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Non-economic factors in violence: Evidence from organized crime, suicides and climate in Mexico☆

Ceren Baysan[a], Marshall Burke[b], Felipe González[c], Solomon Hsiang[d], Edward Miguel[d,*]

[a] University of Essex, England, United Kingdom
[b] Stanford University USA
[c] Instituto de Economía, Pontificia Universidad Católica de Chile, Chile
[d] University of California, Berkeley, USA

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ABSTRACT

Organized intergroup violence is almost universally modeled as a calculated act motivated by economic factors. In contrast, it is generally assumed that non-economic factors, such as an individual's emotional state, play a role in many types of interpersonal violence, such as "crimes of passion." We ask whether non-economic factors can also explain the well-established relationship between temperature and violence in a unique context where intergroup killings by drug-trafficking organizations (DTOs) and other interpersonal homicides are separately documented. A constellation of evidence, including the limited influence of a cash transfer program as well as comparisons with both other DTO crime and suicides, indicate that economic factors only partially mitigate the relationship between temperature and violence that we estimate in Mexico. We argue that non-economic psychological and physiological factors that are affected by temperature, modeled here as a "taste for violence," likely play an important role in causing both interpersonal and intergroup violence.

1. Introduction

The positive relationship between changes in temperature and violence has now been documented across diverse geographic settings and for many types of human conflict, ranging from institutional collapse to civil war, riots, and crime.[1] Yet the mechanisms underlying these estimates remain poorly understood, and are of primary concern in order to inform policies that can mitigate higher rates of conflict as temperature continues to rise (Dell et al., 2014). While studies in the

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* Corresponding author.
E-mail address: emiguel@berkeley.edu (E. Miguel).

[1] A meta-analysis finds that interpersonal and intergroup conflict rise by approximately 4% and 10% for each 1 standard deviation increase in temperature, respectively (Hsiang et al., 2013). This implies a large historical role for temperature variation in shaping conflict risk, and an even larger potential role for future climate change in shaping these outcomes, given the anticipated $>4\sigma$ increase in temperature expected across much of the tropics over the next century.

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economics and psychology literature demonstrate that rising temperatures can amplify interpersonal violence and aggression even when economic factors are held constant, the role of non-economic factors in explaining broader patterns of inter*group* conflict remains unexplored. Such group-level conflict remains a key source of premature death and livelihood loss throughout much of the developing world, and is almost exclusively modeled as the result of a strategic and rational calculation, with physiological or psychological factors not assumed to play an important role. Understanding whether this assumption is correct is critical for a broader understanding of the origins of conflict, and an understanding of climate's role in a range of conflict outcomes.

Why might changes in temperature induce violence and conflict, and what can this tell us about the broader underpinnings of violence? To date, economic models of violence treat interpersonal and intergroup violence as different phenomena. Instances of interpersonal violence, such as assault and murder, are generally thought of as "crimes" that may have either an economic or emotional motivation—assaulting an individual in order to expropriate their assets is clearly economic, whereas "crimes of passion" presume emotional factors. In contrast, violence between groups of individuals is almost always modeled as a strategic calculation where the economic costs of conflict are weighed against potential gains. In many cases, this decision to focus on economic factors is well-motivated and generates sharp predictions that often agree with data.[2]

Accordingly, economists often interpret the temperature-conflict relationship as largely an income effect: hotter temperatures and lower rainfall are known to lower incomes, particularly in agricultural areas, and this in turn could temporarily lower the opportunity cost of participation in violence. In an early study, Miguel et al. (2004) provide empirical evidence that rainfall shocks that lower economic growth also increase the likelihood of civil war in Sub-Saharan Africa. Chassang and Padró-i-Miquel (2010) explain this result by developing a bargaining model in which violence occurs when a shock to economic productivity temporarily lowers the opportunity cost to violence, but does not affect the future value of winning the contest.

This economic explanation for a temperature-violence relationship, however, has difficulty accounting for the observed response of individual-level violence to daily or even hourly variations in temperature, as income is unlikely to change over these short periods (Jacob et al., 2007; Card and Dahl, 2009; Larrick and et al, 2011; Ranson, 2014). Vrij et al. (1994) offer perhaps the clearest case, where police officers were observed utilizing more violence during a training exercise when temperature in the room was manipulated to be hotter.[3] Thus, while interpersonal violence is often conceived of as an action with private costs and benefits that also imposes costs on others (Becker, 1968), and which agents may rationally undertake to affect the allocation of resources (Donohue and Levitt 1998; Chimeli and Soares 2017; Castillo et al. 2018), existing evidence indicates that non-economic factors are at least partially responsible for generating the observed temperature-violence link at the individual level.

Given that most instances of group-level violence are, at the most basic level, implemented by individuals, this then suggests a potential additional role for non-economic factors in intergroup violence. Consider the group member on the front lines of a conflict who is personally implementing violence to further a group's strategic objectives. There are many decision points where non-economic psychological factors could play a role in his decision making, with the individual having some discretion in exactly how much violence to employ when contact with an opponent actually occurs. If the agent personally enjoys violence, she may employ more of it when given some discretion over its use, and if the agent dislikes violence she may employ less. Changes in the opportunity cost of violence will not necessarily be the key determinant of the agent's use of violence. If there are multiple opportunities for non-economic factors to influence the individual's use of violence, then non-economic factors could become important determinants of the level of intergroup conflict.

We propose a unified framework in which both interpersonal and intergroup violence may be influenced by both economic and non-economic factors, although their relative influence may differ (making it ultimately an empirical question). We expand a standard economic model of violence by allowing the aggressor to experience pure consumption value from using violence, which we model as a positive or negative input into utility, depending on the individual's "taste for violence."[4] Introducing this single non-economic factor and allowing it to respond positively to temperature, as indicated by prior analyses, substantially improves the ability of the model to account for observed patterns in the relationship between temperature changes and intergroup violence.

We then test multiple hypotheses generated by this unified model in Mexico, a context where exceptional levels of violence by drug-trafficking organizations (DTOs) motivated law enforcement to gather separate data on intergroup homicides. This allows us to observe variation in comparable group-level and individual-level acts of violence, i.e., homicides in both cases, in a single context where geographical, political, and institutional factors can be "held fixed." This provides a unique

[2] See, for example, Collier and Hoeffler (1998); Miguel et al. (2004); Angrist and Kugler (2008); Berman et al. (2011); Besley and Persson (2011); Dube and Vargas (2013), among others.

[3] In another laboratory experiment, which is unfortunately rather poorly documented, Rohles (1967) reports, "When [participants] were subjected to high temperatures in groups of 48, there was continual arguing needling, agitating, jibing, fist-fighting, threatening, and even an attempted knifing. At lower temperatures or in small groups, this behavior diminished."

[4] In a similar vein, Tauchen et al. (1991), Farmer and Tiefenthaler (1997), Bowlus and Seitz (2006), and Aizer (2010) explain domestic violence as expressive behavior that provides positive utility to some men. Their partners tolerate it in return for higher transfers. Card and Dahl (2009) adopt this interpretation of family violence as motivation to consider the role for emotional cues (or "visceral factors") in precipitating violence. They use unexpected losses in football games as the trigger for these emotional cues. A key contribution of our paper is to extend this framework beyond domestic violence and to introduce these psychological factors into the rapidly growing literature on intergroup conflict. Blattman et al. (2017) provide experimental evidence on the role non-cognitive skills and preferences could play in shaping violence.

