

The Effects of Weather on Crime

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Abstract

This paper uses daily data from 43 districts across New Zealand from 2000 to 2008 and employs panel econometric techniques to investigate the effect of weather on crime. Temperature and precipitation are found to have a significant effect on the number of violent crimes recorded and temperature also affects the number of property crimes recorded. Studies of this nature are important for the allocation of police resources.

As an extension, the common belief that the Nor'wester wind causes 'disorderly' behavior is empirically investigated. Data on violent crime from three Canterbury police districts is used. The Nor'wester is found to be statistically insignificant in determining the number of violent crimes in Canterbury.

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1. Introduction

Criminal activity and the factors driving it have received a lot of attention. One factor that is believed to affect criminal activity is weather. A small body of literature empirically investigates this relationship and mostly supports the conclusion that weather has a causal effect on criminal activity. This paper investigates whether this relationship holds in New Zealand. Incorporating weather into the dynamics of criminal behavior potentially provides important explanatory power for models of criminal behavior. In addition, weather could be used as an instrumental variable in analyses of the effects of crime on a number of variables such as property prices, quality of life indices, economic growth, and so on. Furthermore, weather could act as a direct predictor of criminal activity. This would be a valuable tool for police in their efforts to allocate resources.

This paper employs panel econometric techniques on daily crime and weather data from New Zealand from 2000 to 2008. Two broad categories of crime are analyzed: property crime and violent crime. Temperature and precipitation are used as measures of weather. The relationship between each of the crime variables and each of the weather variables is investigated. Evidence is found to suggest that weather has a significant effect on criminal activity.

As an extension, the effect of the North-westerly wind, which is often thought to induce ‘disorderly’ behavior, on violent crime in Canterbury is measured.

2. Theoretical Framework

The supply of criminal offences depends on the individual-specific costs and benefits of the crime as well as individual-specific preferences and circumstances (Becker 1968). A crime will

be committed if the expected utility of committing a crime exceeds the expected costs (including the opportunity costs, i.e., the expected utility of using the same amount of time and resources elsewhere). For example, as the probability of being caught increases, the expected cost of committing an offence increases, thereby decreasing the number of offences committed. Similarly, if the expected punishment for an offence increases, the expected cost of committing an offence increases, thereby decreasing the number of offences committed. Several studies provide empirical evidence for these assertions (Sjoquist 1973). Other important determinants of criminal activity include the potential income derived from criminal activity, moral attitudes towards criminal behavior, risk aversion, and the opportunity set outside of criminal activity. Weather may have an effect on the probability of being caught committing a crime as well as on several other determinants of criminal behavior.

2.1 Violent Crime

Previous literature emphasizes the psychological impacts of weather and the resulting changes in the propensity to commit a violent crime. For example, the Negative Affect Escape (NAE) model stipulates that aggression increases with temperature because of increases in irritation and discomfort, but only up to a certain point. At this point, the relationship changes to being negative as the discomfort increases to a level where the motivation to escape uncomfortable situations outweighs the motivation to be aggressive (Bell 1992). Thus, there is an ‘inverse-U-shaped’ relationship between temperature and aggression. As aggression increases/decreases, the expected utility of crime which releases that aggression also increases/decreases.

The General Affect (GA) model suggests that higher temperatures facilitate *affective* aggression (Cohn and Rotton 2000a). That is, higher temperatures facilitate aggression that has its primary

purpose in injuring another person. The Routine Activity (RA) theory stipulates that a criminal event requires three elements: a suitable target, a motivated offender, and the absence of capable guardians against crime (Felson 1987; Cohn and Rotton 2000a). Relating this to weather, ‘better’ weather conditions are likely to increase the likelihood of a suitable target occurring, thus increasing the expected utility of crime. For example, better weather will increase mobility and social interaction as more people leave their homes thereby presenting more opportunities for violent crime to occur. However, better weather is also likely to increase the presence of capable guardians, increasing the probability of being caught and thus the expected costs of crime. If more people are interacting, then there will be more capable guardians (e.g., companions or bystanders) to prevent a crime. As a result, ‘worse’ weather may increase violence when people do come in contact due to the lack of capable guardians. An example of this latter effect is domestic violence. Regarding the third necessary element, motivation to commit a violent crime may be related to temperature (as stipulated by the NAE and GA models). Thus, the overall impact of weather on violent crime will depend on the magnitudes of the effects on all of the three elements. For example, if temperature increases, will the increase in capable guardians (i.e., the increase in expected costs) counter the increase in suitable targets and motivation (i.e., the increase in expected utility)? The RA theory is ambiguous on this point and the answer is essentially an empirical matter.

2.2 Property Crime

Weather is likely to have an impact on social mobility. If the weather is ‘fine’, people are less likely to be at home (Schmallager 1997). People may be more likely to go out in the evening or go away for the weekend. The RA theory described above illustrates how this might impact on criminal activity through the likelihood of encountering a suitable target, a motivated offender,

and the absence of capable guardians against crime. First, in ‘fine’ weather, it is less likely that people will be in their homes, therefore decreasing the probability of a capable guardian being present. This decreases the probability of being caught, thereby decreasing the expected costs and increasing the number of property crime offences, *ceteris paribus*.

Second, if more homes are unoccupied, potential burglars will have a greater selection of suitable targets. This increases the expected utility of committing a property crime as the most suitable target can be chosen. For example, if all houses on a street are unoccupied, the burglar can choose the most expensive house on the street, thereby increasing the expected monetary benefits of a burglary.

Third, criminals may be less motivated to commit crimes during ‘bad’ weather. For example, precipitation may discourage a criminal from undertaking a burglary because of the discomfort of being outside in bad weather (and the associated expected costs). In addition, bad weather could make transporting stolen goods, in particular electronic equipment, more difficult. Thus, overall, we may expect ‘fine’ weather to be associated with more property crime.

2.3 Effect of Weather on Policing

It is possible that the police incorporate weather as a decision variable when deciding on the level and intensity of policing. First, police departments may have already observed the relationship between weather and crime and adjusted police presence accordingly. If the police presence is consistently higher in finer weather, we would expect this to result in fewer crimes occurring as criminals acknowledge the increased probability of being caught. This would introduce a downward bias to the relationship between weather and crime observed in the data, making the

results of this study conservative (i.e., representing a lower bound of the true effect of weather on crime, *ceteris paribus*). Second, effort levels of police officers may change depending on weather. For example, if it is raining, police may not decide to do a foot patrol. The temperament of police officers may also be affected by weather. In line with the NAE model, increased temperatures may increase police aggression resulting in more arrests. It is important to note, however, that the crime data used in this study consist of recorded crimes and so a police officer does not necessarily have to witness the crime or apprehend the offender for it to be recorded. The issue of variation in policing is a small but noteworthy limitation of our study.

