Temperature and Interpersonal Violence in Mexico

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Abstract

We estimate the effect of temperature on criminality in Mexico and confront three social theories relating aggression to high temperatures. Using high-frequency data, we find a positive effect of temperatures on criminality. A large part of the relationship between temperatures and criminality is explained by a higher consumption of alcohol and a change in time allocation during warm weekends. In addition, heat-related criminality is largely driven by short-term displacements, causing no additional victim. We find no evidence that displacements are due to premeditation in crime. These elements are consistent with Cohen and Felson's (1979) routine activity theory of criminal activity.

Keywords: extreme weather events; temperature; criminality; distributed lag model; routine activity.

JEL codes: K42, K49, Q54, Q56.

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1. Introduction

Global surface temperatures are expected to increase by at least 2°C as compared to pre-industrial levels by the end of the century (IPCC, 2014). This alarming perspective has motivated the production of a new strand of economic literature devoted to the economic consequences of climate change. In particular, a significant amount of research now makes a clear link between climate and conflict; both at intergroup and interpersonal levels (see Burke, Hsiang and Miguel, 2015; Hsiang, Burke and Miguel, 2013; Hsiang, Meng and Cane, 2011 for detailed reviews).

In the climate change literature, two explanations are usually given to understand the impact of climate on interpersonal conflict (Burke, Hsiang and Miguel, 2015). In developing countries, drier weather can reduce agricultural yields and income, which in turn can lead to an increase in economically-motivated crime. On the other side, results from experimental and quasi-experimental studies show that exposure to higher temperatures increase the likelihood of aggressive behaviour between individuals. Psychologists and criminologists often consider that criminal offenses are instigated by abnormal behaviour. If hot temperatures produce negative affect, they could unsettle people under stress or with already fragile mental health (Anderson, 2001).

In this paper, we use data from one of the hottest countries in the world to examine with more scrutiny one of these two allegations, namely that interpersonal conflict could raise because heat may severely upset some people. Whereas a correlation has been observed between hot weather and criminality rates, we are aware of no field study proving that this correlation was caused by alterations of human psychology. The major contribution of this paper is to provide evidence and confront it with all possible explanations of the short-term effect of temperature on criminality.

Even though there may be such a thing as heat-triggered violence, two other major social theories could explain a short-term correlation between heat and criminality. At least since Becker (1968), economists have argued that criminal acts could be utility maximising. If temperatures alter the probability of success of a criminal offense, or reduces the probability of being punished afterwards, the correlation between temperature and criminality could be the reflection of a rational calculation from offenders. In parallel, there is a sociological interpretation of the impact of temperatures on criminality. Potential victims and offenders may modify their routine activities when confronted to a change in temperature. Victims may prefer outdoor leisure activities when the weather permits, potential offenders may participate in gatherings or be more likely to consume drugs or alcohol. Changes in time allocation or habits may modify exposure to criminality or the tendency to commit offenses (Cohen and Felson, 1979).

To confront these three theories – the psychological, the economic and the sociological, we analyse the effect of temperature on different types of crime accusations in Mexico. More precisely, we use daily crime records on accusations and processed individuals from the "First Instance Courts" from 1997 to 2012. We combine this dataset with daily temperature and rainfall data from the Mexican National Weather Service. Our dataset covers 90% of Mexican municipalities for 16 years and consists of about 12 million daily crime rates at the municipality level.

We resort to two different types of econometric specifications. A model of contemporaneous effects simply correlates daily criminality rates with local daily temperatures. We use municipality by month of the year fixed effects to restrict the analysis to short term effects and control for a large set of unobservable factors that could explain differences in criminality levels across municipalities and seasons. In addition, we also run distributed lag models to account for delayed impacts and displacement effects. With this additional approach, we can assess if sudden pikes in criminality rates are offset by lower criminality rates in the following days. To our knowledge, this paper is the first to use daily data and a distributed lag model à la Deschenes and Moretti (2009) to look at the additional effect of temperatures on criminality in a developing country.[3] Accounting for delayed effects is of utmost importance to properly quantify the short-term effect of temperatures on criminality.

We find an almost linear and positive contemporaneous relationship between temperature and criminal activity. An increase of one degree Celsius increases the accusation rate of all types of crimes by 1.3%. During a hot day (>32°C), the accusation rate is expected to be higher than the rate of a cold day by one third (<10°C). These results on the contemporaneous correlation between criminality and temperature are consistent with previous research in Ranson (2014) and Horrocks and Menclova (2011) among others. The results of the distributed lag model indicate, however, that 35% of the peaks in criminality rates occurring during hot days are compensated by reductions in criminality levels during the following days.

[3] Jacob, Lefgren and Moretti (2007) apply such a methodology with weekly U.S. data. We are comparing hereafter our results to theirs.

We disaggregate crime records by type of crimes to investigate differences in their response to rises in temperature. In the model of contemporaneous effects, we find a strong effect of higher temperature on a series of violent crimes: homicides, injuries, rapes and sexual aggressions, and possessions of weapon. We find a small causal effect on property damage, thefts and drug-related crimes. In the distributed lag model, the effect of temperature on criminality rates is no longer visible for most types of crimes. Displacement effects may therefore offset most of the immediate correlation between violent crimes and temperature. However, there are two types of crimes from which we find a long-lasting effect of temperatures: rapes and sexual aggression, on the one hand, and drug-related crime accusations on the other. Further analyses show that the effect on drug-related crime accusations may mostly be due to a reduction in the production of drugs when temperatures reach low levels (e.g. <0°C). The additional and long-lasting effect for rapes and sexual aggression is mostly due to lower records during colder days. However, this element is noteworthy since these crimes are particularly impulsive, violent crimes perpetrated by mentally ill, deviant subjects.

The magnitude of our results can be put in perspective by looking at climate change impacts. We use the RCP4.5 intermediate scenario to project future temperatures changes in Mexico and find that crime accusations would increase by 4.3% and 3.3% in the contemporaneous and the distributed lag model, respectively, at the end of this century. The distributive lag model predicts an increase by10.6% of the amount of rapes and sexual aggressions under climate change by 2100.

Our general results show the importance of transitional effects and the impact of colder temperatures on rapes, but do not allow favouring either the psychological, sociological or economic explanations. The second part of this paper asks five questions about the circumstances of committed offenses with the aim of uncovering evidence capable of giving more ground to one or the other explanations.

The first question regards the intentionality of crimes: are heat-related crimes intentional or unintentional? This question is essential to understand if there is any economic rationality behind the offenses that have been recorded. The second one regards the psychophysical status of offenders: did they consume drugs and alcohol? This question is essential to assess if we are capturing the direct effect of heat on criminality, or its indirect effect through an increased use of psychotropic substances. The third one is about the temporality of offenses: are they committed during the week or the weekend? If more crimes occur because victims and criminals modify their routine activities, we should expect a stronger effect of heat on criminality on nonworking days. Fourth, are offenses committed during day-time or at night? Night temperatures are significantly lower and are unlikely to generate heat-related violence. Fifth, is the judicial system more or less effective when dealing with crimes committed during hot days? A rational criminal could prefer hot days to commit a crime if this increases its chances not to be caught.

We find that both intentional and unintentional crimes are committed during hot days. However, we find no evidence that premeditated crimes are committed more often during hot days. We also uncover that a significant amount of the additional crimes committed during hot days are committed under the influence of alcohol. Furthermore, hot temperatures have a statistically stronger impact on criminality during weekends than during weekdays. Rapes and sexual aggressions appear to be equally sensitive to night and day temperatures. Furthermore, this additional set of analyses confirms that their amount does not seem to be significantly higher during hot days, but significantly lower during cold days instead. We find that most of the displaced crimes – committed during hot days but with no additional effect – are committed during day time, not night time. Finally, the offenders that commit a crime during a hot day have the same probability of being caught than offenders active during other days.

All these findings do not seem to back up the theory that criminals would act during hot days because this is rational. Our results on the timing of heat-related crimes and the use of alcohol corroborate the theory that changes in routines during the day and at night are a preponderant factor explaining the short run correlation between temperature and criminality. Finally, we find little evidence if no evidence supportive of the idea that hot temperatures may cause major outbreaks of heat-related violence.

These results have important policy implications. Since we can only be certain about the sociological effect of hot temperature on criminality, we can only back up policy responses to heat-related criminality that account for modifications of routine activities during hot days. Physiological moderators such as air conditioning, proper hydration or environmental measures aiming at reducing the heat island effect in city centres are not the appropriate response based on the evidence that we have gathered. On the opposite, we expect that increased surveillance and prevention policies during hot days could be more effective to cope with heat-related criminality. In particular, since we observe a very strong, persisting impact of temperatures on rapes and sexual aggression, police should increase surveillance activities during hotter days around areas where these crimes have previously happened. Awareness campaigns about sexual abuses and rapes should also mention changes in habits and hot weather as risk factors. More research is needed, however, to assess the effectiveness of different measures in reducing heat-related criminality.

The paper consists of six sections. Section 2 summarizes the existing literature. Section 3 presents the data on crime accusations, processed individuals and weather in Mexico during our sample period. Section 4 explains our empirical strategy, presents the general results and the results by type of crime. Section 5 analyses the possible channels through which temperature may affect crime accusations. Finally, Section 6 provides concluding remarks.

2. Related scientific literature

The study of how weather changes can affect interpersonal conflict is not new, even though recent concerns about climate change has produced renewed interest on this topic. Researchers in psychology have long observed that high temperatures correlate with aggression in a large series of circumstances. In a cross-sectional analysis of 260 US cities, Anderson (1987) examines the correlation between crime rates and temperature, finding that high ambient temperatures were a good predictor of high criminality rates. Anderson, Bushman and Groom (1997) observe a positive relation between temperature and serious and deadly assault in the years 1950-1995. They also find a correlation between the average number of hot days (≥90°F) and the size of the usual summer increase in violence. In parallel, Vrij, Van der Steen and Koppelaar (1994) examine the attitude of police offers while using a fire arms training system, at normal and high ambient temperatures. They find that high temperatures result in increased tension, a more negative impression of the offender and aggressive behaviour. Likewise, Auliciems and DiBartolo (1995) find that in a positive association between higher air temperatures and calls to police complaining of domestic violence in Brisbane, Australia.

In other domains, Reifman, Larrick and Fein (1991) observe that hot temperatures increase the aggressiveness of pitchers during major league baseball matches. Kenrick and MacFarlane (1986) examine the influence of ambient temperature on responses to a car stopped at a green light. They find that horn honking increased linearly with temperature, and that the effect was stronger for those drivers who had their windows rolled down.

More recent studies have also found an association between hot temperatures and criminality. Horrocks and Menclova (2011) use daily data from 2000 to 2008 for 43 districts in New Zealand and find that higher temperature increases violent crime and property damage while increases in rainfall reduce both types of crimes. Ranson (2014) uses a panel approach with monthly crime and weather data at for about 3,000 counties in the U.S. from 1980 to 2009. The study finds a linear positive effect of temperature on violent crimes and a non-linear effect on property crime. In a study also closely related to this research, Baysan *et al.* (2015) analyse if economic factors are the main explanation of killings by drug-trafficking organizations, homicides and suicides during hot days in Mexico. The authors use a panel approach with monthly crime and weather data at the municipal level from 2006 to 2010 and at the state level from 1990 to 2010. They find that higher temperatures are associated with increases drug-related killings, homicides, and suicides. They also exploit a quasi-experimental variation in income and find that only killings due to drug trafficking are influenced, albeit weakly, by such variation. Baysan *et al.* (2015) conclude that all three types of violent deaths seem to be triggered by a similar underlying pattern, possibly the effect of heat on human psychology.

Most psychological explanations for the temperature-aggression relationship revolve around the notion of “crankiness” (Anderson, 2001). High temperatures produce lack of comfort and this would affect the way people perceive things. For example, minor insults would often be perceived as major ones under heat. In this matter, Baylis (2015) analyses one billion tweets in the United States and finds strong evidence of a sharp decline in tweets’ moods when temperature is above 70 F. People may also become impatient: Wearden and Penton-Voak (1995) find that time seems to pass faster for people exposed to warmer temperatures.

The notion of crankiness is compatible with several theories of social behaviour. For example, Berkowitz's (1984) cognitive neo-association theory suggests that the people that are repeatedly exposed to aggression develop networks of aggressive thoughts. These networks would be more easily triggered by external factors, such as violent media or, eventually, uncomfortable temperatures. Likewise, Zillmann's (1971) excitation transfer theory also suggests that high temperatures could increase violence. In this framework, uncomfortably hot temperatures produce negative affect. This affect may be transferred to an external object. In the end, the negative affect produced by hot temperatures is misattributed to the foreign object (Anderson, 2001). Another psychological theory that could explain the impact of hot temperatures on aggressive behaviour is the negative-affect escape model (Anderson, 1989; Anderson et al, 2000; Bell and Baron, 1976). In this model, hot temperatures should increase violence when subjects are exposed to moderate levels of negative affect. However, as soon as the amount of negative affect becomes overwhelming, temperature may increase escape strategies and therefore reduce violence. Anderson (2001) conducts a meta-analysis and finds that there is supportive evidence of a linearly positive effect of heat on aggression, but finds little support for any decrease in aggression levels when additional negative affect-producing factors are present in conjunction with heat (Anderson et al., 2000).[4]

In our view, the psychological theories building on the crankiness of hot temperatures are not fully satisfactory as the sole factor explaining that hot temperatures increase interpersonal violence. Early evidence shows that other factors that create discomfort could have no effect on aggressive behaviour. For example, Bell (1980) studies the behaviour of 80 male American college students and finds an effect of heat but no effect of noise on aggressiveness. This poses the question of the specificity of heat on increasing violence. In this matter, an unresolved problem for a psychological theory of the relationship between heat and aggression regards the lack of effect of cold on aggression: cold also produces discomfort, but there is no statistical evidence that cold might lead to more violence. Anderson *et al.* (2000) and Baylis (2015) argue that asymmetric responses between cold and heat are to be expected because protective measures against cold temperatures tend to be more widespread, while many people do not protect themselves against heat. This explanation is sensible but cannot rule out the eventuality that heat and cold trigger different levers.