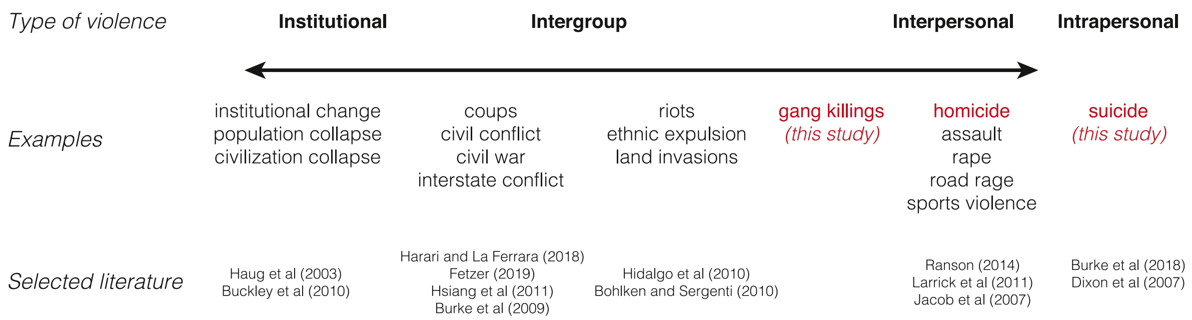

Fig. 1. Spectrum of violence.

opportunity to compare the effect of temperature on both interpersonal and intergroup violence without the comparison being confounded by contextual differences that usually differ between studies.[5] Such comparisons allow us to consider whether these two types of violence might share a common non-economic mechanism.

Consistent with earlier meta-analyses, we show that higher monthly temperatures have a positive and significant effect on both killings by drug-trafficking organizations (DTOs) and "normal" (non-DTO) homicides in Mexico. Effects in both cases are contemporaneous, large in magnitude, and generalizable across regions in Mexico. We find that a one standard deviation increase in temperature is associated with a 28% increase in drug-related killings and 5% increase in regular homicides.

We next use a variety of approaches to investigate whether these results are driven or mitigated by economic factors. We find that economic mechanisms can only partially explain the relationship between temperature and DTO killings, and they have almost no explanatory power in the case of non-DTO homicides. For instance, changes in temperature have no comparable effect on non-violent and primarily economic crimes committed by DTOs, such as extortion and car theft, which we would expect to respond similarly to temperature if both were caused by a single underlying mechanism. Similarly, exogenous variation in the level of government social assistance through the large scale Progresa/Oportunidades program has limited effect in dampening the effect of high temperatures on group conflict. Finally, growing season temperatures matter little for harvest season violence, and other measures of economic conditions and inequality have limited predictive power in explaining the observed temperature-violence relationship.

Data on suicides in Mexico provide further evidence that psychological factors better explain the observed link between temperature and violence. Suicides, which could be thought of as intrapersonal violence, are known to be heavily influenced by psychological factors, and we show that the response of suicide to temperature in Mexico strongly matches the responses of interpersonal and intergroup violence to temperature: the response is linear, contemporaneous, common across regions, not mediated by observable economic factors or Progresa/Oportunidades, and only barely affected by growing season temperatures. We interpret this pattern-matching exercise as further evidence that psychological factors play a role in temperature's effect on group violence

Beyond our primary contribution to the understanding of the channels linking climate and intergroup violence, our work broadens the "spectrum of violence" known to be affected by climatic events (Fig. 1). This includes evidence on large-scale institutional responses to climatic change (Haug et al., 2003; Buckley et al., 2010), on more localized intergroup conflict (Harari and Ferrara, 2018; Fetzer et al., 2019; Hsiang et al., 2011; Burke et al., 2009), and on interpersonal conflict (Ranson, 2014; Larrick and et al, 2011; Jacob et al., 2007). To our knowledge, our evidence on gang responses to temperature is novel. Gangs are smaller and less organized than armed militias but larger and more organized than spontaneous groups, such as mobs, both of which have been previously linked to extreme climate. Similarly, we add to a small but growing literature on the link between suicide and climate (Burke et al., 2018; Dixon et al., 2007). By further expanding and filling in this spectrum of social phenomena affected by climate, this work bolsters our understanding of how climatic conditions may affect the peacefulness of modern societies (Hsiang et al., 2013).

2. Understanding violence

2.1. Drug trafficking in mexico

Drug trafficking organizations in Mexico appeared in the 1990s (Grillo, 2012) and have since grown in size and sophistication, nowadays constituting an industry that earns between 14 and 48 billion USD annually (U.S. State Department, 2009).

[5] Hsiang et al. (2013) compare results from 60 studies and find that the average effect of temperature on interpersonal violence differs substantially from the effect on intergroup violence. However, each study only examined one form of violence in a given context, and none were from comparable contexts (e.g., civil war in African countries vs. domestic abuse in Australia), complicating the interpretation of differences across categories of violence.

In addition to trafficking, these organizations engage in extortion and kidnapping (Rios, 2014) and rose from 6 in 2007 to approximately 16 in 2010 (Guerrero, 2012a).[6]

Starting in 2007 drug-related violence has increased dramatically, claiming more than 50,000 lives (Dell, 2015). Following the presidential election of 2006, president Felipe Calderón declared war on drug trafficking organizations. Shortly after this event, crackdowns spread through the country, and violence escalated to unprecedented levels (Merino, 2011; Guerrero, 2011b; Escalante, 2011). Several factors have been offered as causes: (1) Felipe Calderón's crackdowns and captures of DTO leaders (Guerrero, 2010; Chaidez, 2014; Calderón et al., 2015; Dell, 2015; Osorio, 2015); (2) U.S.–Colombia efforts to reduce the supply of drugs (Castillo et al., 2018); and (3) exogenous movements in international crop prices affects the opportunity cost of joining the drug industry (Dube et al., 2016). The relative contribution of each of these factors is, however, a matter of ongoing debate. To our knowledge, this is one of the first papers to link DTO violence to climatic shocks.

To understand drug violence "on the ground," we need to know more about DTO front-line workers, how they were recruited, and how is violence taking place. According to the Secretary of Defense department in Mexico, there are currently more than 500,000 DTO workers, among them more than 75,000 children and adolescents. They are usually recruited through more than 800 recruiting and training centers spread throughout the country (Cruz Santiago et al., 2012), and local economic factors and opportunities seem to be an important explanation behind the individual decision to join, both in rural and urban areas (Dube et al., 2016; Dell et al., 2019). In implementing the DTO's operations – violence, trafficking, and other criminal activities – these are the individuals whose decisions might be affected by climatic factors. Regarding the nature of violence taking place after 2007, Osorio (2015) provides the most comprehensive data. As crackdowns diminished the power of incumbent DTOs, competing organizations exerted effort to take control of these territories (Dell, 2015; Osorio, 2015), resulting in violence between DTOs and with state agents in charge of the crackdown. In line with this explanation, Osorio (2015) uses text analysis to study national and local newspapers and finds that most violence in this period was between DTOs. While we cannot rule out that non-gang victims are included in our DTO data, evidence in Osorio (2015) suggest that most of the violence recorded as DTO killings was due to gangs fighting gangs.

2.2. Non-economic factors in violence

A large body of research has dissected the logic of violence and documented the role that economic factors can play (Miguel et al., 2004; Angrist and Kugler, 2008; Berman et al., 2011; Besley and Persson, 2011; Dube and Vargas, 2013).[7] This work would also seem to provide a *prima facie* explanation for the now well-documented role that changes in temperature appear to play in instigating violence and human conflict (Hsiang et al., 2013; Burke et al., 2015), given that changes in temperature are also known to induce variation in both agricultural and non-agricultural incomes (Hsiang, 2010; Dell et al., 2012).

Accumulating scientific evidence, however, also points toward an important role for physiological and psychological factors in explaining certain types of human violence, and importantly (for our purposes) also the potential for temperature to shape these non-economic factors. For instance, the psychological roots of *intra*personal violence – i.e., suicide – have been well documented, and the role of temperature in this particular type of violence, as well as in interpersonal human aggression, have been explored by researchers since at least the 1930s.[8] While scientific understanding of temperature regulation in the human body remains imperfect (e.g., Hammel 1974, Werner 1980, Cooper 2002, and Mekjavic and Eiken 2006)), there is growing evidence that neural structures are directly involved in this process (Benzinger, 1970; Morrison et al., 2008; Ray et al., 2011). This is important because particular neurotransmitters that have been shown to participate in body temperature regulation – in particular, serotonin – have also been linked to mood, emotion, and range of human behaviors (National Institutes of Health, 2011; Lovheim, 2012). For serotonin specifically, there is growing consensus that decreased serotonergic neurotransmission in the brain may be an important deficit that leads to aggressive behavior (Edwards and Kravitz, 1997; Seo et al., 2008). Thus there appears to be growing support in the medical literature for a physiological link between temperature and violent behavior: when ambient temperature increases, serotonin levels decrease, with attendant effects on impulsive and aggressive behavior.

