. Papers investigating how precipitation affects crime have obtained mixed results, with some finding a negative relationship and others finding no evidence for any link. However, these studies leave some additional questions about the effect of weather on crime.

Most previous research has analyzed the effect of weather on crime using daily and hourly fluctuations in temperature and precipitation. Using short time periods makes it difficult to distinguish the effect of ambient weather conditions from the effect of short term weather fluctuations, the latter of which are known to cause stress. Additionally, many older studies have focused on relatively small geographic regions. Regional variation in weather may have different effects on crime than short-term temporal variation.

Many previous studies have also lumped crimes together into violent and property categories. Studies on the effect of weather on individual crime types (e.g., robbery, homicide, etc.) as opposed to broader categories are not prevalent in the literature. While grouping crime types together is convenient for research, it may not provide the whole story. Not all violent crimes are committed for the same reasons, and neither are property crimes. A criminal likely has vastly different motives for committing a murder than he or she does for committing a robbery. Without examining individual crime categories separately, it is difficult to know why weather affects them.

Additionally, researchers have only recently begun using more advanced methods to investigate the relationship between weather and crime. Older studies tend to use rudimentary techniques, such as correlations and linear regressions with few controls, and many newer studies don't control for additional economic and demographic variables that have been known to affect crime levels. By ignoring other crime-causing phenomena, researchers may be overstating the effect weather has on crime. Weather conditions could be driving unobserved factors that affect crime levels, rather than crime itself.

Finally, while previous studies have largely found that warmer weather tends to increase crime, they haven't been able to confirm why it does. Some people theorize that the relationship exists due to the stress that comes with extreme weather. Others hold that weather affects crimes committed for rational reasons as well, by making them easier to commit or altering the probability of being caught.

**1.2 Research Questions**

This paper attempts to address the questions left by previous literature. It utilizes panel data techniques along with numerous control variables to glean the relationship between weather, as measured by precipitation and temperature, and four specific crime types (robbery, homicide, rape, and burglary), over annual time periods in all 58 counties in California.

Using annual data allows this study to control for many of the short-term changes in crime due to weather shocks. Changes in crime due to weather shocks can be largely attributed to biological factors, as extreme weather can hamper the human decision-making process (Anderson, 2001). While variation in annual crime rates likely captures some biological responses to weather, a large portion of them are smoothed out due to the tendency for periods of extreme weather to be short-lived. This paper is then better able to address the mechanisms through which weather affects crime. If the analysis of annual data finds no evidence that weather affects crime, it may be a sign that rational criminals don't heavily factor weather into their decision to commit a crime. If this were the case, biological factors would be a stronger explanation for relationships found by previous studies.

**1.3 Overview**

Temperature is initially found to be linked to homicide, robbery, and burglary levels, with results showing that more robberies and homicides occur during cooler weather, and more burglaries occur in warmer weather. However, after adding in controls and using more advanced panel data techniques, these effects become statistically insignificant for all crime types. No evidence is initially found that yearly precipitation amounts affect crime levels. With the addition of control variables, though, this paper does find that wetter weather might lead to more burglaries.

## 2. Theoretical Framework

Biological influences and rational-choice theory are the most dominant explanations for why weather affects crime. Although there are other theories that attempt to explain why weather and crime would be related, these two have received the most attention in previous literature.

### 2.1 Biological Influences

Some researchers hold that the effect of weather on crime is due to biological stresses brought on by weather shocks. When weather becomes extreme or changes sharply, people experience stress, which can lead to agitation (Cohn, 1990). Anderson (2001) details the evidence for a relationship heat and aggressive behavior and explores the psychological mechanisms by which increased temperatures may cause violent crimes. He cites decreased cognitive performance, biased interpretations of social interactions, and decreased comfort levels as possible reasons for the link between warm temperatures and aggression.

While the biological influences of heat on cognitive functioning nicely explain changes in violent crime associated with weather shocks and extreme temperatures, they fail to explain the relationship between weather and crimes that are generally premeditated, such as burglaries and property damage. Additionally, psychological stresses brought on by heat do not explain variation in crime due to weather over long time periods and across geographies. Sharp changes in weather tend to be smoothed out over monthly or annual data, and periods of extreme weather are usually short-lived and geography-specific. Potential changes in crime levels due to precipitation are also poorly explained by biological mechanisms, as little evidence exists to associate rain and snow levels with increased aggression.

**2.2 Rational-Choice Theory**

Rational-choice theory, which is derived from the expected utility model in economics (Akers, 1990), offers a more convincing basis for how weather might affect premeditated crime rates over long time periods and across geographies. Popularized by Gary Becker (1968) in his seminal essay “Crime and Punishment: An Economic Approach,” rational-choice theory posits that an individual’s decision to commit a crime is based on the expected utility received from committing that crime. Each individual has his or her own utility function for committing a crime, which relies on numerous factors including the potential benefit of successfully committing the crime, the ease of committing the crime, the likelihood of being caught, and the severity of punishment if the criminal is caught and convicted. If an individual deems that the risks of committing a crime outweigh the costs, he or she will commit it.

Burglary and robbery are perhaps the two most “rational” crimes examined by this study, due to the fact that both involve a clear reward. To successfully commit a robbery or burglary, criminals likely have to make careful plans and strike when they’re least likely to get caught. Rape and murder can also be committed by rational criminals, particularly if they’re premeditated. According to Hamlin (2001), approximately 71% of rapes are premeditated. This high percentage indicates that rapists may weigh risk and reward when deciding whether to commit a crime. A portion of homicides are premeditated, too, providing a basis to explain them with rational choice theory.