Anderson, Anderson and Deuser (1996) identify three separate channels through which temperature could impact aggressiveness: the affective route (the development of negative feelings), the cognitive route (the development of aggressive thoughts) and the arousal route (physiological responses such as increases in heart rates). They test for the impact of both cold and hot temperatures, as well as the impact conveyed by images of guns, on the first two of these routes in lab experiments. Both cold and heat contribute to the development of negative feelings, consistently with the psychological theory that temperature creates some level of discomfort which may translate into aggressiveness. On the opposite, they find no impact of temperatures on the cognitive route, which is nonetheless activated by the display of images of weapons. The authors finally suggest that high temperatures could have a positive impact on the arousal route whereas cold temperatures could reduce arousal. This last element, namely

[4] Psychologists have mentioned a couple of solutions to cancel off the violent outbursts caused by high temperatures. Anderson (2001) notices that reducing ambient temperature in closed environments should be effective in reducing aggression, particularly in violent-prone places such as prisons. An early study by Baron and Bell (1976) finds that a cooling drink seems to lessen heat-related aggressiveness. This study however relies on a rather small sample of individuals. Other solutions could be foreseen. For example, Lafortezza, Carrus, Sanesi and Davies (2009) show that the availability and use of green spaces could alleviate the perception of thermal discomfort during periods of heat stress.

the difference in the physiological response to heat and cold, is an alternative explanation about why cold and heat have asymmetric effects on violent behaviour.

We are aware of no scientific paper that exposes the full linkages between neurological and endocrine systems; temperature stress and thermoregulation; and aggressiveness. The neurobiological mechanisms that determine aggressive behaviour are not yet fully understood, let alone their possible interaction with environmental factors such as ambient temperatures. Recent reviews of neuroscience research on anger and aggression (Angus et al., 2016; Montoya et al., 2012) explain that three major hormones influence aggressive behaviour: testosterone, cortisol and serotonin. Researchers have observed a mutually antagonistic effect of testosterone and cortisol on aggressive behaviour (van Honk et al., 2010). An imbalance in the two hormones, characterised by relatively high levels of testosterone and low levels of cortisol, create the ideal hormonal cocktail for aggressiveness in humans. Since testosterone is present in significantly higher amounts among men, differences in aggressiveness between men and women find a biological root. In addition, cortisol and serotonin interact in a complex manner. Much of the neurocircuitry for stress and aggression overlaps. The neurotransmitter serotonin (5-HT) responds rapidly to stress, and also appears to play an important role in the inhibitory regulation of aggressive behaviour. High cortisol seems to augment the inhibitory effect of serotonin on aggression (Summers and Winberg, 2006; Summers et al., 2005).

These hormonal effects may explain a diversity of social phenomena. Sherman et al. (2016) find that individuals with both high testosterone and low cortisol are more likely to occupy high-status positions in social hierarchies. The anti-social behavior of delinquents, young offenders and disruptive children has also been explained by hormonal factors in recent research (e.g. Popma et al. 2007; Banks and Dabbs, 1996; Scerbo and Kolko, 1994; Dabbs, Jurkovic and Frady, 1991). However, it is difficult to conclude that these studies necessarily capture the causal effect of hormonal differences on aggression. Testosterone is known to respond to external factors. For example, its concentration increases before men engage in competition (e.g. Archer, 2006; Carré et al., 2010; Carré and Olmstead, 2015). Therefore, the causal impact of testosterone on aggressiveness is not totally clear, since reverse causality is also possible: high levels of testosterone could be the outcome of social interactions, and not their cause. In this matter, Mazur and Booth (1998) show that testosterone levels of the same individuals before marriage, during marriage and after divorce are radically different. When single, men display higher testosterone levels. Mazur and Booth (1998) hypothesize that single men are more likely than married men to face confrontations and challenges while lacking the social support of a spouse. The risks of frequent confrontations could impact testosterone synthesis in specific moments of their lives.

As for now, we have only considered a psychological or physiological route for the immediate impact of temperatures on aggression. However, we cannot discard that aggression has many other determinants that could be confounded with temperature. Anderson and Bushman (1997) identify provocation and retaliations as the major reason behind most aggressions (physical or verbal), in support of a theory in which temperatures could alter perceptions about mild provocations and contribute to an escalation of violence. However, they also mention three other factors influencing aggressive behaviour in the short run: anonymity, alcohol and media violence. Out of these three factors, the interaction between anonymity and temperature and the interaction between alcohol and temperature seem of interest for the researcher interested in the impact of temperature on interpersonal violence. If social interactions and gatherings occur more often during hot days than during cold days, then aggressions conducted in anonymous groups (e.g. hooliganism) or perpetrated under the influence of alcohol could become more frequent because of high temperatures. Some increments in violence during hot days could be due to changes in performed activities.

The idea that we just developed resembles the sociological theory of routine activities of Cohen and Felson (1979). These authors consider that offenses can only occur if motivated offenders and suitable targets meet in a specific place and at a specific moment in time. The likeliness that such encounters occur varies from hour to hour, or day to day.[5] Applied to the context of ambient temperature, the theory of routine activities implies that temperature-induced changes in time allocation can significantly impact criminality. Using UK data, Field (1992) is supportive of this view. Field (1992) finds a strong correlation between temperature and criminality in the UK, a country in which temperatures are always mild – they are never hot enough to trigger any psychological effect. He concludes that criminality increases during hot days in the UK plausibly because households spend more time outdoors.

Cohen and Felson (1979) also consider that, for offenses to occur, not only do criminals must meet their victims, they also should meet them in a situation where the is no guardian capable of disarming the offense. In the footsteps of Becker (1968), economists have been particularly

[5] Furthermore, structural change in routine activities could lead to an increase or a decrease in criminality. Cohen and Felson (1979) argue that a reduction in the time spent on routine activities performed at home in favour of other activities performed away from home was responsible for a significant rise in US criminality rates between the 1960s and the 1970s.

interested in the design of mechanisms that could deter from criminal attempts. Rational criminal actors should alter their conduct in response to a change in the likelihood and the severity of punishment. In the specific context of sudden temperature shocks, one cannot discard the eventuality that the probability of being caught may be different when an act is perpetrated during a cold day vs. a hot day. In a radically opposite direction as the one taken by psychologists, hot temperatures could encourage rational criminals to misbehave if the expected probability or severity of any punishment somehow reduces. Sudden temperature shocks may therefore alter crime deterrence.[6]

More generally, shocks on the expected value of committing a crime may lead to increases in criminality. Whether these shocks lead to transitional increases or permanent increases in criminality in less certain. We are aware of only one study, apart from this one, that looks at the short-run dynamics of criminal acts. Jacob, Lefgren and Moretti (2007) use a panel of weekly crime data for 116 jurisdictions in the U.S. from 1995 to 2011. They aim to see if criminality in one week is followed by more criminality in the following weeks (due to imitation and retaliation) or, on the opposite, reduces the criminality levels of following weeks (due to a marginal decrease in the value of committing additional criminal acts). Whereas a simple OLS regression shows a positive correlation between today's and past criminality, these authors think that unobservables that persist over time could as well be responsible this association. To exclude the effect of such unobservables from their analysis, they instrument lagged crime rates with lagged weather conditions (temperature and rainfall). With this method, Jacob, Lefgren and Moretti (2007) find that weeks with above average crime rates due to a weather shock are followed by weeks with below average crime rates. Displacement effects could account for about 40% of all violent crimes committed during one week: committing again the same type of crime does not provide the same benefits. The case of property crimes can be analysed along the lines of the permanent income theory: if a crime produces an increase in permanent income, the latter will may reduce the need for committing more property crimes in the following weeks.

On the other hand, weather conditions could produce negative income shocks that could trigger economically-motivated crimes. Economic studies have shown that certain types of crime are more likely to take place during warmer weather and during floods or droughts, above all in

[6] The argument requires some sort of rationality of criminals, an idea that has been extensively criticised: many crimes often take the form of irrational acts of violence. Yet, criminal law and its enforcement should be designed to counter any benefit that could rise from rational utility maximisation: to ensure safety, there should be no rational calculation that would make criminal conducts advantageous (Kramer, 1990).

economies that are dependent on agriculture. Blakeslee and Fishman (2015) use district-level yearly data on crime, agriculture and weather from 1971 to 2000 in India. They find that droughts and elevated heat lead to substantial increases in almost all type of crimes. They also present additional evidence that suggests that, for droughts, agricultural income shocks drive the effect on crime. However, they do not find evidence that the agricultural income shock is present in the relationship between higher temperatures and crime. Iyer and Topalova (2014) look at the effect of rainfall and trade shocks in India. As in the case of Blakeslee and Fishman (2015), they also use district-level yearly data on crime and weather in India but their sample goes from 1971 to 2010. They find that decreases in rainfall are associated with lower property and violent crime, while higher average temperature increase crimes against public order and against women. The authors also find evidence that, in India, the main effect of rainfall on crime is through income. Likewise, Miguel (2005) shows that extreme rainfall events (droughts or floods) increase the murder of elderly women accused of being witches by their relatives in Tanzania. However, they do not affect other murders. Miguel (2015) explains that witch killings is a form of gerontocide since it focuses on old women, and that it could be explained on economic grounds since these women are not productive anymore. In a historical perspective, Mehlum, Miguel and Torvik (2006) show low rainfall in Bavaria during the 19th century lead to higher price of rye and property crime. In early 20th century Mexico, Dell (2012) finds that municipalities that experienced severe drought before the Mexican Revolution were more likely to have to have insurgent activity than those nearby municipalities with less severe droughts.

We can furthermore draw a parallel between evidence that weather shocks could influence interpersonal violence and the increasing evidence that inclement weather is associated to civil and armed conflict throughout the world and for different periods of time. A consensus has now emerged that increases in temperature and reductions in rainfall are associated to increases in civil unrest (see Burke, Hsiang and Miguel, 2015 and Dell, Jones and Olken, 2014, for a complete review of this literature).

In the remaining of this paper, we consider that the psychological and physiological arguments constitute only one explanation for the impact of heat on criminality, and give room to alternative explanations such as the sociological and the economic ones that we just reviewed.

3. Data and summary statistics

For our analysis, we have gathered daily data on criminal activity, temperature and rainfall at municipality level.

3.1. Criminality data

The criminality data comes from the Judicial Statistics on Penal Matters of Mexico published by the National Institute of Statistics and Geography (INEGI, 1997-2012). The data comes from the administrative records of the Criminal Courts of First Instance (*Juzgados Penales de Primera Instancia*). These are the courts where the initial criminal accusations are recorded, prosecuted and eventually sentenced by a judge. Our data contains information on accusations and prosecutions. Prosecutions include information on presumed criminals that have gone through a trial. On the opposite, the data on accusations is recorded at an earlier stage and is more likely to include information on crimes for which nobody will be sentenced. In this paper, we concentrate on the accusations because we are primarily interested in the occurrence of crimes. We however use the data on convictions at the end of this paper, when we study the treatment of identified criminals by the judicial system.

The accusations and prosecutions datasets contain detailed information on the type of crime, the intentionality of the crime (e.g. premeditation, negligence) as well as the municipality, state, day, month and year where the crime took place. The dataset also includes socioeconomic information of the person processed for a crime and the psychophysical status of the offender while committing the crime.

The original dataset contains a wide range of over 400 detailed crimes categories which we aggregate into broader crime categories. Table 1 shows the ten categories that we use in our analysis and they cover 97% of the total number of crimes recorded in the original dataset. Next, we divide the overall and by-type number of crimes in each day by the yearly county population to compute daily accusation crime rates per million inhabitants. The population data comes from the Mexican censuses of 1995, 2000, 2005 and 2010. We perform a linear interpolation of the population for the years between two censuses and after 2010 to obtain estimates of the Mexican population of each municipality in each year between 1990 and 2012.

Table 1 displays the average accusation and prosecution rates by type of crime and according to a few circumstances surrounding offenses for the period 1997-2012. The average accusation rate in Mexico was around 5.8 accusations per million inhabitants. The most common type of crime was thefts (1.68 accusations per million inhabitants), followed by injuries (0.85) and property damage (0.48). Most crimes were intentional crimes with no premeditation. There was a slight increase (by about 9%) in criminal offenses over the weekend. In general, the prosecution rate was 30% lower than the accusation rate.