A few recent studies provide complementary evidence that non-economic factors are significant in explaining reduced form relationships between temperature on violence (Garg et al., 2018; Blakeslee et al., 2018). These papers focus on interpersonal conflict, using a similar empirical strategy to ours, and both conclude (in very different settings) that the response of violent crime to temperature has a strong non-economic component. This work complements our focus on understanding the mechanisms behind intergroup conflict.

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[6] Most new organizations are factions of older groups and appear after traditional leaders are arrested or killed (Guerrero, 2012b; Rios, 2013). Guerrero (2011a) discusses the issue of DTO fractionalization in greater detail. See Table A.1 for characteristics of DTOs.

[7] See Appendix A.1 for a brief review of the literature estimating the negative consequences of violence.

[8] See Appendix A.2 for a review of the literature estimating the relationship between temperature and suicide and the seasonality of suicides. For example, Baron and Bell (1976) show that individuals were more likely to behave aggressively towards others when ambient temperature was higher. Burke et al. (2018) estimate the causal impact of temperature on suicides in Mexico and the U.S., and provide evidence of an increase in aggression in online networks when temperature is abnormally high.

3. Theoretical framework

To understand how non-economic physiological and psychological factors might complement the standard way in which economists have understood the logic of violence, we develop a simple model of violence that builds on the framework in Chassang and Padró-i-Miquel (2010) and incorporates a new mechanism affecting how high temperature can lead to violence. In the model, two sides, $i \in \mathcal{I} = \{1, 2\}$, decide whether or not to engage in costly violence and redistribution when bargaining fails. The players cannot commit to not engage in conflict for an infinite number of periods, where time is indexed by t. On the production side, each side combines l units of labor, which we normalize to $l = 1$, with time-varying technology θ_t.

The sides can engage in two possible actions, namely being violent or peaceful, $a \in \mathcal{A} = \{V, P\}$, which they choose simultaneously. Both groups want to maximize their economic output at the end of the game. If one player attacks first, then it has a first strike advantage and captures all of the opponent's output with probability $p > .5$. An attack costs both the aggressor and defender a fraction $c \in (0, 1]$ of output. If both agents choose to attack simultaneously, they each win with probability 0.5. Additionally, we assume there is common knowledge of a non-rival psychological consumption value of violence, which is a function of temperature τ, i.e., $\gamma_t = \gamma_t(\tau)$ with $\frac{\partial \gamma_t(\tau)}{\partial \tau} > 0$, and $\gamma_t(\tau) \in \mathbb{R}$. If $\gamma_t(\tau) > 0$ then the player gains positive utility from engaging in violence. In terms of notation, we omit the argument, τ, in setting up the model, but return to it when discussing its role in explaining violence through different channels.

We consider a dynamic model where the two groups interact in every period t. There is at most one round of fighting, and the winning group reaps the benefits of its prize into the future. If there is no attack in the current period, then each agent expects a peaceful continuation value V^P, which is the discounted (δ) per capita utility of expected future consumption from the player's initial assets and which captures expectations of future values of all parameters. Similarly, if one side wins, then they have a continuation value of winning V^V, which is the per capita expected utility from consumption of both their initial assets and the assets that they capture from their opponent through violence.

The condition for peace can be written as:

$$\underbrace{\theta_t + \delta V^P}_{value\ of\ peace} > \underbrace{p(2\theta_t(1-c) + \delta V^V) + \gamma_t}_{value\ of\ violence} \quad (1)$$

In terms of interpretation, a player finds it privately beneficial to choose peace if the per capita value of consuming all output with initial assets plus discounted expected utility under peace δV^P (left hand side) exceeds the expected utility of consumption from both the player's original assets and captured assets, less expenditures on the conflict, plus the expected continuation value $p\delta V^V$ and the psychological consumption value of violence, γ_t (right hand side).

Rearranging (1), the condition for peace becomes:

$$\theta_t(1 - 2p(1-c)) - \gamma_t > \delta[pV^V - V^P] \quad (2)$$

where the left side of the inequality is the marginal value of peace in the current period weighed against the discounted marginal expected utility from attacking (on the right side).

In considering the mechanism, the economics literature on conflict has focused on the impact of temperature on θ_t in explaining violence. The left hand side of (2) shows that if economic conditions are sufficiently bad (i.e., θ_t is sufficiently close to zero), and ignoring psychological factors for the moment, conflict will occur. For example, a drought has a contemporaneous effect on productivity, which reduces the current opportunity cost of conflict more than it alters the continuation value of peace (note that θ_t does not feature in the right hand side).

Here we highlight the importance of the novel term capturing the non-rival psychological consumption value of violence, γ_t. If climatic conditions influence γ_t by increasing the utility (or decreasing the psychological cost) of acting violently, i.e., $\frac{\partial \gamma_t(\tau)}{\partial \tau} > 0$, then these changes may increase the likelihood that (2) does not hold and violence occurs.[9] Focusing on levels, if both sides have a general distaste for violence ($\gamma_t(\tau) < 0$), then there will be less conflict than would be predicted by economic factors alone. Yet even in this case, if extreme climatic conditions such as high temperatures decrease this psychological cost of engaging in violence, $\frac{\partial \gamma_t(\tau)}{\partial \tau} > 0$, the likelihood of violence would increase with temperature.

4. Empirical framework

4.1. Data and descriptive statistics

We collected monthly information on reported homicides and suicides at the municipality level from Mexico's Bureau of Statistics (INEGI) for the period between January 1990 and December 2010.[10] This data corresponds to the universe of

[9] An alternative would be to introduce a physiological mechanism discussed in the literature on cognition. A number of studies have reported the importance of environmental factors, such as heat, on cognitive performance (Mackworth 1946, Fine and Kobrick 1978). Fine and Kobrick (1978) found that heat has significant effects on individuals' ability to perform complex cognitive tasks involved in artillery fire and in which they were trained. In the above model, we can think of this effect as an additive error term, ϵ, whose variance increases with temperature, in which the players simply err in making their fighting decision, a decision they might not make at lower temperatures.

[10] This section discusses the main variables to be used in the empirical analysis. Additional data, and the corresponding descriptive statistics, can be found in Appendix B.

Table 1
Descriptive statistics.

Period:	*January 1990 – December 2006*			*January 2007 – December 2010*		
	Mean	St. Dev.	St. Dev within	Mean	St. Dev.	St. Dev within
DTO killings per 100,000 inhabitants	–	–	–	0.59	7.88	7.67
Homicides per 100,000 inhabitants	0.98	5.23	5.02	0.83	4.14	3.71
Suicides per 100,000 inhabitants	0.21	1.93	1.92	0.26	2.21	2.19
Population	39,057	116,901	12,435	44,584	130,760	2449
Temperature (°C)	20.10	5.00	2.83	20.05	5.09	2.97
Precipitation (millimeters)	92.87	111.83	99.48	80.70	107.09	95.18
Municipalities	2456			2456		
Observations	493,908			117,458		

Notes: Each observation corresponds to a municipality-month. Population is estimated using linear interpolations within municipalities with the 1990, 2000, and 2010 Census as reference numbers. Temperature and precipitation are weighted by population. The summary statistic **St. Dev within** is the standard deviation of the corresponding variable after removing municipality fixed effects.

homicides and suicides officially reported. We split this time frame into a "pre-war" period between January of 1990 and December of 2006, and a "war" period between January of 2007 and December of 2010 because drug-related killings (henceforth DTO killings) are only available for the latter period. In the pre-war period there were 218,970 homicides and 55,206 suicides, with a monthly per municipality average (standard deviation) of 0.44 (2.49) and 0.11 (0.77), respectively. Homicides in this period include both non-DTO-related episodes and DTO killings.