Under rational choice theory, there are clear avenues through which temperature and precipitation could affect crime levels, but the direction of these potential effects is ambiguous. Warmer weather could increase the risk of committing a crime, as people may be more likely to venture outside, creating more potential witnesses. However, in hot enough weather, people may also stay indoors to keep cool, leading to fewer witnesses. Additionally, if warmer weather does cause people to move around more, it could increase the number of potential targets, making it easier to commit a crime. There are many different avenues through which temperature could influence rational criminals.

Precipitation levels could also affect people's movement patterns, as rain or snow may make individuals reluctant to leave their homes. If fewer people leave their houses, it's harder to commit crimes like burglary without getting caught. Alternatively, rain or snow could also wash away evidence left by criminals, decreasing the risk of being caught. The utility gained from committing a crime could also be altered by precipitation levels, as committing a crime in wet weather might be less pleasurable.

Rational-choice theory also motivates the decision to investigate the effect of weather on specific rather than broad categories of crime (e.g., property crime and violent crime). Under rational-choice theory, individuals have unique production functions for different crime types (Cohn, 1990). The decision to commit a homicide likely weighs determinants of expected utility differently than the decision to commit a burglary. By examining crime types individually, this paper is able to draw more specific conclusions about how weather is included in expected utility functions.

**3. Previous Literature**

Early empirical literature on the topic of crime and weather largely focuses on variations in crime and weather over short time periods and in small geographic areas. A literature review by Cohn (1990) summarizes early research on the relationship between crime and weather, and finds that some crimes, including assault and burglary, tend to increase with temperature. However, Cohn also reports that most previous studies relied on simple correlations, neglecting to control for other crime-influencing factors. Original research by Cohn (1993) helped advance the literature on the effect of weather on crime by using multiple linear regression to investigate the effect of temporal and weather variations on rape and domestic violence. She finds that as temperature increases, instances of domestic violence do as well. Cohn and Rotton (2000) contributed new techniques to the literature again, using time-series methods to examine the effect of weather on property crimes. They find that temperature is significantly- and positively-related to property crimes.

Moving away from the tendency of previous research to only analyze crime in one geographic region, Butke and Sheridan (2010) use spatial and econometric techniques to analyze the effect of temperature on crime in different parts of Cleveland, Ohio. They find that although crime does increase with temperature, warmer weather doesn’t alter the spatial pattern of crimes committed in Cleveland. Horrocks and Menclove (2011) examine daily crime and weather data encompassing eight years from New Zealand. They use controls for geographic region, day of the week, whether a day is part of the weekend, month, and year. Horrocks and Menclove find that temperature and precipitation have significant effects on violent crime, and temperature has significant effects on property crime. Liu (2016) examines daily crime data from seven different cities in the United States to see how temperature affects crime across geographies. He controls for several demographic and economic variables, and adds city-level fixed to his model. He finds that temperature has a statistically-significant and positive effect on violent crimes, and finds evidence that this relationship reverses in higher temperatures.

A few papers have investigated how weather affects crime over time and across geographic regions. Cohn and Rotton (2003) use annual crime, demographic, and economic state-level data from 1960 through 1998 to see how temperature affects several different crimes over long time periods and across states. Controlling for state-specific fixed effects and several demographic and economic variables, they find that higher annual temperatures are associated with higher burglary, robbery, larceny, rape, and assault rates. Ranson (2012) takes a slightly different approach to investigate how crime and weather vary together over time and across regions by using monthly county-level data from across America and modeling the relationship with county-specific fixed effects. He finds evidence that higher temperatures increase most crime types.

## 4. Data

This paper uses annual county-level data from California for several reasons. First, limiting data to a single state ensures that definitions of crime are consistent. Things that are defined as criminal in one state might not be in another, and inconsistencies in crime definitions could bias the results. Additionally, states allocate law-enforcement resources differently, and have different behavioral protocols for law-enforcement. On a per-capita basis, states that spend less on law enforcement are likely to report less crime than states that spend more. If states with different levels of law-enforcement spending and different police behavioral guidelines were to be included in a regression, the results would be inconsistent unless police spending and police behavior were controlled for. State law-enforcement spending statistics may be obtainable, but reliable data on how police behave are not. Fixed effects could factor out police behavior differences between states, but only if they were time invariant. It is likely that states tend to train police officers differently over time, however, especially given the scrutiny law-enforcement officers are constantly subjected to.

Limiting the study to one state could create misleading results, though, due to a lack of heterogeneity. For instance, a small state dominated by rural populations would have consistent laws, but using it in the study would capture little heterogeneity, making conclusions only applicable to that state.  Focusing on California eliminates the problem of inconsistent laws and crime definitions, while also capturing diverse geographies and people. California is the most populous state in America, and the people who live in it are diverse. Economic diversity also exists in California, with prevalent industries running the gamut from agriculture to entertainment. California’s climate is varied, too, being home to desert areas, temperate coastal areas, mountains, and national forests. California also has well-kept statistics on crime, weather and demographic variables. The ease of collecting this data allows for more accurate results.

Using data from California addresses several problems that could arise due to using other states or geographic regions, but it also creates potential limitations for this study. While California does contain fairly diverse climates, it’s still warmer, on average, than most of the United States. People who are used to warmer temperatures could be influenced by weather differently than those living in more moderate climates. In warmer climates, it is possible that rises in temperature cause people to stay indoors, creating fewer potential victims for criminals. Previous literature has found evidence for a curvilinear relationship between temperature and crime; that is, after a certain level, increases in temperature lead to decreases in crime (Cohn, 1990; Horrocks and Menclove, 2011). However, this turning point has generally been found to occur at temperatures at or above 80 degrees Fahrenheit (Cohn, 1990; Horrocks and Menclove, 2011). The average temperature among all counties in California between 2000 and 2010 was 58.2 degrees Fahrenheit, well below the threshold found by most studies. It is still possible, though, that people accustomed to warmer climates don’t alter their routines and behaviors due to temperature changes as much as people living in moderate climates would.

