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# Extreme climate and crime: Empirical evidence based on 129 prefecture-level cities in China

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Climate change is having profound effects on natural and socio-economic systems, especially *via* extreme climate events. Using panel data from 129 prefectural-level cities in China from 2013 to 2019, this paper explores the effects of extreme climate on crime rates based on a climate index and manual collection of crime data. The results showed that extreme climate has a significant positive effect on crime rates, increasing by 0.035% for every 1% increase in the extreme climate index. This occurs through two mechanistic pathways: reduced agricultural output and lower employment income. The heterogeneity analysis shows that extreme climate has a greater impact on crime rates in eastern areas which are economically developed and have high levels of immigration. This study provides new perspectives on the impact of extreme climate on the economy and society, in which governments can actively participate in climate governance through environmental protection, energy conservation and emission reduction, and technological innovation to reduce crime rates by reducing the occurrence of extreme climate.

KEYWORDS

**climate change, global warming, crime rates, quantile regression model, mechanisms of effect**

## Introduction

Crime is considered a major factor affecting social stability. At the Third Plenary Session of the 18th CPC Central Committee, it was stressed that comprehensive management of social security should be strengthened, and all types of criminal activities should be prevented and punished strictly following existing laws. In January 2018, the CPC Central Committee and the State Council issued the Notice on the Special Struggle against Darkness and Evil, to ensure that people live and work in peace, society is stable and orderly, and the country enjoys long-term peace and stability. China's crime rate is growing at a much faster rate than that of other developed countries (Hu et al., 2005). The arrest rate increased from 3.64 per 10,000 people in 1998 to 7.78 per 10,000 people in 2017, and the prosecution rate increased from 3.34 per 10,000 people to 12.28 per 10,000 people for the same period. Historically, scholars have studied the causes of crime by focusing on traditional social factors such as age, gender, race, education, and social and economic status (Hindelang, 1981; Devine et al., 1988; Kolvin et al., 1988). However, as the economy and society continue to develop, the legal system improves, and the standard of living increases, the rate of criminal offenses continues to increase. This suggests that crime rates are no longer influenced by these social factors alone, but that unknown factors may also influence the occurrence of crime (Cohn, 1990).

The Sixth Assessment Report (AR6) of the United Nations Intergovernmental Panel on Climate Change (IPCC) points out that climate change and the frequency of extreme climate events pose a growing threat to the economy, health, and security, and their impact is increasing in magnitude. In particular, the government may aim to reduce the extremes through policies such as restructuring industries and strengthening environmental management. This may have an impact on social stability, and people's behavior may become more extreme due to the stimulus from extreme climate events. According to the China Blue Book on Climate Change (2021), China is a sensitive impact area for global climate change, with a warming rate significantly higher than the global average. With the second largest economy in the world, the negative ecological, social, and economic impacts of climate change faced by China should not be ignored (Duan et al., 2019). In this context, considering that factors other than social factors indirectly influence crime rates, climate extremes, which have a profound negative impact on socioeconomic stability, may be one of the important reasons for influencing crime. While extreme climates bring about macroscopic damage, they may also influence people's propensity to commit crimes at the microscopic level. So, does climate extremes affect crime rates? What is the mechanism of action of extreme climate affecting crime rates? Answering these questions is the main purpose of this paper.

## Literature review and theoretical analysis

### Literature review

The effects of high temperatures on people have been a long-standing concern in the field of psychology. Several experimental psychological studies have found a direct positive relationship between temperature and aggression—high temperatures enhance aggression and criminal tendencies (Anderson, 1989; DeWall and Bushman, 2009). Being randomly assigned to a hot room rather than a suitably warm room makes subjects more likely to be hostile and to behave more aggressively toward others (DeWall et al., 2011); presenting words or pictures associated with high temperatures also makes subjects more irritable (Wilkowski et al., 2009). In addition to studies based on experimental paradigms, many scholars have also studied the relationship between temperature and crime based on correlational data. Crime has been found to show a clear seasonal pattern: violent crime (Stevens et al., 2019) and property crime (Linning et al., 2017) increase significantly in the summer months.

However, the correlation between temperature and violent crime can be overestimated, and the correlation between violent crime and temperature disappears when social variables are excluded (Rotton, 1986). This suggests that the relationship between climate and criminal behavior cannot be explained by a single factor and that seasonal fluctuations in crime rates are determined by a combination of environmental and social factors (McDowall et al., 2012). Moreover, because there is a negative correlation between crime rates in the short term in region: where crime rates are high in 1 week, they are lower in subsequent weeks (Jacob et al., 2007), studies using daily or weekly data cannot accurately estimate the long-term effects of climate change on crime (Ranson, 2014). Yet, other studies, using hourly or daily data, have shown a correlation between temperature and crime rates (Brunsdon et al., 2009; Mares, 2013a; Baryshnikova et al., 2021). However, when annual data are used for estimation, studies show that the correlation between temperature and crime rates is not significant (Lynch et al., 2020, 2022).

Some scholars have also studied the impact of meteorological factors, such as sunlight, heat, and rainfall on crime. The theory of daily activities suggests that the three elements of criminally motivated offenders, suitable criminal targets, and lack of effective protection are important conditions for crime to occur (Miró, 2014). Weather conditions can influence crime by altering people's daily activities and social behavior (Hipp et al., 2004; Miles-Novelo and Anderson, 2019). Specifically, warmer temperatures increase the frequency of interpersonal interactions, thereby increasing the likelihood of interpersonal violence or crime (Rotton and Cohn, 2003; Berman et al., 2020). As people go on holiday more often in summer, they are more likely to be burgled (Cohn and Rotton, 2000). Frequent rainfall makes it easier for offenders to avoid surveillance, leading to higher rates of crime on rainy days (Shen et al., 2020). Reduced daylight also makes it easier for crimes to be concealed, increasing the frequency of offenders committing crimes on cloudy days (Doleac and Sanders, 2015). In addition to weather conditions, recent literature has also discussed the impact of factors such as air pollution (Burkhardt et al., 2019; Bondy et al., 2020) and environmental damage (Mbonane et al., 2019) on crime rates, finding that unsuitable environments can contribute to crime.

The impact of extreme climate on social stability and economic development has been documented in many areas, including agricultural production (Deschênes and Greenstone, 2007), industrial output or economic growth (Dell et al., 2012; Chen and Yang, 2019), international trade (Jones and Olken, 2010), labor productivity (Zhang et al., 2018; Letta and Tol, 2019), and population mortality (Deschênes and Greenstone, 2011). Extreme weather events often lead to reduced crop yields

(Rehman et al., 2022), rangeland degradation (Holechek et al., 2020; Nanzad et al., 2021), and wildfires and floods that cause property damage (Irish et al., 2010; Rossiello and Szema, 2019). These lead to widening income disparities, increased individual discontent, reduced opportunity costs of violence, countries political conflict, and even war (Burke et al., 2009; Hsiang et al., 2011; Koubi, 2017; Roche et al., 2020). Particularly for countries already facing severe economic problems, extreme climate can further exacerbate stress and induce more violence (Mares, 2013b). Extreme climate shocks can lead to large-scale group migrations and the cultural and socio-economic pressures of a migrating population can indirectly increase conflict (Ghimire et al., 2015; Burrows and Kinney, 2016; Koubi et al., 2018). Studies have also found a significant contribution to crime rates from hurricane disasters (Spencer and Strobl, 2019).

In summary, past studies on the impact of climate on crime rates have focused on the relationship between the mean climate distribution, such as mean temperature and mean precipitation, with crime rates, without emphasizing the impact of climate extremes on crime rates; although some literature has explored the impact of climate extremes on conflict and violence at the national level, fewer studies have directly analyzed the impact of climate extremes on crime rates at the regional level within a country; finally, most of the existing literature simply regresses crime rates on climate variables, which lacks precision in identification strategies and lacks the analysis of causal mechanisms between the variables. To remedy the shortcomings of the existing literature, this paper manually collected crime and climate data from 129 prefectural-level cities in China, and explored the influence of extreme climate on regional crime rates and its mechanism of action based on the construction of an extreme climate index using daily temperature data.

## Theoretical analysis

Extreme climate does not directly contribute to regional crime rates—there must be intermediate mechanisms at work. From an economic point of view, crime is a risky choice in which the expected benefits to the individual are higher than the opportunity costs, and lower incomes are the main way in which the opportunity costs to the individual are reduced. The main income of rural and urban residents is derived from agricultural business income and wage income, respectively. When the income of rural and urban residents is insufficient to support their household expenses, individuals may take the risk of increasing their household income by committing crimes.