3. Previous Findings

Several studies have been conducted internationally on the effects of weather on criminal activity. The weather variables used and crimes measured vary across studies.

3.1 Violent Crime

Using weekly data from 116 jurisdictions in the U.S. from 1995 to 2001, Jacob, Lefgren, and Moretti (2006) find that a 10°F increase in average weekly temperature is associated with a 5% increase in violent crime. For precipitation, they find that a 1 inch increase in average weekly precipitation is associated with a 10% reduction in violent crime. Using monthly data from England and Wales, Field (1992) finds that temperature is positively and significantly correlated with violent crime, sexual offences, and criminal damage. Precipitation provides no explanatory power and is insignificant for all dependent variables. Cohn and Rotton (2000b) use data on complaints about disorderly behavior from Minnesota over two years and find that temperature is significantly correlated with the number of complaints. Their evidence supports the existence of a

curvilinear relationship, with the number of complaints increasing with temperatures up to 70°F and then exhibiting a negative relationship at temperatures above this point.

Cohn and Rotton (2000c) test for a curvilinear relationship between violence and temperature. Their data consists of calls for service relating to aggravated assault over a two year period in Dallas, Texas. When analyzing the relationship between temperature and violent crime over three hour time periods, the authors find a curvilinear pattern, with temperature positively correlated with calls up to 85°F and negatively correlated thereafter. Interestingly for the purposes of this study, the relationship is not as prominent when the data is aggregated into 24 hour time periods.

To summarize, the literature is largely consistent with the hypothesis that violent crime is strongly correlated with temperature. In addition, there is evidence of an inverse-U-shaped relationship between temperature and violent crime. The literature is ambiguous about the effect of precipitation on violent crime.

3.2 Property Crime

Jacob, Lefgren, and Moretti (2006) find that a 10°F increase in the average weekly temperature is correlated with a 3% reduction in property crime. Their results indicate that precipitation is insignificant. Field (1992) finds that burglary, theft and robbery are all positively and significantly correlated with temperature. Precipitation is insignificant in his results. Since monthly data is used, the paper does not provide evidence on the effects of brief weather shocks.

Cohn and Rotton (2000a) analyze theft, burglary and robbery in Minneapolis over two years using calls for service to measure criminal activity. They find that theft is negatively correlated

with precipitation and temperature and that both burglary and robbery are positively correlated with precipitation and temperature.

To summarize, the literature is ambiguous about the effects of temperature and precipitation on property crime.

4. Data

Daily data on recorded crime was obtained from the New Zealand Police. It covers 43 districts in New Zealand from 1st January 2000 to 31st December 2008 and several crime categories are available (Table 1).

From the raw data, violent and property crime variables were constructed by aggregating different categories, as illustrated below. This aggregation largely removed zero values.

$$\begin{aligned}\text{Violent Crime} &= \text{Violence} + \text{Property Damage} + \text{Property Abuse} \\ \text{Property Crime} &= \text{Theft} + \text{Burglary}\end{aligned}$$

‘Property Damage’ and ‘Property Abuse’ were categorized as violent crimes because they constitute violence against property. Other categories were excluded from the main specification because there was no theoretical justification for their inclusion. For example, fraud is unlikely to be related to weather. In addition, most of the existing literature does not include these categories and so excluding them makes our results more comparable.

A crime is recorded upon the report of an incident if that incident is deemed to be an offence and there is no evidence to the contrary. In the majority of cases, violent crimes are reported on the

day of the crime; however, this could be an issue for some categories of violent crime. For example, 'Property Abuse' such as vandalism may be reported days after the actual incident occurred (for example, when the property owners return from holidays). Delayed reporting is a more serious issue for property crime, as crimes are less likely to be reported immediately after the crime has occurred. This represents a limitation of our study but an attempt is made to address this issue by employing several lags of the weather variables.

Daily weather data was obtained from the National Institute of Water and Atmospheric Research (NIWA) from 1st January 2000 to 31st December 2008. Weather variables collected were maximum and minimum daily temperature (in °C) and total precipitation (in millimeters).

For each of the district/day crime observations, a corresponding weather observation had to be found. This was done by matching police districts to the nearest weather station(s). While there are many weather stations in New Zealand, finding the appropriate data was complicated by the fact that weather stations often have incomplete (missing) records or do not measure either temperature or precipitation. Another complicating issue is the treatment of large police districts. For example, Rural Otago has a large geographic area with population concentrated in Queenstown, which is located in the mountains, and Oamaru, which is located on the coast. As expected, an inspection of temperature and precipitation variables for these areas revealed large differences in weather conditions. While imperfect, our method for constructing weather variables for areas such as Rural Otago was to take weighted averages based on population estimates obtained at the small town level from Statistics New Zealand. So, for example, the weather variables for Rural Otago were created by weighting Queenstown and Oamaru weather conditions by the corresponding population estimates. This is similar to the method used by

Jacob, Lefgren, and Moretti (2006) in their treatment of county-level weather variables. In our study, this method was used for 11 of the 43 police districts.

A further issue was that due to the proximity of some police districts, the same weather data had to be used for more than one police district. This was only a problem for the 8 police districts within Auckland. Weather data was missing for less than 1% of the days covered in the sample.

Annual population data was collected as a control. Data was sourced from Statistics New Zealand. In some regressions, observations are weighted by population. This is done in order to give a greater weight to observations that affect more people and thus to make the results nationally representative. The regression results are robust to the use of population weights, presumably largely because police districts are defined so that population is evenly dispersed.

Quarterly unemployment data was sourced from the Household Labour Force Survey (HLFS). The data available is aggregated across 12 regions in New Zealand which means that some police districts had to be linked with the same unemployment data. The regional unemployment rate was used as a control in recognition of the fact that unemployment has previously been found to be a determinant of crime in New Zealand (Papps and Winkelmann 2000).