We use the total number of deaths per 100,000 inhabitants in a municipality as the dependent variable, as is standard in the literature (see Hsiang et al. 2013). A municipality in Mexico is similar to a city in the United States. Table 1 presents descriptive statistics for these variables in the two periods of interest. We observe an average of 0.98 homicides and 0.21 suicides per 100,000 inhabitants per municipality-month in the pre-war period, and an average of 0.83 homicides and 0.26 suicides between years 2007 and 2010. The variation in these variables is substantial, as shown by the within standard deviations of 5.23 and 1.93 for homicides and suicides respectively. At the state level, some have as many as 6.2 homicides per 100,000 inhabitants – an extremely high homicide rate.[11]

DTO killings were compiled by a committee with representatives from all ministries of the National Council of Public Security in Mexico. The committee met weekly to classify each homicide as drug-related or not. A drug-related homicide was defined as one civilian killing another one with at least one involved in drug trade. The data is available from December 2006 to December 2010 at the municipality level. There were a total of 34,436 DTO killings between 2007 and 2010, with an average (standard deviation) of 0.29 (3.94) killings per municipality-month. The variation in this variable is striking, with roughly 20% of state-months having zero killings and some having as many as 452.[12] Panel B in Table 1 presents descriptive statistics for this variable. DTO killings rates are roughly half the size of homicides rate during this period, and the distribution is more skewed.

Fig. 2 shows time averages (weighted by population) for DTO killings (2007–2010) and homicides (1990–2006) in all municipalities in Mexico. Homicides seem to be decreasing during this time period, something analyzed in more detail by Escalante (2011).[13]

Finally, we construct monthly temperature and precipitation for each municipality-month using data from Willmott and Matsuura (2014). This is a gridded dataset with monthly information for cells of size 0.5 degrees.[14] In order to transform this gridded dataset into a municipality-level dataset, we take the average of temperature and the sum of precipitation for all pixels inside the polygons that represent Mexican municipalities. Municipalities during our sample period have an average temperature of 20 degrees celsius, with a standard deviation of 5.0 degrees celsius. However, after removing municipality, year, and month fixed effects, following our econometric specification (below), the standard deviation of this variable at the municipality-month level is approximately 2.8 degrees celsius. Figure A.4 presents the distribution of temperature by period.

[11] Monthly rate of 6.2 homicides in our dataset implies a rate of 74.4 homicides per 100,000 per year. This is an extremely high homicide rate. To put this in perspective, the most violent country in the world in 2012 (Honduras) had a rate of 90.4 homicides per 100,000 inhabitants, and the second most violent (Venezuela) had a rate of 53.7. Figure A.1 also compare rates of these types of violence to the US. Homicide rates in Mexico were twice as high in Mexico compared to the US in 2006 and have been rising ever since. Suicide rates, however, are substantially higher in the US. Finally, and not surprisingly, organized crime killings are far higher in Mexico, a difference that has again been increasing since 2006.

[12] Our results are robust to excluding states with a large upward trend in DTO killings, i.e. Baja California, Chihuahua, Durango, Guerrero, Sinaloa, and Tamaulipas. Results are also robust to including state specific trends, as discussed below.

[13] Dube and Ponce (2013) study violence in Mexico before 2006. These authors find that an expiration that relaxed the permissiveness of gun sales caused an increase of roughly 239 deaths annually in municipalities close to the relevant state borders.

[14] "Gridded weather datasets use interpolation across space and time to combine available weather station data into a balanced panel of observations on a fixed spatial scale or grid. This approach deals with the problem of missing observations at a given station or missing data because a station does/did not exist at a particular location. (...) Each 'grid' approximates a weather measure for the spatial unit by interpolating the daily station data while accounting for elevation, wind direction, rain shadows, and many other factors.", (Auffhammer et al., 2013).

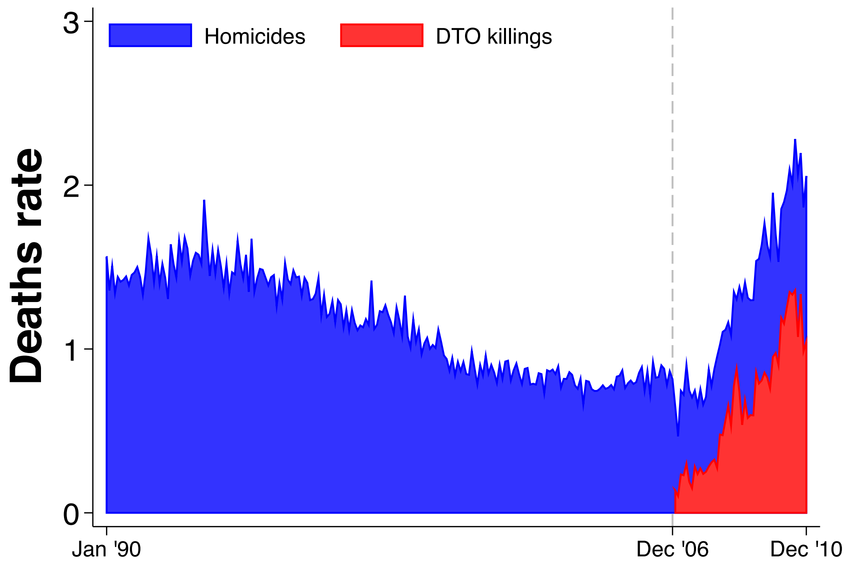

Fig. 2. Time series of violence *Notes*: Time averages (weighted by population) for our main outcome variables in all municipalities in Mexico. The dash vertical black line denotes the beginning of the Mexican Drug War.

4.2. Econometric strategy

To estimate a causal link between temperature and our dependent variables of interest, we follow Deschenes and Greenstone (2007), and the preferred method employed by Hsiang et al. (2013) (see Dell et al. 2014 for a review). Accordingly, we control for unobservable time-invariant factors at the municipality level that could be correlated with both average temperatures and violence, unobserved shocks common to all municipalities within in a state in a given year, and average seasonal patterns in both temperature and violence. Specifically, in our preferred specification we estimate the following regression:

$$y_{nsmt} = \beta \text{Temp}_{nsmt} + \delta \text{Precip}_{nsmt} + \xi_m + \lambda_t + \zeta_n + \varepsilon_{nsmt} \quad (3)$$

where y_{nsmt} is the number of DTO killings, homicides, or suicides per 100,000 inhabitants in municipality n, state s, month m, and year t; ξ_m and λ_t are full sets of month and year fixed effects; ζ_n is a full set of municipality fixed effects, respectively; Temp_{nsmt} is average temperature, measured in degrees celsius; Precip_{nsmt} is total precipitation, measured in thousands of millimeters; and ε_{nsmt} is an error term clustered at the state level. In robustness tests, we also estimate equation (3) adding state-specific linear time trends (to account for differential state-level trends in, for instance, policies to fight violence), or replacing the month-of-year fixed effects ξ_m with state-by-month-of-year fixed effects ξ_{sm}—to account for state specific seasonality in violence and temperature; there is some evidence, for instance, for seasonality in suicides in particular (Ajdacic-Gross et al., 2010). Our main coefficients of interest are β and δ, which are identified through natural exogenous fluctuations in weather conditions, conditional on location and time effects. After demonstrating that our results are robust across specifications, we report results from (3) for most of the analyses.

We also present temperature response functions using the number of days in a set of bins and estimates of the effect of leads and lags of temperature on violence. The latter exercise is important for a number of reasons. First, there may be temporal displacement: it may be the case that an event that would have occurred in the future anyway is triggered earlier by extreme climatic conditions. With full displacement, the contemporaneous and lagged effects would be of similar magnitude but opposite in sign, and there would be no overall effect of climate on violence. Even with partial displacement, a sole focus on contemporaneous impacts could overstate the total effect of a change in temperature.

Lags can also be useful in identifying delayed or persistent effects. For example, a negative temperature shock during the growing season in an agricultural based economy may increase violence during the harvest season when income for the farming season is realized (a delayed effect), or a weather shock could trigger a conflict that persists for multiple periods. Finally, the temporal pattern of response to temperature shocks could also shed light on the mechanism underpinning the response. Given that we are using monthly data, certain income effects (such as the agricultural income story just told) might be expected to show up with a few-month lag. Physiological effects, on the other hand, would be expected to show up contemporaneously, given the immediacy of the body's thermoregulatory response.