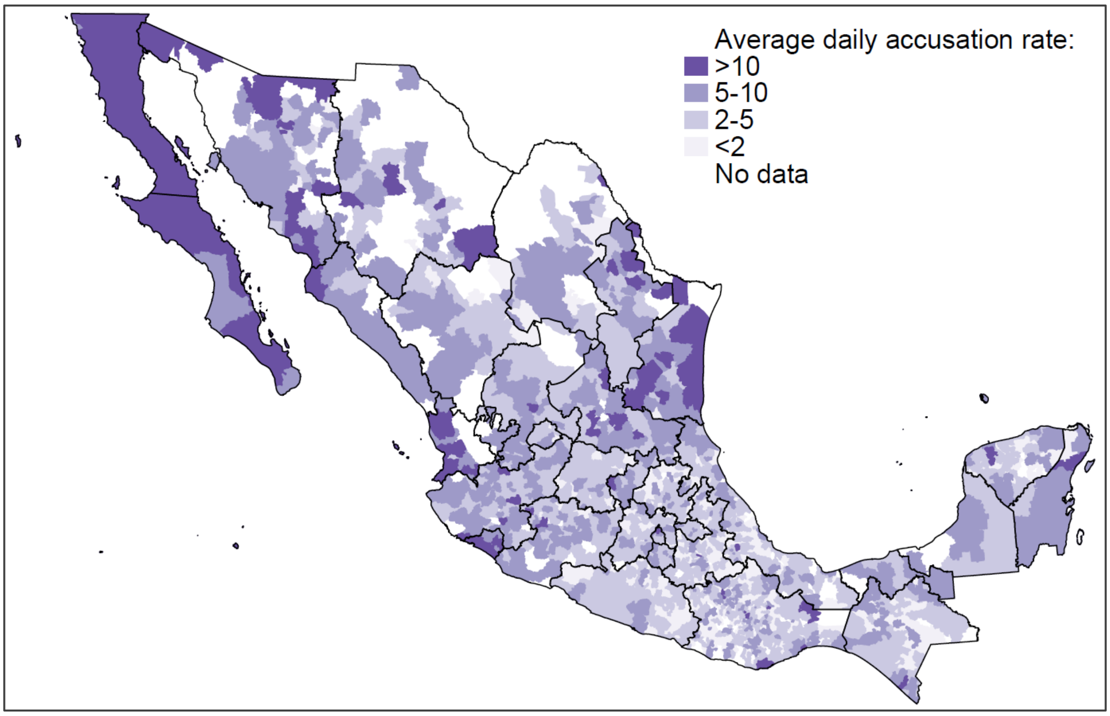
Table 1: Average daily accusation and prosecution rates by type of crime and circumstance (in accusations per million inhabitants, 1997-2012)

Type of crime	Daily accusation rate	Daily prosecution rate
All crimes	5.78	4.07
Homicide	0.20	0.16
Injury	0.85	0.55
Rape and sexual aggression	0.16	0.12
Possession of weapons	0.42	0.35
Property damage	0.48	0.28
Drug-related crime	0.38	0.28
Theft (excl. car theft)	1.68	1.34
Car theft	0.03	0.03
Manslaughter	0.01	0.01
Kidnapping	0.03	0.02
Unintentional	0.54	0.36
Intentional	5.16	3.66
Premeditated	0.013	0.004
Weekdays	5.64	3.98
Weekends	6.14	4.29
Found guilty	-	3.57
Found not guilty	-	0.48

Notes: The accusation rates correspond to the average daily accusation and prosecution rates per million inhabitants at municipality level. Rates are weighted by the population in each municipality. These figures are averages based on the dataset finally used for the regressions. They therefore exclude observations for which weather data was missing. Note that, for some crimes, we do not have information on intentionality or crime resolution, explaining why the total of crimes by intentionality or guilt does not match the national average.

Figure 1 provides information of the geographical distribution of accusations at municipality level. In general, northern and coastal states (Baja California, Sonora, Sinaloa, Chihuahua, Nayarit, Colima, Nuevo León and Tamaulipas) registered a higher intensity of offenses.

Figure 1: Average daily accusation rate by municipality (in accusations per million inhabitants, 1997-2012)



3.2. Weather and climate data

We have gathered daily temperature and precipitation data from the National Climatological Database of Mexico. Records correspond to the data from around 5,500 operating and formerly operating land-based stations in Mexico. However, the data has been aggregated at municipality level to match the criminality data.[7]

Figure 2 below presents the historical distribution of daily average temperatures in Mexico from 1997 to 2012.[8] The data presented below is used in the econometric models later on. We have constructed 13 temperature bins: the "less than 10°C" bin is the lowest, the "more than 32°C" bin the highest, and there are eleven 2°C bins in between.

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[7] We match the municipalities in Mexico with the closest land-based stations. We calculate the longitude and latitude of the centroid of each municipality (averaging the coordinates of all the locations that are part of a municipality) based on the data from the National Geostatistical Framework (*Marco Geoestadístico Nacional*) of the INEGI. Then we compute the distance between this centroid and all the land-based stations of the climatological data. We consider a land-based station to be within a municipality if it is less than 20km from its centroid. For municipalities that are isolated, we may have less than 5 active stations in the 20km radius. In this case, we match each municipality with the five closest stations within a maximum radius of 50km. Once we have identified the land-based stations relevant to a municipality, we compute the daily mean temperature and precipitation levels in a municipality by averaging the records of all the stations considered to be relevant to a given municipality.

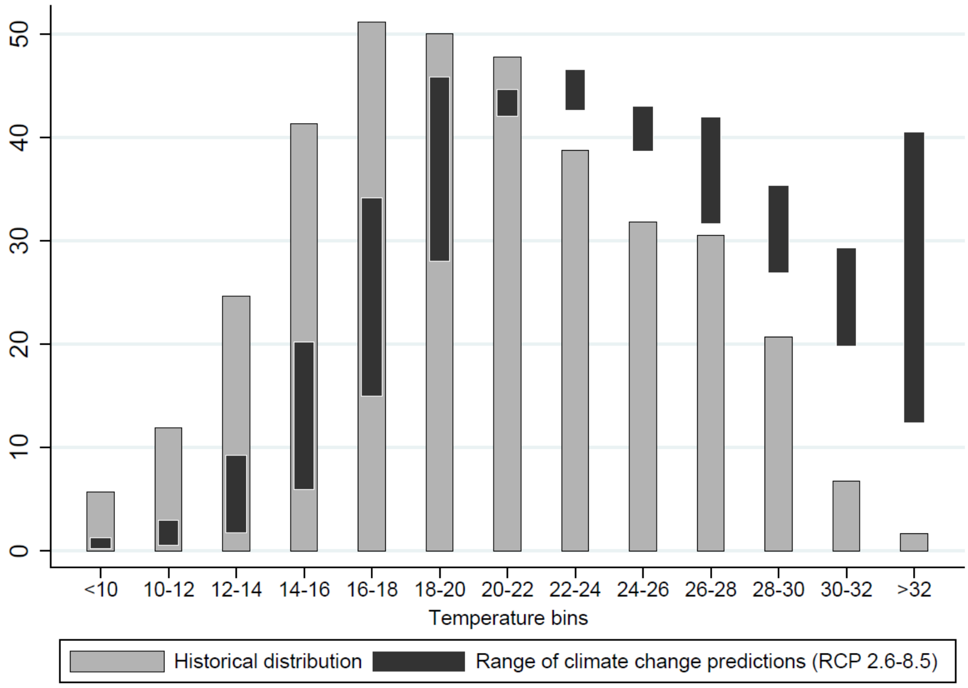
[8] The daily average temperature is defined as the average between the maximum and the minimum temperature of that day, following recommendations by the World Meteorological Organization (2011).

The climate in Mexico is hotter than in most countries. Days between 16 and 18°C are the most frequent, and the daily mean temperature oscillates between 14 and 22°C during more than half of the year. At the extremes of the distribution, there are 5.7 days per year below 10°C (50°F) and 1.7 days above 32°C (90°F) on average.[9] Furthermore, Mexico is expected to be heavily impacted by climate change, and therefore remain one of the hottest spots in the world. Figure 1 provides information about the distribution of cold and hot days under climate change, based on the output of the Coupled Physical Model of the Geophysical Fluid Dynamics Laboratory (GFDL CM3) of the National Oceanic and Atmospheric Administration (NOAA). Our estimates are derived from the monthly average temperature predictions for 2075-2099 and three IPCC emissions scenarios (RCP2.6, RCP4.5 and RCP8.5). For each month of the year, we have computed the difference between the monthly predictions and the historical averages, and then added this difference to all the observed temperature levels in our dataset to make a forecast of the distribution of days that will fall within each temperature bin. We therefore make the simplifying assumption that climate change does not alter the variance of the distribution of hot and cold days, but simply the average.[10]

[9] We may compare this climate with the US climate, for example. Deschenes and Greenstone (2011) provide a distribution of daily mean temperatures in the U.S. On average, temperatures are much lower: there are around 120 days with a mean temperature below 10°C and 1.3 days with temperatures greater than 90°F (32.2°C).

[10] We obtain the model output from the *Atlas Climático Digital de México*. This Atlas provides climate model output for Mexico online and is monitored by *Centro de Ciencias de la Atmósfera* of the *Universidad Nacional Autónoma de México* (UNAM).

Figure 2: Distribution of hot and cold days in Mexico across 13 temperature bins (in °C) for historical data (1997-2012) and 2 climate change scenarios based on GFDL CM3 model output (2075-2099)



Notes: The Figure shows the distribution of daily average temperatures in Mexico across 13 temperature-day bins. Each light grey bar represents the average number of days in each temperature bin over 1997-2012. The climate change results depend on the scenario chosen (from RCP2.6 to RCP8.5). The dark grey bar represents the range that can be obtained with a low emissions scenario (RCP2.6) or a high emissions scenario (RCP8.5). The largest deviations from historical temperatures (upwards for high temperatures and downwards for low temperatures) are caused by the high emissions scenario.

4. The impact of daily ambient temperatures

4.1. Empirical strategy

Daily records ensure correct identification of the causal effect of temperature on accusation in the short run, i.e. while maintaining constant all sorts of socioeconomic factors influencing criminal behaviour such as income, social inequalities, or the effectiveness of the legal system. This is since we can correlate daily accusation records (either accusations or prosecutions) with daily temperatures while controlling for most municipality-level changes in average accusation rates. More precisely, we use municipality-by-month-by-year fixed effects. These fixed effects control for all unobservable characteristics of a municipality for a specific month in a given year: only the municipal level variations from one day to the other within a month remain to be explained. The model is as follows:

$$Y_{i,d,m,t} = \theta . T_{i,d,m,t} + \mu_{i,m,t} + \varepsilon_{i,d,m,t}$$

where $Y_{i,d,m,t}$ is the accusation rate of municipality i on day d of month m and year t, θ is a vector of parameters, $T_{i,d,m,t}$ is a vector of climatic variables that we discuss in detail in the paragraph below, $\mu_{i,m,t}$ is a vector of municipality-by-month-by-year fixed effects and $\varepsilon_{i,d,m,t}$ is the error term. Heteroskedasticity is accounted for by computing cluster-robust standard errors. Each cluster corresponds to a given municipality in a given month in a given year.[11]

The regression coefficients need to be weighted by the population or by the square root of the population in each municipality.[12] This is because, without any weights, coefficients would be representative of municipalities and not the population. Furthermore, $Y_{i,d,m,t}$ is noisily estimated in small municipalities and the effect of such noise on the estimation is mitigated when population-based weights are used.

$T_{i,d,m,t}$ includes our climatic variables of interest. Since the accusation-temperature relationship might be non-linear, the most conservative approach consists in using temperature bins to specify the relationship between temperature and accusation, as it has been done in other applications, e.g. looking at mortality or energy demand (e.g. Deschenes and Greenstone, 2011; Cohen and Dechezlepretre, 2017). The model requires as many dummy variables in $T_{i,d,m,t}$ as temperature bins, each one taking the value of 1 when the day's temperature falls within the range of the bin. We use 2-Celsius-degree temperature bins (e.g. 10-12°C, 12-14°C and so on) to construct the vector $T_{i,d,m,t}$. The lowest bin covers days with temperature below 10 Celsius degrees, and the highest bin covers days with temperature above 32 Celsius degrees.

The above-mentioned model does not take into account that criminal's response to high or low temperatures may be delayed. For example, criminals may wait for good climatic conditions before acting: good or bad weather could therefore delay or accelerate criminal acts without having any additional effect on the total amount of criminal activities. In fact, some criminal activities are unlikely to occur twice over a short time period (e.g. murders). However, criminal acts could be followed by retaliations: if high or low temperatures trigger murders or thefts among cartels, cold or hot days could be followed by days with higher accusation levels.

[11] In an alternative specification, we have also used State-level clusters to relax the hypothesis of zero correlation between municipalities, and zero correlation between observations of a same municipality but pertaining to a different month or year. Standard errors slightly increase and the statistical significance of the effects remains.
[12] Deschenes and Moretti (2009) use total population as a weight. We are using the square root. Using total population instead of the square root has no significant impact on the results.