First, is the agricultural output reduction effect. Agriculture in rural China plays a role in social stabilization, yet it is agricultural production that is most vulnerable to climate change (Castellano and Moroney, 2018). Traditional agriculture cannot effectively offset severe weather (Piontek et al., 2014), and extreme weather events such as high-temperature periods (Burke et al., 2015), drops or increases in rainfall (Barrios et al., 2010; Zhang and Huang, 2012), or snow (Boehm et al., 2016) can severely affect normal agricultural production (Chen et al., 2016; Yang et al., 2017; Pickson et al., 2022). Specifically, high temperatures can affect photosynthesis in crops (Shah and Paulsen, 2003), droughts can affect irrigation (Lesk et al., 2016), and heavy rainfall can lead to large-scale loss of soil fertility (Li and Fang, 2016). Natural disasters, such as floods (Qin et al., 2022), hurricanes (Martinez, 2020), and hail storms (Raihan et al., 2020), can directly damage crops. As a result, the range of negative impacts of extreme climate on agricultural output can reduce farming incomes, forcing some farming populations into economic hardship, inducing criminal behavior. Extreme climate may also drive farmers to towns and cities, thereby increasing urban crime rates.

Second, is the employment income reduction effect. Agriculture is a component of the regional economy, but extreme climate can also affect the non-farm sector of the economy (Hsiang, 2010). Extreme climates generally reduce employment income for urban dwellers through both lower labor productivity and higher production costs. High temperatures can prevent workers from concentrating on their work (Qiu and Zhao, 2022) and increase worker fatigue, thereby reducing overall worker productivity (Flouris and Schlader, 2015). Although increased mechanization can offset the negative effects of high temperatures on industrial labor productivity to some extent (Day et al., 2019), high temperatures are more disruptive to brain-intensive complex labor than physically intensive simple labor (Zander and Mathew, 2019), such that the negative effects of extreme heat on individual labor productivity in urban environments are pervasive and persistent (Cai et al., 2018; Lee et al., 2018). Furthermore, in addition to reducing labor productivity, extreme heat can also lead to an overall reduction in working hours (Caldeira and Brown, 2019), which can increase life stress and lower life expectations, further reducing the opportunity cost of criminal behavior (White, 2016). Natural disasters caused by extreme climate can lead to a global surge in energy prices (Lee et al., 2021), pushing up the cost of raw materials, as well as increasing the cost of labor for businesses, ultimately leading to a reduction in demand for labor. This results in increased unemployment and lower incomes, thereby triggering crime. The theoretical mechanism by which climate change affects crime rates is shown in **Figure 1**. Based on the above theoretical analysis, the following research hypotheses are proposed:

> **Hypothesis 1:** There may be a significant positive effect of extreme climate on crime rates.

> **Hypothesis 2:** The extreme climate may affect crime rates in two ways: by reducing agricultural output and by lowering employment income.

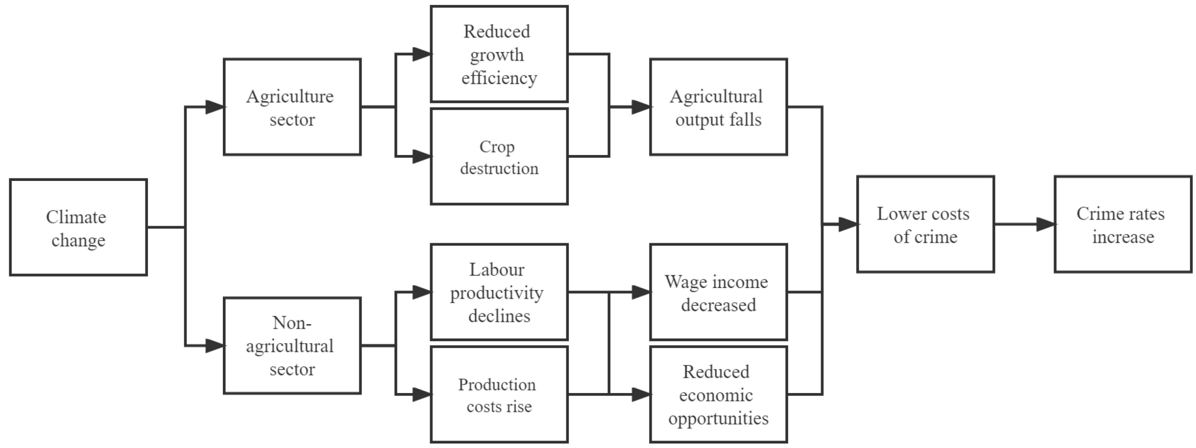


FIGURE 1
Mechanisms of climate change increasing crime rates.

# Data and methods

## Data source

This paper compiles panel data for 129 prefecture-level cities in China from 2013 to 2019. Among them, the crime rate data were obtained from the annual work reports of local procuratorates in each region, the daily temperature data were obtained from the National Meteorological Science Data Center, and the control data were obtained from the China Urban Statistical Yearbook, provincial statistical yearbooks, and regional statistical bulletins. Since some regions did not publish crime rates for some years, this paper uses linear interpolation to fill in the missing values.

## Variable definition and descriptive statistics

### Extreme climate

The independent variable in this paper is extreme climate. Extreme climate is a phenomenon in which the weather and climate of a place deviate significantly from its average state, and it can be expressed in terms of anomalous records of climate elements or the number of days exceeding a specific threshold value (Ren et al., 2010). The World Meteorological Organization (WMO) has proposed a set of index systems to measure an extreme climate index, which consists of 27 variables, including daily temperature and precipitation. The concept of the index is to count the number of days in a year that exceed a defined absolute or relative threshold (Chen et al., 2013). In this paper, three temperature variables were selected to measure the extreme climate index: "summer days (the number of days with daily maximum temperature > 25°C)," "hot night days (the number of days with daily minimum temperature > 20°C)," "warm day days (days with daily maximum temperature > 90% quantile)." These three variables are brought into RClimDex software for the calculation to derive the extreme climate index values. RClimDex was developed by Zhang and Yang (2004) of the Canadian Meteorological Research Center and has been promoted by the World Meteorological Organization's Climate Commission (Peterson et al., 2008; Choi et al., 2009; Xu et al., 2013). The greater the calculated extreme climate index, the greater the number of days of extreme climate in the year in that region.

### Crime rate

The dependent variable in this paper is the crime rate, which is measured as the number of criminal arrests per 10,000 people, referring to the definition of crime by Edlund et al. (2013). The robustness of the model was analyzed using the criminal prosecution rate per 10,000 people as a second measure of crime. The criminal arrest rate and criminal prosecution rate may underestimate the true level of crime, but as long as they are consistent over time and location, they will provide a robust relative measure of trends (Li et al., 2019). To exclude the effect of extreme values on the regression results, the crime rate variables were winsorized at 1% and 99% percentiles.

### Control variables

To control for factors other than extreme climate that affect crime rates, population density, household registration rate, per capita GDP, urban–rural income ratio, urban employee unemployment insurance rate, higher education rate, and the unemployment rate were added to the regression model, drawing on previous studies (Cheong and Wu, 2015; Chang et al., 2019). In addition, climate variables including annual

TABLE 1 Descriptive statistics of all variables.