Annual county-level crime data were obtained from the California Office of the Attorney General. These data were collected from nearly every law-enforcement agency in California from 2000 to 2010 and attempt to capture all crime committed by adults. Although the data contains many different crime types, this paper focuses on homicide, rape, robbery, and burglary. Crime levels appear to be largely stable for the years of interest, with no significant growing or shrinking trends. It is worth noting that this data only contains reported crimes. For this reason, it is likely that true crime numbers are understated, as many crimes go unreported. Additionally, the data contains no information for whether a reported crime resulted in a conviction. It is possible that some reported crimes were the result of false accusations. This could bias the results, particularly if law-enforcement officers in certain areas make significantly more false accusations than others.

Weather data (temperature and precipitation) for the paper were obtained from the National Atmospheric and Oceanic Institute. These data were collected from weather-monitoring stations throughout California, which release monthly reports. To calculate the average annual temperature for each county, this paper takes the yearly average temperature for each weather station, and then averages these temperatures by county. Within-county variation in temperature was modest, with no significant warming or cooling trends. Average annual precipitation is calculated by aggregating the monthly precipitation reports, which measure rain and snow in inches, annually by weather station, and then calculating the average of these total annual precipitation numbers by county. Precipitation levels remain relatively stable throughout the years included in this study.

There is a potential weakness in the aggregation process. While most counties have multiple weather-monitoring stations, it is likely that many of them are concentrated in urban areas. If this is the case, the temperatures may be biased upwards, due to the urban heat-island effect. However, urban areas tend to be more populated and own a disproportionate share of county-level crime as compared to rural areas (Cullen and

Levitt, 1999). The tendency for crime to be concentrated in urban areas likely evens out the effect of this potential bias, as temperatures data is then reflective of the areas where most crime tends to occur.

County-level demographic control variables, including racial makeup, marital status, gender makeup, median age, percentage of the population living in rural areas, and education level, were obtained from the American Community Survey and the Decennial US Census. Each of these demographic variables has a well-documented effect on crime levels (Lochner, 2007; Sampson, Laub, and Wimer, 2006; Francisco and Chénier, 2005; Denno, 1994; Farrington, 1986). Including them as controls allows this study to better isolate the effect of weather on crime. There is a gap between the 2000 Census and when the American Community Survey first began collecting data in 2006. Because of this gap, this paper used a simple equation to impute values from 2001 to 2005, defined below as

$$D_{it} = D_{it-1} + \frac{(D_{i2006} - D_{it-1})}{2006 - (t - 1)}$$

where $D_{it}$ is a given demographic variable in county i in year t, $D_{it-1}$is a given demographic variable in county i in year t – 1, and $D_{i2006}$ is a given demographic variable in county i in 2006 (The first year of the American Community Survey). Most demographic variables remained relatively stable; but some, including the percentage of the non-white population and educational attainment, showed an increase over time.

County-level economic data, consisting of median household income and unemployment rates, were also obtained from the American Community Survey and Decennial Census. Economic variables were also included in the models due to their well-established theoretical basis in predicting crime levels. Higher unemployment is associated with higher crime rates, and lower levels of income are associated with lower crime rates (Winter-Ebmer and Raphael, 2001; Sharkey, Besbris and Friedson, 2016). Economic data were also not available from 2001-2005, so this paper imputed it using a simple growth trend, defined below as

$$E_{it} = E_{it-1} + \frac{(E_{i2006} - E_{it-1})}{2006 - (t-1)}$$

where $E_{it}$ is a given economic variable in county i in year t, $E_{it-1}$ is a given economic variable in county i in the year t – 1, and $E_{i2006}$ is a given economic variable in county i in 2006.

Data from 2006-2010 were available, so the effects of the Great Recession were captured. As would be expected, median household income rose from 2000-2006, and then fell in 2007. Unemployment rates exhibited a trend nearly inverse to median household income, staying relatively stable through 2000-2006, then rising sharply in 2007.

Table 1 contains summary statistics for the variables used in the models. These summary statistics showed no clear data problems, with all variables taking on realistic values. However, data on temperature and precipitation couldn’t be gathered for Alpine County from 2005-2010; for Lake County in 2008 and 2010; and for Sutter County in 2007. As a result, the panel was unbalanced, containing only 629 observations as opposed to 638 (11 years for each 58 counties). The imbalance in the panel is not of huge concern to this study, as the counties missing tend to have small populations and experience few crimes.

## 5. Models

This paper uses several different models to understand the relationship between crime and weather. It begins with simple OLS models. After obtaining estimates for these models, controls and county-level fixed effects were added to better understand how weather affects crime levels. Using both rudimentary and advanced techniques allows this study to highlight the importance of using correctly specified models.

### 5.1 Simple OLS Model

This paper first uses simple OLS models to examine the relationship between crime and weather. Four models are estimated, each with precipitation, temperature, and population as independent variables. These independent variables are regressed on different dependent variables in each model: robbery, rape, homicide, and burglary. The model is defined below as

$$Crime_{it} = \beta_1 Temp_{it} + \beta_2 Precip_{it} + \beta_3 Population_{it} + \varepsilon_{it}$$

where $Crime_{it}$ denotes the amount of a given crime (either homicide, rape, robbery, or burglary) in county i in year t; $Temp_{it}$ denotes the average temperature in county i in year t; $Population_{it}$ denotes the total population in county i in year t; $Precip_{it}$ denotes total precipitation in county i in year t; $\varepsilon_{it}$ is the stochastic error term for county i in year t; and $\beta_1$, $\beta_2$and $\beta_3$ are estimable coefficients.