5. Descriptive Statistics

The average number of violent crimes per day per district is 7.21 and the average number of property crimes is 11.79 (Table 2). On ‘cold days’ when the maximum temperature is less than 14°C (57°F), representing the coolest quintile of days, the average numbers of violent and

property crimes are lower than the overall means. On ‘very hot’ days when the maximum temperature is greater than 27°C (80°F), the temperature that other studies have identified as a turning point (Cohn 1990), the average numbers of violent and property crimes are also lower than the overall mean. This is consistent with the inverse-U-shaped relationship discussed above. On days with more than 10 millimeters (0.04 inches) of precipitation (three times the daily average precipitation in the sample), the average number of violent crimes per district is 6.46 which is significantly lower than the sample average of 7.21. The average number of property crimes per district is 11.50 on days with more than 10 millimeters of precipitation, which is slightly lower than the sample average of 11.79. The maximum precipitation in our sample (241 mm; 0.95 inches) occurred in the Bay of Plenty in May 2005 during heavy flooding. The maximum temperature (36°C; 97°F) was recorded in mid-south Canterbury in January 2004.

6. Methods and Results

6.1 Temperature and Violent Crime

Ordinary least squares (OLS) was used to estimate the following base specification:

$$O_{d,t}^v = \beta_0 + \beta_1 \text{tempmax}_{d,t} + \beta_2 \text{tempmax}_{d,t}^2 + \beta_3 \text{controls}_{d,t} + \varepsilon_{d,t}$$

where

$O_{d,t}^v$ = violent offences in district d on day t

$\text{tempmax}_{d,t}$ = maximum temperature in district d on day t

$\text{controls}_{d,t}$ = a set of controls

The set of controls includes annual district population, region-specific quarterly unemployment rate, day of the week dummy variables, an interaction term between city districts and the weekend, month dummy variables, year dummy variables, district dummy variables, and a linear time trend for each district. The above specification – specification (1) – is our preferred

specification for its intuitive appeal, simplicity, as well as its goodness-of-fit ($R^2=0.43$). However, as shown below, the coefficients on the temperature variables remain robust to different alternative specifications. The results of specification (1) are presented in the first column of Table 3. Robust standard errors are used in all specifications to correct for possible heteroskedasticity.

The results in specification (1) - and in all other specifications - suggest that temperature has an effect on the number of violent crimes recorded. The daily maximum temperature coefficient is positive and significant as expected, and the coefficient on daily maximum temperature squared is negative and significant, consistent with the proposed inverse-U-shaped relationship.

It is crucial to note that by including district and month dummies in our regressions, we are only estimating the effects of unexpected (i.e., not given by geography and season) weather changes. Thus, we may be underestimating the full effects of weather on crime. Unfortunately, the alternative approach of omitting district and month dummies will produce biased estimates of the effects of weather/climate on crime if some other factors (e.g., school holidays or immigration to Auckland) are correlated with both of these variables. Therefore, we prefer our fixed effects specification but note that caution is needed when deriving policy recommendations from our findings. In particular, we emphasize that in allocating its resources, police should use information on both district and seasonal characteristics (e.g., January in Auckland) and current weather conditions (from short-term weather forecast) into account.

Specification (2) weights observations by annual district population, giving greater weight to observations that affect more people. Specification (3) adds three lags of the dependent variable

(i.e., violent crime) to specification (2). Note that although the first and second lags are highly significant, the effect of temperature on violent crime remains robust. Specification (4) adds precipitation and an interaction term between temperature and precipitation as explanatory variables to specification (3). The coefficient on precipitation is negative and significant as expected. The interaction term is very small and insignificant which indicates that the effects of temperature and precipitation are separate from each other. Specification (5) uses the crime rate calculated as crimes per 100,000 people as the dependent variable with the same controls as specification (1), excluding population. Specification (6) uses the Tobit procedure with censoring at zero with the same controls as specification (1). The dependent variable had a value of zero in 2.5% of the sample and so the Tobit procedure was used to address any bias that may have occurred using OLS. The coefficient estimates for temperature and temperature squared are almost identical to the OLS estimates suggesting that no serious bias occurs when using OLS.

Specification (7) uses the average temperature of the preceding seven days as an explanatory variable. The coefficient is small and insignificant indicating that sudden deviations from the average temperature rather than simply warmer periods are important in determining crime. Specification (8) allows each district to have a non-linear time trend to account for the fact that crimes within each district may evolve differently over time. An interaction between district and year dummy variables was used to achieve this. This specification did not alter the observed effect of temperature on violent crime. Similarly, each month was allowed to have a district-specific effect by interacting each district with each month. The relationship between temperature and violent crime was unaffected by this specification (results available on request). As an additional robustness check, specification (1) was run without temperature as an explanatory variable. This produced an AIC value of 777,510 compared with an AIC value of 767,953 when

the temperature controls are included. This suggests that temperature adds explanatory power to the specification.

Coefficients on most of the controls used (available on request) have the expected sign. As expected, Friday and Saturday have higher levels of crime than Mondays. This result also suggests that violent crimes are recorded when they occur; more crimes are expected on the weekend and this is when more crimes are recorded. Population is positive and significant. Unemployment does not have a statistically significant impact which is contrary to previous findings in New Zealand (Papps and Winkelmann 2000). A potential source of this difference is that Papps and Winkelmann used annual data whereas this study uses daily data: unemployment is more likely to affect the propensity to commit crimes over a much longer time period, rather than explaining day to day variation in crime. The coefficients on the weekend*city interaction terms are positive and significant. This can be explained by high transitory population over the weekend in cities relative to other districts and by increased social activity. The city districts used were Auckland Central City, Hamilton, Wellington, Christchurch and Dunedin. The month dummy variables produced some interesting results; with April to July having the lowest number of violent crimes and November the highest number of crimes relative to January. A joint coefficient test on the eleven month dummy variables produced an F-statistic of 87.42; confirming a strong seasonal component of crime. The year dummy variables suggest that violent crime was decreasing in the period from 2000 to 2005 and then increasing slightly in 2005 to 2008.

What specifically do our results imply about the effects of regional temperature changes on violent crime? As an example, take consecutive Wednesdays in Counties-Manukau South in July

2004. These days were chosen because precipitation was zero on both days and all other controls such as the day of the week, month, year, the unemployment rate, population and district are held constant. This enables us to isolate the effect of an increase in temperature. The temperature on the first Wednesday was 14.2°C (57.6°F) and on the second Wednesday 17.2°C (63.0°F). Our model predicts an increase in the number of violent crimes by 2.2% (from 7.20 to 7.36) due to this change in temperature (the actual number of violent crimes on both these days was 5).

