

Contrasting impacts of heat stress on violent and nonviolent robbery in Beijing, China

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1 **Contrasting impacts of heat stress on violent and non-violent robbery**
2 **in Beijing, China**

3
4 **Xiaofeng Hu^{1*}, Peng Chen¹, Hong Huang², Ting Sun³, Dan Li⁴**

5
6 **Abstract:** Previous studies investigating the relation between heat stress and crime incidents often
7 focus on violent crimes. In this study, the impacts of heat stress on two types of robbery (violent
8 and non-violent) in China are compared using crime statistics collected in Beijing and heat stress
9 indices that consider the combined effects of temperature and humidity. The results indicate that
10 the abrupt change in the trend of robbery rates is affected by the 2008 Beijing Olympic Games.
11 The non-violent robbery rates have a more pronounced seasonality and are better correlated with
12 heat stress at daily scales, especially during the period from 2009 to 2014 when no trend exists.
13 The results also demonstrate that both violent and non-violent robbery rates significantly increase
14 with heat stress in spring. The non-violent robbery rates also significantly increase with heat stress
15 in summer. The influence of heat stress on violent robbery rate is more complicated and
16 non-linear.

17 **Key words:** violent, robbery, temperature, relative humidity, heat stress

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18 **1 Introduction**

19 The impact of heat stress on human conflicts has been widely acknowledged. Many studies
20 argued that higher temperatures increased the risks of interpersonal violence and intergroup
21 conflict (Barnett and Adger, 2007; Bernauer et al., 2012; Burke et al., 2009; Field, 1992; Gamble
22 and Hess, 2012; Hsiang et al., 2013; Hsiang et al., 2011; Mares, 2013; O'Loughlin et al., 2012;
23 Scheffran et al., 2012; Tol and Wagner, 2010; Zhang et al., 2011). In addition to human conflicts,
24 studies also demonstrated a strong impact of heat stress on common crimes (Brunsdon et al., 2009;
25 Chen et al., 2011; Horrocks and Menclova, 2011; Ranson, 2014).

26 Most previous studies (Field, 1992; Horrocks and Menclova, 2011; Jacob et al., 2006; Mares,
27 2013; Ranson, 2014) suggested that temperature had a significantly positive effect on violent
28 crimes. For example, Jacob et al. (2006) pointed out that a 10°F increase in average weekly
29 temperature was associated with a 5% increase in violent crime. Mares (2013) showed an average
30 1% monthly increase in violent crimes for each degree increase in anomalous temperature.
31 However, there seems no consensus regarding the impact of heat stress on property crimes. Field
32 (1992) indicated that burglary, theft and robbery were all positively and significantly correlated
33 with temperature, which was also supported by Chen et al. (2011). However, Cohn and Rotton
34 (2000) showed that theft was negatively correlated with temperature while both burglary and
35 robbery were positively correlated with temperature. Some studies suggested that property crimes
36 may be affected by heat stress in more complicated ways. For example, Ranson (2014)
37 demonstrated that the relationship between temperature and property crimes (such as burglary and
38 larceny) was highly non-linear.

39 More importantly, few studies directly compared impacts of heat stress on violent and

40 non-violent crimes, which motivates our study. In this study, we aim to investigate the contrasting
41 impacts of heat stress on violent and non-violent crimes in China using robbery as an example.
42 Previous studies (Horrocks and Menclova, 2011; Ranson, 2014) have pointed out that robbery was
43 affected by heat stress factors (e.g., temperature), but those studies did not separate violent and
44 non-violent robbery. The reason that robbery is selected is because China separates violent robbery
45 from non-violent robbery, which is not always the case in western countries, thereby providing a
46 good testbed for studying the contrasting impacts of heat stress on violent and non-violent crimes.
47 The violent robbery refers to crimes to obtain properties by violence (Chen et al., 2011). The
48 non-violent robbery is to obtain properties when someone is unaware first but instantly becomes
49 aware of the conduct. This is different from stealing in the sense that stealing is conducted secretly
50 throughout the conduct. As an example, if someone steals a necklace from a lady when the lady is
51 unaware throughout the whole incident, it is stealing; if someone takes the necklace away from the
52 lady's neck when she is unaware, but at the instant the lady realizes that someone is taking her
53 necklace away but could not stop it, this is non-violent robbery; if someone obtains the necklace
54 from the lady by violence, it is a violent robbery. Will both types of robbery be affected by heat
55 stress in the same way? If not, what is the difference and why does the difference occur? These
56 questions frame the scope of our study.

57

58 **2 Data**

59 The analysis is based on a ten-year (from 2005 to 2014) data set of daily robbery numbers
60 provided by Beijing Municipal Public Safety Bureau. Beijing is the capital of China, which has a
61 monsoon-influenced, humid continental climate. More than 21.1 million people live in Beijing
62 now. Between 2005 and 2014, more than 40 thousands robbery incidents were reported in Beijing.