### 5.2 OLS Model with Control Variables

This paper then uses OLS models with county-level demographic and economic control variables, including the percent of the population that is non-white and median household income. The model is defined below as

$$Crime_{it} = \psi_1 Temp_{it} + \psi_2 Precip_{it} + \boldsymbol{\chi}_{it}'\theta + \eta_{it}$$

where $Crime_{it}$ denotes the amount of a given crime in county i in year t; $Temp_{it}$ denotes the average temperature in county i in year t; $Precip_{it}$ denotes total precipitation in county i in year t; $\eta_{it}$ is the stochastic error term for county i in year t; and $\psi_1$ and $\psi_2$ are estimable coefficients. $\chi_{it}$ is a vector of county-level control variables including the population of the county; the percentage of the county population that is female; the percentage that is non-white; the percentage that lives in rural areas; the percentage with greater than a high-school education; the percentage with only a high-school education; the median age; the unemployment rate; and the median household income. $\theta$ is a vector of estimable coefficients.

**5.3 Simple Fixed-Effects Model**

Because the data were collected at the county level, and because there are variations between counties across different dimensions, this study estimates a fixed-effects regression to better isolate the effect of weather on crime. Fixed-effects estimators control for all time-invariant unobserved heterogeneity by subtracting off the mean of each variable for each county. After subtracting mean values, only differences that vary with time are captured in the regression. The fixed effects control for many time-invariant variables that this paper couldn't obtain, such as county-level attitudes toward crime, to the extent that they don't vary over time. The fixed effects model is defined below as

$$Crime_{it} = \phi_1 Temp_{it} + \phi_2 Precip_{it} + \phi_3 Population_{it} + \alpha_i + \varrho_{it}$$

where $Crime_{it}$ denotes the amount of a given crime (either homicide, rape, robbery, or burglary) in county i in year t; $Temp_{it}$ denotes the average temperature in county i in year t; $Precip_{it}$ denotes total precipitation in county i in year t; $Population_{it}$ is the population of county i in year t; $\alpha_i$ is a time fixed-effect for county i; $\varrho_{it}$ is a stochastic error term for county i in year t; and $\phi_1$, $\phi_2$, and $\phi_3$ are estimable coefficients.

**5.4 Fixed- and Random-Effects Models with Control Variables**

While fixed effects estimations do control for time-invariant heterogeneity, they don't hold time-varying differences between units of observation constant. To control for variables that change over time, this paper estimates another fixed effects model with added county-level controls, including racial makeup and household income. The model is defined below as

$$Crime_{it} = \delta_1 Temp_{it} + \delta_2 Precip_{it} + \nu_i + \boldsymbol{\Gamma}'_{it}\varsigma + \tau_t + \varpi_{it}$$

where $Crime_{it}$ denotes the amount of a given crime in county i in year t; $Temp_{it}$ denotes the average temperature in county i in year t; $Precip_{it}$ denotes total precipitation in county i in year t; $\nu_i$ are county fixed-effects; $\Gamma_{it}{}'$ is a vector of time-varying county-level control variables including the population of the county; the percentage of the county population that is female; the percentage that is non-white; the percentage that lives in rural areas; the percentage with greater than a high-school education; the percentage with only a high-school education; the median age; the unemployment rate; and the median household income; $\varsigma$ is a vector of estimable coefficients; $\tau_t$ are year fixed-effects; $\varpi_{it}$ is the stochastic error term for county i in time t; and $\delta_1$ and $\delta_2$ are estimable coefficients.

Because temperature and precipitation vary little across time within each observation, a random effects model with time, demographic, and economic controls is also estimated. Random effects differ from fixed effects in that random effects don't kill the entire time fixed effect, allowing for some time-invariant differences between counties to be accounted for. Random effects do have a weakness, though, in that they assume that the between-entity error term is entirely uncorrelated with the predictors. Under this assumption, all unobserved factors that affect variation between counties must be uncorrelated with the model's independent variables. This assumption is generally thought to be unrealistic. However, the random effects model is estimated anyways because of the possibility that the fixed effects regressions are eliminating too much variation in weather.

**5.5 Estimation and Diagnostics**

To determine whether fixed effects are preferable to the random effects techniques, this study performs a Hausman Test on the two models for all crime types. These tests examine the between-county standard errors of both regressions to determine if they are correlated with any of the independent variables. If there is evidence of correlation, then fixed effects are preferable to random effects. The Hausman tests show evidence of regressor-error term correlation, making the fixed-effects models this study's preferred specification.

Because the counties in California vary in size, heteroscedasticity is a concern in all the models. If heteroscedasticity is present, it can bias standard errors, resulting in misleading test statistics and conclusions. Serial correlation is another concern in all the models, as the factors encompassed by the error term for a county in one year probably influence the error term for that county in the following year. To address these potential sources of bias, all models are estimated with robust standard errors clustered at the county level.

It is also worth noting the potential for multicollinearity in several of the models, due to the number of control variables relative to observations and because of potential relationships between the control variables. A correlation matrix of all the control variables reveals that counties with higher rural populations also tend to have a lower percentage of non-white residents, lower levels of education, and higher marriage rates. The correlation coefficients between these variables are moderately strong, making robustness checks for multicollinearity necessary. To test for multicollinearity, this paper obtains the variance inflation factors from each of the OLS models with added control variables.