When daily data is available, Deschenes and Greenstone (2011) recommend using a distributed lag model to account for dynamic effects. We consider 12 temperature bins and include 20 lags for each bin:

$$Y_{i,d,m,t} = \sum_{k=0}^{K=20} \sum_{s} \theta_{s,-k}.B_{s,i,d-k,m,t} + \sigma.P_{i,d,m,t} + \mu_{i,m,t} + \varepsilon_{i,d,m,t}$$

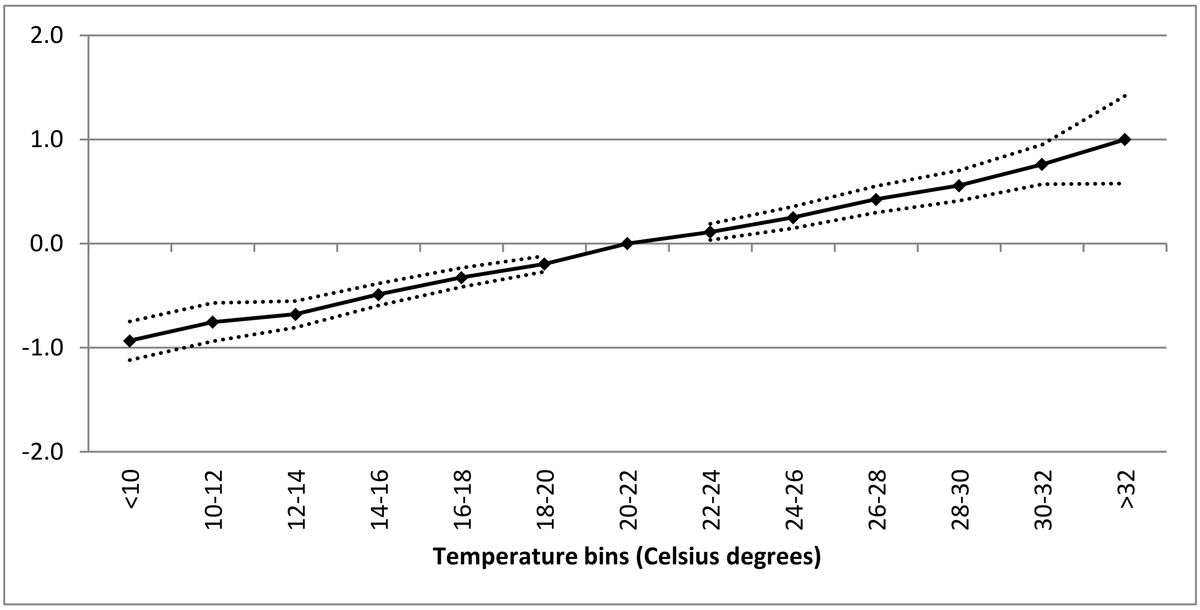
Above, the subscript s stands for the various temperature bins, and $B_{s,d-k,i}$ is a dummy variable equal to one if the temperature in day (d-k) of district i falls within bin s. Furthermore, we use on-the-day average precipitation ($P_{i,d,m,t}$) to control for the confounding effect of precipitations on accusation. Due to the lag structure of the model, the effect of an unusually cold or hot day on accusation is the sum of all the coefficients for the contemporaneous and lagged variables representing the temperature bins at the extreme of the spectrum. Such a model is applicable in our case since we have daily accusation and prosecution rates and average temperatures for 16 years for the vast majority of municipalities in Mexico. Our very large sample allows overcoming the multicollinearity problems arising when many lags and temperature bins are considered simultaneously.

Hereafter, we present the results for the contemporaneous correlation between temperature and accusations to analyse the temperature-accusation relationship. We use data on accusations, and not prosecutions, since we think that it is a better reflection of the quantity of crimes being committed in Mexico. Second, we use a distributed lag model to analyse if criminals delay or accelerate their activities to take advantage of good weather conditions. Then, we reproduce the analysis by breaking down accusations into ten different types of criminal activities. In general, we find an impact on hot weather on accusations that varies across types of crimes.

4.2. General results

The contemporaneous correlation between temperature and criminal activities is reported in Figure 3. We find a quasi-linear relationship between the average daily temperature and accusation rates. An increase by 1 degree Celsius roughly increases the daily accusation rate by 0.08 crimes per million inhabitants. This roughly corresponds to a 1.3% increase in the average accusation rate. The difference between a cold day (<10°C) and a hot day (>32°C) is sizeable: it corresponds to an increase by 1.9 daily accusations per million inhabitants, roughly equal to a third of the average daily accusation rate. Therefore, the weather appears to be a very good predictor of the frequency of criminal activities.

Figure 3: correlation between on-the-day temperature and accusations (all types of crimes)

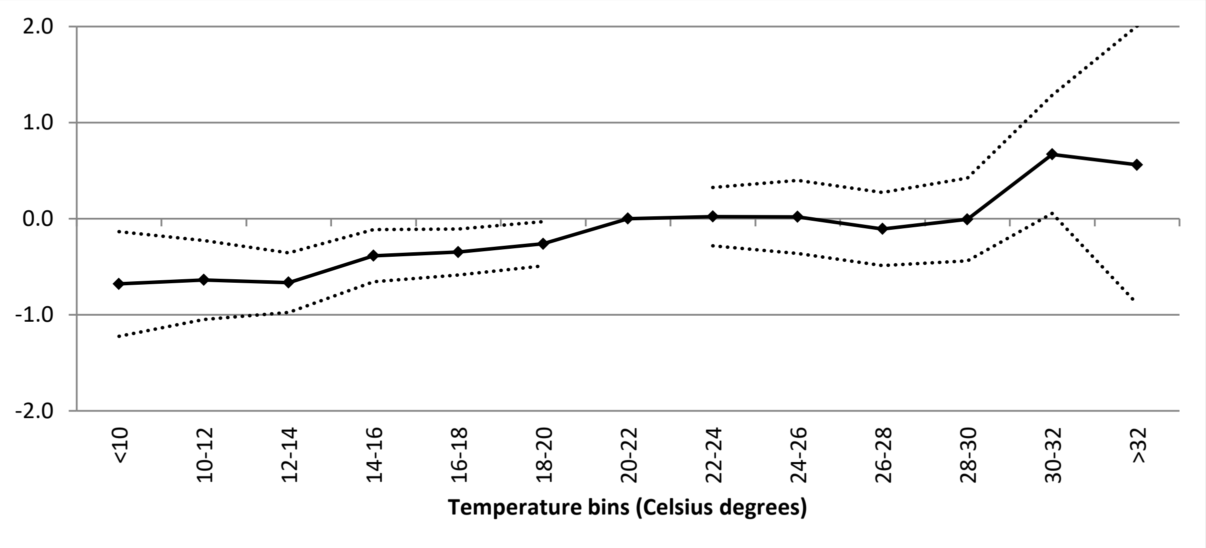


Notes: The dependent variable is the daily accusation rate in crimes per 1,000,000 inhabitants. The independent variables are all the listed temperature bins and the amount of precipitation in the day. The regression also includes municipality by-month by-year fixed effects and is weighted by the square root of the population in each municipality. 95% confidence intervals are in indicated by dashed lines for standard errors clustered at the level of municipalities. The reference bin is 20-22 Celsius degrees. 370,094 groups and 30.1 observations per group.

Figure 4 reports the cumulative dynamic relationship between temperature and accusations over 21 days. It is obtained by adding the effect of each temperature bins for all its lags in a distributed lag model. All in all, we also find a correlation for temperature and accusations. Yet, the average estimated effects have flattened. At the extremes, the differential between unusually hot and cold days (>32°C vs. <10°C) is of 1.2 crimes per million inhabitants with the distributed lag model, against 1.9 crimes per million inhabitants with a simple correlation with contemporaneous temperatures (the effect is 35% lower). In the middle of the distribution of temperatures, we observe attenuated effects with a distributed lag model for days between 10°C and 18°C, and no additional effect for days between 22°C and 30°C as compared to days with a temperature of 20-22°C.

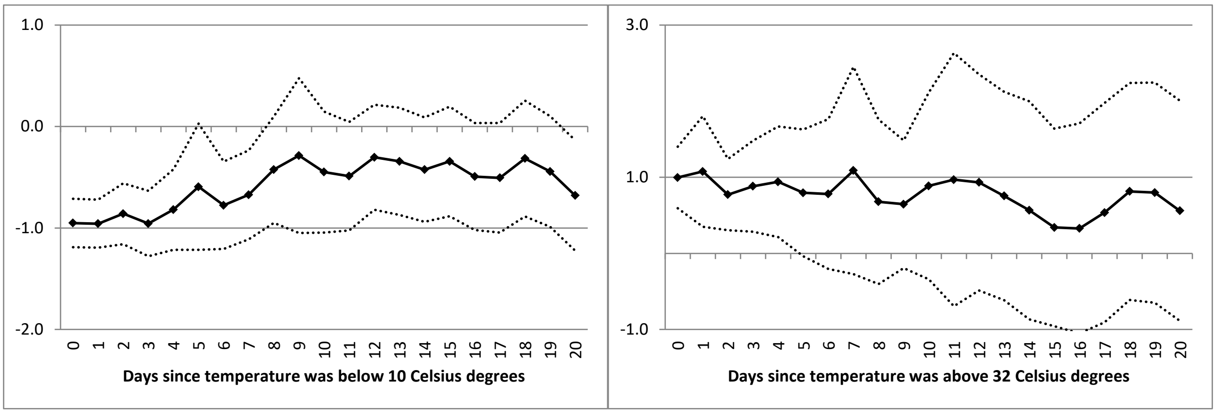
Figure 5 looks at how the effect of days below 10°C (left panel) and above 32°C (right panel) on accusation accumulates over 21 days. It shows that, whereas there is a high correlation between on-the-day temperature and accusation, higher accusation rates are observed on the days following a very cold day (left panel), and lower accusation rates are observed on the days following a very hot day (right panel). It follows that only one part of the crimes committed during hot days are additional crimes, whereas the others would have been committed anyways in the following days. One main reason for this effect is that some criminals may wait for climatic conditions to be as good as they can be before acting.

Figure 4: 21-day cumulative effect of temperature on accusations (all types of crimes)



Notes: The dependent variable is the daily accusation rate in crimes per 1,000,000 inhabitants. The independent variables are all the listed temperature bins and the amount of precipitation in the day. The y-axis reports the long-run multiplier of each temperature bin on the accusation rates. The multiplier includes on-the-day temperature and 20 lags. The independent variables are all the listed temperature bins and the amount of precipitation in the day. The regressions also include municipality by-month by-year fixed effects and are weighted by the square root of the population in each municipality. 95% confidence intervals are in indicated by dashed lines for standard errors clustered at the level of municipalities. 95% confidence intervals are in indicated by dashed lines for standard errors clustered at the level of municipalities. The reference bin is 20-22 Celsius degrees. 370,094 groups and 30.1 observations per group.

Figure 5: Roll-out of the cumulative effect of temperature on accusation (all types of crimes) for days below 10 Celsius degrees and above 32 Celsius degrees



Notes: The information displayed above comes from the same estimation results as for Figure 4. The dependent variable is the daily accusation rate in crimes per 1,000,000 inhabitants. The independent variables are all the listed temperature bins and the amount of precipitation in the day. The y-axis reports the long-run multiplier of each temperature bin on the accusation rates. The multiplier includes on-the-day temperature and 20 lags. The independent variables are all the listed temperature bins and the amount of precipitation in the day. The regressions also include municipality by-month by-year fixed effects and are weighted by the square root of the population in each municipality. 95% confidence intervals are in indicated by dashed lines for standard errors clustered at the level of municipalities. The reference bin is 20-22 Celsius degrees. 370,094 groups and 30.1 observations per group.

4.3. Results by type of crime

By breaking down the accusation rate by type of crimes, it is possible to identify crimes that are most likely to occur during hot days. Figure 6 reproduces the regression that correlates on-the-day temperature with accusation rates for ten types of crimes (homicide; injury; rape and sexual aggression; possession of weapon; property damage; drug-related crime; theft excluding car theft; car theft; manslaughter and kidnapping). To ease comparability, each graph has been rescaled based on the average accusation rate observed in the data for each type of crimes. These averages are the ones reported on Table 1 (in the data section). We find that accusations for violent crimes (homicide, injury, rape and sexual aggression and possession of weapon) are the crimes that are the most correlated with hot weather: there is an increase equivalent to 50% of the average accusation rate during unusually hot days (>32°C) as compared to unusually cold days (<10°C). To a lesser extent, we also find a correlation with hot temperatures and property damage, thefts, and drug-related crimes but the magnitude of the impacts is smaller. We find no conclusive evidence for car thefts, manslaughter and kidnapping. We may lack statistical power though since these events are less frequent in our dataset.

This correlation between violent crimes can be consistent with any social theory of the impact of temperature on criminality. In the economic theory, violent crimes may be easier to commit during hot days. In the sociological theory of routine activities, the crimes that are committed outside the home should be the ones that are most impacted when the weather improves (Field, 1992): the increase in violent crimes should therefore be sharper that the increase in burglaries. For the psychological theory, heat directly impact violent attitudes, so the increase in criminality should primarily consist in an increase in violent outbursts. However, the linearity of the impacts implies that it is not only excessive heat that causes extra criminality.