| Type | Variable | Abbreviation | Definitions | Mean | SD | Min | Max |
|---|---|---|---|---|---|---|---|
| Dependent variables | The arrest rate | Arrest | Criminal arrests per 10,000 people | 6.24 | 3.15 | 1.86 | 33.85 |
| | The prosecution rate | Prose | Criminal prosecutions per 10,000 people | 10.46 | 4.49 | 2.37 | 38.43 |
| Independent variables | The extreme climate index | Climdex | extreme climate indices | 77.43 | 32.95 | 4.93 | 159.41 |
| | Warm days | tx90p | Sum of the number of days with daily maximum temperature ( 90% quantile (days) | 2.21 | 0.77 | 0.48 | 5.11 |
| | Tropical nights | tr | The sum of the number of days in a year when the daily minimum temperature is ( 20 (C (days) | 88.86 | 55.48 | 0 | 229 |
| | Summer days | su25 | Sum of the number of days in a year with a daily maximum temperature ( 25°C (days) | 141.22 | 45.8 | 14 | 274 |
| | Above 35°C | | Sum of the number of days in a year with a daily maximum temperature ( 35°C (days) | 11.19 | 12 | 0 | 64 |
| Control variables | Population density | PD | Population density (persons / km$^2$) | 519.36 | 565.72 | 5.52 | 4, 250 |
| | Household registration rate | HRR | Household population / resident population (%) | 1.04 | 0.21 | 0.19 | 1.56 |
| | Per capita GDP | lnPCG | The logarithm of per capita GDP (yuan) | 10.82 | 0.56 | 9.22 | 12.58 |
| | Unemployment insurance rate | UIR | Number of urban unemployment insurance participants/number of urban workers (%) | 0.87 | 0.34 | 0.05 | 2.3 |
| | Urban–rural income ratio | UER | Disposable income of urban residents / disposable income of rural residents (%) | 2.31 | 0.41 | 1 | 3.57 |
| | Higher education rate | HER | Number of people with a Bachelor's Degree or above per 10,000 people | 172.86 | 188.75 | 0.74 | 1, 064.77 |
| | Unemployment rate | UR | Number of urban registered unemployed / number of urban workers (%) | 0.06 | 0.03 | 0 | 0.24 |
| | Average annual temperature | AAT | Annual average temperature (°C) | 16.21 | 4.43 | − 0.16 | 24.41 |
| | Relative humidity | RH | Annual average relative humidity (%) | 70.32 | 10.01 | 40 | 88 |
| | Precipitation | Prec | Annual accumulated precipitation (mm) | 1, 195.33 | 1, 774.92 | 41.8 | 50, 223.55 |
| | Hours of sunshine | HS | Annual accumulated sunshine hours (h) | 1, 862.73 | 540.72 | 754.1 | 3, 376.1 |
| Mechanistic variables | Percentage of agriculture output | PAO | The ratio of agricultural output to regional GDP (%) | 10.98 | 0.26 | 10.26 | 12.06 |
| | Per capita wage income | lnPWI | The logarithm of per capita wage income (yuan) | 10.95 | 6.45 | 0.3 | 37.19 |
| | Area | | 1 ( east; 2 ( mid; 3 ( west | 10.98 | 0.26 | 10.26 | 12.06 |
| | Degree of regional development | DRD | 0 ( developed; 1 ( under-developed | 1.91 | 0.77 | 1 | 3 |
| | Population flow | PF | Resident population minus household population (10,000 persons) | 0.5 | 0.5 | 0 | 1 |

Population flow greater than 0 indicates an inflow of population and less than 0 indicates an outflow of population. Number of observations is 903.

average temperature, precipitation, sunshine duration, and relative humidity, were controlled (Li et al., 2015; Auffhammer et al., 2020). The descriptive statistics for all variables as shown in **Table 1**.

## Model

Based on the above hypotheses, this paper will construct a panel data of 129 prefecture-level cities in China from 2013–2019 for further empirical analysis. In order to better identify the effect of extreme climate on crime rate, this paper will control the region fixed effect and the time trend term in the panel model, which can also greatly reduce the risk of omitted variable bias in the model and further improve the accuracy of the model estimation by constructing a time-region double fixed panel model, and the specific regression model is shown in Equation 1.

$$CR_{it} = \beta_0 + \beta_1 Climdex_{it} + \beta_2 X_{it} + \mu_i + \nu_t + \varepsilon_{it} \qquad (1)$$

where $i$ denotes the region, $t$ denotes the year, $CR_{it}$ indicates the crime rate, $Climdex_{it}$ indicates extreme climate index, $X_{it}$ is a set of control variables, $\mu_i$ is the region fixed effect, $v_t$ is the year fixed effect, and $\varepsilon_{it}$ is the random error. $\beta_1$ is our main coefficient of interest, and if it is significantly positive, this indicates that extreme climate increases regional crime rates.

Panel OLS (ordinary least squares) estimation can only obtain the average effect of extreme climate on crime rates, and cannot portray the dynamic effect of extreme climate at different quartiles of the crime rate. To further investigate the effect of extreme climate at different levels of crime rates, the panel quantile method is applied to the regression model (2) to portray the dynamic trajectory of the marginal effect of extreme climate on the change in crime rates. The basic idea of panel quantile regression is to treat the independent variable as a functional distribution, sum the absolute values of the minimization-weighted residuals, and estimate the effect of the independent variable at the conditional quantile point of the independent variable. Since the fixed effects in the traditional panel quantile model decompose the random perturbation term into different components, it is difficult to explain the estimation results for each quantile. Powell (2022) proposed a non-additive fixed effects panel quantile model (QRPD), which introduces the panel quantile estimation into the framework of the instrumental variable approach so that the random perturbation term contains fixed effects and ensures the inseparability of the random perturbation term. The estimated coefficients are more accurate and the estimation results are more robust than the traditional panel quantile model. In this paper, five quartiles (5%, 25%, 50%, 75%, and 95%) are selected to construct the panel quantile function.

$$Q_{CR_{it}} = \theta(\tau)Climdex_{it} + \beta(\tau)X_{it} \tag{2}$$

where τ indicates the corresponding quantile, $Q_{CR_{it}}$ indicates the crime rate at the corresponding quantile, $Climdex_{it}$ indicates the extreme climate index at the corresponding quantile, and $X_{it}$ is a set of control variables, the same as in model (1).

## Results and discussion

### Baseline regression results of climate extremes on crime rates

Using model (1), the effect of extreme climate on crime rates was examined using a fixed panel OLS model. Column (1) of Table 2 shows the regression results without the inclusion of control variables, column (2) shows the regression results with the gradual inclusion of regional characteristic variables to control for the effects of factors other than climate on crime rates, and column (3) shows the regression results with the inclusion of all control variables. It can be seen that there is a significant positive relationship between extreme climate and crime rate regardless of the number of control variables added, and the regression coefficients increase with the gradual addition of regional characteristics variables and climate variables, indicating that the accuracy of the model estimation is improving. The regression coefficient of the extreme climate index on the crime rate in column (3) is 0.035 and is significant at the 1% level, indicating that extreme climate significantly increases the crime rate. Specifically, each 1% increase in the extreme climate index increases the crime rate by 0.035%, or 3.5 additional arrests per 10,000 persons authorized.

TABLE 2 Baseline regression results of climate extremes on crime rates.

| Variable | (1) | (2) | (3) |
|---|---|---|---|
| Climdex | 0.023*** | 0.028*** | 0.035*** |
| | (0.006) | (0.005) | (0.005) |
| PD | | −0.002 | −0.002 |
| | | (0.003) | (0.003) |
| HRR | | 4.393 | 4.698 |
| | | (2.971) | (3.015) |
| lnPCG | | 0.509** | 0.494** |
| | | (0.256) | (0.246) |
| UIR | | −1.063** | −1.028** |
| | | (0.461) | (0.473) |
| UER | | −0.318 | −0.255 |
| | | (0.312) | (0.278) |
| HER | | 0.008* | 0.008* |
| | | (0.004) | (0.004) |
| UR | | 2.555 | 2.584 |
| | | (2.142) | (2.045) |
| AAT | | | −0.309*** |
| | | | (0.110) |
| RH | | | −0.015 |
| | | | (0.021) |
| Prec | | | −0.000*** |
| | | | (0.000) |
| HS | | | 0.000 |
| | | | (0.001) |
| Cons | 4.387*** | −4.800 | −0.436 |
| | (0.517) | (5.186) | (5.496) |
| Year FE | Yes | Yes | Yes |
| City FE | Yes | Yes | Yes |
| N | 903 | 903 | 903 |
| $r^2$ | 0.119 | 0.218 | 0.231 |

***, **, and * denote significance at the 1, 5, and 10% levels, respectively.

In terms of control variables, per capita GDP is significantly positively correlated with crime rate, suggesting that areas with higher economic levels have higher crime rates. The unemployment insurance rate is significantly negatively correlated with the crime rate, suggesting that better social security can reduce crime rates. Educational attainment is significantly positively correlated with the crime rate, possibly due to the presence of more new high-tech crimes with higher education. The significant negative association between annual mean temperature and crime rate seems to be contrary to our expectation, probably because the annual mean temperature does not reflect the economic and social impact of temperature extremes, which is around 16°C in the sample data, a temperature range that is favorable for economic production.

Moreover, the direct estimation of the effect of annual mean temperature on crime rates is not complete (Mares, 2013a), and the relationship between the two may be the result of aggregation bias (Hsiang et al., 2011). Such estimates are meaningful only if the elevating effect on crime rates occurs when temperatures exceed a certain threshold or reach extremes. In addition, the expected regression coefficient of the unemployment rate, as an important indicator of the degree of social instability, should be significantly positive, but the actual regression coefficient is not significant. This may be because the ratio of the number of urban registered unemployed to the number of urban workers does not reflect the real unemployment situation. Some studies show that the effect of unemployment on crime is not certain, the relationship between the two depends on the arrest rate (Lee, 2018), and that unemployment insurance benefits may mitigate the impact of unemployment on crime (NoghaniBehambari and Maden, 2021).