The variance inflation factors for two control variables, the percentage of the population with greater than a higher school education and median household income, are over 10, raising some concerns that imperfect multicollinearity may be a problem in the models. While imperfect multicollinearity doesn't violate any of the OLS assumptions, it can create inaccurate estimates and inflate standard errors (O'brien, 2007). The variance inflation factors on the variables of interest, average temperature and total precipitation, though, are both relatively small. Temperature's variance inflation factor is 2.72, and precipitation's is 1.96. When variance inflation factors are only high for control variables, imperfect multicollinearity isn't a concern, as it does not affect the variables of interest, and no OLS assumptions are violated (Allison, 2012). As a result, no additional steps are taken to deal with the imperfect multicollinearity.

## 6. Results

The results from the estimations are presented in the attached tables. Initial findings for most crimes show a relation with weather; however, after control variables are added in, most of these effects become statistically insignificant. With the addition of controls, though, this paper does find that higher levels of precipitation are associated with fewer burglaries. Explanations for these results are discussed by crime type below.

### 6.1 Robbery

The results for the regressions on robbery are displayed in Table 2. Both linear models find that warmer temperatures lead to fewer robberies. These effect sizes are relatively large, with a one degree increase in temperature being associated with roughly 45 and 65 fewer robberies under the simple OLS model and OLS model with controls, respectively. Under rational-choice theory, there are several explanations for this result. It may be the case that more people stay indoors in cooler weather, leading to fewer potential witnesses. Because of California's warm temperatures, it is also possible that more people venture outside in cooler weather, creating more targets. These model specifications find no evidence that precipitation affects robbery levels. The random effects model also finds that higher temperatures are associated with lower robbery levels.

The basic fixed effects regression finds evidence that both higher temperatures and higher levels of precipitation lead to fewer robberies. These findings could suggest that robbers prefer cool, dry weather for committing crimes. Perhaps there are fewer witnesses in cooler temperatures, decreasing the risk of getting caught, and the presence of rain decreases the utility of committing a crime. While these results seem interesting, they may not provide an accurate representation of how and if weather affects robbery levels. To do that, more control variables are needed. The fixed-effects regression with added control variables addresses this need. With economic, demographic, and yearly controls, the coefficients on both temperature and precipitation become statistically-insignificant.

This finding contradicts previous studies, most of which find evidence of a relationship between weather and robbery. However, the longer time periods and regional variations captured in this paper’s data may explain this difference. It is possible that the changes in robbery levels are more strongly explained by the stresses brought on by sudden local weather changes than by ambient weather conditions across geographies. Additionally, the use of county-specific fixed effects along with demographic and economic variables may reveal the true effect of weather on robbery levels better than more rudimentary techniques. The fact that both OLS models employed by this paper to obtain baseline results found evidence for a relationship between weather and robbery underscores the importance of controlling for as many external factors as possible.

**6.2 Rape**

The results for the regressions on rape can be found in Table 3. None of these regressions find evidence that weather affects rape levels. These results are consistent with Cohn (1993), who also finds no evidence of a link between weather and rape. The lack of evidence is initially confounding since the majority of rapes are premeditated, with 71%

being planned ahead of time (Hamlin, 2001). With such a high level of premeditation, rape seems to be a crime that is very well explained by rational-choice theory.

However, there may be reasons for the lack of evidence for a relationship between weather and rape. Hamlin (2001) states that 60% of reported rape victims know their attacker. It is then reasonable to assume that attackers tend to be aware of their victims routines, which are, for the most part, unaffected by weather. With access to a victim's schedule, a perpetrator need not plan for the rape based on expected weather. Instead, he can simply find a time when the victim is alone in a secluded area, such as her house. Hamlin also reports that many rapes take place in a victim's home, reinforcing the theory that a potential rapist has little need to worry about weather.

**6.3 Homicide**

Results for the regressions on homicide can be found in Table 4. The simple OLS model and the OLS model with controls both find that higher temperatures are associated with lower homicide levels. Like robbery, this contradicts the findings of previous studies, which tend to find positive relationships between homicide and temperature. The disparity between these results and previous ones can largely be explained by this study's use of annual time periods. As mentioned before, the longer time periods factor out many of the sharp changes in weather and extreme temperatures, both of which affect crime levels by creating stress and agitation. As with robbery, rational choice theory offers a few possible explanations for the tendency for homicides to decrease as temperature rises. The link could be due to differences in how people's movement and activity patterns change in cooler weather, which could alter the number of potential targets or potential witnesses. Neither model found evidence that precipitation affects the level of homicides.

The results for the simple OLS model show that an increase in temperature by one degree will lead to roughly one fewer murder, holding population and precipitation constant; and the OLS model with controls finds that a one degree increase in temperature will lead to roughly two fewer murders, holding all the other control variables constant. While this effect size might seem small, it can be explained by the fact that far fewer homicides occur than other crime types. The average annual number of murders per county was 37, compared to hundreds of rapes and thousands of burglaries and robberies.

The simple fixed-effects model, random-effects model, and fixed-effects model with added control variables are unable to find evidence of a relationship between temperature and homicide, contradicting the linear models' findings. The lack of evidence may be due to unobserved factors, like counties' attitudes towards crime, better explaining homicide levels than temperature. Like robbery, these results seem to clash with previous studies' findings. However, due to this study's use of annual time-periods to factor out short-term changes in homicide levels caused by weather shocks and extreme weather, the results aren't necessarily incompatible with the evidence found by other studies. The differing findings between studies with different time periods suggests that the relationship between weather and temperature may be better explained by weather shocks than by ambient weather, and rational criminals might not weigh weather heavily in their expected utility function for committing a homicide. Both fixed effects models and the random effects model also find no evidence that precipitation affects homicide levels.

### 6.4 Burglary

Regression results for burglary can be found in Table 5. The baseline model finds that higher temperatures are associated with higher burglary levels, with an increase in temperature by one degree leading to 81 more burglaries, holding population and precipitation constant. These findings have strong theoretical footing, as warmer temperatures could draw people away from their property, leaving it unguarded. This would suggest that criminals weigh how guarded property is in their decision to commit a burglary. Precipitation was insignificant in this model specification.