63 To examine and compare the relation between the two types of robbery and heat stress in
64 Beijing, four heat stress indices that combine temperature and relative humidity are used in this
65 paper, including the Discomfort Index (DI), the simplified Wet Bulb Globe Temperature (sWBGT),
66 the Humidex (HUMIDEX) and the Temperature Humidity Index for Comfort (THIC), as
67 described in Table A1 of Appendix. Only the results with DI are discussed here since results with
68 other heat stress indices are very similar (e.g., the results with sWBGT are shown in the Appendix).
69 The DI was developed as a calibration index for air conditioners (Thom, 1959), which is defined
70 based on the air temperature and the wet bulb temperature:

$$71 \quad \text{DI} = 0.5T_w + 0.5T_c \quad (1)$$

72 where T_c is the air temperature ($^{\circ}\text{C}$) and T_w is the wet bulb temperature ($^{\circ}\text{C}$) whose definition can
73 be found in Appendix. The risk levels associated different heat stress values (Buzan et al., 2015)
74 are shown in Table A2.

75 The heat stress indices are calculated based on the climate data downloaded from the website
76 of rp5 (<http://rp5.ru/>), where the weather information comes from server of international data
77 exchange, NOAA, the United States and the automated data transfer system (ADT) of
78 Roshydromet. We select the daily weather data covering the same period as the crime data. The
79 robbery rate is defined as the robbery incidents per 10 million (10^7) people. Here we use “robbery

80 rate” instead of “the number of robbery incidents” based on the assumption that a larger
81 population lead to more crime incidents even under the same climatic conditions, thus normalizing
82 the robbery incidents by the total population of Beijing avoids, to some extent, the influence of
83 population increase in Beijing over the study period. To examine the relationship between the
84 robbery rate and heat stress, we further divide the robbery rate (daily incidents/ 10^7 ·people) into 11
85 bins (i.e., 0~1, 1~2, ... , 9~10 and >10) and then calculate the average heat stress in each bin. Then
86 we use simple linear regression analysis to evaluate the relations between the two types of robbery
87 and heat stress.

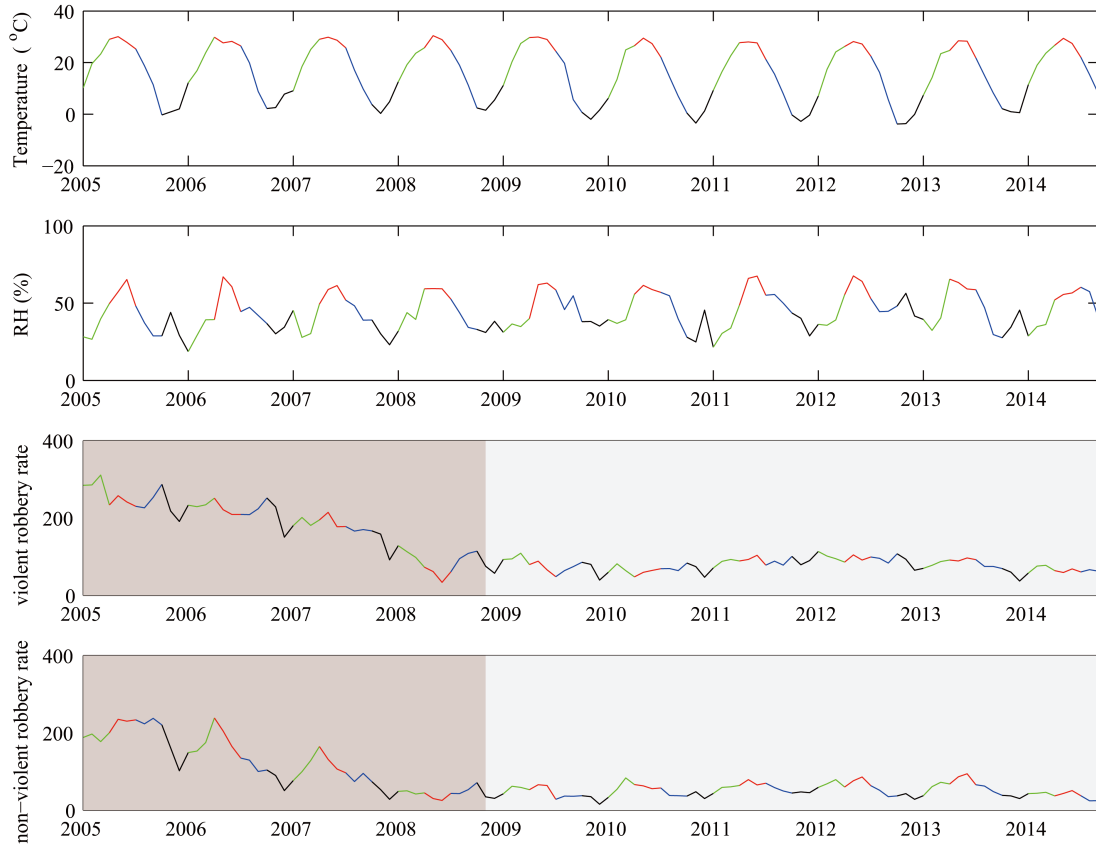
88 Motivated by previous studies (Hsiang et al., 2013; Mehluma et al., 2006; Miguel, 2005) , we
89 also examine the relation between rainfall amounts and crime rates. However, we do not find clear
90 relations between rainfall and the two types of robbery in Beijing. Since the focus of our study is
91 on heat stress, the results about rainfall are not presented.