To explore these temporal dynamics, we estimate the following regression:

$$y_{nsmt} = \sum_{k=t-6}^{k=t+6} \beta_k \text{Temp}_{nsmk} + \sum_{k=t-6}^{k=t+6} \delta_k \text{Precip}_{nsmk} + \xi_m + \lambda_t + \zeta_n + \varepsilon_{nsmt} \quad (4)$$

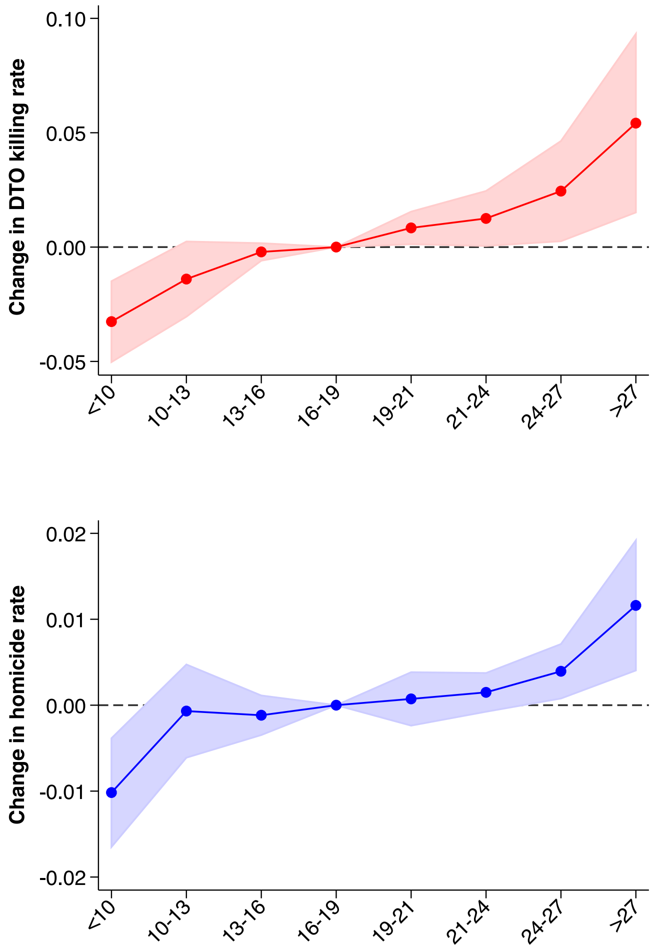

Fig. 3. Temperature and violence in Mexico *Notes:* These figures present non-parametric estimates of equation (3). Temperature response functions for DTO killings (upper panel) and homicides (lower panel) using temperature bins of width 3 °C. The *x*-axis is interpreted as the average temperature in a given municipality-month, and the *y*-axis is interpreted as deviation from that municipality-month average in the corresponding measure of violence.

where all variables are defined as before, and we include six monthly leads and six lags of temperature. Our interest lies in the parameters β_k and δ_k. In particular, a violation of our identification assumption would be reflected in any of the coefficients $(\beta_{t+1}, \ldots, \beta_{t+6})$ being statistically different from zero, i.e., future climate variation should not be correlated with past violence. Persistent effects or displacement would translate into the coefficients $(\beta_{t-6}, \ldots, \beta_{t-1})$ being statistically different from zero.

5. Climate and violence

Fig. 3 non-parametrically displays the relationship between temperature and measures of group and interpersonal violence (DTO killings and homicides, respectively), with municipality-, year-, and month-fixed effects partialled out of both the dependent variables and temperature. The *x*-axis is interpreted as the average temperature in a given municipality-month, and the *y*-axis is interpreted as deviation from that municipality-month average in the corresponding measure of violence. For reference, a one standard deviation in the temperature variable within a municipality corresponds to 2.8 degrees celsius. The thick line corresponds to the non-parametric conditional mean, while the lighter color depicts the 95 percent confidence interval. These temperature response functions are clearly upward sloping for both variables, and appear roughly linear through most of the temperature support.

Table 2 presents regression results from estimating equation (3) under various sets of fixed effects. To facilitate the interpretation of these coefficients, and comparison across outcomes and studies, standardized effects are presented in square brackets, which we express as percentage change in the dependent variable per one standard deviation change in the climate variable of interest. The first three columns show results using DTO killings per 100,000 inhabitants as dependent variable, and the last three show corresponding results for homicides in the pre-2007 period.

Table 2
Temperature and violence in Mexico.

Dependent variable:	*DTO killings*			*Homicides*		
	(1)	(2)	(3)	(4)	(5)	(6)
Temperature	0.058**	0.066**	0.053***	0.016***	0.023**	0.014***
	(0.022)	(0.030)	(0.019)	(0.004)	(0.011)	(0.003)
	[28.4]	[33.6]	[26.9]	[4.7]	[7.0]	[4.3]
Precipitation	0.016	−0.013	0.025	−0.004	−0.001	−0.009*
	(0.041)	(0.027)	(0.035)	(0.007)	(0.007)	(0.005)
	[2.7]	[−2.2]	[4.2]	[−0.4]	[−0.1]	[−0.9]
Municipality F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Month F.E.	Yes	No	Yes	Yes	No	Yes
Month–state F.E.	No	No	Yes	No	No	Yes
State trends	No	Yes	No	No	Yes	No
Observations	117,458	117,458	117,458	493,908	493,908	493,908

Notes. Each observation corresponds to a municipality-month. Estimates of equation (3) using data for all municipalities in Mexico in different periods (2007–2010 in columns 1–3, 1990–2006 in columns 4–6). **State trends** is a complete set of year indicators interacted with state indicators. Standard errors clustered at the state level in parenthesis. Standardized effects in brackets. All regressions are weighted by population. Levels of significance are reported as $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Several interesting patterns emerge. First, we observe a positive and significant effect of temperature on both intergroup and interpersonal violence, a result that is robust across all specifications. The magnitude of these estimates varies across columns, but is particularly large for DTO killings: in our base specification (Column 1), we find that a 1σ increase in temperature in a given month is associated with a 28% increase in the rate of DTO killings. This result is robust to inclusion of either state-specific time trends or state-month FE. Given the large level of killings during this period – over 34,000 DTO killings over the 2007–2010 period – a 22% increase is large in both percentage and absolute terms. The roughly 5% effect for homicides is smaller in magnitude, but is also substantial given again the high homicide rate in the country over the period (285,000 total homicides during the 1990–2010 period). We find no statistically significant effect of precipitation on either intergroup or interpersonal violence, and in all specifications we can confidently reject large effects of precipitation. The effects of climate on violence in Mexico appear to occur through temperature.

Why is the impact of temperature shocks on violence larger for organized groups?[15] Although our setting prevents us from providing a complete explanation, we believe there are at least three leading possibilities that merit further exploration. First, DTO operatives on the ground might be more equipped to engage in violent behavior (i.e., they are often armed) and as a result temperature shocks might have a larger impact on them. Second, DTO individuals might simply be more violent by nature, either because they were trained by the organization with that purpose or because they were selected from the population in part due to an underlying tendency to violence. Third, social interactions within or across groups could exacerbate the effects of temperature. Examples of these potential "social multipliers" are peer effects within groups and retaliation across groups.

Anticipating our more formal treatment of treatment-effect heterogeneity below, in Figure A.2 we explore whether there are apparent spatial patterns in the responsiveness of DTO killings or homicides to temperature. We estimate state-specific responses of violence to temperature, and display these in the figure as the ratio of the state-specific estimate to the pooled country-wide estimate reported in Columns 1 or 4 of Table 2 – i.e. $\frac{\widehat{\beta}_{s,y}}{\beta_y}$. Although there is some apparent variation in estimated effects across states, results are remarkably homogeneous: point estimates are positive in all states for DTO killings and positive in all but one state for homicides, the ratio of state-specific estimates to pooled estimates is near unity for most states, and in the case of DTO killings, in only 4 out of 32 states do confidence intervals on state-specific estimates not contain the pooled estimate (equivalent to 13% of states, only slightly higher than what sampling variability alone would predict). For homicide, there does appear to be somewhat more variation in effect sizes across states, with 38% of state-specific confidence intervals not containing the country-wide estimate (8 estimates are significantly larger than the pooled estimate, 4 are smaller). Below we explore more extensively whether economic factors can explain this heterogeneity.