## Endogeneity test results of regression models

Extreme climate, as an exogenous variable, is not influenced by crime rates and the existence of reverse causality is not likely. However, it may still lead to endogeneity due to the omission of other key variables, so the instrumental variable approach is applied. In this paper, "Volume of industrial soot (dust) emission" and "Greenery coverage" are selected as the instrumental variables of the extreme climate index. Smoke and dust particles can reduce the amount of solar radiation reaching the ground by blocking sunlight (Wang et al., 2009), which in turn reduces the atmospheric temperature; while urban greening plays an important role in reducing urban temperature due to photosynthesis and transpiration of plants (Zhu et al., 2017). Smoke (dust) emission and greening coverage of built-up areas are related to regional air temperature, but cannot directly affect crime rate, satisfying the assumption of instrumental variables. Column (1) in **Table 3** shows the regression results of the first stage of the two-stage least-squares method. There are significant correlations between soot emissions and green coverage with an extreme climate, and the F-value of the first stage is larger than 10, indicating that the instrumental variables are reasonably chosen. Column (2) shows the IV estimation results, and the results of the over-identification test support the original hypothesis that all instrumental variables are exogenous, indicating that there is no over-identification problem in the model. The results show that after considering the endogeneity problem, there is still a significant positive effect of the extreme climate index on the crime rate, indicating that the regression results are robust.

TABLE 3 Endogeneity test results of regression models.

| Variable | (1) | (2) |
|---|---|---|
| | Climdex | Arrest |
| Climdex | | 0.095*** |
| | | (2.630) |
| lnEmission | −2.432*** | |
| | (0.564) | |
| Green | −0.105** | |
| | (0.050) | |
| PD | −0.004 | −0.002 |
| | (0.004) | (0.002) |
| HRR | −9.884** | 5.229*** |
| | (4.818) | (1.685) |
| lnPCG | −2.819*** | 0.670*** |
| | (1.038) | (0.242) |
| UIR | 2.472 | −1.128*** |
| | (2.265) | (0.360) |
| UER | −4.483*** | −0.008 |
| | (1.424) | (0.281) |
| HER | −0.008 | 0.009*** |
| | (0.008) | (0.003) |
| UR | −12.435 | 3.064* |
| | (10.170) | (1.744) |
| AAT | 4.414*** | −0.577*** |
| | (0.826) | (0.185) |
| RH | −0.175 | −0.004 |
| | (0.123) | (0.019) |
| Prec | 0.000*** | −0.000** |
| | (0.000) | (0.000) |
| HS | −0.002 | 0.001 |
| | (0.002) | (0.001) |
| _Cons | 92.789*** | −7.488* |
| | (16.736) | (−1.906) |
| Year effect | Yes | Yes |
| City effect | Yes | Yes |
| F value | 440.13 | |
| Hansen J statistic | | 0.484 |
| *P* value | | 0.487 |
| N | 903 | 903 |
| $r^2$ | 0.972 | 0.889 |

***, **, and * denote significance at the 1, 5, and 10% levels, respectively.

## Quantile regression results of extreme climate on crime rate

To more intuitively examine the marginal effects of extreme climate at different levels of crime rates, model (2) was applied

TABLE 4 Quantile regression results of extreme climate on crime rate.

| Variable | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | 5% | 25% | 50% | 75% | 95% |
| Climdex | 0.005*** | 0.008*** | 0.013*** | 0.024*** | 0.026*** |
| | (0.001) | (0.001) | (0.002) | (0.007) | (0.002) |
| PD | 0.000*** | 0.001*** | 0.001 | −0.000*** | −0.000 |
| | (0.000) | (0.000) | (0.001) | (0.000) | (0.000) |
| HRR | −0.909*** | −1.996*** | −5.980*** | −4.088*** | −8.166*** |
| | (0.156) | (0.086) | (0.186) | (0.640) | (0.173) |
| lnPCG | 1.299*** | 0.570*** | 0.457*** | 1.031*** | 1.599*** |
| | (0.084) | (0.041) | (0.097) | (0.088) | (0.175) |
| UIR | 0.752*** | 0.591*** | −0.944 | 1.243*** | 1.009*** |
| | (0.111) | (0.078) | (0.915) | (0.071) | (0.139) |
| UER | 0.634*** | −0.186*** | −0.016 | 0.508*** | 1.355*** |
| | (0.040) | (0.053) | (0.0590) | (0.0530) | (0.178) |
| HER | 0.001*** | 0.002*** | 0.002*** | 0.004*** | 0.002*** |
| | (0.000) | (0.000) | (0.001) | (0.001) | (0.000) |
| UR | 1.648* | −1.618*** | 2.228 | −2.356 | −14.794*** |
| | (0.925) | (0.355) | (3.703) | (1.680) | (1.299) |
| AAT | 0.1410*** | 0.058*** | 0.032 | 0.006 | −0.166*** |
| | (0.009) | (0.007) | (0.040) | (0.047) | (0.033) |
| RH | −0.0270*** | −0.007 | 0.002 | 0.068*** | 0.035*** |
| | (0.002) | (0.004) | (0.012) | (0.010) | (0.012) |
| Prec | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.001*** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| HS | −0.000*** | 0.000*** | 0.001 | 0.001*** | −0.000** |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Year FE | Yes | Yes | Yes | Yes | Yes |
| City FE | Yes | Yes | Yes | Yes | Yes |
| N | 903 | 903 | 903 | 903 | 903 |

***, **, and * denote significance at the 1, 5, and 10% levels, respectively.

using panel quartiles, and the standard errors of the regression coefficients were obtained using the adaptive Monte Carlo (MCMC) method with 1,000 samples. From the estimated results (Table 4), the regression coefficients of the extreme climate index at each quantile are all positive and significant at the 1% level, which again verifies the finding that extreme climate significantly increases the crime rate in the baseline regression. The trend of the regression coefficients of the extreme climate index at each quartile shows that as the crime rate quartile increases, the regression coefficients of the extreme climate at the corresponding quartile also increase. The effect of extreme climate on areas with lower crime rates is weaker and the effect of extreme climate on areas with higher crime rates is stronger. The possible reason for this result is that areas with higher crime rates are more vulnerable to negative external shocks due to social instability. Extreme climate can be more damaging to these areas, and thus crime rates in high crime areas are more affected by extreme climate than in low crime areas.

## Robustness test

To ensure the reliability of the previous estimation results, robustness tests were conducted using substitution variables and adjusting for standard errors. Since there are multiple measures of the crime rate and extreme climate, we conducted regressions after replacing the independent variables. First, the number of criminal offenses prosecuted per 10,000 people is used as a proxy for the crime rate. Second, as defined by the China Meteorological Administration, the sum of the number of extreme temperature days ( > 35°C) in a year is used as a proxy indicator of extreme climate. The robust standard errors in the baseline model have been clustered to the regional level and, considering that the standard errors of regions within the same province may still be correlated, the standard errors are further clustered to province–year interactions as a way to test the robustness of regression models. Column (1) in Table 5 shows the regression results after replacing the dependent variables, column (2) shows the regression results after replacing the

TABLE 5 Robustness test results of regression models.

| Variable | (1) | (2) | (3) |
|---|---|---|---|
| | Prose | Arrest | Arrest |
| Climdex | 0.047*** | | 0.027*** |
| | (0.011) | | (0.004) |
| Above 35°C | | 0.024*** | |
| | | (0.006) | |
| PD | −0.001 | −0.002 | −0.002 |
| | (0.003) | (0.003) | (0.002) |
| HRR | 7.117* | 4.195 | 1.461 |
| | (3.819) | (3.068) | (2.234) |
| lnPCG | 0.429 | 0.398 | 0.341 |
| | (0.359) | (0.252) | (0.329) |
| UIR | −1.135* | −0.920** | 0.186 |
| | (0.636) | (0.448) | (0.556) |
| UER | −0.936* | −0.386 | 0.000 |
| | (0.558) | (0.280) | (0.226) |
| HER | 0.011** | 0.007 | 0.006 |
| | (0.005) | (0.005) | (0.004) |
| UR | −0.624 | 1.697 | −0.029 |
| | (3.936) | (2.110) | (1.857) |
| AAT | −0.192 | −0.184 | 0.126 |
| | (0.1650) | (0.126) | (0.099) |
| RH | 0.0150 | −0.016 | 0.019 |
| | (0.032) | (0.023) | (0.028) |
| Prec | −0.000*** | −0.000*** | −0.000*** |
| | (0.000) | (0.000) | (0.000) |
| HS | 0.001 | −0.000 | 0.000 |
| | (0.001) | (0.001) | (0.001) |
| _Cons | −3.396 | 3.015 | −4.410 |
| | (8.1280) | (5.773) | (4.343) |
| Year FE | Yes | Yes | Yes |
| City FE | Yes | Yes | Yes |
| Year × Prov Effect | No | No | Yes |
| N | 903 | 903 | 903 |
| r2 | 0.272 | 0.213 | 0.510 |

***, **, and * denote significance at the 1, 5, and 10% levels, respectively.

independent variables, and column (3) shows the regression results for clustering to province- and year-level standard errors. The results show that the robustness tests are significant at the 1% level and the sign of the regression coefficients is positive, as expected.