92

93 **3 Results and discussions**

94 **3.1 Long-term trends**

95 To investigate the influence of heat stress on robbery, which occurs at daily scales and is
96 influenced by weather variability, we need to first understand the long-term trends in robbery rates
97 and their variations at longer, climate scales. Fig. 1 shows the temporal variations of temperature
98 ($^{\circ}\text{C}$), relative humidity (%), violent and non-violent robbery rates (daily incidents/ 10^7 ·people)
99 from 2005 to 2014 in Beijing. Here we aggregate all the data to monthly scales. It is clear that
100 temperature and relative humidity (RH) have distinct seasonal cycles, but there is no trend in
101 temperature or RH or their diurnal ranges. The story about robbery rates is the opposite. Although
102 seasonal variations seem to exist, they are not as strong as those of temperature or RH. But it is
103 evident that before the summer of 2008, decreasing trends are associated with both violent and
104 non-violent robbery rates; while after 2008, these decreasing trends disappear. From 2005 to 2014,
105 the gross domestic production (GDP) and population of Beijing increase continuously, thus neither
106 of these two factors seems to be able to explain why the summer of 2008 is a turning point. The
107 most likely reason is the 2008 summer Beijing Olympic Games. After winning the bid to host the
108 2008 Summer Olympics in 2001, the Beijing government initiated anti-crime campaigns and
109 increased law enforcement forces, and as a result, the crime incidents number decreased gradually.
110 It is clear that both violent and non-violent robbery rates were very low in the summer of 2008 and
111 remained at a low level from 2008 to 2014. From Fig. 1 it can be concluded that the long-term
112 trends of crime rates in Beijing are dominated by socio-economic reforms and changes that occur
113 at longer time scales.

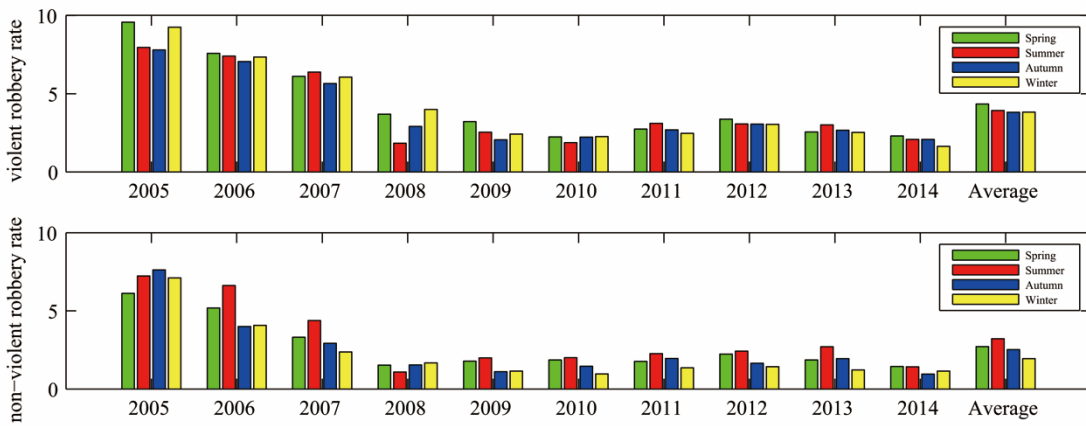


114

115 Fig. 1 Temporal variations of temperature ($^{\circ}\text{C}$), relative humidity (%), violent and non-violent robbery rates (daily

116 incidents/ 10^7 ·people·day) from 2005 to 2014 in Beijing. The green color represents spring, the red color represents

117 summer, the blue color represents autumn and the black color represents winter.



118

119 Fig. 2 Distribution of violent and non-violent robbery rates (daily incidents/ 10^7 ·people) in different seasons from

120 2005 to 2014 in Beijing. The green bar represents spring, the red bar represents summer, the blue bar represents

121 autumn and the yellow bar represents winter. “Average” means the average robbery rate of the whole period from

122 2005 to 2014.

123 Fig.2 shows the distribution of violent and non-violent robbery rates (daily incidents/10⁷
124 people) in different seasons from 2005 to 2014. As can be seen, the violent robbery rates in
125 different seasons are very close across seasons (except in 2005 and 2008), and the average rates of
126 the whole period are also similar in different seasons (with a slightly higher number in spring).
127 The non-violent robbery rate is in general the highest in summer and lowest in winter, which
128 seems to suggest that non-violent robbery has stronger seasonal variations than violent robbery.
129 Close inspection of Fig.1 reveals that this is indeed the case. It is also clear that both violent and
130 non-violent robbery rates in the summer of 2008 are much lower than their counterparts in other
131 seasons of 2008 and other years. This is again because of the Beijing Olympic Games, which
132 encouraged the Chinese government to improve the security level.