Finally, as shown in Fig. 4, our benchmark estimates of how intergroup and interpersonal violence respond to temperature in Mexico are remarkably consistent with other reported temperature-conflict estimates from the literature (none of which were from Mexico). Fig. 4 plots the distribution of standardized coefficients from an earlier meta-analysis (Hsiang et al., 2013), showing in the bottom two panels either the 24 studies from Hsiang et al. (2013) that examined intergroup conflict or the 12 studies that examined interpersonal conflict. The estimated effects for DTO killings and homi-

[15] Although a meta-analysis finds a larger effect of temperature on intergroup violence (Hsiang et al., 2013), the results in Table A.3 cannot reject that the temperature response is similar for homicides and DTO killings. However, this result needs to be interpreted with caution because it only uses data for the 2007–2010 period.

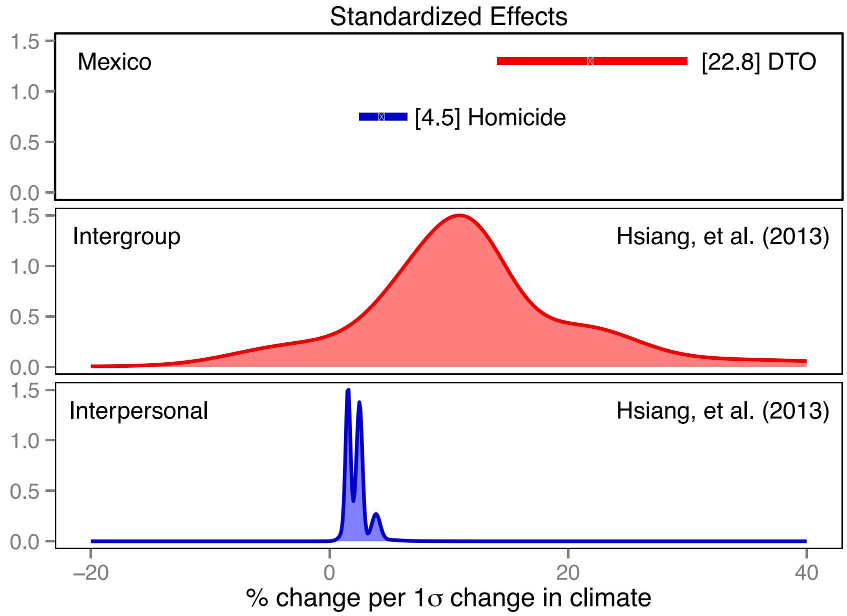

Fig. 4. Meta-analysis *Notes:* **Top panel** presents estimated standardized effects and confidence intervals from this study. **Bottom panels** show the distribution of standardized effects of climate on interpersonal (e.g. rapes) and intergroup (e.g. civil conflict) outcomes from Hsiang et al. (2013).

cides from Mexico lie within the expected distributions for intergroup and interpersonal conflict, respectively. In particular, in the existing literature a one standard deviation rise in temperature increases interpersonal violence by 4% and intergroup conflict by 14%, quite close to the 4.5% and 22.8% we estimate for homicides and DTO killings, respectively, in Mexico.

6. Economic factors

6.1. Other DTO criminal activities

Can economic factors explain the strong and robust relationship between temperature and violence in Mexico? In the absence of a way to experimentally manipulate the income of drug-trafficking organizations, we approach the problem indirectly. First, we study whether other (plausibly) economically-motivated DTO criminal activities also respond to temperature. Besides killings, drug trafficking organizations are also known for other criminal activities such as kidnappings, extortion, and car thefts. These crimes appear to have a clear economic motivation, and so if economic factors such as income are what is mediating how DTO violence responds to temperature, a similar temperature response might be evident in these similarly economically-motivated activities.

We assembled administrative data on the monthly occurrence of kidnappings, extortion, and car thefts during the period between January of 2007 and December of 2010. Unfortunately these data is not available at the municipality level but at the state level instead. Table 3 present the estimates of interest, and include our main results on DTO killings and homicides for comparison. Strikingly, we do not observe any significant relationship between temperature and these other criminal activities. In fact, estimated coefficients have a negative sign in the case extortions and kidnappings, although are not statistically significant, and the effect on car thefts is fairly small and not statistically significant. Temperatures appear to increase violent crime but not these other criminal activities.

6.2. Income, unemployment, and inequality

The first approach suggests that the observed relationship between temperature and violence cannot be explained by an economic mechanism. To further substantiate the argument that psychological factors drive the results, our second approach is to look directly at whether municipality-level income variables mediate the temperature-violence relationship. To do this, we augment equation (3) and include an interaction term between temperature and various measures of income or income inequality at the municipality level. In particular, we examine interactions with municipality-level income and with the municipality-level Gini coefficient.

Results are shown in Table 4. We find little evidence that these municipality-level measures of income mediate the temperature-violence relationship. For the per-capita income measure, the interaction has the expected sign for DTO killings, but is statistically insignificant and the coefficient is small: a one standard deviation increase in log GDP per capita, which we think of as being a fairly large increase in income, attenuates the effect of temperature on DTO killings by 13 percent

Table 3
Temperature and economically motivated crimes.

Dependent variable:	*DTO killings* (1)	*Homicides* (2)	*Car thefts* (3)	*Extortions* (4)	*Kidnappings* (5)
Temperature	0.050**	0.050**	0.067	−0.005	−0.001
	(0.024)	(0.023)	(0.092)	(0.004)	(0.001)
	[22.8]	[13.7]	[1.7]	[−4.5]	[−3.1]
Precipitation	0.080	−0.285	−0.363	0.220	0.060
	(0.447)	(0.411)	(2.430)	(0.255)	(0.036)
	[0.8]	[−1.7]	[−0.2]	[3.9]	[6.2]
Mean of dep. variable	0.737	1.217	13.414	0.407	0.070
(Within st. dev.)	(0.962)	(0.827)	(5.600)	(0.360)	(0.088)
Municipality, year & month F.E.	Yes	Yes	Yes	Yes	Yes
Observations	1536	1535	1535	1535	1534
R^2	0.649	0.714	0.886	0.603	0.392

Notes. Each observation corresponds to a state-month. Estimates using data for all states in Mexico in the period 2007 – 2010. All dependent variables are rates per 100,000 inhabitants. Source is *Secretariado Ejecutivo del Sistema Nacional de Seguridad Pública* (SESNSP). Standard errors clustered at the state level in parenthesis. Standardized effects in brackets. Levels of significance are reported as $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 4
Interaction with economic variables.

Dependent variable:	*DTO killings*				*Homicides*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Temperature	0.063**	0.059**	0.082**	0.060**	0.014***	0.016***	0.021***	0.016***
	(0.024)	(0.023)	(0.038)	(0.023)	(0.004)	(0.004)	(0.005)	(0.004)
× **Income (1990)**	−0.008				0.003			
	(0.011)				(0.002)			
× **Gini (1990)**		−0.007				0.001		
		(0.007)				(0.003)		
× **Houses with air conditioning (2010)**			−0.007				−0.002*	
			(0.006)				(0.001)	
× **Average temperature (1990–2010)**				-0.006				0.000
				(0.008)				(0.002)
Municipality F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	114,384	113,616	28,752	117,458	486,132	482,868	121,056	493,908

Notes. Each observation corresponds to a municipality-month. Estimates use data for the period 2007–2010 in columns 1–4 and for the period 1990–2006 in columns 5–8. Income and gini are own calculations using the 1990 Census. Houses with air-conditioning is data from *Encuesta Nacional de Ingresos y Gastos de los Hogares* in Mexico and it is available for a subsample of 600 municipalities. Standard errors clustered at the state level in parenthesis. Levels of significance are reported as $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

($-0.008/0.063 \approx 0.13$). The interaction in the homicide regression is also statistically insignificant, and is of the opposite sign than expected.