## Mechanism of the effect of climate extremes on crime rates

In this paper, agricultural output is the key variable for rural areas and the per capita wage income is chosen to measure employment income in urban areas. In Table 6, the dependent variable in column (1) is the number of arrests per 10,000 people; the dependent variable in column (2) is the agricultural output, and the dependent variable in column (3) is employment income. Extreme climate reduces agricultural output, which weakens the role of agriculture as a “stabilizer.” The results in column (3) show that the regression coefficient of the extreme temperature index is significantly negative at the 10% level, indicating that it reduces the income of non-agricultural workers. By reducing labor productivity and increasing the production costs of enterprises, the extreme climate may lead to a decrease in the demand for labor and an increase in unemployment in enterprises. This leads to a decrease in the income of workers and the opportunity cost of crime, thus inducing more criminal activity.

TABLE 6 Mechanism of the effect of climate extremes on crime rates.

| Variable | (1) | (2) | (3) |
|---|---|---|---|
| | Arrest | PAO | PWI |
| Climdex | 0.035*** | −0.041*** | −0.001* |
| | (0.005) | (0.009) | (0.000) |
| PD | −0.002 | −0.001 | 0.000*** |
| | (0.003) | (0.001) | (0.000) |
| HRR | 4.698 | 1.837 | 0.089 |
| | (3.015) | (1.610) | (0.081) |
| lnPCG | 0.494** | −2.058*** | 0.036*** |
| | (0.246) | (0.372) | (0.009) |
| UIR | −1.028** | 1.0590 | 0.051** |
| | (0.473) | (0.701) | (0.022) |
| UER | −0.255 | 0.664 | −0.064*** |
| | (0.278) | (0.549) | (0.016) |
| HER | 0.008* | −0.005** | −0.000 |
| | (0.004) | (0.003) | (0.000) |
| UR | 2.584 | 7.841** | 0.072 |
| | (2.045) | (3.457) | (0.138) |
| AAT | −0.309*** | 0.196 | 0.001 |
| | (0.110) | (0.118) | (0.006) |
| RH | −0.015 | −0.073** | 0.001 |
| | (0.021) | (0.028) | (0.001) |
| Prec | −0.000*** | 0.000*** | 0.000 |
| | (0.000) | (0.000) | (0.000) |
| HS | 0.000 | −0.001** | −0.000 |
| | (0.001) | (0.001) | (0.000) |
| _Cons | −0.436 | 36.989*** | 10.281*** |
| | (5.496) | (6.396) | (0.205) |
| Year FE | Yes | Yes | Yes |
| City FE | Yes | Yes | Yes |
| N | 903 | 903 | 903 |
| r2 | 0.231 | 0.398 | 0.921 |

***, **, and * denote significance at the 1, 5, and 10% levels, respectively.

TABLE 7 Heterogeneous effects of climate extremes on crime rates.

| Variable | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | Eastern | Middle | Western | Backward | Developed | Outflow | Inflow |
| Climdex | 0.051*** | 0.013 | 0.028*** | 0.032*** | 0.047*** | 0.031*** | 0.062*** |
| | (0.016) | (0.010) | (0.007) | (0.008) | (0.014) | (0.008) | (0.014) |
| PD | −0.006 | 0.006*** | −0.0077 | 0.007*** | −0.005 | 0.003 | −0.006 |
| | (0.004) | (0.001) | (0.005) | (0.002) | (0.004) | (0.003) | (0.005) |
| HRR | 12.404** | 8.717*** | 2.704 | 10.790*** | 6.482 | 10.802*** | 6.687 |
| | (5.402) | (1.642) | (5.794) | (1.979) | (4.222) | (1.560) | (8.253) |
| lnPCG | −0.051 | 0.736** | −0.299 | 0.423 | 0.359 | 0.615** | 0.426 |
| | (0.518) | (0.341) | (0.358) | (0.328) | (0.389) | (0.248) | (0.529) |
| UIR | −0.800 | 0.248 | 0.779 | −0.008 | −1.915** | −0.255 | −1.230 |
| | (0.908) | (0.619) | (0.476) | (0.369) | (0.877) | (0.426) | (0.928) |
| UER | −0.857 | −1.296 | 0.098 | −0.672 | 0.201 | −0.259 | 0.065 |
| | (0.590) | (0.802) | (0.166) | (0.461) | (0.317) | (0.389) | (0.599) |
| HER | 0.013 | 0.004 | −0.001 | 0.004 | 0.009 | 0.004 | 0.010 |
| | (0.011) | (0.003) | (0.004) | (0.003) | (0.007) | (0.003) | (0.010) |
| UR | 8.279 | 2.759 | 0.454 | 2.286 | −0.234 | 0.892 | 6.551 |
| | (7.457) | (2.329) | (2.355) | (2.181) | (3.288) | (2.042) | (7.242) |
| AAT | −0.371** | −0.101 | 0.028 | −0.184 | −0.457** | −0.279** | −0.238 |
| | (0.184) | (0.134) | (0.134) | (0.116) | (0.188) | (0.127) | (0.187) |
| RH | −0.031 | −0.016 | −0.008 | 0.010 | −0.015 | −0.018 | 0.070 |
| | (0.046) | (0.024) | (0.025) | (0.020) | (0.037) | (0.020) | (0.073) |
| Prec | −0.000** | −0.000* | 0.000 | −0.000* | −0.000* | −0.000*** | −0.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.001) |
| HS | 0.001 | 0.000 | 0.000 | −0.000 | 0.001 | 0.000 | 0.001 |
| | (0.002) | (0.001) | (0.001) | (0.000) | (0.001) | (0.000) | (0.002) |
| _Cons | 3.611 | −10.569* | 3.999 | −11.051* | 2.741 | −11.248** | −5.480 |
| | (9.135) | (6.132) | (9.486) | (6.325) | (7.295) | (4.780) | (11.325) |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| City FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| N | 315 | 357 | 231 | 455 | 448 | 609 | 294 |
| $r^2$ | 0.274 | 0.536 | 0.351 | 0.438 | 0.216 | 0.383 | 0.216 |

***, **, and * denote significance at the 1, 5, and 10% levels, respectively.

## Heterogeneous effects of climate extremes on crime rates

### Geographic heterogeneity

China is a vast country with distinctly different geographic conditions and regional climates. To further examine the geographical heterogeneity of extreme climate on crime rates, the sample was divided into eastern, middle, and western areas for regression according to the criteria of the National Bureau of Statistics, and the regression results are presented in columns (1) to (3) in Table 7. The regression results show that extreme climate has a significant positive effect on crime rates in the eastern and western areas, and the contribution to crime rates in the eastern area is more pronounced. This is because eastern China has a long coastline and is often subject to extreme natural disasters, such as typhoons and tsunamis. Western China has low levels of economic development and the effects of extreme climate on agricultural production are severe, both of which lead to a high crime rate.

### Heterogeneity of economic levels

There may be differential effects of extreme climate on crime rates in regions with different levels of economic development. Referring to Kumar and Khanna (2019), the sample is divided into economically under-developed and economically developed regions according to the median regional GDP, and estimation results are presented in columns (4) and (5) in Table 7. Extreme climate contributes more significantly to the crime rate in economically developed regions, which may be because the extreme climate is more likely to increase the cost of energy consumption and pollution emissions (Li et al., 2015). This leads to an increase in raw material costs and labor costs for enterprises, which will reduce labor demand and employee wages, resulting in increased unemployment. More unemployed people increase the inequality of development (Yang and Tang, 2022), and endangers the social stability and sustainable livelihood of residents, leading to more crime.

### Population mobility heterogeneity

The mobile populations generated by urbanization usually have an impact on regional crime rates (Chen et al., 2017). This paper divides the sample into population inflow and population outflow regions based on the difference between the resident and registered populations (columns 6 and 7 in **Table 7**). The estimation results show that extreme climate contributes more to the crime rate in the inbound areas, which may be because mobile populations tend to lack stable social relationships and social security, and have lower risk tolerance than residents when exposed to extreme climate shocks (Zhong et al., 2017). This makes them more vulnerable to the negative economic impact of extreme climate, thus driving higher crime rates in the inbound areas.