Figure 1 illustrates the general effect of temperature on the total number of violent crimes implied by our empirical models. The turning point occurs at 27°C (80°F – similar to Cohn 1990; Cohn and Rotton 2000b and 2000c), indicating that violent crime increases with temperature up to that point but then begins to decrease. To further examine this relationship, total violent crime was regressed on the maximum temperature for days when the maximum temperature was lower than 27°C and for days when the maximum temperature was higher than 27°C (available on request).

On days when the maximum temperature is lower than 27°C, maximum temperature has a positive and significant effect. On days when temperature is greater than 27°C, maximum temperature has a negative but insignificant coefficient. These findings are consistent with the curvilinear relationship estimated in specification (1), although the insignificance of the maximum temperature variable at temperatures greater than 27°C also allows for a zero effect of temperature on crime – consistent with a positive but diminishing (in the limit to zero) marginal effect of temperature on violent crime. Alternatively, the insignificance of the temperature variable on ‘very hot’ days could be due to a small sample size (3,820 observations).

Care is required when interpreting the above results. Firstly, the coefficient on temperature indicates the effect of relative (compared to other districts) temperature changes. Seasonal effects are accounted for by the month dummy variables and any national time trend by the year dummy variables. Since year to year changes are accounted for, no inference can be made about national, long run changes to the average temperature. So, for example, we cannot conclude that global warming would increase the number of violent crimes committed. Furthermore, we note that out-of-sample predictions should not be made based on our results. For example, our results do not apply to temperature changes at extremely low or extremely high temperatures not observed in New Zealand.

Specification (1) was used to estimate the relationship between temperature and each of the three subcategories of violent crime: ‘Violence’, ‘Property Abuse’, and ‘Property Damage’ (available on request). ‘Violence’ did not exhibit the curvilinear relationship found in the aggregated category. When the quadratic term was excluded from regressions on ‘Violence’, the coefficient on maximum temperature increased to 0.017 with a t-statistic of 7.22. ‘Property Abuse’ and ‘Property Damage’ did exhibit the curvilinear relationship witnessed in the aggregated category.

6.2 Precipitation and Violent Crime

OLS was used to estimate the following base specification:

$$O_{d,t}^v = \beta_0 + \beta_1 \text{precip}_{d,t} + \beta_3 \text{controls}_{d,t} + \varepsilon_{d,t}$$

where

$O_{d,t}^v$ = violent offences in district d on day t

$\text{precip}_{d,t}$ = millimetres of precipitation in district d on day t

$\text{controls}_{d,t}$ = a set of controls

The controls are the same as those used in specification (1) for temperature and violent crime. Specification (1) is again our preferred specification, for its simplicity and performance on goodness-of-fit measures ($R^2=0.43$; Table 4). Again, robust standard errors are used in all specifications to correct for possible heteroskedasticity.

Specifications (1) to (6) and specification (8) use the same controls and procedures as used in the temperature and violent crime specifications. The coefficient on precipitation is always negative and significant, as expected. Specification (7) adds a quadratic term for precipitation to specification (1). The coefficient on precipitation squared is positive (but small), suggesting that the marginal effect of precipitation on violent crime decreases as precipitation increases. The turning point is 90 millimeters (0.35 inches) of precipitation. However, only 66 days in the sample had more than 90 millimeters of precipitation and so we do not infer that crime starts to increase after 90 millimeters of rain. In addition, we could find no theoretical justification for such a relationship. Rather, we infer that in the limit, the effect of precipitation on violent crime is zero. The coefficients estimated for the controls (available on request) are very similar to those reported in the temperature and violent crime regressions.

The effect of precipitation on violent crime is negative and significant across all of our models and the magnitude of the coefficient is robust to the different specifications. In specification (1), the coefficient on precipitation is -0.019 (t-statistic -14.38), which can be interpreted as follows: a 10 millimeter (0.04 inch) increase in daily precipitation causes a decrease of 0.19 violent crimes committed per day per district. The average number of violent crimes per day per district is 7.21 and so the effect of precipitation is not negligible.

Specification (1) was used to estimate the relationship between precipitation and each of the three subcategories of violent crime: ‘Violence’, ‘Property Abuse’, and ‘Property Damage’ (available on request). The three subcategories all have a negative and significant relationship with precipitation.

6.3 Temperature and Property Crime

The baseline model was identical to the temperature and violent crime regression. Specification (1) was again selected as the preferred regression ($R^2=0.68$; Table 5). The relationship between temperature and property crime remained robust to alternative specifications.

Consistent with our hypothesis, specification (1) indicates that temperature increases the incidence of property crime (at least up to a point). This relationship is verified by all of our robustness checks. Specification (2) weights observations by annual district population, giving greater weight to observations that affect more people. Specification (3) adds lags of the dependent variable (i.e. property crime). Nine lags of property crime are used to deal with autocorrelation issues. Additional lags were used in the property crime regression compared to the violent crime regressions because shocks to property crime have previously been found to persist for longer time periods (Jacob, Lefgren, and Moretti 2006). The coefficients on the lag of property crime remain significant but their magnitude decreases. The positive sign on the lag of property crime indicates that higher crime today is associated with higher crime tomorrow. This seems contrary to the hypothesis that higher levels of property crime in one period reduce crimes in successive periods due to an income effect; however, an analysis of this issue is not developed further in our research. The coefficients on temperature and temperature squared remain

significant and similar in magnitude with the addition of the lags of property crime. Specification (4) adds precipitation and an interaction term between temperature and precipitation as explanatory variables to specification (3). Both precipitation and the temperature and precipitation interaction term are insignificant. The coefficients on temperature and temperature squared are not sensitive to the addition of precipitation and the temperature and precipitation interaction term. Specification (5) uses the crime rate calculated as crimes per 100,000 people as the dependent variable with the same controls as specification (1) except for population. The coefficients on temperature and temperature squared are slightly smaller, but the combined effect is similar to the other specifications. The coefficients remain significant at the 95% confidence level. Specification (6) uses the Tobit procedure with censoring at zero with the same controls as specification (1). The dependent variable had a value of zero in 1.2% of the sample. The coefficient estimates for temperature and temperature squared are almost identical to the OLS estimates.

Specification (7) adds the average temperature in the preceding seven days as an explanatory variable to specification (3). The coefficient is significant and negative. This suggests that warmer temperatures in the preceding week decrease the number of property crimes committed. A 10°C (18°F) increase in the average temperature in the preceding week decreases the number of property crimes committed on a given day by 0.24. This is not a particularly large effect considering that the average number of property crimes committed is 11.79. It is difficult to find a theoretical justification for this result. Specification (8) allows each district to have a non-linear time trend to account for the fact that crimes within each district may evolve differently over time. This specification did not alter the observed effect of temperature on property crime. As an additional robustness check, specification (1) was run without temperature as an explanatory

variable. This produced an AIC value of 828,654 compared with an AIC value of 818,716 when the temperature controls are included. This suggests that temperature adds explanatory power to the specification.