Another economic measures is economic inequality, measured here with time-invariant municipality-level Gini coefficients (constructed by Jensen and Rosas 2007). Income inequality has been argued in the literature to be an important driver of violence and conflict in different settings. But as shown in the table, it does not appear to substantially affect how either intergroup or interpersonal violence respond to temperature in Mexico. In the case of DTO killings, a one standard deviation in inequality decreases the effect of temperature on violence by roughly 12 percent, but it is not statistically significant.

Finally, we explore the mediating influence of two other variables that are typically correlated with income: the adoption of air conditioning (typically positively correlated with income), and municipality-level average temperature (negatively correlated with income across countries as well as across Mexican states).[16] Air conditioning could be viewed as an income-related adaptation, and as such could represent an alternative pathway through which higher incomes could break the link between temperature and violence.[17] The "mediating" effect of higher average temperatures on the response of violence to temperature deviations is perhaps more subtle. One the one hand, states with higher average temperatures might be more adapted to hot temperatures, and thus less effected by additional increases in temperature. On the other hand, if the under-

[16] Davis and Gertler (2015) find a positive relationship between household income and air conditioner adoption within warm areas of Mexico; adoption in cooler areas is close to zero.

[17] Barreca et al. (2016) find that the effect of higher temperature on mortality declined dramatically over the course of the 21st century in the United States. They show that the diffusion of residential air conditioning explains nearly all of this decline.

Table 5
Progresa transfers.

Dependent variable:	*DTO killings*			*Homicides*		
	(1)	(2)	(3)	(4)	(5)	(6)
Temperature	0.039**	0.039**	0.039**	0.012***	0.012***	0.012***
	(0.018)	(0.018)	(0.018)	(0.003)	(0.003)	(0.003)
Progresa transfers		−0.009	−0.009		0.003	0.004
		(0.013)	(0.013)		(0.012)	(0.012)
Progresa transfers × Temperature			0.001			−0.001
			(0.003)			(0.002)
Municipality F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Month F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Observations	88,092	88,092	88,092	262,992	262,992	262,992

Notes. Each observation corresponds to a municipality-month. Estimates use data for the period 2007–2010 in columns 1–3 and for the period 1998–2006 in columns 4–6. Progresa transfers is the total amount of transfers to a municipality divided by total population. Estimates restricted to the period 1998–2009, in which the program Progresa/Oportunidades was being implemented. Standard errors clustered at the state level in parenthesis. Levels of significance are reported as $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

lying temperature response is non-linear (as in agricultural productivity), then additional heat exposure on top of an already high mean should induce a more negative response.

Results of including air conditioning penetration or average temperature as interaction variables are show in columns 3 and 7 of Table 4. The evidence on whether either variable mitigates the temperature-violence response function is inconclusive. The estimates are not statistically significant, but we can bound the potential for mitigation: there is at most a 10–12% reduction in the effect as a response to an increase of one standard deviation in AC penetration. Thus we find little additional evidence of income-induced adaptation (at least through the AC channel), nor strong evidence that hotter average temperatures reduce impacts (through adaptation) or worsen them (through non-linearities).

6.3. Quasi-experimental variation in monetary transfers

Our third approach to studying the role of economic factors is to exploit the roll-out of a large-scale conditional cash transfer program, Progresa, which induced quasi-experimental variation in income across much of Mexico during our study period. Progresa is a very large program, with a budget of approximately 133 million USD in 1997 (roughly 0.03% of GDP), which has since expanded to almost 5 billion USD in 2010 (roughly 0.5% of GDP). In terms of the roll-out of the program, the government originally chose 320 treatment and 185 control rural villages. The former villages were located in 110 municipalities, were chosen at random, and received the first treatment in August 1998; the latter villages received the treatment two years later (Skoufias et al., 2001).

After 2002, municipalities treated first were presumably more vulnerable. This is because the government used a variety of methods to identify eligible households, including estimates of household income and self-selection methods with ex-post verification of eligibility (more details in Levy 2006). Nevertheless, because our estimation strategy employs local fixed effects, exploits the timing in the implementation of the program using monthly variation, and temperature shocks are unlikely to be correlated with program roll-out, this feature of the program should not bias our results.[18]

In terms of the data, we observe bimonthly transfers to every municipality during the period between January 1998 and December of 2009 from administrative sources. Importantly, cash transfers in this program targeted women with children, and so we cannot be certain the extent of income variation that the program induced among the population likely to participate in DTO related activities (young men).[19] Nevertheless, we augment our main regression equation by including the logarithm of Progresa transfers as an additional independent variable, and an interaction term between this variable and temperature.

Results from this exercise are presented in Table 5. First, transfers alone seem to decrease the rate of DTO killings, although the effect is relatively modest and not statistically significant: an *increase* of 10 percent in transfers *decreases* killings by 0.1 percent. The effect is smaller in the case of homicides and not statistically significant. Regarding the interaction term, the coefficient is also negative and marginally significant in the case of DTO killings, which suggests transfers also modestly decrease the local sensitivity of violence to temperature, but it is again a fairly precise estimated zero in the case of homicides.

In Figure A.5 we also incorporated an interaction term between leads and lags of Progresa transfers and temperature and we reach the same conclusion: transfers modestly decrease DTO killings, but only contemporaneously, these have no

[18] In fact, the results in this section are virtually identical in the Progresa phase (1998–2001, coef. -0.003, *p*-value 0.67) and the Oportunidades period (2002–2006, coef. -0.003, *p*-value 0.38).

[19] This is one reason our results likely diverge from Fetzer et al. (2019), who shows that the relationship between monsoon shocks and insurgent conflict is largely eliminated in India after the introduction of a public employment program (NREGA) that guaranteed wage labor to everyone.

effect on homicides, and the interaction term is marginally significant and negative only for the case of DTO killings. Overall, it seems that even large monetary transfers to poor households in a very high-profile anti-poverty social assistance program can only slightly reduce levels of intergroup violence and have no effect in the case of interpersonal violence – again subject to the caveat that we cannot be sure how much of this income reached those individuals likely to participate in DTO activities.

6.4. Harvest and growing season effects

Our final approach to exploring the role of economic factors is to study whether temperature shocks during economically critical periods have a greater impact on violence compared to shocks at other times in the year. In particular, as a substantial portion of the Mexican labor force continues to earn their living in agriculture (roughly 15%), and as agricultural income has been one of the most salient variables emphasized in the literature as a potential mediating factor between climate and conflict, we examine the effect of temperature during the growing and harvest seasons relative to during non-agricultural seasons. More precisely, we construct an indicator variable that takes the value of one for the months of April to September, which is considered the rainy season for the majority of Mexico and includes both the canicula and pre-canicula period.[20] The harvest season indicator variable, on the other hand, takes on a value of one during the months of October to December.

We perform two different analyses. In the first one, we simply augment our main regression equation with an interaction between temperature and the indicator variable for the growing season. Our expectation is that this interaction will be positive if agricultural income is a mediating factor and if agricultural incomes (e.g., wages) respond rapidly to changes in temperature. Given that these income shocks might occur with some lag, with hot temperatures during the growing season only showing up as negative incomes shocks after crops have been harvested a few months later, our second approach studies how violence in the harvest season reacts to temperature shocks during the growing season.

Results are shown in Table 6. We find that temperature shocks during the growing season appear to *reduce* DTO killings somewhat, the opposite of what the agricultural income story would suggest, with the coefficient on the interaction not significant at conventional levels. For the test on whether growing season shocks affect harvest season violence, point estimates for both DTO killings and homicides are positive, but standard errors are too large to be able to rule out either zero effect or large positive or negative effects. Finally, we also include interaction terms with the percentage of households living in rural areas and the percentage of workers in the agricultural sector, and find similar results. Taken as a whole, these results provide little evidence that agricultural income is the critical mediating factor.

7. The role of non-economic factors in violence

Results from Section 6 suggest that economic factors have only limited power to explain the observed effect between temperature and both intergroup and interpersonal violence in Mexico or to mitigate what we argue is at least in part a psychological channel. We find that changes in temperature do not affect other economically motivated non-violent crimes, that other measures of economic conditions such as municipality-level income do not predict the temperature response, that random variation in governmental income assistance have only a modest dampening effect, and that growing season temperature shocks are not differentially harmful. None of these results is definitive on its own, but together they suggest that economic factors are unlikely to be the driving force in explaining the large response of violence to temperature in this setting.