## Conclusion and policy insight

Using crime data from 129 prefectural-level cities in China from 2013–2019, this paper analyzed the impact of extreme climate on crime rates and its mechanism of action based on the construction and measurement of the extreme climate index. It is found that extreme climate has a significant positive effect on crime rate, with crime rate increasing by 0.035% for every 1% increase in the extreme climate index. The results based on the panel quantile model showed that the effect of extreme climate on crime rate increased continuously with the increase of regional crime rate, which means that extreme climate has a greater effect on the areas with high quantile crime rate. The action mechanism test showed that extreme climate can increase crime rates *via* the agricultural output path and the employment income path. From the heterogeneity analysis, it is clear that the differences in the effects of climate extremes on crime rates are related to geographic characteristics, economic level and population movement, and specifically, the climate extremes has a greater impact on crime rates in eastern regions, economically developed regions and population inflow regions.

The findings of this paper confirm that climate extremes are an important factor influencing criminal offending behavior. This study provides a new perspective for understanding the impact of climate change on the economy and society, and has policy implications for promoting climate governance and social stability. In the context of climate change, to reduce the impact of climate extremes on social stability, the government should pay attention to the following aspects: First, strengthen environmental protection. Atmospheric environmental pollution from fossil fuel combustion is the main source of climate change, and the emission of atmospheric pollutants should be reduced and the quality of atmospheric environment should be improved to cope with climate change. In addition to the atmospheric environment, ecological environmental protection also needs attention. Strengthening ecological protection and restoration of ecologically fragile areas can enhance the regional climate coping capacity and use the cyclic function of the natural ecosystem to achieve sustainable carbon reduction. Second, adjust the industrial structure. We should firmly follow the green and low-carbon development path and actively respond to the negative impact of global warming on social stability in the medium and long term. Specifically, we should vigorously develop green and low-carbon industries and strictly control greenhouse gas emissions in key industries in key cities to promote and force a green transformation of the economic structure, which will mitigate the adverse effects of climate change while also helping to promote high-quality sustainable economic development and improve the region's resilience in the face of extreme climate shocks. Third, pay attention to technological innovation. Technological innovation is an important way to address climate change, and the government should call on the whole society to attach importance to low-carbon technological innovation and application, actively support the R&D and industrialization demonstration and promotion of various low-carbon technologies, and build a clean, low-carbon, safe and efficient energy system. Climate change is a common challenge for all countries in the world, and countries should increase exchanges and cooperation to enable the research and development, deployment and large-scale promotion and application of climate change technologies on a global scale. China is the largest developing country in the world, and the conclusion of this paper that climate extremes significantly contribute to regional crime rates has important implications for climate governance and social governance issues in other developing countries. In the context of global warming, developing countries should pay attention to the exogenous impact of extreme climate events on social stability and regional crime and actively participate in global climate governance. There are some limitations to this paper. Climate is dynamic and its impact on society and the economy occurs in the long term. As such, panel data over longer periods than in this study would be useful for further analysis. Second, there are many types of crime, and the impact and mechanisms of extreme climate on different types of crimes will vary. However, due to the availability of data, in this paper, a more general rate is used—the types of crimes should be further subdivided and examined in the future. Third, this paper uses the analysis concept of "extreme climate–economy–crime," but the mechanisms of extreme temperature influencing crime are more complicated, and areas such as psychology, society, and ecology should be studied further.

## Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author/s.

## Author contributions

JP conceived of the study. JP and ZZ conducted the experiments and acquired and analyzed the data. ZZ conducted the statistical analysis and drafted the manuscript. Both authors contributed to the final version of the manuscript.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2022.1028485/full#supplementary-material

## References

Anderson, C. A. (1989). Temperature and aggression: Ubiquitous effects of heat on occurrence of human violence. *Psychol. Bull.* 106, 74–96. doi: 10.1037/0033-2909.106.1.74

Auffhammer, M., Hsiang, S. M., Schlenker, W., and Sobel, A. (2020). Using weather data and climate model output in economic analyses of climate change. *Rev. Environ. Econ. Policy* 7, 181–198. doi: 10.1093/reep/ret016

Barrios, S., Bertinelli, L., and Strobl, E. (2010). Trends in rainfall and economic growth in Africa: A neglected cause of the African growth tragedy. *Rev. Econ. Stat.* 92, 350–366. doi: 10.1162/rest.2010.11212

Baryshnikova, N., Davidson, S., and Wesselbaum, D. (2021). Do you feel the heat around the corner? The effect of weather on crime. *Empir. Econ.* 63, 179–199. doi: 10.1007/s00181-021-02130-3

Berman, J., Bayham, J., and Burkhardt, J. (2020). Hot under the collar: A 14-year association between temperature and violent behavior across 436 US counties. *Environ. Res.* 191:110181. doi: 10.1016/j.envres.2020.110181

Boehm, R., Cash, S. B., Anderson, B. T., Ahmed, S., Griffin, T. S., Robbat, A. Jr., et al. (2016). Association between empirically estimated monsoon dynamics and other weather factors and historical tea yields in China: Results from a yield response model. *Climate* 4:20. doi: 10.3390/cli4020020

Bondy, M., Roth, S., and Sager, L. (2020). Crime is in the air: The contemporaneous relationship between air pollution and crime. *J. Assoc. Environ. Resour. Econ.* 7, 555–585. doi: 10.1086/707127

Brunsdon, C., Corcoran, J., Higgs, G., and Ware, A. (2009). The influence of weather on local geographical patterns of police calls for service. *Environ. Plan. B Plan. Des.* 36, 906–926. doi: 10.1068/b32133

Burke, M., Hsiang, S. M., and Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature* 527, 235–239. doi: 10.1038/nature15725

Burke, M. B., Miguel, E., Satyanath, S., Dykema, J. A., and Lobell, D. B. (2009). Warming increases the risk of civil war in Africa. *Proc. Natl. Acad. Sci. U.S.A.* 106, 20670–20674. doi: 10.1073/pnas.0907998106

Burkhardt, J., Bayham, J., Wilson, A., Carter, E., Berman, J. D., O'Dell, K., et al. (2019). The effect of pollution on crime: Evidence from data on particulate matter and ozone. *J. Environ. Econ. Manage.* 98:102267. doi: 10.1016/j.jeem.2019.102267

Burrows, K., and Kinney, P. L. (2016). Exploring the climate change, migration and conflict nexus. *Int. J. Environ. Res. Public Health* 13:443. doi: 10.3390/ijerph13040443

Cai, X., Lu, Y., and Wang, J. (2018). The impact of temperature on manufacturing worker productivity: Evidence from personnel data. *J. Comp. Econ.* 46, 889–905. doi: 10.1016/j.jce.2018.06.003

Caldeira, K., and Brown, P. T. (2019). Reduced emissions through climate damage to the economy. *Proc. Natl. Acad. Sci. U.S.A.* 116, 714–716. doi: 10.1073/pnas.1819605116

Castellano, R. L. S., and Moroney, J. (2018). Farming adaptations in the face of climate change. *Renew. Agric. Food Syst.* 33, 206–211. doi: 10.1017/s174217051700076x

Chang, Y. S., Kim, H. E., and Jeon, S. (2019). Do larger cities experience lower crime rates? A scaling analysis of 758 cities in the US. *Sustainability* 11:3111. doi: 10.3390/su11113111

Chen, C., Zhang, Y., Wang, L., Yan, T., and Song, J. (2013). Research on the change of extreme precipitation in Jiangxi province based on RClimDex model. *China Rural Water Hydropower* 11, 41–45. doi: 10.3969/j.issn.1007-2284.2013.11.011

Chen, J., Liu, L., Zhou, S., Xiao, L., and Jiang, C. (2017). Spatial variation relationship between floating population and residential burglary: A case study from ZG, China. *ISPRS Int. J. Geo Inf.* 6:246. doi: 10.3390/ijgi6080246

Chen, S., Chen, X., and Xu, J. (2016). Assessing the impacts of temperature variations on rice yield in China. *Clim. Change* 138, 191–205. doi: 10.1007/s10584-016-1707-0

Chen, X., and Yang, L. (2019). Temperature and industrial output: Firm-level evidence from China. *J. Environ. Econ. Manage.* 95, 257–274. doi: 10.1016/j.jeem.2017.07.009

Cheong, T. S., and Wu, Y. (2015). Crime rates and inequality: A study of crime in contemporary China. *J. Asia Pac. Econ.* 20, 202–223. doi: 10.1080/13547860.2014.964961

Choi, G., Collins, D., Ren, G., Trewin, B., Baldi, M., Fukuda, Y., et al. (2009). Changes in means and extreme events of temperature and precipitation in the Asia-Pacific Network region, 1955–2007. *Int. J. Climatol.* 29, 1906–1925. doi: 10.1002/joc.1979

Cohn, E. G. (1990). Weather and crime. *Br. J. Criminol.* 30, 51–64. doi: 10.1093/oxfordjournals.bjc.a047980