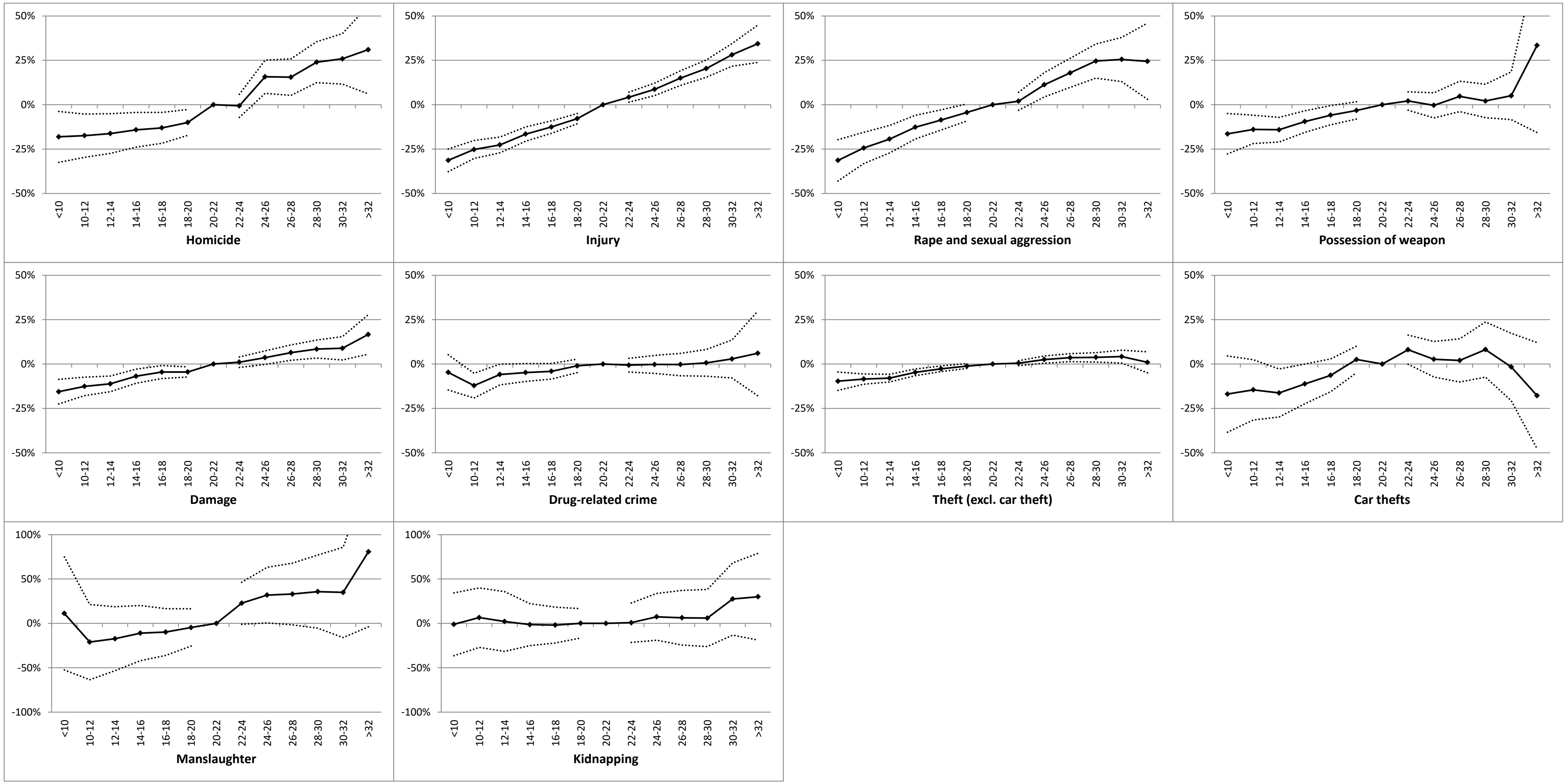
Figure 7 accounts for displacement effects using a distributed lag model of each type of crimes. After 21 days, we find no statistically significant impact of high temperature on most categories of crimes. The result is particularly sharp for homicides, property damage and thefts, but also holds for injuries and possession of weapons. On the opposite, the result of a strong correlation between temperature and accusation rates remains for rapes and sexual aggressions and, to a lesser extent, for drug-related crimes: these appear to be less frequent when temperatures get below 20°C. We show later on that the effect on drug-related crimes could be due to a supply-side effect: crop yields for marijuana and opium may suffer from low temperatures. We further discussed the effect on rapes in section 5.

In general, sharp displacement effects are more aligned with the economic or the sociological theory of criminality than with the psychological one. This is because violent outburst should be additional to the baseline amount of crimes since these are committed for other purposes than heat. On the other hand, rational criminals could take advantage of hot weather to commit a crime that they wanted to perpetrate anyways. Likewise, hot days could increase social interactions and therefore allow for criminal-victim encounters, which would have been spread out over the course of a week under different circumstances.

4.3 Climate change impacts

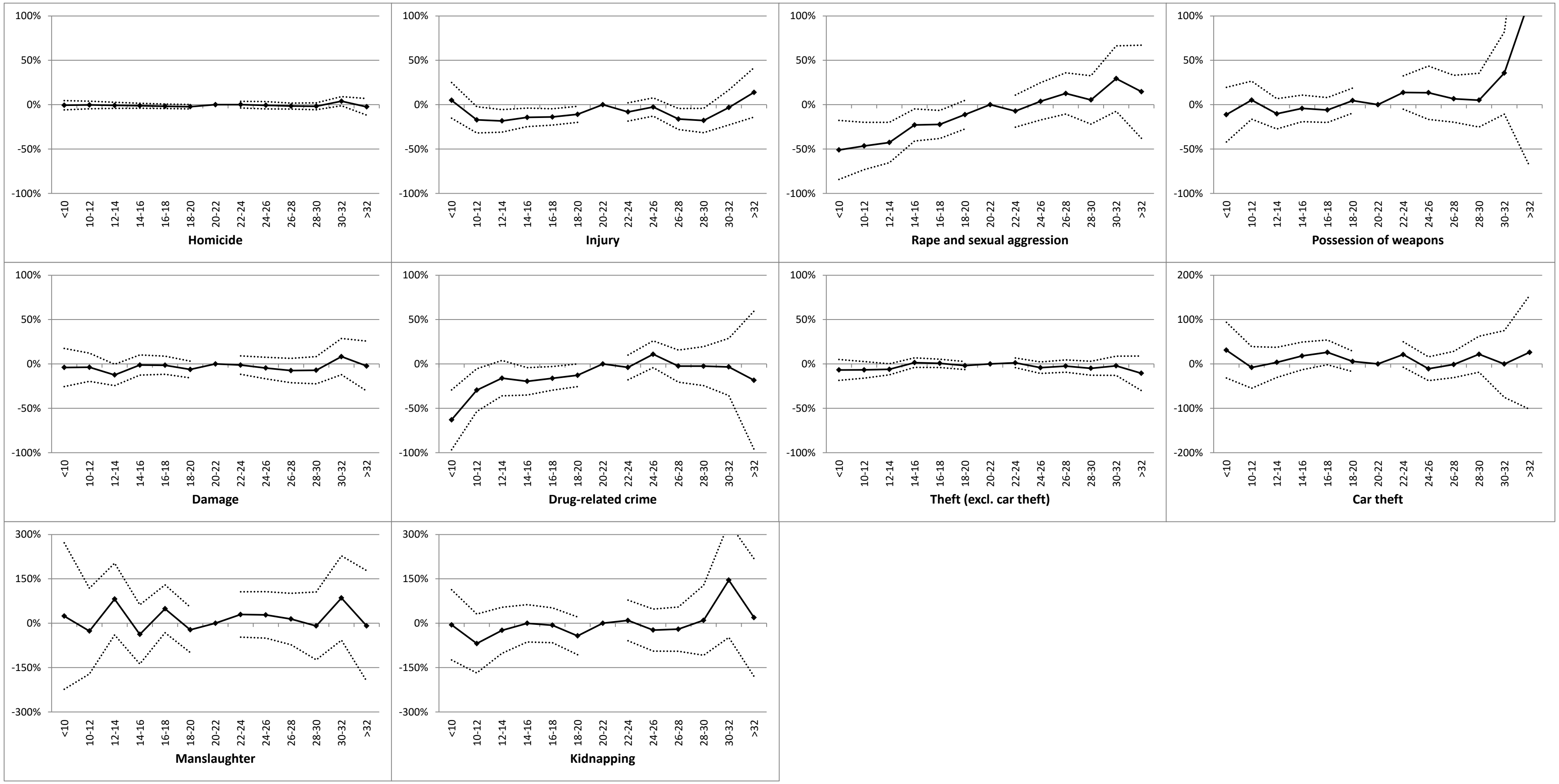
The distribution of temperatures under climate change (see Figure 2) can be used to compute the number of crimes triggered by high temperatures that might occur under climate change in Mexico. These are many limitations in doing this. First, we can only account for modifications in the short-term effects of temperature on criminality. The longer-term impacts, e.g. through changes in agricultural yields, induced migration, etc. are not captured. On the other side, we assume similar demographics and technologies to prevent criminality.

Figure 6: correlation between on-the-day temperature and daily accusation rates by type of crime



Notes: each graph corresponds to a separate regression. The dependent variable is daily accusation rate as a share of the average accusation rate of each category. The independent variables are all the listed temperature bins and the amount of precipitation in the day. The regressions also include municipality by-month by-year fixed effects and are weighted by the square root of the population in each municipality. 95% confidence intervals are in indicated by dashed lines for standard errors clustered at the level of municipalities. The reference bin is 20-22 Celsius degrees.

Figure 7: 21-day cumulative effect of temperature on daily accusation rates by type of crime



Notes: each graph corresponds to a separate regression. The dependent variable is daily accusation rate as a share of the average accusation rate of each category. The independent variables are all the listed temperature bins and the amount of precipitation in the day. The y-axis reports the long-run multiplier of each temperature bin on the accusation rates. The multiplier includes on-the-day temperature and 20 lags. The independent variables are all the listed temperature bins and the amount of precipitation in the day. The regressions also include municipality by-month by-year fixed effects and are weighted by the square root of the population in each municipality. 95% confidence intervals are in indicated by dashed lines for standard errors clustered at the level of municipalities. The reference bin is 20-22 Celsius degrees.

We produce a climate change forecast by multiplying the estimated coefficients of Figure 3 and Figure 4 by the average number of days falling in each temperature bin. We take care of weighting this average number of days by the population in each municipality, and assume a constant population of 120 million inhabitants. For concision, we only report the main results for the intermediate, RCP4.5 scenario, in Table 2.[13] We find that predictions are sensibly different if account is made of the fact that high temperatures may mostly accelerate (by a few days) the criminal acts that are committed with premeditation. In general, we find that climate change will lead to 10,773 more accusations annually if we use the model that correlates on-the-day temperatures with accusation rates. With an average accusation rate of around 250,000 crimes annually for 120 million inhabitants, climate change would increase the accusation rate by 4.3%. This figure is 22% lower when account is made of dynamic effects using the distributed lag model, falling down to a 3.3% increase in the accusation rate. Yet, we cannot exclude the possibility that both figures are the equivalent at standard confidence levels.

Whereas we find statistically significant impacts for most crime categories with on-the-day correlations, only two categories remain statistically significant with a distributed lag model: rape and sexual aggression; and injuries. The absolute figures correspond to a relative increase in crime rates by 10.6% for rapes and sexual aggressions, and 3.9% for injuries. The result for injuries should be interpreted with caution since the 21-day relationship between temperature and injuries in unclear as per Figure 7.

Table 2: Impact of climate change on annual accusations in the RCP4.5 climate scenario

Type of crime	Estimates with on-the-day correlation	Estimates with distributed lag model
All crimes	10,773* (8,877–12,670)	8,416* (3,621–13,211)
Homicide	654* (343–966)	202 (-384–788)
Injury	3,053* (2,499–3,607)	1,451* (304–2,597)
Rape and sexual aggression	440* (247–633)	727* (346–1109)
Possession of weapons	814* (242–1,386)	1927 (-169–4023)
Property damage	904* (581–1,227)	243 (-424–911)
Drug-related crime	245 (-128–619)	776 (-244–1797)

[13] The results for the RCP2.6 scenarios are in the same lines, but attenuated, with a total number of additional crimes equal to 6,205 (3,037–9,373) when using the coefficients from the distributed lag model. With the RCP8.5 scenario, this figure reaches 11,993 (3,400–20,587).

Type of crime	Estimates with on-the-day correlation	Estimates with distributed lag model
Theft (excl. car theft)	1,458* (896–2,019)	-213 (-1481–1055)
Car theft	11 (-45–67)	-23 (-135–89)
Manslaughter	35 (-2–73)	-1 (-81–79)
Kidnapping	32 (-78–142)	146 (-125–417)

Notes: the 95% confidence interval in brackets only take into account the uncertainty of the impact of temperature bins on accusation. Statistically significant results at 5% are marked with a (*). It does not take into account the uncertainty of climate models in the magnitude of daily temperatures. Estimates are obtained while assuming a Mexican population equal to 120 million inhabitants.

4.4 Comparison with other studies

It is interesting to compare our results with at least three studies. Ranson (2014) performs a similar analysis of the impact of temperatures on criminality in the US. Our general estimate lies in the same order of magnitude as Ranson (2014). Yet, the distribution of impacts across crime categories is different. We find no impact on murders when Ranson (2014) predicts that climate change will increase the number of murders by 2.2%. On the other hand, we predict a very strong impact on rapes and sexual aggressions (10.6% increase), whereas Ranson (2014) finds a milder effect (3.1% increase). Differences in results could be due to the fact that both countries display radically different criminological patterns. Furthermore, Mexico and the US are not exposed to the same temperature range. The impact of temperatures on a few crime categories appears to be non-linear, both in Ranson (1994) and in our study, suggesting that a 1°C temperature increase could yield to radically different effects in the US and Mexico.

In this respect, the study by Baysan *et al.* (2015) is more closely related to ours since it also relies on Mexican data. Baysan *et al.* (2015) find that a one standard deviation increase in temperature is associated with a 23% increase in drug-related killings, a 5% increase in "normal" homicides, and a 7% increase in suicides. The work in Baysan *et al.* (2015) suggests that all three types of violent deaths seem to be triggered by a similar underlying pattern, possibly the effect of heat on human psychology.