Coefficients on most of the controls used have the expected sign. As expected, Friday and Saturday have higher levels of property crime than Mondays. The impact of the weekend on property crime is not as large as the impact on violent crime. The coefficient on the dummy variable for Saturday is 1.67 for property crime (the average number of property crimes per day per district is 11.79) whilst the coefficient on Saturday is 3.99 for violent crime (the average number of violent crimes per day per district is 7.21). Population is positive and significant. The coefficient on unemployment is 0.03 and is significant at the 95% confidence level. This coefficient suggests that a 1 percentage point increase in unemployment causes the number of property crimes recorded in a district per day to increase by 0.03. This is consistent with previous findings in New Zealand (Papps and Winkelmann 2000). The coefficients on the weekend*city interaction terms (not reported) are positive and significant. The month dummy variables produced some interesting results; with March to June having the lowest number of property crimes (relative to January) and July and August having the highest number. A joint significance test on the eleven month dummy variables produced an F-statistic of 105.36; confirming a strong seasonal component to property crime. The year dummy variables suggest that property crime offences have been declining since 2003.

Figure 2 illustrates the effect of temperature on the total number of property crimes. The turning point occurs at 21°C (70°F), indicating that property crime increases with temperature up to that

point but then begins to decrease. To further examine this relationship, total property crime was regressed on the maximum temperature for days when the maximum temperature was lower than 21°C and for days when the maximum temperature was higher than 21°C (available on request).

On days when the maximum temperature is lower than 21°C (104,013 observations), maximum temperature has a positive and highly significant effect. On days when temperature is greater than 21°C (34,704 observations), the maximum temperature variable has a negative coefficient (significant at the 90% confidence level). These findings are consistent with the curvilinear relationship estimated in specification (1).

Specification (1) was used to estimate the relationship between temperature and each of the two subcategories of property crime: ‘Theft’ and ‘Burglary’ (available on request). ‘Theft’ and ‘Burglary’ both exhibit the same curvilinear relationship found in the aggregate category.

6.4 Precipitation and Property Crime

The baseline model was identical to the precipitation and violent crime regression. Specification (1) is again our preferred specification ($R^2=0.68$; Table 6).

Specifications (1) to (6) and specification (8) use the same controls and procedures used in the precipitation and violent crime specifications. The coefficient on precipitation is positive and significant which is an unexpected result as we hypothesized that higher levels of precipitation would *decrease* property crime. However, the magnitude of the coefficient is small. Interpreting the coefficient on precipitation in specification (1), a 10 millimeter (0.04 inch) increase in precipitation causes a 0.04 increase in the number of property crimes committed on that day. This

is a minor effect given that the average number of property crimes committed per day is 11.79. Specification (7) adds lags of precipitation for the three preceding days. This was done to deal with possible delays in reporting property crime – property crimes may occur in periods of low precipitation but only get reported in the succeeding days as people return from holiday. If this was the case, the coefficients on the lags of precipitation would be negative and significant – less rain on one day would cause an increase in the number of crimes reported in the following one to three days. This relationship is not observed, with all three lags of precipitation being insignificant. As an additional robustness check, a quadratic of precipitation was used and this also indicated that property crime and precipitation have a weak relationship.

Specification (1) was used to estimate the relationship between precipitation and the two subcategories of property crime: ‘Theft’ and ‘Burglary’ (available on request). The results indicate that precipitation has no effect on ‘Theft’ and the effect on ‘Burglary’ is negligible (with a positive, significant but very small coefficient).

6.5 Limitations to Empirical Work

There are several limitations to our empirical work. First, our model does not capture all the factors that explain criminal activity. For example, alcohol consumption is likely to be correlated with criminal activity. However, the purpose of our study is to investigate as precisely as possible the causal effect of weather on crime rather than build a comprehensive model explaining criminal activity. A more serious issue is that factors such as alcohol consumption may be correlated with weather. However, this only means that our work investigates the total effect of weather on crime: an indirect effect through its impact on daily activities as well as a direct effect through aggression relief etc.

Second, spatial correlation in crime could be an issue, particularly in areas such as Auckland. For example, higher crime in Auckland city could ‘spill over’ into neighboring police districts. We have not explicitly dealt with this issue but we take some comfort in the large size of police districts (average population of 94,600) and thus believe that spatial correlation does not have significant implications for our results. If police districts were city blocks, then it would be far more likely for a wave of burglaries to affect a cluster of city blocks. However, as our police districts are far larger than this, spatial correlation is unlikely to be a major issue.

Third, Augmented Dickey Fuller Tests revealed that within each district, the property crime and violent crime time series are characterized by unit roots. However, the effect of current weather on crime in our regressions is robust to the addition of lags of the dependent variable. Our study does not address the dynamic properties of crime beyond their effect on the coefficient estimates for the weather variables.

Fourth, it is possible that the weather variables are statistically significant due to the large number of observations rather than a causal relationship. In order to check whether the large number of observations is a key reason for the significance of the weather variables, we regressed ‘Fraud’ on temperature and precipitation. We could find no theoretical reason for a relationship between ‘Fraud’ and temperature/precipitation and so we expected that temperature and precipitation would be insignificant. Our findings confirmed this hypothesis, suggesting that the large number of observations was not the (only) reason for the significance of precipitation and temperature in our other results.

7. The Nor'wester and Violent Crime

The Nor'wester wind allegedly incites 'disorderly' behavior in the Canterbury region. For example, suicide rates and domestic violence rates are said to increase (Brenstrum 1989). In this section, we present a preliminary empirical test of this assertion, using the number of total violent crimes as a proxy for 'disorderly' behavior. We do not attempt to establish any effect of wind in general, but instead to investigate the special alleged effect of the Nor'wester.

We use data from the Christchurch, North Canterbury and South Canterbury police districts which are exposed to the Nor'wester. The Nor'wester is associated with warm weather. On days when the North Westerly wind is greater than 7 meters per second (25 km/h; 16 miles/h), the average maximum daily temperature is 20.5°C (68.9°F), compared to a sample mean of 17.0°C (62.6°F). The mean number of total violent crimes across the three regions is 9.8. On days when the North Westerly wind is greater than 7 meters per second, the average number of violent crimes is 11.3, indicating a possibility of a causal relationship.