Both the OLS model with controls and the simple fixed effects model without controls find no evidence that temperature and precipitation have any effect on burglary levels. This result is not a huge departure from previous studies, which find mixed evidence regarding the effect of weather on property-related crimes.

The fixed effects model with controls finds no evidence that temperature affects burglary levels, but does find evidence that precipitation levels have a negative effect on burglaries. An increase in precipitation by one inch led to 8 fewer burglaries under these results. The magnitude of this effect is smaller than temperature's in the simple OLS model, but it is still statistically significant at $p < .05$. Due to the relatively small number of observations (629), statistical significance being attributed solely to a large sample size was not a concern.

The reason the relationship between precipitation and burglaries is statistically-insignificant in previous regressions is unclear. It is possible that the effect of precipitation on burglary levels was being suppressed by other demographic, economic and unobserved factors. Once these variables were controlled for in conjunction, perhaps the true effect of precipitation on burglary levels was revealed.

Rational-choice theory has more power explaining burglaries than biological factors, as the decision to successfully break into a house and steal items requires planning. Most burglars probably have some idea of the risks and rewards associated with their crime. A rational burglar would then try to minimize the risks associated with his crime, as this would lead to the highest expected utility. To minimize risk, the burglar would want to strike property that is unguarded. If someone is in the property the burglar plans to steal from, several bad outcomes become more likely. The police could be called; there could be a potentially-violent confrontation; or the burglar may not have time to steal as much.

During dry weather, it's possible that more people are away from home to enjoy the outdoors. This would create more empty homes to strike, decreasing the risk of being caught and potentially increasing the expected reward from successfully committing a burglary. A rational burglar would take this into account, incorporating precipitation into his expected utility function, and striking in dry weather.

## 7. Conclusion

This study contributes to extant literature by examining the relationship between weather and crime over annual time periods and across counties, thus removing the effects of short-term fluctuations in weather; by examining individual crime types rather than categories of crime, thus allowing for more insight into the decision-making process behind each type of crime; and by using fixed-effects methods with additional demographic and economic variables to control for time-variant heterogeneity.

This study reveals several interesting relationships between crime and weather. The fact that temperature and precipitation were significant in the simple models and insignificant in fixed effects models with controls shows the importance of control variables and fixed effects. There are many factors that affect crime, and without controlling for as many of them as possible, studies run the risk of finding spurious correlations significant. The lack of evidence for a relationship between weather and homicide, rape, and robbery over long time periods may also indicate that the relationship between weather and these crimes are better explained by biological factors than rational-choice theory. Peoples' expected utility functions for committing these crimes may not place much weight on ambient weather conditions. It is also interesting that the only property crime investigated by this paper (burglary) was significant. Previous literature has reached no consensus on the effect of weather on property crimes.

Under rational-choice theory, though, burglary has a very strong basis for being influenced by weather. This is because burglaries are very rarely spur-of-the-moment decisions brought on by agitation or stress. They require planning and a clear understanding of the risks and rewards. And precipitation levels affect the risks of being caught. To successfully commit a burglary, a criminal must be sure that no one is in the property he plans to strike. If someone is present, the burglar runs a very high risk of being caught. If fewer people venture outside the confines of their homes in rainy or snowy weather, it makes sense for a criminal to avoid committing any burglaries. But in dry weather, with more people away from their homes, the criminal has a lower risk of being caught.

The relationship between precipitation and burglary also has intriguing implications. The significant results suggest that criminals tend to factor precipitation levels into their decision to commit a burglary. This finding can help policy-makers and police departments allocate resources. In dry weather, it could be prudent to increase patrols in areas with many houses. It may also be wise for policy-makers to incentivize residents to keep their homes secure during dry weather as well.

This study was not without its limitations. Demographic and economic data were imputed for the years 2001-2005, using a simple trend based on the values in 2000 and 2006 for each county. It is possible that some variation was lost in this process. Part of the reason for many results becoming insignificant in the fixed-effects regressions could be due to little variation within counties over time. If this were the case, the linear and random effects models may do a better job of capturing the true effect of weather on crime than the fixed effects models. This paper also only had data for crimes that were reported to police. In periods of heavy rain or snow, crimes may be more likely to go unreported, as there are fewer witnesses to contact police. Likewise, in dry weather, with more people out of their houses, there may be more burglaries that go unnoticed. For this reason, the effects of weather on some crimes may be understated by this paper.

California's climate, which tends to be warmer than most of the United States, could also be a limiting factor in this study. As mentioned earlier, it is possible that people in warmer climates may not alter their behaviors and routines much due to changes in temperature. If this were the case, warmer weather wouldn't necessarily lead to more potential targets, and colder weather wouldn't necessarily lead to fewer potential witnesses. Differences in behavior between people in warmer and more moderate climates could also account for this paper's results being different than previous literature that examined crime over time and across regions. Because of the possibility that people in warmer climates might not change their habits and behavior as a result of temperature variation, it might be prudent to only apply the results found by this paper to warm regions.

In addition to these limitations, there is an inherent endogeneity problem that comes with investigating the effect of weather on crime over large geographic regions. It is possible that people who are more likely to commit crimes tend to prefer areas with certain climates. Individuals who commit crimes against other people may purposefully try to live in areas with pleasant weather conditions, as these areas tend to have higher populations. If this were the case, then any findings that link weather and crime would be circumspect, as the effect of weather on criminals' living choices would be nearly indistinguishable from the actual effect weather has on crime. To control for this endogeneity problem, researchers would have to find an instrumental variable that is correlated with weather but not crime.