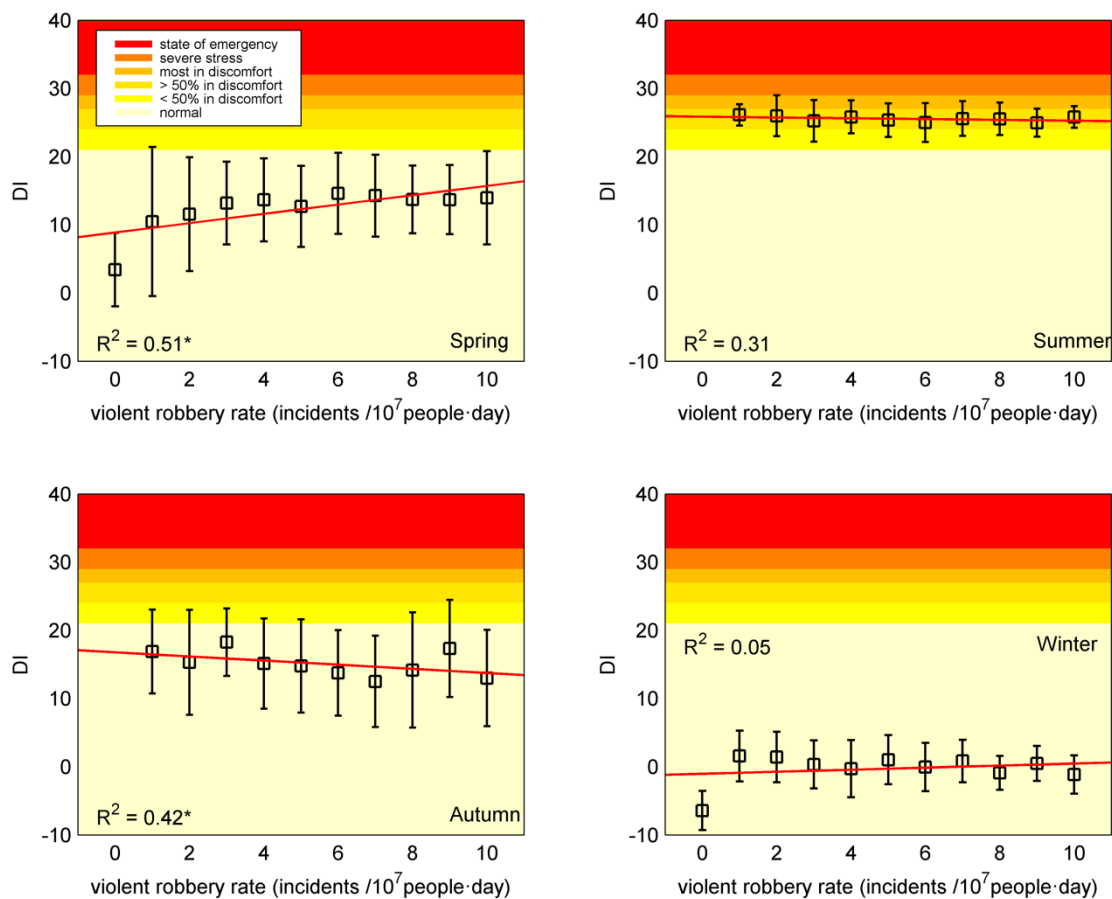
133 From the above analysis it can be seen that the two types of robbery are both significantly
134 affected by the Beijing Olympic Games, and non-violent robbery shows a more pronounced
135 seasonality than violent robbery. Given these findings, we divide the dataset into two periods:
136 from 2005 to 2008 and from 2009 to 2014. For the first period, linear trends exist as described by
137 the following equations:

$$\begin{aligned} 138 \quad R &= -0.0048t + 9.55, \text{ for violent robbery with } R^2 = 0.41 * \\ R &= -0.0048t + 7.41, \text{ for non-violent robbery with } R^2 = 0.45 * \end{aligned} \quad (2)$$

139 where t represents the t^{th} day, R is the crime rate, and * donates a significance level lower than
140 0.05. For the second period (from 2009 to 2014), no significant trend is detected. The linear trends
141 again suggest that crime rates are strongly affected by socio-economic factors (beyond the total
142 population) such as government regulations and increases in security level. More importantly,
143 these trends suggest that socio-economic factors affect crime rates at long-term scales (e.g., larger

144 than seasonal scales), as compared to heat stress affecting human discomfort at daily scales. To
 145 avoid the influence of these trends, which we assume were induced by changes in socio-economic
 146 factors, we remove the linear trends in both violent and non-violent robbery rates when we
 147 investigate the relation between robbery rates and heat stress index (HSI) at daily scales. We
 148 acknowledge that this treatment is a simplification and further investigations with more data are
 149 recommended. However, this is a logical starting point given the lack of appropriate data sets to
 150 constrain the influence of socio-economic factors.

151 **3.2 The influence of heat stress at daily scales**



152
 153 Fig. 3 The relation between violent robbery rates and DI values in Beijing before 2009. The red lines are fitted
 154 linear relations.

155 In the following, we investigate the relation between robbery rates and heat stress index (HSI)
156 at daily scales. To do so, we separate the results in different seasons. This is because the relations
157 between heat stress and robbery can be induced by correlations with both daily (meteorological)
158 variations and seasonal (climate) variations. For example, students have long summer/winter
159 vacation that increases the opportunity of interpersonal contact in cities like Beijing where the
160 student population is large; people also tend to wear light cloths during summer, which could
161 expose their valuable belongings and lead to robbery. For these reasons, crime incidence would be
162 higher during summer. Our data indeed indicate that the relation between heat stress and crime
163 rates is very strong when different seasons are not separated (not shown). This is, however, not
164 related to how hot the summer is. To examine the influence of heat stress, it would be necessary to
165 show that hot days in summer have higher incidence than cool days in summer, or that heat stress
166 indices are related to crime rates within each season. Thus, in this study the linear regression is
167 conducted separately for four seasons.