To investigate the effects of the Nor'wester, a dummy variable was constructed using wind direction and speed (at 1 pm) and daily maximum temperature. The Nor'wester is colloquially defined as a warm, strong wind from the North West. No formal definition of the Nor'wester could be found and so, for our purposes, we define a Nor'wester to be a North Westerly wind that exceeds a speed of 10 meters per second (36 km/h; 22 miles/h) and a temperature of 17°C (63°F) - definition (1). The threshold for wind is based on the Beaufort wind scale which defines a 'fresh wind' to be 30–39 km/h (19-24 miles/h) and the temperature threshold was chosen at the average

temperature for the sample. Alternative definitions of the Nor'wester were employed as robustness checks (Table 7). OLS was used to estimate the following specification:

$$O_{d,t}^v = \beta_0 + \beta_1 \text{nor'wester}_{d,t} + \beta_2 \text{tempmax}_{d,t} + \beta_3 \text{tempmax}_{d,t}^2 + \beta_4 \text{precip}_{d,t} + \beta_5 \text{controls}_{d,t} + \varepsilon_{d,t}$$

where

- $O_{d,t}^v$ = violent offences in district d on day t
 nor'wester $_{d,t}$ = a dummy variable for a Nor'wester in district d on day t
 precip $_{d,t}$ = millimetres of precipitation in district d on day t
 tempmax $_{d,t}$ = maximum temperature in district d on day t
 controls $_{d,t}$ = a set of controls

The controls used are the same as those in specification (1) from the preceding sections. It is worth noting that β_1 in the above specification does not capture the full effect of a Nor'wester but only any *extra* effect Nor'wester might have after controlling for daily temperature and precipitation.

The coefficient on the Nor'wester is positive but insignificant across all four definitions. The Nor'wester variable calculated using our preferred definition, definition (1), is only significant at the 73% confidence level and so we cannot infer a strong extra effect of the Nor'wester on violent crime. Notably, the coefficients on the temperature and precipitation variables remain significant and of similar magnitudes to our previous findings.

Although the Nor'wester coefficient is statistically insignificant, its size is large. According to definition (1), a Nor'wester day causes an extra 1.08 violent crimes (the sample mean is 9.80). This is in addition to any effect of temperature or precipitation in general as both are controlled for. While the statistical insignificance of the Nor'wester coefficient limits our ability to draw

strong conclusions, it appears that the Nor'wester might have an effect on the number of violent crimes and a future study using a longer time period might address the issue.

The insignificance of the Nor'wester variable may be due to the small number of days that fit the definition of a Nor'wester (only 42 out of 8,826 in definition (1)). In addition, wind at 1 pm was used to represent the wind conditions for the entire day. If the wind direction and/or speed change during the day, 1 pm wind will not be representative of the day's wind conditions. Finally, the number of total violent crimes may not be a good proxy for the 'disorderly' behavior associated with the Nor'wester.

8. Conclusions

Our empirical work suggests that weather is an important determinant of the number of criminal offences recorded. In particular, temperature and precipitation both have a significant effect on the number of violent crimes recorded and temperature has a significant effect on the number of property crimes recorded. We were unable to establish that the Nor'wester has any special effect on the number of violent crimes committed, although there is evidence to suggest a study with more data and a more robust measure of wind conditions may find a positive and substantial relationship.

Our results suggest that police should respond to weather shocks characterized by increases in temperature and/or decreases in precipitation by increasing the resources allocated to policing on those days. For example, additional patrols of residential areas could be undertaken in 'fine' weather in response to an anticipated increase in property crime. Importantly, however, our

models are only estimating the effects of *unexpected* (i.e., not given by geography and season) weather changes. Thus, when allocating its resources, police should use information on both district and seasonal characteristics (e.g., January in Auckland) and current weather conditions (from short-term weather forecast) into account.

Our study is limited in several ways. First, the police districts are often too large for us to generate representative weather variables. However, if anything, this is likely to bias our results downwards. Second, as discussed above, there are potential issues with variation in policing as weather changes. To the extent that police effort already responds to weather changes as recommended here, our results are again a conservative estimate of the true effect of weather on crime. Third, we do not have data available for a number of variables that affect crime. However, our research is a partial analysis of the effect of weather on crime; we do not aim to explain all variation in crime levels.

Despite the above limitations, our study makes several significant contributions. Most importantly, we use a large and detailed dataset and demonstrate that the relationship between weather and crime remains robust to different model specifications. Our empirical results are largely consistent with our theoretical framework and previous studies and provide solid recommendations for the allocation of police resources.

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Figure 1. The Estimated Effect of Temperature on Violent Crime