Our main results complement their analysis in an interesting fashion. Whereas we find a strong impact of on-the-day temperatures on homicides, this impact yield no additional effect with our distributed lag model. Our climate change estimates for homicides drop from a 1% increase (with 654 murders per year) with on-the-day correlations to a non-statistically significant 0.3% increase (with 202 murders per year) when we use a distributed lag model.

To our understanding, Baysan *et al.* (2015) could be capturing longer term trends and not a short term psychological response to high temperatures. This is since there are important methodological differences between Baysan *et al.* (2015) and this research. These authors correlate monthly statistics on killings from drug trafficking organisations, homicides and suicides at State level with Mexican weather data for Mexico over the period 1990-2010. Therefore, they use more aggregate data and less powerful controls for seasonality and displacement effects. Above all, they consider long-run impacts over 6 months whereas we focus on short-run effects over a maximum of 21 days.

As for drug trafficking, we find a persisting impact of temperatures on drug-related criminality. Yet, we find a statistically significant effect of cold temperatures – not hot temperatures – in reducing drug-related crimes. The two categories (killings associated with drug trafficking and drug-related crimes) do not match, such that the results of Baysan *et al.* (2015) and ours are not contradictory. However, it is still interesting to notice that the effect of cold, not heat, seem to be at play in our data, suggesting that temperatures may affect drug-related activities (including killings) in several, complex ways. We dig into this aspect in section 5 and find that low temperatures below 0°C substantially reduce the number of drug-related offenses in the short run. We think this may be due to a reduction in marihuana and opium crop yields.

Finally, it is interesting to compare our results with the ones of Fields (1992), who looks at the correlation between temperature and criminality in the UK. Fields (1992) finds that a 1-standard deviation from seasonal norm in temperature causes an increase in criminality rates by around 1% (and 1.5% for sexual offenses) and concludes that this increase is caused by a change in activities of UK residents on hot days. With our data, a 1-standard deviation from seasonal norms would correspond to an increase in the all-causes accusation rate by around 1.5% (4.8% for sexual offenses).[14] Therefore, the figures in the case of Mexico as higher but comparable to the UK evidence.

5. Understanding the channels

The results provided in the previous section appeal for more analyses so as to understand the exact channels through which temperatures affect accusation rates. In this section, we aim to

[14] We found a 3.3% increase in the accusation rate with the RCP4.5 scenario and the distributed lag model. This scenario corresponds to a 3.5°C increase. We can rescale this figure to a 1-standard deviation from the monthly temperature average: this is a deviation of around 1.6°C. For a 1.6°C temperature increase, and using a simple rule of them, we have an increase in the accusation rate by about 1.5% (4.8% of sexual offenses).

provide complementary results with the objective of corroborating or invalidating possible conjectures on the reasons behind the short-run impact of temperatures on criminal activities as observed with our data. We run five different complementary analyses on the circumstances of the offenses and the treatment of offenders by the judicial system. We ask following questions:

1. Were offenses intentional or unintentional?
2. Are offenders using drugs or consuming alcohol?
3. Were offenses committed during the week or the weekend?
4. Were they committed during day-time or at night?
5. Finally, is the judicial system more or less effective to deal with crimes committed during hot days?

Providing answers to these questions allows shedding light on mechanisms that may validate or invalidate some theories. For example, if impunity is higher for criminals that take action during hot days, this could explain why criminals would prefer the hottest days to commit misdeeds. If this is not the case, then we may cast the doubt on the idea that the opportunity channel is the main driver of the relationship between temperature shocks and criminal activities.

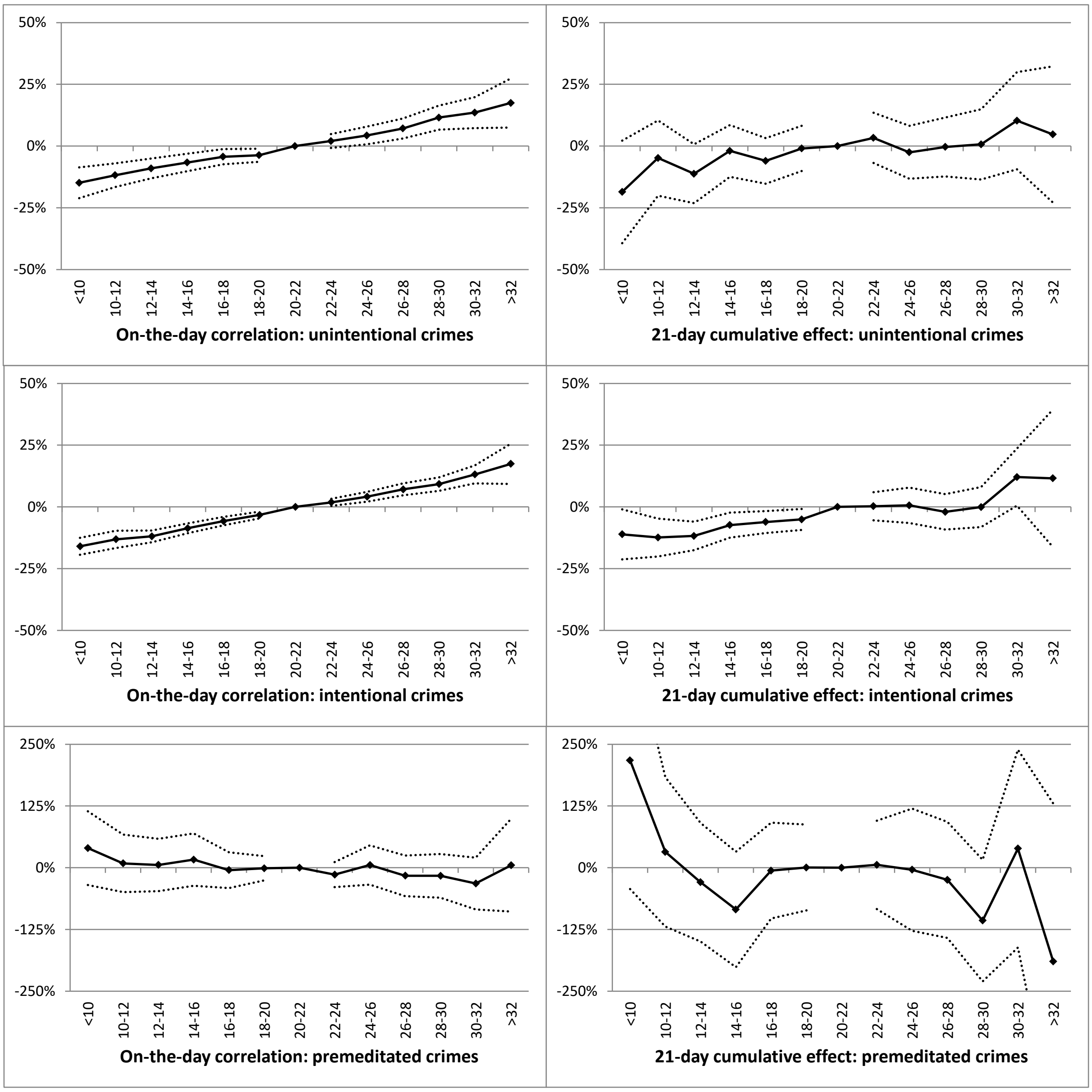
5.1. Intentions

The first thing that the reader may want to know is whether most of these crimes were intentional or not. If offenses were committed "by mistake", e.g. road accidents, then we would be discarding the idea that criminals were opportunistic.

Intentionality is one of the variables recorded in the data on accusations. More precisely, the data makes the distinction between unintentional, intentional and premeditated crimes. Intentional crimes are the ones committed voluntarily but with no planning, whereas the premeditated ones are carefully planned.

Figure 8 separates the effect of temperature on accusations according to intentionality. Unintentional crimes are on the upper panels, intentional crimes in the middle, and premeditated crimes on the lower panels. Results for on-the-day correlations are on the left, and the right panels display the outcome of distributed lag models, i.e. the long-run multiplier of each temperature bin after 21 days. Results for unintentional and intentional crimes look very similar: there seem to be an effect of hot temperatures on increasing the number of crimes in the short run, and eventually after 21 days (this is imprecisely estimated though). The orders of magnitude for these two types of crimes seem similar. On the other hand, results for premeditated crimes seem to indicate that there is no effect of temperatures on premeditated crimes, but this is imprecisely estimated, plausibly because we lack of statistical power since this category is rather infrequent.

Figure 8: on-the-day and 21-day cumulative effect of temperatures on the daily accusation rate for unintentional, intentional and premeditated crimes



Notes: each graph corresponds to a separate regression. The dependent variable is daily accusation rate as a share of the average accusation rate of each category. The independent variables are all the listed temperature bins and the amount of precipitation in the day. On the left panels, the y-axis reports the contemporaneous effect of temperatures on accusation rates for unintentional crimes (upper left panel), intentional crimes (middle left panel) and premeditated crimes (lower left panel). On the right panels, the y-axis reports the long-run multiplier of each temperature bin on the accusation rates for unintentional crimes (upper right panel), intentional crimes (middle right panel) and premeditated crimes (lower right panel). The multiplier includes on-the-day temperature and 20 lags. The independent variables are all the listed temperature bins and the amount of precipitation in the day. The regressions also include municipality by-month by-year fixed effects and are weighted by the square root of the population in each municipality. 95% confidence intervals are in indicated by dashed lines for standard errors clustered at the level of municipalities. The reference bin is 20-22 Celsius degrees.

Therefore, this analysis seems to discard the idea that heat-related crimes are exclusively opportunistic crimes, since unintentional crimes are apparently more responsive to temperatures than premeditated crimes. However, the absence of any effect for premeditated crimes could be caused by a lack of statistical power. Furthermore, most crimes in our dataset are intentional crimes, and they are also influenced by the weather.

5.2. Psychophysical status

Higher alcohol consumption or drug usage could partly explain criminality rates during hot days. Our dataset reports if the offenders were in a normal state, or consumed drugs or alcohol. Figure 9 separately reports the results of our two econometric models for these three groups of offenders. Offenders in a “normal state” are in the upper panels, drunk offenders in the middle, and drugged ones in the lower panels. Results for on-the-day correlations are on the left, and the right panels display the outcome of distributed lag models.

The on-the-day correlation between accusation rates and temperatures is steeper for drunk offenders as compared to the ones in a normal state, suggesting that a share of heat-related offenses is triggered by the consumption of alcohol. More precisely, the difference in the rates of accusation between an unusually cold (<10°C) and an unusually hot day (>32°C) represents around 30% of the average daily accusation rates for offenders in a normal state. This figure reaches 50% for drunk offenders. In our dataset, there are about 0.82 accusations per day and per million inhabitants that are committed in Mexico under the influence of alcohol. This implies that, as compared to an unusually cold day (<10°C), the accusation rate may be higher during an unusually hot day (>32°C) by about 0.17 points because more alcohol is being consumed.[15] Since the difference between a cold day (<10°C) and a hot day (>32°C) corresponds to an increase by 1.9 daily accusations per million inhabitants, higher alcohol consumption during hot days may therefore explain around 9% of the increase in the accusation rates found during hot days (>32°C) as compared to cold days (<10°C).[16]

There are too few offenses committed under the influence of drugs to find statistically robust evidence for this category. Likewise, the distributed lag models do not allow us to find statistical different results for these three groups.

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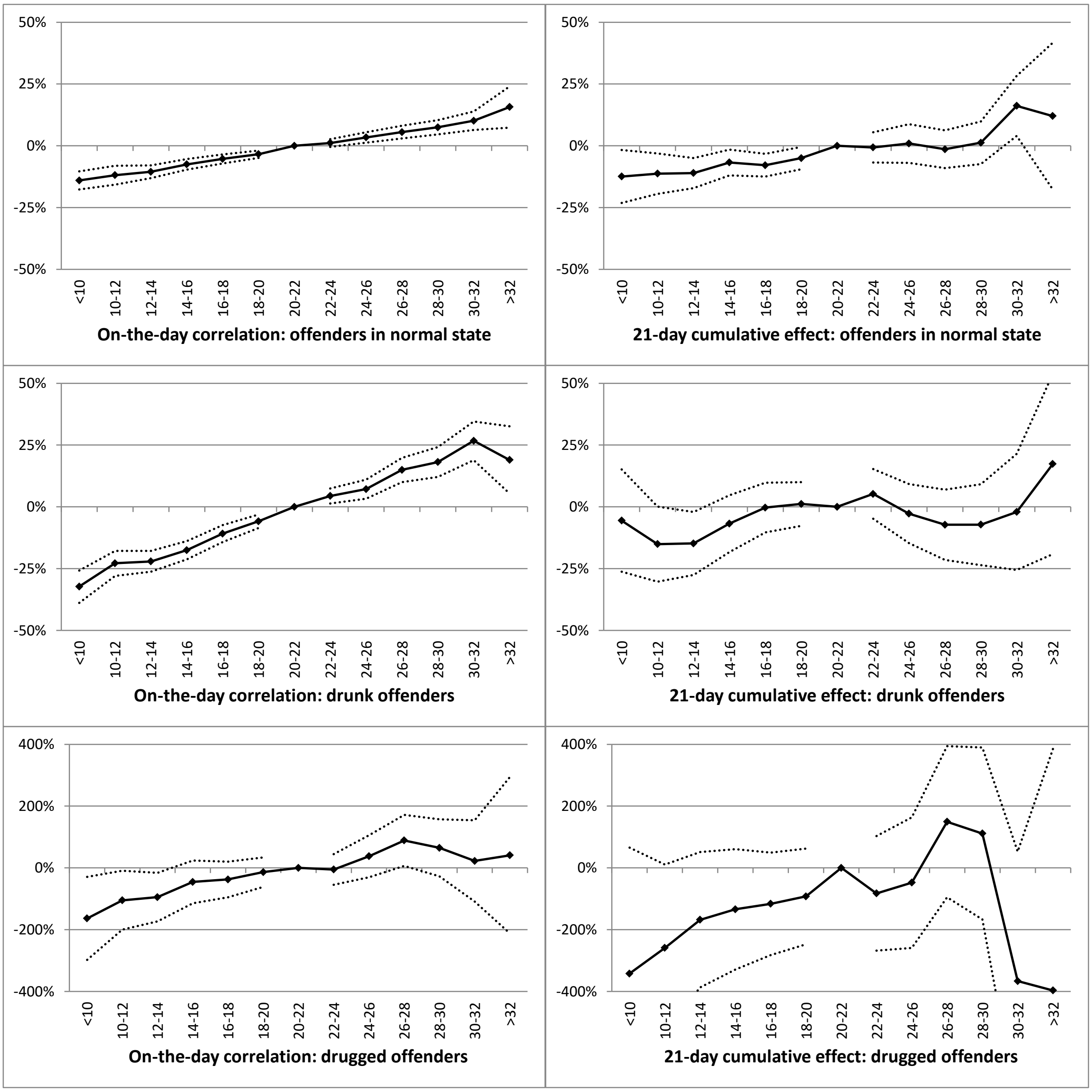
[15] This is: 0.86 x (50% - 30%)
[16] 0.17 / 1.9 ≈ 8.4%