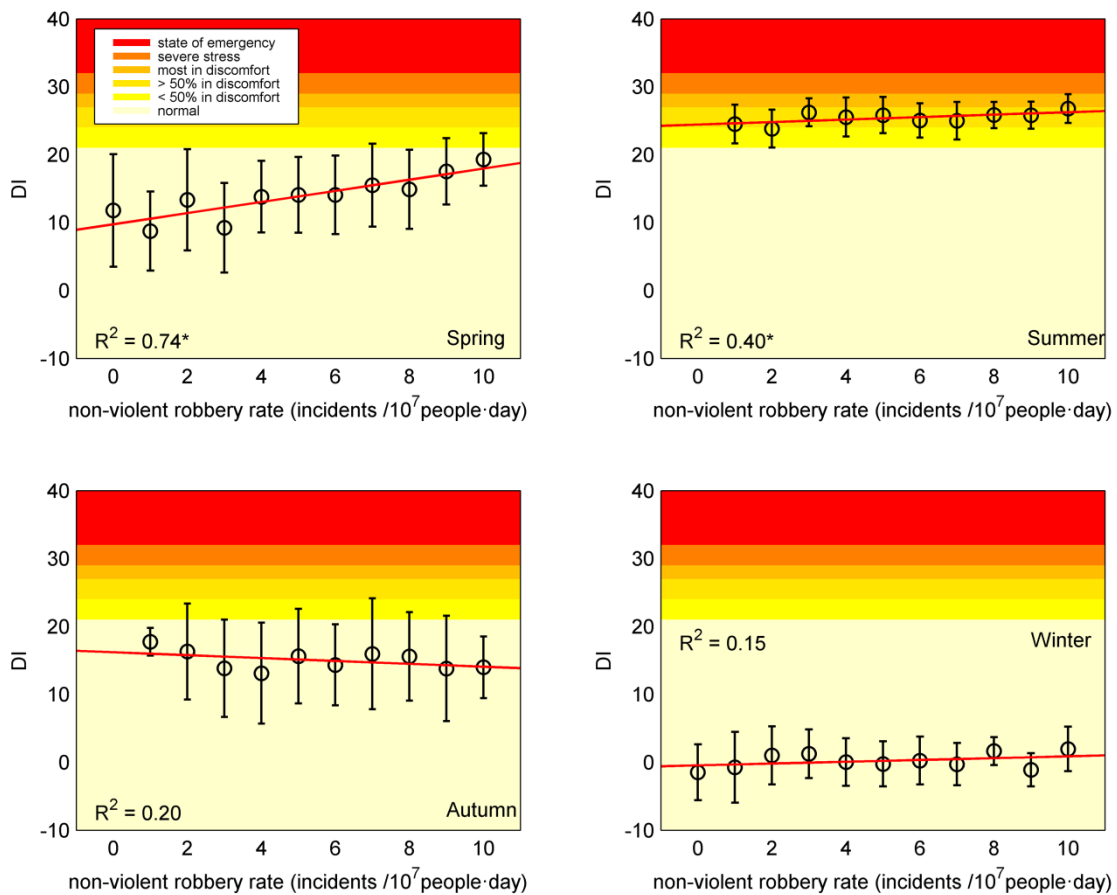
168 Fig. 3 shows the relation between violent robbery rates and DI values in different seasons
169 before 2009. As shown in Fig. 3 (also shown in Fig. 4, Fig. 5 and Fig. 6), most DI values in
170 Beijing are in the risk level of “normal” in spring, autumn and winter; while all DI values are in
171 the risk level of “<50% in discomfort”, “>50% in discomfort” or “most in discomfort” in summer.
172 The violent robbery rate increases with DI value in spring and winter, but decreases with DI value
173 in summer and autumn. Simple regression analysis is also conducted to quantify the relation
174 between violent robbery and DI, and the results are shown in Table1 (also shown in Fig. 3). The R^2
175 values are larger than 0.4 and significant in spring and autumn, but are lower than 0.3 and not
176 significant in summer and winter.

177 Table 1 The results of simple regression analysis between DI and robbery rates.

| Season | before 2009 | | after 2009 | |
|--------|-----------------|---------------------|-----------------|---------------------|
| | violent robbery | non-violent robbery | violent robbery | non-violent robbery |
| Spring | 0.51* (0~10) | 0.74* (0~10) | 0.63* (0~8) | 0.96* (0~7) |
| Summer | 0.31 (0~10) | 0.40* (0~10) | 0.30 (0~9) | 0.89* (0~7) |
| Autumn | 0.42* (0~10) | 0.20 (0~10) | 0.01 (0~8) | 0.69* (0~6) |
| Winter | 0.05 (0~10) | 0.15 (0~10) | 0.44 (0~7) | 0.66 (0~4) |

178 *denotes a significance level lower than 0.05. Numbers in parentheses represent the ranges of the robbery rate

179 data.