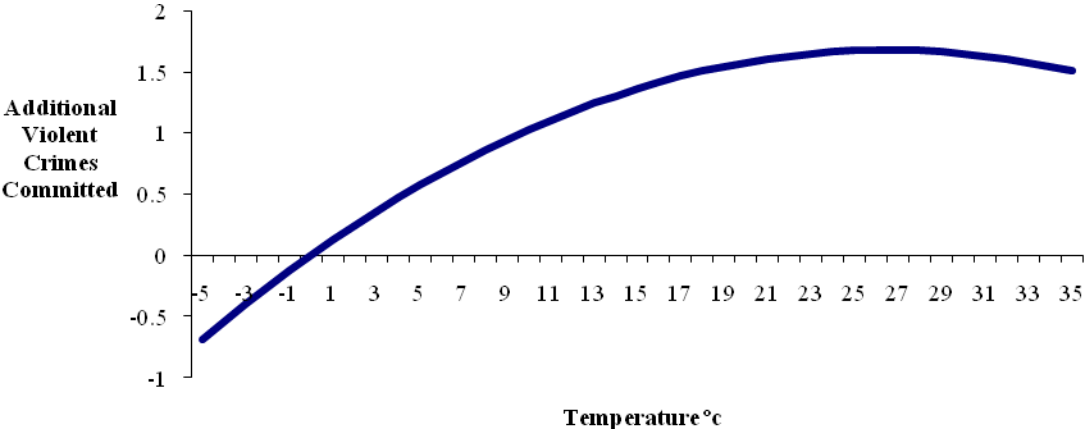


Figure 2. The Estimated Effect of Temperature on Property Crime

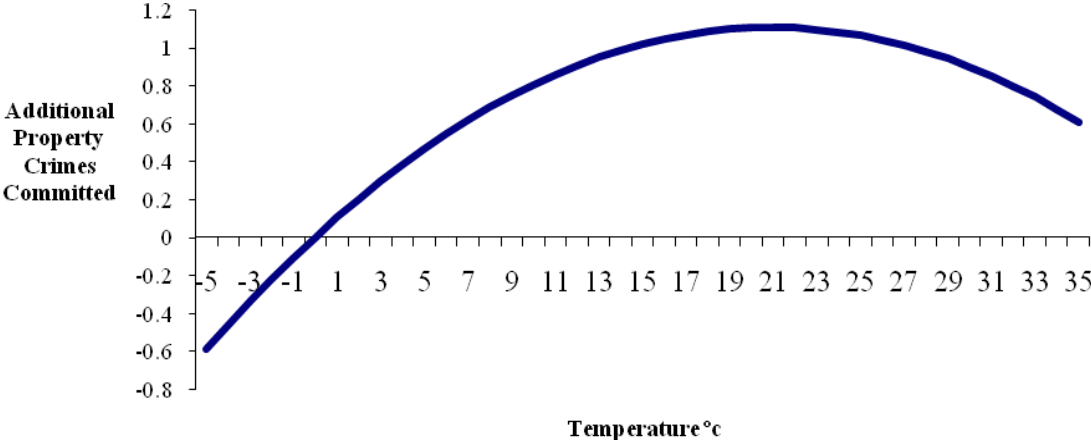


Table 1. Categories of Crime Data Provided by the New Zealand Police

Aggregated Data Available	Prominent Subcategories
Violence	Forms of assault (~70%), intimidation and threats (~15%), homicide (~0.3%)
Sexual	Indecent assault (~35%), sexual violation (~20%)
Drugs and Anti-social	Cannabis use (~45%), disorder (~35%)
Property Damage	Willful damage (~90%)
Property Abuse	Trespass (~65%)
Administrative	Offences against justice (~80%)
Burglary	Burglary - day (~40%) Burglary - night (~40%)
Car Conversion Etc	Unlawful taking of a car (~50%), Unlawful interference with a car (~40%)
Fraud	Document fraud (~50%), bank card fraud (~20%)
Receiving	Receiving stolen goods (~95%)
Theft	Shoplifting (~50%), theft under \$500 (~25%)

The approximate weightings of the subcategories were obtained by analyzing annual data from Statistics New Zealand. Unfortunately, the daily data provided to us could not be disaggregated into these subcategories. However, even if data for the narrow subcategories could be obtained, many district/day values would be zero.

Table 2. Crime and Weather Descriptive Statistics

	All	Max. temperature<14 °C	Max. temperature>27 °C	Precipitation>10mm	Min	Max
Total Violent (per day, per district)	7.21	6.80	6.35	6.46	0.00	108.00
Violence	3.09	2.61	2.68	2.86	0.00	54.00
Property Abuse	1.24	1.14	1.03	1.14	0.00	95.00
Property Damage	2.88	3.05	2.64	2.46	0.00	103.00
Total Property (per day, per district)	11.79	10.66	9.26	11.50	0.00	202.00
Theft	7.94	7.37	6.15	7.64	0.00	200.00
Burglary	3.85	3.29	3.11	3.85	0.00	115.00
Daily Maximum Temp (°C)	11.75				2.52	36.06
Daily Precipitation (mm)	3.51				0.00	240.60
Total Observations	141,384	25,680	3,820	13,636		

Table 3. The Effects of Temperature on Violent Crime

	Spec (1)	Spec (2) (Spec 1 + popul. weights)	Spec (3) (Spec 2 + crime lags)	Spec (4) (Spec 3 + precip.)	Spec (5) (Spec 1 with crimes/ 100,000)	Spec (6) (Spec 1 with Tobit)	Spec (7) (Spec 1 + aver. temp in prev. 7 days)	Spec (8) (Spec 1 + district t- trend)
R ²	0.432	0.407	0.412	0.413	0.396	0.095	0.432	0.439
Max. temperature	0.126*** (7.30)	0.169*** (7.43)	0.149*** (6.60)	0.147*** (6.46)	0.145*** (6.05)	0.130*** (7.32)	0.128*** (7.28)	0.132*** (7.61)
Max. temperature ²	-0.002*** (-5.20)	-0.003*** (-5.56)	-0.003*** (-5.09)	-0.003*** (-5.19)	-0.003*** (-4.07)	-0.003*** (-5.24)	-0.002*** (-5.11)	-0.003*** (-5.56)
Average temperature in preceding seven days	-	-	-	-	-	-	-0.007 (-0.94)	-
Violent crimes _{t-1}	-	-	0.083*** (21.38)	0.082*** (20.92)	-	-	-	-
Violent crimes _{t-2}	-	-	0.013*** (3.57)	0.012*** (3.48)	-	-	-	-
Violent crimes _{t-3}	-	-	0.000 (0.17)	0.000 (0.11)	-	-	-	-
Precipitation	-	-	-	0.021*** (2.78)	-	-	-	-
Max. temperature *Precipitation	-	-	-	0.000 (0.06)	-	-	-	-

T-statistics are reported in parentheses. *** denotes statistical significance at 99% confidence level.

Table 4. The Effects of Precipitation on Violent Crime

	Spec (1)	Spec (2)	Spec (3)	Spec (4)	Spec (5)	Spec (6)	Spec (7)	Spec (8)
		(Spec 1 + popul. weights)	(Spec 2 + crime lags)	(Spec 3 + temp.)	(Spec 1 with crimes/ 100,000)	(Spec 1 with Tobit)	(Spec 1 + precip ²)	(Spec 1 + district t- trend)
R ²	0.432	0.409	0.414	0.413	0.396	0.095	0.432	0.440
Precipitation	-0.019*** (-14.38)	-0.024*** (-14.20)	-0.021*** (-12.87)	-0.021*** (-2.78)	-0.022*** (-11.76)	-0.020*** (-14.30)	-0.026*** (-9.74)	-0.019*** (-14.44)
Violent crimes _{t-1}	-	-	0.083*** (21.34)	0.082*** (20.92)	-	-	-	-
Violent crimes _{t-2}	-	-	0.013*** (3.69)	0.012*** (3.48)	-	-	-	-
Violent crimes _{t-3}	-	-	0.000 (0.14)	0.000 (0.11)	-	-	-	-
Max. temperature	-	-	-	0.147*** (6.46)	-	-	-	-
Max. temperature ²	-	-	-	-0.003*** (-5.19)	-	-	-	-
Max. temperature*	-	-	-	0.000*** (0.06)	-	-	-	-
Precipitation Precipitation ²	-	-	-	-	-	-	0.000*** (2.79)	-

T-statistics are reported in parentheses. *** denotes statistical significance at 99% confidence level.