Cohn, E. G., and Rotton, J. (2000). Weather, seasonal trends and property crimes in Minneapolis, 1987–1988. A moderator-variable time-series analysis of routine activities. *J. Environ. Psychol.* 20, 257–272. doi: 10.1006/jevp.1999.0157

Day, E., Fankhauser, S., Kingsmill, N., Costa, H., and Mavrogianni, A. (2019). Upholding labour productivity under climate change: An assessment of adaptation options. *Clim. Policy* 19, 367–385. doi: 10.1080/14693062.2018.1517640

Dell, M., Jones, B. F., and Olken, B. A. (2012). Temperature shocks and economic growth: Evidence from the last half century. *Am. Econ. J. Macroecon.* 4, 66–95. doi: 10.1257/mac.4.3.66

Deschênes, O., and Greenstone, M. (2007). The economic impacts of climate change: Evidence from agricultural output and random fluctuations in weather. *Am. Econ. Rev.* 97, 354–385. doi: 10.1257/aer.102.7.3749

Deschênes, O., and Greenstone, M. (2011). Climate change, mortality, and adaptation: Evidence from annual fluctuations in weather in the US. *Am. Econ. J. Appl. Econ.* 3, 152–185. doi: 10.1257/app.3.4.152

Devine, J. A., Sheley, J. F., and Smith, M. D. (1988). Macroeconomic and social-control policy influences on crime rate changes, 1948-1985. *Am. Sociol. Rev.* 53, 407–420. doi: 10.2307/2095648

DeWall, C., and Bushman, B. (2009). Hot under the collar in a lukewarm environment: Hot temperature primes increase aggressive cognition and biases. *J. Exp. Soc. Psychol.* 45, 1045–1047. doi: 10.1016/j.jesp.2009.05.003

DeWall, C. N., Anderson, C. A., and Bushman, B. J. (2011). The general aggression model: Theoretical extensions to violence. *Psychol. Violence* 1, 245–258. doi: 10.1037/a0023842

Doleac, J. L., and Sanders, N. J. (2015). Under the cover of darkness: How ambient light influences criminal activity. *Rev. Econ. Stat.* 97, 1093–1103. doi: 10.1162/rest_a_00547

Duan, H., Zhang, G., Wang, S., and Fan, Y. (2019). Robust climate change research: A review on multi-model analysis. *Environ. Res. Lett.* 14:033001. doi: 10.1088/1748-9326/aaf8f9

Edlund, L., Li, H., Yi, J., and Zhang, J. (2013). Sex ratios and crime: Evidence from China. *Rev. Econ. Stat.* 95, 1520–1534. doi: 10.1162/REST_a_00356

Flouris, A., and Schlader, Z. (2015). Human behavioral thermoregulation during exercise in the heat. *Scand. J. Med. Sci. Sports* 25, 52–64. doi: 10.1111/sms.12349

Ghimire, R., Ferreira, S., and Dorfman, J. H. (2015). Flood-induced displacement and civil conflict. *World Dev.* 66, 614–628. doi: 10.1016/j.worlddev.2014.09.021

Hindelang, M. J. (1981). Variations in sex-race-age-specific incidence rates of offending. *Am. Sociol. Rev.* 46, 461–474. doi: 10.2307/2095265

Hipp, J. R., Curran, P. J., Bollen, K. A., and Bauer, D. J. (2004). Crimes of opportunity or crimes of emotion? Testing two explanations of seasonal change in crime. *Soc. Forces* 82, 1333–1372. doi: 10.1353/sof.2004.0074

Holechek, J. L., Geli, H. M., Cibils, A. F., and Sawalhah, M. N. (2020). Climate change, rangelands, and sustainability of ranching in the Western United States. *Sustainability* 12:4942. doi: 10.3390/su12124942

Hsiang, S. M. (2010). Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America. *Proc. Natl. Acad. Sci. U.S.A.* 107, 15367–15372.

Hsiang, S. M., Meng, K. C., and Cane, M. A. (2011). Civil conflicts are associated with the global climate. *Nature* 476, 438–441. doi: 10.1038/nature10311

Hu, L., Hu, A., and Xu, S. (2005). A case study of the impact of the disparity between the rich and the poor upon criminal offences. *J. Manage. World* 6, 34–44+171–172. doi: 10.19744/j.cnki.11-1235/f.2005.06.005

Irish, J. L., Frey, A. E., Rosati, J. D., Olivera, F., Dunkin, L. M., Kaihatu, J. M., et al. (2010). Potential implications of global warming and barrier island degradation on future hurricane inundation, property damages, and population impacted. *Ocean Coast. Manage.* 53, 645–657. doi: 10.1016/j.ocecoaman.2010.08.001

Jacob, B., Lefgren, L., and Moretti, E. (2007). The dynamics of criminal behavior evidence from weather shocks. *J. Hum. Resour.* 42, 489–527. doi: 10.2139/ssrn.647644

Jones, B. F., and Olken, B. A. (2010). Climate shocks and exports. *Am. Econ. Rev.* 100, 454–459. doi: 10.1257/aer.100.2.454

Kolvin, I., Miller, F. J., Fleeting, M., and Kolvin, P. A. (1988). Social and parenting factors affecting criminal-offence rates: Findings from the Newcastle Thousand family study (1947–1980). *Br. J. Psychiatry* 152, 80–90. doi: 10.1192/bjp.152.1.80

Koubi, V. (2017). Climate change, the economy, and conflict. *Curr. Clim. Change Rep.* 3, 200–209. doi: 10.1007/s40641-017-0074-x

Koubi, V., Böhmelt, T., Spilker, G., and Schaffer, L. (2018). The determinants of environmental migrants' conflict perception. *Int. Organ.* 72, 905–936. doi: 10.1017/s0020818318000231

Kumar, S., and Khanna, M. (2019). Temperature and production efficiency growth: Empirical evidence. *Clim. Change* 156, 209–229. doi: 10.1007/s10584-019-02515-5

Lee, C.-C., Wang, C.-W., Ho, S.-J., and Wu, T.-P. (2021). The impact of natural disaster on energy consumption: International evidence. *Energy Econ.* 97:105021. doi: 10.1016/j.eneco.2020.105021

Lee, K. (2018). Unemployment and crime: The role of apprehension. *Eur. J. Law Econ.* 45, 59–80. doi: 10.1007/s10657-016-9526-3

Lee, S.-W., Lee, K., and Lim, B. (2018). Effects of climate change-related heat stress on labor productivity in South Korea. *Int. J. Biometeorol.* 62, 2119–2129. doi: 10.1007/s00484-018-1611-6

Lesk, C., Rowhani, P., and Ramankutty, N. (2016). Influence of extreme weather disasters on global crop production. *Nature* 529, 84–87. doi: 10.1038/nature16467

Letta, M., and Tol, R. S. (2019). Weather, climate and total factor productivity. *Environ. Resour. Econ.* 73, 283–305. doi: 10.1007/s10640-018-0262-8

Li, C., Xiang, X., and Gu, H. (2015). Climate shocks and international trade: Evidence from China. *Econ. Lett.* 135, 55–57. doi: 10.1016/j.econlet.2015.07.032

Li, J., Wan, G., Wang, C., and Zhang, X. (2019). Which indicator of income distribution explains crime better? Evidence from China. *China Econ. Rev.* 54, 51–72. doi: 10.1016/j.chieco.2018.10.008

Li, Z., and Fang, H. (2016). Impacts of climate change on water erosion: A review. *Earth Sci. Rev.* 163, 94–117. doi: 10.1016/j.earscirev.2016.10.004

Linning, S. J., Andresen, M. A., and Brantingham, P. J. (2017). Crime seasonality: Examining the temporal fluctuations of property crime in cities with varying climates. *Int. J. Offender Ther. Comp. Criminol.* 61, 1866–1891. doi: 10.1177/0306624x16632259

Lynch, M. J., Stretesky, P. B., and Long, M. A. (2020). Climate change, temperature, and homicide: A tale of two cities, 1895–2015. *Weather Clim. Soc.* 12, 171–181. doi: 10.1175/WCAS-D-19-0068.1

Lynch, M. J., Stretesky, P. B., Long, M. A., and Barrett, K. L. (2022). The climate change-temperature-crime hypothesis: Evidence from a sample of 15 large US cities, 2002 to 2015. *Int. J. Offender Ther. Comp. Criminol.* 66, 430–450. doi: 10.1177/0306624X20969934

Mares, D. (2013a). Climate change and crime: Monthly temperature and precipitation anomalies and crime rates in St. Louis, MO 1990–2009. *Crime Law Soc. Change* 59, 185–208.