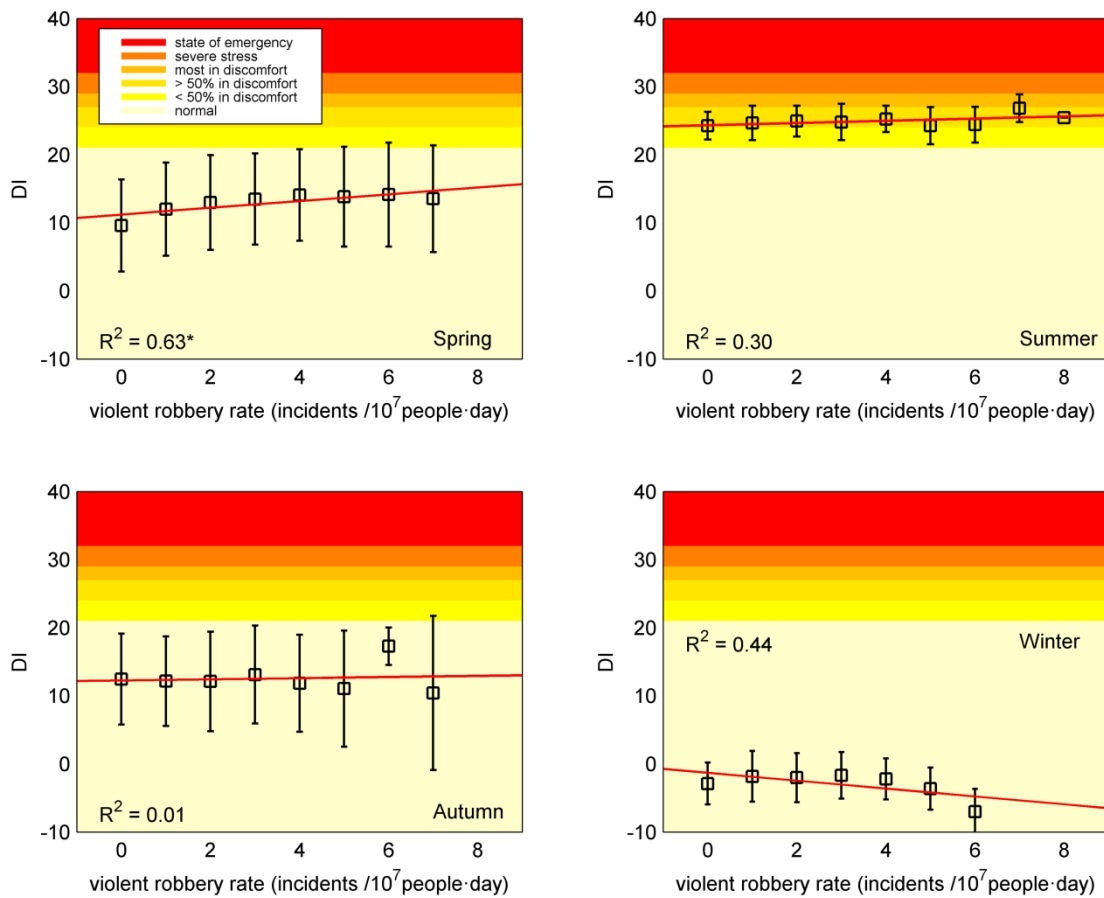


180

181 Fig. 4 The relation between non-violent robbery rates and DI values in Beijing before 2009. The red lines are fitted

182 linear relations.

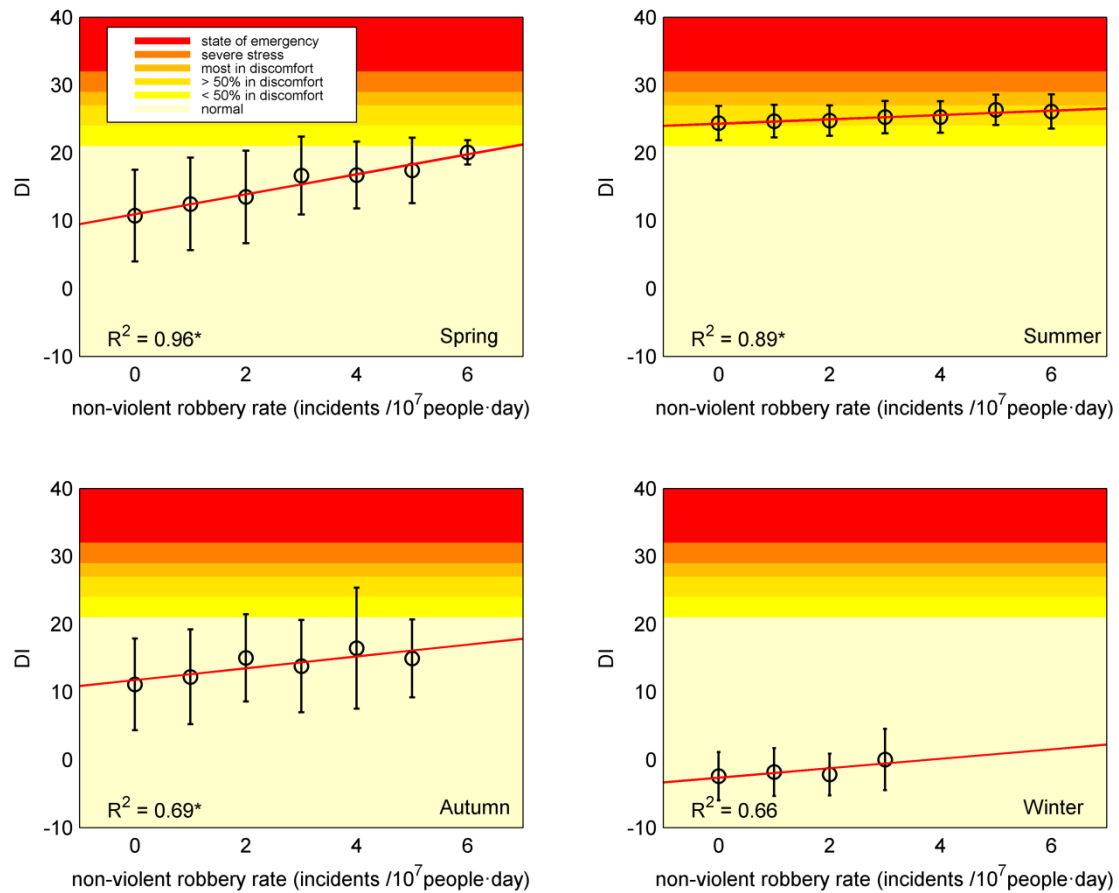
183 Fig. 4 shows the relation between non-violent robbery rates and DI values in different
 184 seasons before 2009. From this figure, we can see that the non-violent robbery rate increases with
 185 DI value in spring and summer, but decreases with DI value in autumn and winter. Simple
 186 regression analysis shows that relation between non-violent robbery and DI is significant, and the
 187 R^2 value is larger than 0.7 in spring and is 0.4 in summer. However, the R^2 values in autumn and
 188 winter are lower than 0.2 and not significant.