Figure 9: On-the-day and 21-day cumulative effect of temperatures on the daily accusation rate for offenders in a normal state vs. drunk and drugged offenders



Notes: each graph corresponds to a separate regression The dependent variables are the daily accusation rate for people in a normal state (upper panels), drunk offenders (middle panels) and drugged offenders (lower panel) as a share of the average rate of each category. The independent variables are all the listed temperature bins and the amount of precipitation in the day. On the left panels, the y-axis reports the contemporaneous effect of temperatures on accusation rates. On the right panels, the y-axis reports the long-run multiplier of each temperature bin on the accusation rates. The multiplier includes on-the-day temperature and 20 lags. The independent variables are all the listed temperature bins and the amount of precipitation in the day. The regressions also include municipality by-month by-year fixed effects and are weighted by the square root of the population in each municipality. The reference bin is 20-22 Celsius degrees.

5.3. Weekdays vs. weekends

Whether heat-related crimes were committed during weekdays or weekends also matters. Weekday activities are constrained by work obligations whereas weekend activities can more easily adapt to good or bad weather. Time allocation for criminals and their victims is likely to respond more to a change in temperature if this change occurs during weekends.

Figure 10 separately estimate the effects of on-the-day temperature (upper panels) and a 21-day cumulative effect (lower panels) for weekdays (left panels) and weekends (right panels). We find that both are sensitive to changes in temperatures, but that the relative effect of hot days during weekends is about 60% higher than the effect of hot days during weekdays.[17, 18] Therefore, stronger changes in activities during weekends seem to partially explain changes in accusation levels. All in all, around 40% of heat-related offenses occur during weekends.[19] We can furthermore calculate the proportion of heat-related crimes that occurred in weekends and would not have occurred during a weekday. It roughly represents 17% of all heat-related crimes.[20] This suggests that changes in time allocation associated with weekends are a contributing factor to heat-related accusation.

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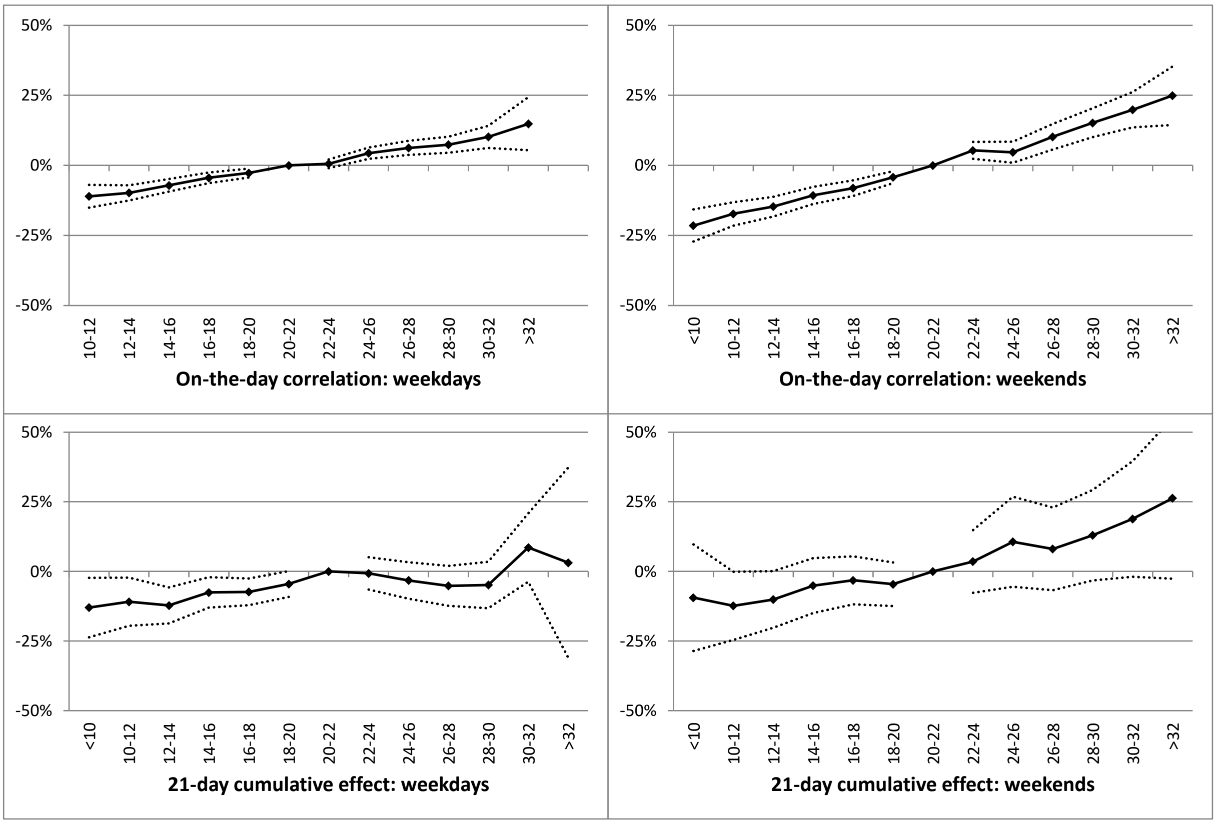
[17] Most of the coefficients of the two curves displayed on the upper panels of Figure 10 are statistically different from one another.

[18] The effect that weekend accusation rates are more sensitive to temperatures than weekday accusation rates can also be found when crimes are broken down by types of crimes. We have observed no strong differences in this pattern for different types of crimes, and decided not to report these results for the sake of concision.

[19] The accusation rate is respectively 5.6 and 6.1 accusations per million inhabitants during weekdays and weekends. A day above 32°C increases this rate by about 15% in weekdays and 25% in weekends. Therefore, in a week at 32°C, there would have respectively 4.1 and 3.0 accusations per million inhabitants made for events related to heat and occurring during weekdays vs. the weekend (5.6 x 15% x 5 and 6.1 x 25% x 2).

[20] The accusation rate increases by 25% during a hot day that occurs in the weekend, vs. by 15% for a hot day occurring during a weekday. The additional effect of weekends on the accusation levels recorded on hot days is 10% of the accusation rate of weekends (at 6.1 accusations per day and per million inhabitants). This is a total of 1.2 accusations during a week with all days above 32°C, or about 17% of all accusations caused by hot days during such a week.

Figure 10: On-the-day and 21-day cumulative effect of temperatures on the daily accusation rate during weekdays and weekends



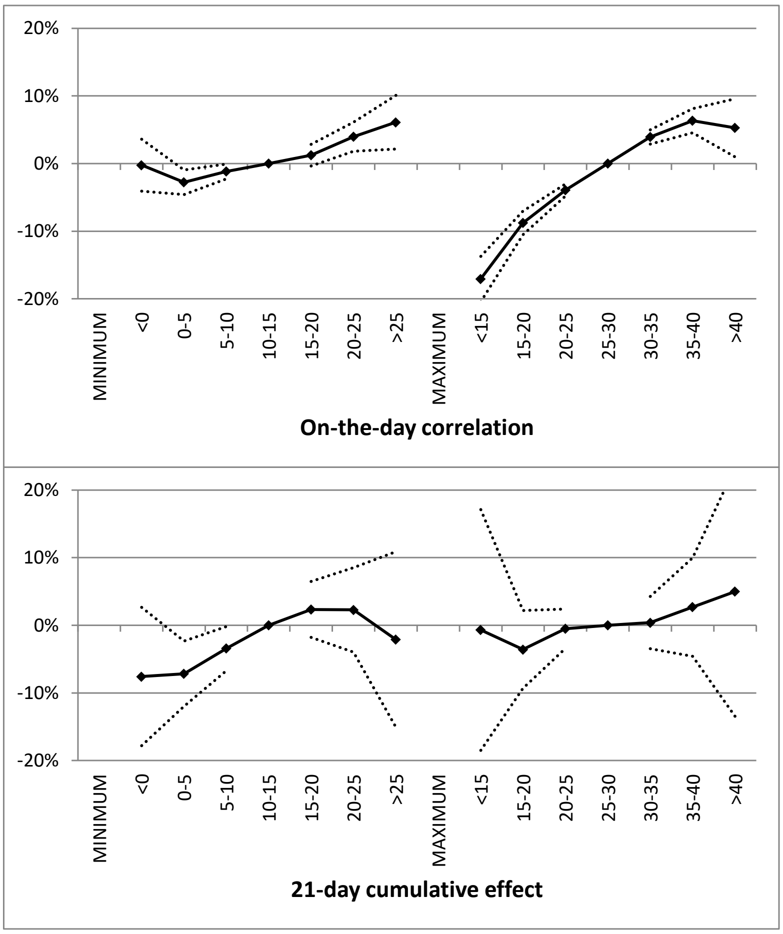
Notes: each graph corresponds to a separate regression. Results are separately displayed for weekdays (left panels) and weekends (right panels). The dependent variable is daily accusation rate as a share of the average accusation rate of each category. The independent variables are all the listed temperature bins and the amount of precipitation in the day. On the upper panels, the y-axis reports the contemporaneous effect of temperatures on accusation rates. On the lower panels, the y-axis reports the long-run multiplier of each temperature bin on the accusation rates. The multiplier includes on-the-day temperature and 20 lags. The independent variables are all the listed temperature bins and the amount of precipitation in the day. The regressions also include municipality by-month by-year fixed effects and are weighted by the square root of the population in each municipality. 95% confidence intervals are in indicated by dashed lines for standard errors clustered at the level of municipalities. The reference bin is 20-22 Celsius degrees.

5.4. Day-time vs. night-time offenses

Another important matter is whether accusations are made for offenses that occur during the day or during the night. On a very hot day, night temperatures are usually not very far from the comfort zone of the human body, at 20-25°C. Therefore, it makes a difference if additional crimes are committed at temperatures that are comfortable to the human body (at night), or if they are committed at annoyingly high day-time temperatures at around 40°C: night-time crimes are much less likely to be spurred by any psychological effect of high temperatures on irritability. On the opposite, night-time crimes could reflect that mild temperatures may increase social interactions at night and alter the usual activities of victims and criminals in a way that favours offenses.

In Figure 11, we report the results obtained when running models that jointly use daily minimum and daily maximum temperatures, instead of the daily average temperature. The idea is to disentangle the effect of temperatures at night (given by the minimum temperature) from the effect of temperatures during the day (more consistently captured by maximum temperature). On-the-day correlations show that the amplitude in accusation rates caused by maximum temperatures is around 2.5 times the amplitude caused by minimum temperatures.

Figure 11: On-the-day and 21-day cumulative effect of minimum and maximum temperatures on the daily accusation rate



Notes: the two graphs correspond to two separate regressions. However, the effects of minimum temperatures and maximum temperatures are simultaneously estimated, i.e. both are put as independent variables in the same regressions. Results are separately displayed for on-the-day correlation (upper panel) and the 21-day cumulative effect obtained with a distributed lag model (lower panel panels). The dependent variable is the daily accusation rate as a share of the average accusation rate of each category. The independent variables are all the listed temperature bins and the amount of precipitation in the day. The regressions also include municipality by-month by-year fixed effects and are weighted by the square root of the population in each municipality. 95% confidence intervals are in indicated by dashed lines for standard errors clustered at the level of municipalities. The reference bin is 20-22 Celsius degrees.

Evidence supports the idea that most crimes triggered by high average daily temperatures are caused by annoyingly high temperatures (or equivalently the absence of comfortably mild to cold temperatures during the day).[21] Yet, unusually cold temperatures at night seem to bear the long-run effect of temperatures on accusations.