Mares, D. (2013b). Climate change and levels of violence in socially disadvantaged neighborhood groups. *J. Urban Health* 90, 768–783. doi: 10.1007/s11524-013-9791-1

Martinez, A. B. (2020). Improving normalized hurricane damages. *Nat. Sustain.* 3, 517–518. doi: 10.1038/s41893-020-0550-5

Mbonane, T. P., Mathee, A., Swart, A., and Naicker, N. (2019). A study protocol to determine the association between lifetime lead exposure and violent criminal behaviour in young males in conflict with the law. *BMC Public Health* 19:932. doi: 10.1186/s12889-019-7025-5

McDowall, D., Loftin, C., and Pate, M. (2012). Seasonal cycles in crime, and their variability. *J. Quant. Criminol.* 28, 389–410. doi: 10.1007/s10940-011-9145-7

Miles-Novelo, A., and Anderson, C. A. (2019). Climate change and psychology: Effects of rapid global warming on violence and aggression. *Curr. Clim. Change Rep.* 5, 36–46. doi: 10.1007/s40641-019-00121-2

Miró, F. (2014). "Routine activity theory," in *The encyclopedia of theoretical criminology*, ed. J. M. Miller (Chichester: John Wiley & Sons), 1–7. doi: 10.1002/9781118517390.wbetc198

Nanzad, L., Zhang, J., Tuvdendorj, B., Yang, S., Rinzin, S., Prodhan, F. A., et al. (2021). Assessment of drought impact on net primary productivity in the terrestrial ecosystems of Mongolia from 2003 to 2018. *Remote Sens.* 13:2522. doi: 10.3390/rs13132522

NoghaniBehambari, H., and Maden, B. (2021). Unemployment insurance generosity and crime. *Appl. Econ. Lett.* 28, 1076–1081. doi: 10.1080/13504851.2020.1798337

Peterson, T. C., Zhang, X., Brunet-India, M., and Vázquez-Aguirre, J. L. (2008). Changes in North American extremes derived from daily weather data. *J. Geophys. Res. Atmos.* 113:D07113. doi: 10.1029/2007jd009453

Pickson, R. B., He, G., and Boateng, E. (2022). Impacts of climate change on rice production: Evidence from 30 Chinese Provinces. *Environ. Dev. Sustain.* 24, 3907–3925. doi: 10.1007/s10668-021-01594-8

Piontek, F., Müller, C., Pugh, T. A., Clark, D. B., Deryng, D., Elliott, J., et al. (2014). Multisectoral climate impact hotspots in a warming world. *Proc. Natl. Acad. Sci. U.S.A.* 111, 3233–3238. doi: 10.1073/pnas.1222471110

Powell, D. (2022). Quantile regression with nonadditive fixed effects. *Empir. Econ.* 63, 1–17. doi: 10.1007/s00181-022-02216-6

Qin, X., Shi, Q., Wang, D., and Su, X. (2022). Inundation impact on croplands of 2020 flood event in three Provinces of China. *IEEE J. Sel. Topics Appl. Earth Obs. Remote Sens.* 15, 3179–3189. doi: 10.1109/jstars.2022.3161320

Qiu, Y., and Zhao, J. (2022). Adaptation and the distributional effects of heat: Evidence from professional archery competitions. *South. Econ. J.* 88, 1149–1177. doi: 10.1002/soej.12553

Raihan, M. L., Onitsuka, K., Basu, M., Shimizu, N., and Hoshino, S. (2020). Rapid emergence and increasing risks of hailstorms: A potential threat to sustainable agriculture in Northern Bangladesh. *Sustainability* 12:5011. doi: 10.3390/su12125011

Ranson, M. (2014). Crime, weather, and climate change. *J. Environ. Econ. Manage.* 67, 274–302. doi: 10.1016/j.jeem.2013.11.008

Rehman, T. H., Shah, A. K., and Hussain, S. J. (2022). Effect of climate change on agricultural productivity in Japan. *J. Agric.* 6, 13–23. doi: 10.53819/81018102t5075

Ren, G., Feng, G., and Yan, Z. (2010). Progresses in observation studies of climate extremes and changes in mainland China. *Clim. Environ. Res.* 15, 337–353. doi: 10.3878/j.issn.1006-9585.2010.04.01

Roche, K. R., Müller-Itten, M., Dralle, D. N., Bolster, D., and Müller, M. F. (2020). Climate change and the opportunity cost of conflict. *Proc. Natl. Acad. Sci. U.S.A.* 117, 1935–1940. doi: 10.1073/pnas.1914829117

Rossiello, M. R., and Szema, A. (2019). Health effects of climate change-induced wildfires and heatwaves. *Cureus* 11, e4771. doi: 10.7759/cureus.4771

Rotton, J. (1986). Determinism redux: Climate and cultural correlates of violence. *Environ. Behav.* 18, 346–368. doi: 10.1177/0013916586183003

Rotton, J., and Cohn, E. G. (2003). Global warming and US crime rates: An application of routine activity theory. *Environ. Behav.* 35, 802–825. doi: 10.4324/9781315095301-9

Shah, N., and Paulsen, G. (2003). Interaction of drought and high temperature on photosynthesis and grain-filling of wheat. *Plant Soil* 257, 219–226. doi: 10.1023/a:1026237816578

Shen, B., Hu, X., and Wu, H. (2020). Impacts of climate variations on crime rates in Beijing, China. *Sci. Total Environ.* 725:138190. doi: 10.1016/j.scitotenv.2020.138190

Spencer, N., and Strobl, E. (2019). Crime watch: Hurricanes and illegal activities. *South. Econ. J.* 86, 318–338. doi: 10.1002/soej.12376

Stevens, H. R., Beggs, P. J., Graham, P. L., and Chang, H.-C. (2019). Hot and bothered? Associations between temperature and crime in Australia. *Int. J. Biometeorol.* 63, 747–762. doi: 10.1007/s00484-019-01689-y

Wang, C., Jeong, G.-R., and Mahowald, N. (2009). Particulate absorption of solar radiation: Anthropogenic aerosols vs. dust. *Atmos. Chem. Phys.* 9, 3935–3945. doi: 10.5194/acp-9-3935-2009

White, R. (2016). Criminality and climate change. *Nat. Clim. Change* 6, 737–739. doi: 10.1038/nclimate3052

Wilkowski, B. M., Meier, B. P., Robinson, M. D., Carter, M. S., and Feltman, R. (2009). "Hot-headed" is more than an expression: The embodied representation of anger in terms of heat. *Emotion* 9, 464–477. doi: 10.1037/a0015764

Xu, W., Li, Q., Wang, X. L., Yang, S., Cao, L., and Feng, Y. (2013). Homogenization of Chinese daily surface air temperatures and analysis of trends in the extreme temperature indices. *J. Geophys. Res. Atmos.* 118, 9708–9720. doi: 10.1002/jgrd.50791

Yang, X., and Tang, W. (2022). Climate change and regional inequality: The effect of high temperatures on fiscal stress. *Urban Clim.* 43:101167. doi: 10.1016/j.uclim.2022.101167

Yang, X., Tian, Z., Sun, L., Chen, B., Tubiello, F. N., and Xu, Y. (2017). The impacts of increased heat stress events on wheat yield under climate change in China. *Clim. Change* 140, 605–620. doi: 10.1007/s10584-016-1866-z

Zander, K. K., and Mathew, S. (2019). Estimating economic losses from perceived heat stress in urban Malaysia. *Ecol. Econ.* 159, 84–90. doi: 10.1016/j.ecolecon.2019.01.023

Zhang, P., Deschenes, O., Meng, K., and Zhang, J. (2018). Temperature effects on productivity and factor reallocation: Evidence from a half million Chinese manufacturing plants. *J. Environ. Econ. Manage.* 88, 1–17. doi: 10.1016/j.jeem.2017.11.001

Zhang, T., and Huang, Y. (2012). Impacts of climate change and inter-annual variability on cereal crops in China from 1980 to 2008. *J. Sci. Food Agric.* 92, 1643–1652. doi: 10.1002/jsfa.5523

Zhang, X., and Yang, F. (2004). RClimDex (1.0) user manual. *Clim. Res. Branch Environ. Can.* 22, 1–23. doi: 10.1007/springerreference_28001

Zhong, H., Xu, J., and Piquero, A. R. (2017). Internal migration, social exclusion, and victimization: An analysis of Chinese rural-to-urban migrants. *J. Res. Crime Delinq.* 54, 479–514. doi: 10.1177/0022427816676861

Zhu, C., Ji, P., and Li, S. (2017). Effects of urban green belts on the air temperature, humidity and air quality. *J. Environ. Eng. Landsc. Manage.* 25, 39–55. doi: 10.3846/16486897.2016.1194276