Future studies can extend on this paper by gathering more data from different geographies, including more years, and finding demographic and economic data for every year and region. While California is somewhat diverse in both climate and population, incorporating other states into a future study would be a good test of whether the relationships revealed in this study hold in other regions. However, potential differences in criminal definitions, laws, and law enforcement levels make this a difficult task. Getting data for more years would also improve on this study by capturing more heterogeneity in crime, demographic, economic, and weather variables. Additional variation in these variables could help researchers paint an even clearer picture of how weather affects crime.

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# Table 1: Summary Statistics

| Variable | N | Mean | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| Homicide | 638 | 38.6 | 127.0 | - | 1,162.0 |
| Rape | 638 | 161.3 | 346.9 | - | 2,894.0 |
| Robbery | 638 | 1,113.0 | 3,652.1 | - | 30,254.0 |
| Burglary | 638 | 4,083.0 | 8,283.9 | 10.0 | 62,055.0 |
| Temperature | 629 | 58.2 | 5.7 | 38.3 | 75.3 |
| Precipitation | 632 | 24.8 | 15.5 | 0.4 | 106.5 |
| Population | 638 | 613,151.8 | 1,373,167.0 | 1,175.0 | 9,818,605.0 |
| Percent Female | 638 | 49.4 | 2.4 | 35.8 | 52.1 |
| Median Age | 638 | 37.3 | 5.4 | 29.0 | 50.9 |
| Percent Non-White | 638 | 28.6 | 13.5 | 5.8 | 57.0 |
| Percent Over High School | 638 | 56.5 | 9.3 | 37.0 | 79.1 |
| Percent High School | 638 | 24.1 | 4.5 | 12.4 | 32.9 |
| Percent Rural | 638 | 30.3 | 29.0 | - | 100.0 |
| Percent Not Married | 638 | 47.0 | 4.5 | 31.9 | 61.9 |
| Unemployment Rate | 638 | 8.2 | 3.6 | 2.9 | 28.8 |
| Median Household Income | 638 | 47,253.1 | 12,263.5 | 27,552.0 | 84,627.0 |

Note: Weather data could not be obtained in several years for several counties. As a result, both temperature and precipitation have fewer than 638 observations.

# Table 2: Robbery Results

| Robbery | Basic OLS | OLS with Controls | Basic Fixed Effects | Fixed Effects with Controls | Random Effects |
|---|---|---|---|---|---|
| Temperature | -45.49** | -64.75** | -9.45** | -12.77 | -23.39* |
| | (17.83) | (28.68) | (4.49) | (8.63) | (14.03) |
| Precipitation | 4.89 | 9.58 | -5.55** | -0.53 | -0.43 |
| | (3.47) | (8.41) | (2.71) | (2.18) | (2.45) |
| Population (in 10,000s) | 26.12***<br>(2.66) | 25.95***<br>(2.20) | -5.81<br>(21.98) | -15.97<br>(23.511) | 23.45***<br>(2.00) |
| % Female | | -12.21 | | 106.01 | 12.34 |
| | | (34.51) | | (124.06) | (32.55) |
| Median Age | | 127.56*** | | -90.74 | 48.22 |
| | | (47.17) | | (70.16) | (35.04) |
| % Non-White | | 35.71* | | 100.87 | 44.86* |
| | | (18.25) | | (64.67) | (24.52) |
| % Greater than High School Education | | -31.77<br>(35.20) | | -46.71<br>(39.92) | -11.75<br>(15.36) |
| % With only High School Education | | -59.03<br>(50.58) | | -66.56<br>(72.06) | -84.53<br>(82.49) |
| % Rural | | -5.84 | | -24.24 | 6.03 |
| | | (6.35) | | (28.94) | (5.45) |
| % Not Married | | 28.73 | | -6.68 | -7.78 |
| | | (24.76) | | (13.13) | (8.34) |
| Unemployment | | 30.59 | | 34.12 | -14.03 |
| | | (50.34) | | (25.74) | (20.37) |
| Income (in $1,000s) | | -37.67 | | 7.71 | -46.28 |
| | | (25.48) | | (26.14) | (35.66) |
| Constant | 2,030.75** | 1,530.99 | 2,177.02 | 2,692.34 | 2,343.60 |
| | (917.47) | (3,597.03) | (1,531.95) | (6,482.31) | (4,321.15) |
| Number of Observations | 629 | 629 | 629 | 629 | 629 |

*denotes significance at 10% level; **denotes significance at 5% level; ***denotes significance at 1% level

Standard errors clustered by county in parentheses

# Table 3: Rape Results

| Rape | Basic OLS | OLS with Controls | Basic Fixed Effects | Fixed Effects with Controls | Random Effects |
|---|---|---|---|---|---|
| Temperature | 0.33 | -0.99 | -0.34 | -1.51 | -1.82 |
| | (0.60) | (1.33) | (0.97) | (1.42) | (1.51) |
| Precipitation | 0.22 | 0.28 | -0.23 | -0.25 | -0.38 |
| | (0.19) | (0.34) | (0.18) | (0.32) | (0.30) |
| Population | 2.48 *** | 2.45*** | -4.14 | -3.96 | 2.33*** |
| (in 10,000s) | (.06) | (0.05) | (3.08) | (3.28) | (.05) |
| % Female | | 0.93 | | 1.04 | -2.17 |
| | | (1.79) | | (16.56) | (2.96) |
| Median Age | | 0.24 | | -7.21 | 7.96* |
| | | (2.18) | | (8.68) | (4.18) |
| % Non-White | | 2.22 | | 8.67 | 2.71 |
| | | (1.39) | | (7.76) | (1.84) |
| % Greater than High | | 3.60** | | -5.38 | 1.04 |
| School Education | | (1.64) | | (4.99) | (1.59) |
| % With only High | | 2.87 | | -10.67 | -7.29 |
| School Education | | (2.86) | | (9.15) | (7.18) |
| % Rural | | -0.56* | | -5.39 | -1.38*** |
| | | (0.33) | | (3.55) | (0.39) |
| % Not Married | | -0.16 | | 1.55 | 0.78 |
| | | (1.57) | | (1.77) | (1.50) |
| Unemployment | | -0.20 | | 4.73 | -1.41 |
| | | (2.71) | | (3.28) | (2.39) |
| Income (in $1,000s) | | -3.42*** | | -1.68 | -6.03** |
| | | (1.15) | | (2.48) | (2.68) |
| Constant | -15.66 | -132.01 | 446.15* | 1,163.66 | 286.95 |
| | (30.60) | (189.60) | (237.50) | (941.69) | (382.36) |
| Number of Observations | 629 | 629 | 629 | 629 | 629 |