189
 190 Fig. 5 The relation between violent robbery rates and DI values in Beijing after 2009. The red lines are fitted linear
 191 relations.

192 Fig. 5 shows the relation between violent robbery rates and DI values in different seasons
 193 after 2009. The violent robbery rate increases significantly with DI only in spring. In winter,
 194 although a decreasing trend is observed and the R^2 value is larger than 0.4, the relation is not

195 significant, which is also the case in summer and autumn.



196

197 Fig. 6 The relation between non-violent robbery rates and DI values in Beijing after 2009. The red lines are fitted

198 linear relations.

199 Fig. 6 shows the relation between non-violent robbery rates and DI values in Beijing after

200 2009. It indicates that the non-violent robbery rates increase with DI values in all four seasons.

201 Simple regression analysis shows that all R² values in the four seasons are larger than 0.6, and for

202 spring and summer, the R² values are even larger than or close to 0.9 (p < 0.05), suggesting that

203 non-violent robbery is strongly affected by heat stress across all four seasons after 2009 in Beijing.

204 In summary, the most consistent and robust results across Figs. 3 to 6 are: 1) both violent and

205 non-violent robbery rates significantly increase with heat stress in spring; 2) non-violent robbery

206 rates also significantly increase with heat stress in summer; 3) in the period of 2009 to 2014 when

207 no trend exists, non-violent robbery rates are more strongly affected by heat stress than violent
208 robbery rates.

209 **3.3 The contrasting impacts of heat stress on violent and non-violent robbery**

210 Here we explore the reasons behind such differences between violent and non-violent
211 robbery. Non-violent robbery is a essentially property crime which happens without violence, thus
212 its relation with heat stress may be explained by the Routine Activity (RA) theory proposed by
213 Cohen and Felson (1979). The RA theory points out that there are three necessary conditions for
214 committing a crime: a likely offender, a suitable target, and the absence of a capable guardian.
215 Higher but not extreme heat stresses are more likely to increase mobility and social interaction
216 thereby increasing the likelihood of a suitable target occurring and thus generating more
217 opportunities for property crimes. The original RA theory, however, did not provide a clear
218 definition of “higher but not extreme heat stresses”. Our results here offer a more quantitative
219 perspective over Beijing area. From Fig. 4 and Fig. 6 one can see that non-violent robbery rates
220 significantly increase with heat stress in the DI ranges from “normal” to “>50% discomfort”.
221 Under such heat stress conditions, the non-violent robbery rate generally increases with the HSI.
222 This is particularly true in the post-2009 period when no long-term trend is observed.

223 On the other hand, the influence of heat stress on violent robbery is more complicated. In the
224 literature, the General Affect (GA) model and the Negative Affect Escape (NAE) model were
225 often used to explain the relation between temperature and violent crime. The GA model is similar
226 to the RA model, which suggests that higher temperatures facilitate effective aggression (Cohn
227 and Rotton, 2000). The NAE model proposes that human aggression increases with temperature

228 because of increases in discomfort, but only up to a certain point beyond which the relationship
229 will be negative. As the discomfort increases over a threshold, the criminal's motivation to escape
230 uncomfortable situations will eventually outweigh the motivation to be aggressive (Bell, 1992).
231 Thus, an 'inverse-U-shaped' relationship should be observed between temperature and aggression.
232 In summary, both GA and NAE models suggest a positive correlation between temperature and
233 crime rate, but the NAE model further suggests a negative correlation when temperature is beyond
234 a threshold. Our results seem to be more consistent with the GA model in the sense that
235 'inverse-U-shaped' relationship is not found. However, negative or no correlations are observed in
236 Beijing, especially in the post-2009 period (see Fig. 5). As such, it is concluded that the relation
237 between violent robbery and heat stress is more complex and less robust than the relation between
238 non-violent robbery and heat stress; and neither GA nor NAE could fully explain such relations.
239