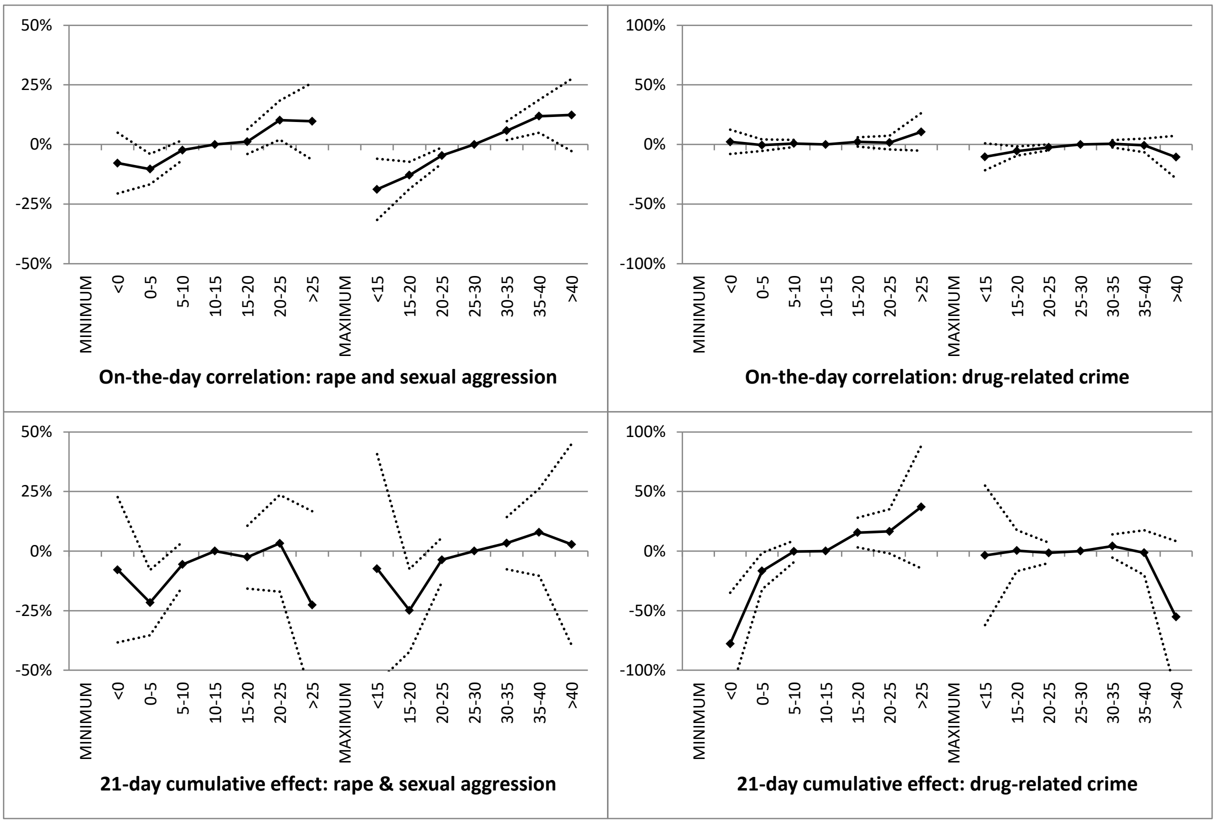
We have run the same types of analysis by type of crimes and found no significant difference between the main results and most crime categories. However, the 21-day cumulative effects lost significance in most cases. Two exceptions, for which we display the results in Figure 12, are worth mentioning: the case of rapes and sexual aggressions; and the case of drug-related diseases.

For rapes and sexual aggressions, we find that maximum temperatures have a stronger influence than minimum temperatures, as for other crimes, but this difference is attenuated. Furthermore, we find statistically significant impacts at 21 days for both maximum and minimum low temperatures (minimum temperatures of 0-5°C and maximum temperatures of 15-20°C). This is very much in line with the main results obtained for this category of crimes, as per Figure 7. The fact that mild temperatures at night might trigger additional rapes suggests that the psychological effect of temperature on crime cannot be the sole explanation for an increase in rapes during hot days.

For drug-related crimes, we find absolutely no effect of on-the-day temperatures for these crimes, but a longer-term impact of temperatures after 21 days. This longer-term impact is clear when minimum temperatures are below 0°C. Instead of measuring here any behavioural effect, we are likely to measure an effect of temperatures on the supply of drugs, since Mexico is a marijuana and opium producer.

[21] We have run analyses where we look at the effect of minimum temperatures and maximum temperatures separately between weekdays and weekends, and did not find any difference in the observed patterns. Hence, there seem to be no significant difference in the way maximum and minimum temperatures impact accusation levels between weekdays and weekends, even though the magnitude of the impacts changes. For the sake of concision, these analyses are not reported.

Figure 12: On-the-day and 21-day cumulative effect of minimum and maximum temperatures on the daily accusation rate for rapes and sexual aggressions and drug-related crimes



Notes: graphs correspond to separate regressions. However, the effects of minimum temperatures and maximum temperatures are simultaneously estimated, i.e. both are put as independent variables in the same regressions. Results are separately displayed for on-the-day correlation (upper panel) and the 21-day cumulative effect obtained with a distributed lag model (lower panel panels). The dependent variable is the daily accusation rate for rapes and sexual aggressions (left panels) and drug-related crimes (right panels) as a share of the average accusation rate of each category. The independent variables are all the listed temperature bins and the amount of precipitation in the day. The regressions also include municipality by-month by-year fixed effects and are weighted by the square root of the population in each municipality. 95% confidence intervals are in indicated by dashed lines for standard errors clustered at the level of municipalities. The reference bin is 20-22 Celsius degrees.

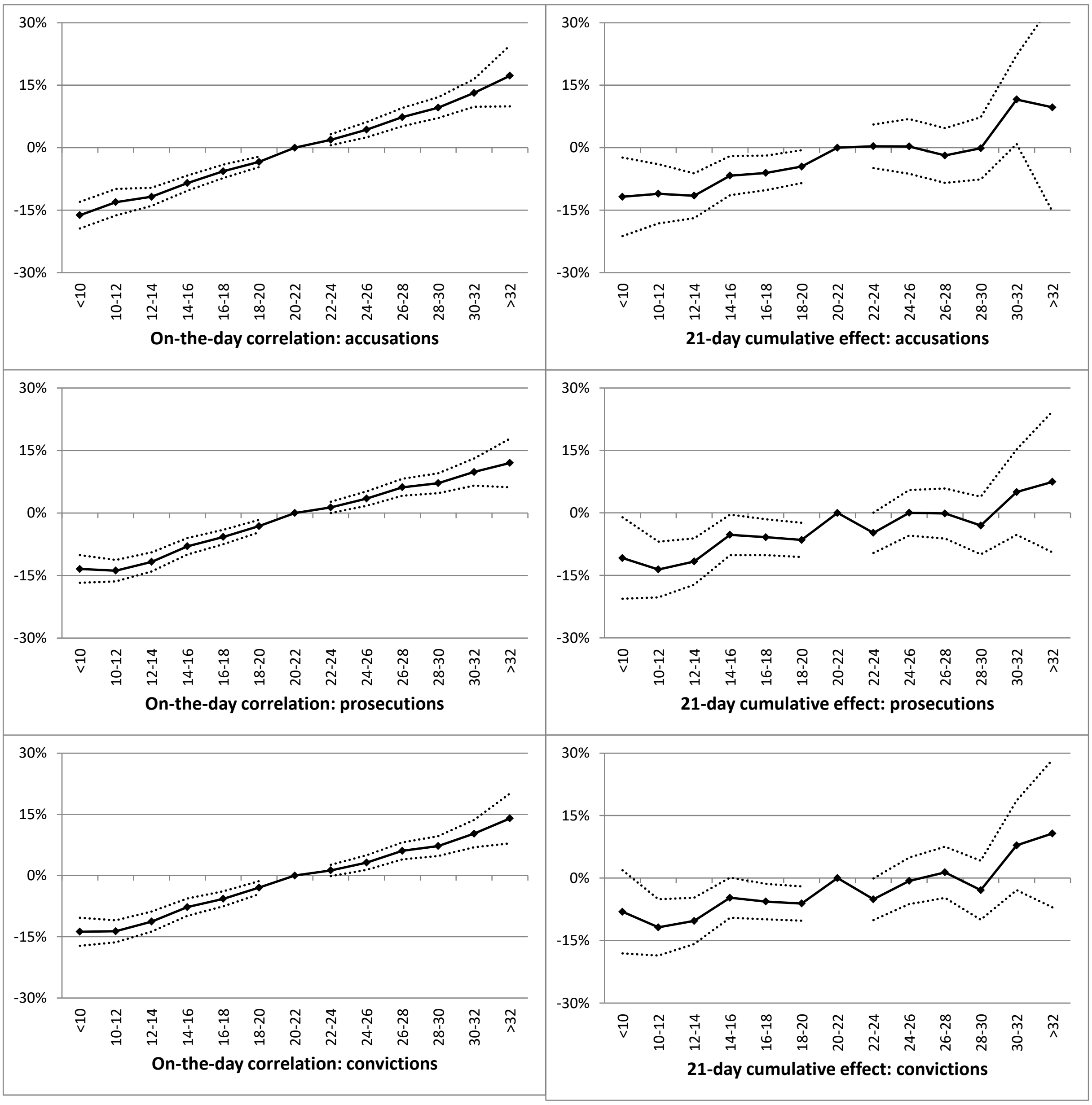
5.5. The judicial treatment of heat-related offenses

So far, we have used the data on accusations and not on prosecutions or convictions since we wanted information on the frequency of crimes and not their resolution by the judicial system. Yet, the same econometric exercises can be conducted with the data on prosecutions in Mexico. We can therefore see if hot days are correlated with prosecutions and then compare the figures obtained with accusations. This can reveal to be useful since, if criminals act during hot days because they have fewer risks to be caught, the correlation between hot days and prosecutions should be smaller than the one between hot days and accusations. Furthermore, we can look at whether prosecuted criminals were found guilty of the crime or not. Likewise, we would expect that the link between temperature and accusations is steeper than the link between temperature and convicted criminals if they can get away more easily with crimes committed during hot days.

Results for all crimes are provided in Figure 13. The results with the accusation rates are redisplayed and rescaled (to ease comparison) on the upper panel, whereas the results for the prosecution and conviction rates are respectively on the middle and lower panels. Prosecuted offenders are held a trial, and convicted ones are found guilty of the charge (88% of cases). The left panels provide the output of the on-the-day correlations, while the right panels consist of the results of distributed lag models.

We find the same results with accusations, prosecutions and convictions, implying that committing a crime during a hot day apparently does not provide better chances of getting away with it. For concision, we are not reporting the results by types of crimes. Yet, we have performed the analysis and using prosecutions or convictions instead of accusations provide very similar results when we breakdown convictions by type of crimes. For all considered types of crime, committing a crime during a hot day apparently does not provide either better or worse chances of getting away with it. We consider that this result corroborates the idea that hot days do not provide better opportunities than normal days to commit most criminal offenses.

Figure 13: Comparison of results obtained with the accusation vs. the prosecution and conviction rates (all types of crimes)



Notes: each graph corresponds to a separate regression The dependent variables are the daily accusation rate (upper panel), prosecution rate (middle panel) and conviction rates (lower panel) as a share of the average rate of each category. The independent variables are all the listed temperature bins and the amount of precipitation in the day. On the left panels, the y-axis reports the contemporaneous effect of temperatures on accusation rates. On the right panels, the y-axis reports the long-run multiplier of each temperature bin on the accusation rates. The multiplier includes on-the-day temperature and 20 lags. The independent variables are all the listed temperature bins and the amount of precipitation in the day. The regressions also include municipality by-month by-year fixed effects and are weighted by the square root of the population in each municipality. The reference bin is 20-22 Celsius degrees.

6. Conclusion

This paper finds a statistically significant impact of temperatures on criminal activities, in line with previous literature. Using a distributed lag model, we however find that 35% of the additional criminal acts performed during hot days would have occurred anyways in the following days. Displacement effects are therefore strong. When breaking down the effects by types of crimes, we are certain of the additional effect of temperatures on crime for only two types of crimes: drug-related crimes; and rapes and sexual aggressions.

In terms of magnitude, we find that Mexico would experience an increase in short-term accusation rates by 3.3%, under the RCP4.5 climate change scenario. The impact on sexual offenses is much stronger, since climate change could increase this type of offenses by 10.6% by the end of the century.

The evidence provided in this paper sheds some light on the reason why temperature correlates with criminality. We can provide evidence that changes in routine activities are a contributing factor. We find that 9% of heat-related crimes occur because of a higher consumption of alcohol during hot days. On the other side, the extra flexibility that people have to modify their schedule during weekends explains, by itself, 17% of all heat-related crimes. On the opposite, rational economic behaviour seems to have little explanatory power on the correlation between temperature and criminality: offenders do not commit more premeditated crimes, neither do they are better off committing a crime during a hot day. On the other hand, the eventuality of a psychological effect cannot be totally discarded, but is strongly challenged by two phenomena. The first one is the linearity in the temperature-criminality relationship. If excessively hot temperatures were the main factor responsible for the correlation between temperature and criminality, we should observe strong non-linearities in the relationship with effects for the warmest temperature bins only. Second, we find an effect of temperature on rapes and sexual aggressions. However, this effect seems to stem more from cold temperatures and to be equally shared between daytime and night time temperatures. This does not fit with the theory that heat would upset rapists.

All in all, our research therefore refutes conventional wisdom that psychological theories have strong explanatory power on the short-term impact of heat on criminality. We however provide supportive evidence in favour of the routine activity theory of Cohen and Felson (1979). More research is required to look at the way changes in activities during hot days may explain changes in criminality patterns, or how this phenomenon should be exploited to efficiently design policy responses in terms of improved awareness and surveillance.

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