*denotes significance at 10% level; **denotes significance at 5% level; ***denotes significance at 1% level

Standard errors clustered by county in parentheses

# Table 4: Homicide Results

| Homicide | Basic OLS | OLS with Controls | Basic Fixed Effects | Fixed Effects with Controls | Random Effects |
|---|---|---|---|---|---|
| Temperature | -1.38** | -2.42** | -0.28 | -0.63 | -1.20 |
| | (0.60) | (1.08) | (0.34) | (0.65) | (0.82) |
| Precipitation | 0.19 | 0.29 | -0.09 | -0.13 | -0.09 |
| | (0.13) | (0.30) | (0.07) | (0.16) | (0.14) |
| Population (in 10,000s) | 0.89*** | 0.90*** | -1.45 | -1.88 | 0.82*** |
| | (0.11) | (0.08) | (1.55) | (1.70) | (0.07) |
| % Female | | 0.27 | | 4.68 | -0.57 |
| | | (1.22) | | (8.23) | (1.19) |
| Median Age | | 3.58** | | -6.65 | 3.02 |
| | | (1.74) | | (4.83) | (2.38) |
| % Non-White | | 0.68 | | 5.14 | 1.28 |
| | | (0.56) | | (4.33) | (0.97) |
| % Greater than High School Education | | -1.90 | | -2.80 | -0.91 |
| | | (1.34) | | (2.71) | (0.77) |
| % With only High School Education | | -1.87 | | -4.16 | -4.89 |
| | | (1.91) | | (4.89) | (4.56) |
| % Rural | | -0.24 | | -1.99 | -0.03 |
| | | (0.29) | | (1.99) | (0.17) |
| % Not Married | | 0.71 | | 0.28 | -0.11 |
| | | (0.82) | | (0.74) | (0.54) |
| Unemployment | | 0.88 | | 1.28 | -1.55 |
| | | (1.78) | | (1.69) | (1.29) |
| Income (in $1,000s) | | -1.07 | | -0.67 | -2.77 |
| | | (.91) | | (1.38) | (1.74) |
| Constant | 58.22* | 120.82 | 148.21 | 379.08 | 244.30 |
| | (29.51) | (133.09) | (110.15) | (441.18) | (226.43) |
| Number of Observations | 629 | 629 | 629 | 629 | 629 |

*denotes significance at 10% level; **denotes significance at 5% level; ***denotes significance at 1% level

Standard errors clustered by county in parentheses

# Table 5: Burglary Results

| Burglary | Basic OLS | OLS with Controls | Basic Fixed Effects | Fixed Effects with Controls | Random Effects |
|---|---|---|---|---|---|
| Temperature | 81.09** | 25.12 | 0.65 | -15.77 | -15.55 |
| | (32.26) | (51.58) | (12.31) | (21.80) | (28.23) |
| Precipitation | -10.37 | -13.36 | -2.07 | -8.43** | -10.55** |
| | (6.68) | (10.82) | (2.19) | (4.08) | (4.21) |
| Population (in 10,000s) | 57.61*** | 57.05*** | -5.16 | -18.44 | 53.85*** |
| | (1.25) | (1.10) | (52.10) | (55.09) | (1.72) |
| % Female | | 92.48 | | 246.47 | 107.48 |
| | | (61.02) | | (317.40) | (75.77) |
| Median Age | | -44.28 | | -279.67* | 4.54 |
| | | (69.73) | | (160.85) | (75.67) |
| % Non-White | | 48.60 | | 238.09* | 92.45** |
| | | (31.51) | | (132.88) | (42.26) |
| % Greater than High School Education | | 84.81 | | -78.40 | 38.91 |
| | | (52.17) | | (99.26) | (33.28) |
| % With only High School Education | | 207.90** | | -67.66 | -27.92 |
| | | (97.32) | | (161.09) | (149.47) |
| % Rural | | -15.58 | | -63.59 | -10.10 |
| | | (10.56) | | (61.05) | (8.89) |
| % Not Married | | 30.77 | | 35.30 | 23.45 |
| | | (40.62) | | (31.92) | (23.56) |
| Unemployment | | 2.11 | | 97.06 | -13.53 |
| | | (83.21) | | (58.92) | (36.16) |
| Income (in $1,000s) | | -60.24 | | -72.69 | -110.41* |
| | | (37.30) | | (52.99) | (58.83) |
| Constant | 3,902.47** | 12,806.87* | 4,472.75 | 6,374.18 | -3,504.73 |
| | (1,707.01) | (6,400.87) | (3,590.50) | (18,771.44) | (7,817.78) |
| Number of Observations | 629 | 629 | 629 | 629 | 629 |

*denotes significance at 10% level; **denotes significance at 5% level; ***denotes significance at 1% level

Standard errors clustered by county in parentheses