Table 5. The Effects of Temperature on Property Crime

	Spec (1)	Spec (2)	Spec (3)	Spec (4)	Spec (5)	Spec (6)	Spec (7)	Spec (8)
		(Spec 1 + popul. weights)	(Spec 2 + crime lags)	(Spec 3 + precip.)	(Spec 1 with crimes/ 100,000)	(Spec 1 with Tobit)	(Spec 3 + aver. temp in prev. 7 days)	(Spec 1 + district t- trend)
R ²	0.685	0.636	0.657	0.657	0.6882	0.165	0.702	0.694
Max. temperature	0.106*** (5.34)	0.152*** (5.49)	0.119*** (4.41)	0.117*** (4.28)	0.068** (2.47)	0.107*** (5.34)	0.089*** (4.53)	0.104*** (5.32)
Max. temperature ²	-0.003*** (-4.76)	-0.004*** (-4.78)	-0.003*** (-3.83)	-0.003*** (-3.71)	-0.002** (-2.40)	-0.003*** (-4.76)	-0.002*** (-3.91)	-0.003*** (-4.81)
Property crimes _{t-1}	-	-	0.11*** (23.49)	0.11*** (23.47)	-	-	0.112*** (28.48)	-
Property crimes _{t-2}	-	-	0.055*** (13.23)	0.054*** (13.17)	-	-	0.057*** (16.09)	-
Property crimes _{t-3}	-	-	0.053*** (13.12)	0.053*** (13.06)	-	-	0.055*** (16.35)	-
Property crimes _{t-4}	-	-	0.047*** (11.89)	0.047*** (11.93)	-	-	0.046*** (13.63)	-
Property crimes _{t-5}	-	-	0.037*** (8.95)	0.037*** (8.91)	-	-	0.04*** (11.75)	-
Property crimes _{t-6}	-	-	0.051*** (13.08)	0.051*** (13.13)	-	-	0.05*** (15.25)	-
Property crimes _{t-7}	-	-	0.078*** (19.08)	0.078*** (19.08)	-	-	0.075*** (22.19)	-
Property crimes _{t-8}	-	-	0.034***	0.034***	-	-	0.034***	-

			(8.87)	(8.86)			(10.72)	
Property crimes t_{-9}	-	-	0.025***	0.025***	-	-	0.025***	-
			(6.56)	(6.52)			(7.86)	
Precipitation	-	-	-	0.001	-	-	-	-
				(0.10)				
Max. temperature*	-	-	-	0.000	-	-	-	-
Precipitation				(0.63)				
Average temperature in preceding seven days	-	-	-	-	-	-	-0.024***	-
							(-3.09)	

T-statistics are reported in parentheses. *** and ** denote statistical significance at 99% and 95% confidence levels, respectively.

Table 6. The Effects of Precipitation on Property Crime

	Spec (1)	Spec (2)	Spec (3)	Spec (4)	Spec (5)	Spec (6)	Spec (7)	Spec (8)
		(Spec 1 + popul. weights)	(Spec 2 + crime lags)	(Spec 3 + temp.)	(Spec 1 with crimes/ 100,000)	(Spec 1 with Tobit)	(Spec 1 + precip. lag)	(Spec 1 + district t- trend)
R ²	0.685	0.638	0.659	0.657	0.688	0.165	0.685	0.694
Precipitation	0.004*** (2.73)	0.007*** (3.24)	0.006*** (3.06)	0.001 (0.10)	0.003 (1.62)	0.004** (2.54)	0.004** (2.38)	0.004*** (2.65)
Property crimes _{t-1}	-	-	0.111*** (23.75)	0.110*** (23.47)	-	-	-	-
Property crimes _{t-2}	-	-	0.055*** (13.24)	0.054*** (13.17)	-	-	-	-
Property crimes _{t-3}	-	-	0.053*** (13.11)	0.053*** (13.06)	-	-	-	-
Property crimes _{t-4}	-	-	0.047*** (11.99)	0.047*** (11.93)	-	-	-	-
Property crimes _{t-5}	-	-	0.036*** (8.86)	0.037*** (8.91)	-	-	-	-
Property crimes _{t-6}	-	-	0.052*** (13.27)	0.051*** (13.13)	-	-	-	-
Property crimes _{t-7}	-	-	0.078*** (19.22)	0.078*** (19.08)	-	-	-	-
Property crimes _{t-8}	-	-	0.034*** (8.85)	0.034*** (8.86)	-	-	-	-
Property crimes _{t-9}	-	-	0.025*** (6.53)	0.025*** (6.52)	-	-	-	-
Max. temperature	-	-	-	0.117*** (4.28)	-	-	-	-

Max.	-	-	-	-0.003***	-	-	-	-
temperature ²				(-3.71)				
Max.	-	-	-	0.000	-	-	-	-
temperature*				(0.63)				
Precipitation								
Precipitation _{t-1}	-	-	-	-	-	-	0.001	-
							(0.73)	
Precipitation _{t-2}	-	-	-	-	-	-	0.001	-
							(0.78)	
Precipitation _{t-3}	-	-	-	-	-	-	-0.001	-
							(-0.86)	

T-statistics are reported in parentheses. *** and ** denote statistical significance at 99% and 95% confidence levels, respectively.

Table 7. The Effects of the Nor'wester Wind on Violent Crime

	Definition (1)	Definition (2)	Definition (3)	Definition (4)
	North West wind	North West wind	North West wind	North West wind
	Max. temperature>17°C	Max. temperature>15°C	-	Max. temperature>25°C
Definition	Wind speed>36km/h	Wind speed>25km/h	Wind speed>36km/h	Wind speed>25km/h
Number of Nor'wester days	42	169	45	22
	1.078	0.578	0.890	1.136
Nor'wester	(1.12)	(1.60)	(0.98)	(1.23)
	0.157***	0.155***	0.156***	0.161***
Max. temperature	(3.36)	(3.32)	(3.36)	(3.46)
	-0.004***	-0.004***	-0.004***	-0.004***
Max. temperature ²	(-3.08)	(-3.06)	(-3.07)	(-3.19)
	-0.059***	-0.059***	-0.059***	-0.059***
Precipitation	(-7.39)	(-7.38)	(-7.39)	(-7.40)

T-statistics are reported in parentheses. *** denotes statistical significance at 99% confidence level.