240 **4 Conclusions**

241 This study investigates the influence of heat stress on two different types of robbery (violent
242 vs. non-violent) using crime statistics and observed climate records in Beijing, China. Heat stress
243 indices (DI, sWBGT, HUMIDEX, and THIC), which combine the effects of temperature and
244 humidity on human comfort, are used in this paper. The results show that the abrupt change in the
245 trends of robbery rates seems to be caused by the 2008 Beijing Olympic Games. As a result, it is
246 assumed that the social and economic influence is responsible for the linear trend in robbery rates.
247 Correlations between both violent and non-violent robbery rates and heat stress at daily scales and
248 in different seasons are also examined. The most important conclusion is that both violent and
249 non-violent robbery rates significantly increase with heat stress in spring. The non-violent robbery
250 rates also significantly increase with heat stress in summer. In the period of 2009 to 2014 when no
251 long-term trend can be detected, non-violent robbery rates are more strongly affected by heat
252 stress than violent robbery rates. The results for non-violent robbery can be reasonably explained
253 by the Routine Activity theory. However, the influence of heat stress on violent robbery is more
254 complicated and cannot be fully explained by the General Affect or Negative Affect Escape theory.

255 One important assumption made in our study is that both socio-economic factors and climatic
256 factors such as heat stress have influences on crime rates, but they affect crime rates at different
257 scales. In particular, socio-economic factors are assumed to only affect crime rates at long-term
258 scales while heat stresses are assumed to affect crime rates at daily scales. A further assumption is
259 that the long-term change is represented by the linear trend. The results in the two periods (before
260 2009 and after 2009) are broadly consistent, suggesting that the treatment of the influence of
261 socio-economic factors is acceptable. However, it is also pointed out that the relation between heat

262 stress and crime rates is generally more robust in the second period when no linear trend exists.

263 Our study is a logical starting point given the data limitation but further investigations on

264 separating the influences of socio-economic factors and climatic factors are recommended.

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272

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334

335

336 **Appendix**

337 The heat stress indices used in this paper are the Discomfort Index (DI), the simplified Wet
 338 Bulb Globe Temperature (sWBGT), the Humidex (HUMIDEX) and the Temperature Humidity
 339 Index for Comfort (THIC). Their definitions can be found in Table A1. The risk levels associated
 340 with different heat stress values are shown in Table A2 (Buzan et al., 2015).

341 **Table A1 Heat stress indices**

| Indices | Descriptions | References |
|---|--|------------------------------------|
| The discomfort Index (DI) | $DI = 0.5T_w + 0.5T_c$ | Thom (1959) |
| The simplified Wet Bulb Globe Temperature (sWBGT) | $sWBGT = 0.56T_c + \frac{0.393e_{RH}}{100} + 3.94$ | ACSM (1984) |
| The humidex (HUMIDEX) | $HUMIDEX = T_c + \frac{5}{9} \left(\frac{e_{RH}}{100} - 10 \right)$ | Masterson and Richardson (1979) |
| The Temperature Humidity Index for Comfort (THIC) | $THIC = 0.72T_w + 0.72T_c + 40.6$ | Ingram (1965) |

342

343 In order to estimate the heat stress indices sWBGT and HUMIDEX, the vapor pressure e_{RH}
 344 (Pa) is firstly calculated by:

345
$$e_{RH} = (RH/100)e_{sPa} \quad (A1)$$

346 The saturated vapor pressure e_{sPa} is calculated using Magnus form approximation:

347
$$e_{sPa} = 6.1078 \exp \left[\frac{17.13(T - 273.16)}{T - 38} \right] \times 100 \quad (A2)$$

348 where T is the temperature in Kelvins.

349 In this paper, to calculate heat stress indices THIC and DI, it is necessary to first calculate the

350 wet bulb temperature T_w ($^{\circ}\text{C}$). Here, we use an approximation from (Oleson et al. (2015)) to

351 calculate the wet bulb temperature:

352
$$T_{ws} = T_c \arctan\left(0.151977\sqrt{\text{RH} + 8.313659}\right) + \arctan(T_c + \text{RH}) - \arctan(\text{RH} - 1.676331) + 0.00391838\text{RH}^{3/2} \arctan(0.023101\text{RH}) - 4.68035 \quad (\text{A3})$$

353 **Table A2 Risk levels of different heat stress indices**

| sWBGT | HUMIDEX | THIC | DI |
|------------------------------------|--------------------------|---------------------------|--|
| Alert: 26.7 – 29.3 | Some discomfort: 30 | Alert: 75 | <50% of population in discomfort: 21 – 24 |
| Caution: 29.4 – 31.0 | Dangerous: 46 | Dangerous: 79 – 83 | >50% of population in Discomfort: 24 – 27 |
| Potentially dangerous: 31.1 – 32.1 | Imminent heat stroke: 54 | Very dangerous: ≥ 84 | Most of the population in discomfort: 27– 29 |
| Dangerous: ≥ 32.2 | | | Severe stress: 29 – 32 State of emergency: > 32 |

354