How can we directly show that psychological factors instead at least partially explain the link between temperature and violence? Because inducing experimental variation in these psychological factors is logistically challenging (and, arguably, ethically undesirable), our approach to understanding their potential role is again indirect. In particular, our basic approach is a “pattern-matching” exercise, where we study whether the response pattern of group violence to temperature matches the response pattern of another type of violence that is almost certainly lined to psychological factors – *intra*personal violence, i.e., suicide.

Suicide has long been understood to have a substantial psychological component. For instance, the medical literature tells us that psychiatric disorders are reported present in at least 90% of suicides (Mann et al., 2005), propensity toward suicidal behavior is strongly associated with genetic inheritance (Brent and Melhem, 2008), and randomized controlled trials suggest that suicide risk can be substantially shaped both by medications and by psychotherapy (Mann et al., 2005). Researchers have also long recognized the role that changes in temperature might play in shaping suicide risk, although the literature is currently inconclusive as to whether stark seasonal patterns in suicide (which characteristically peak during warm spring and summer months) are due to temperature per se or to other factors that also vary seasonally (see Appendix A.2 for a review of this literature).

Using an identical econometric strategy to that used for DTO killings and homicides above, and building on recent work in Burke et al. (2018), we begin by showing that suicides in Mexico also respond strongly to deviations from average temperature. The non-parametric relationship between suicide and temperature is shown in Fig. 5, and corresponding regression results are given in the first column of Table 7. As with DTO killings and homicides, the temperature-suicide relationship

[20] Canicula is a mid-summer drought period in Mexico. Both the growing and harvest season were specified following Skoufias (2012), who examines the effect of weather shocks on household welfare in Mexico.

Table 6
Interaction with agricultural variables.

Dependent variable	*DTO killings*					*Homicides*				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Temperature	0.058**	0.068***	0.060***	0.058***	0.057***	0.016***	0.013**	0.015***	0.015***	0.013**
	(0.022)	(0.020)	(0.016)	(0.017)	(0.015)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)
× Growing season indicator		-0.022					0.005			
		(0.043)					(0.006)			
× Households in rural areas (1990)			0.002		0.012			−0.000		0.002
			(0.011)		(0.017)			(0.002)		(0.003)
× Workers in agricultural sector (1990)				0.000	−0.001				−0.000	0.002
				(0.009)	(0.012)				(0.002)	(0.003)
× Workers × Rural					0.006					0.002
					(0.007)					(0.002)
Municipality F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	117,458	117,458	115,008	115,008	115,008	493,908	493,908	488,784	488,784	488,784

Notes. Each observation corresponds to a municipality-month. Estimates use data for the period 2007–2010 in columns 1–5 and for the period 1990–2006 in columns 6–10. Growing Season as an indicator for the months of April to September; this is considered the wet season for the majority of Mexico and includes both the canicula and pre-canicula period. Canicula is a mid-summer drought period in Mexico. The harvest season is during the months of October through December. We specified these months following Skoufias (2012) who look at the effect of weather shocks on household welfare in Mexico. All regressions control for **precipitation** and are weighted by population. Standard errors clustered at the state level in parenthesis. Levels of significance are reported as $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 7
Temperature and suicides in Mexico. *Dependent variable is suicides rate per 100,000 inhabitants.*

Economic variable:	None (benchmark)	Income	Gini	Houses with air conditioning	Municipality average temperature	Progresa transfers	Growing season	Households in rural areas	Workers in agricultural sector
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Temperature	0.007***	0.006***	0.007***	0.005***	0.007***	0.009***	0.009***	0.007***	0.006***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
×*Economic variable*		0.001	0.000	0.001	0.001	−0.001	−0.004**	−0.000	−0.001
		(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)
Economic variable		–	–	–	–	−0.009*	−0.004	–	–
						(0.005)	(0.010)		
Municipality F.E	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month F.E	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	493,908	486,132	482,868	121,056	493,908	262,992	493,908	488,784	488,784

Notes. Each observation corresponds to a municipality-month. Estimates use data for the period 1990–2006 except in column 6 in which we use data for the period 1998–2006. Standard errors clustered at the state level in parenthesis. Levels of significance are reported as ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

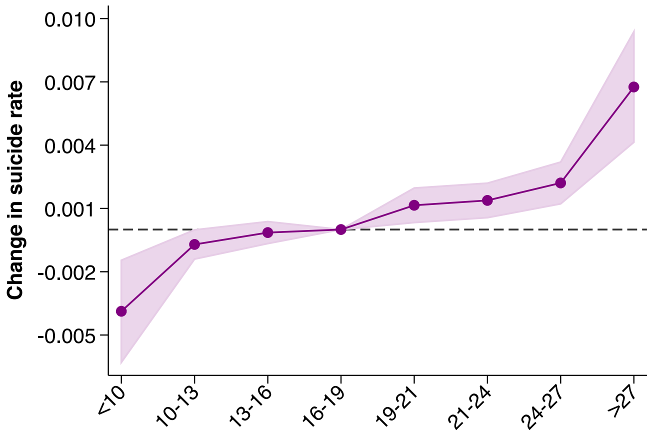

Fig. 5. Temperature and suicides *Notes*: This figure presents non-parametric estimates of equation (3). These temperature response functions use bins of width 3 °C. The *x*-axis is interpreted as the average temperature in a given municipality-month, and the *y*-axis is interpreted as deviation from that municipality-month average in suicides per 100,000 inhabitants.

appears strongly linear, with an estimated standardized effect of a 7% increase in suicide per σ increase in temperature (Table 7). This estimate falls between the estimated effects for DTO killings and homicides. As with these latter outcomes, the suicide response also appears fairly homogenous across states, with positive estimates in all but 2 states (see Figure A.2-C).

As with DTO killings and homicide, we then explore whether the temperature-suicide relationship is mediated by economic factors. This is, in essence, a further gut check on whether suicide is a fair "benchmark" for an outcome that we presume is mainly non-economic in nature. Results from including interactions with income, inequality, Progresa transfers, and growing season temperature are shown in the remaining columns of Table 7. Most coefficients on interactions are small and statistically insignificant, and the two interactions with statistical significance have signs that go in the opposite direction than what the typical income story would suggest: higher average incomes appear to slightly worsen the impact of hot temperatures, and hotter-than-average growing seasons appear to reduce the impact of temperature.

As a final pattern matching exercise, we study the temporal pattern of how intergroup, interpersonal, and intrapersonal violence respond to temperature, using the leads/lags approach described in Eq. 4. As discussed above, studying the temporal pattern of responses can help shed additional light on mechanisms, since income effects might be expected to show up with some lag in monthly data but physiological effects should show up immediately. Studying lags also allows us to understand whether contemporaneous effects are simply "displacement", causing violence to occur earlier than it would have otherwise, but not changing the overall level of violence. Studying leads offers a simple placebo test, as idiosyncratic variation in future temperature should not affect current violence.

Results from estimating Eq. 4 on all three outcomes are shown in Fig. 6, with point estimates and confidence intervals for contemporaneous effects, 6 lags, and 6 leads plotted for each outcome (for instance, a value of "-1" on the x-axis corresponds to the effect of temperature in month $t-1$ on violence in month t). Although estimates are again more imprecise for DTO killings due to the smaller sample size, a number of common patterns are apparent. First, statistically significant effects occur only in contemporaneous periods for all three outcomes. That is, the most robust predictor of violence in a given month is temperature in that month, suggesting that the primary effects of temperature are immediate. We interpret this as additional evidence in favor of physiological mechanisms, since these would be expected to respond immediately to temperature change.

We also find evidence of some displacement, with lagged coefficients for both homicide and suicides negative and (for suicides) significant. In absolute value, these coefficients are about 1/3rd the size of the contemporaneous effects, suggesting that roughly one-third of the temperature-induced increase in homicides and suicides were events that were likely to have occurred anyway. Interestingly, we do not see a similar pattern for DTO killings, although generally larger standard errors on the DTO estimates limit our ability to say anything very precise. Finally, results on the leads (our placebo test) are largely reassuring, with most point estimates of the 6 leads near zero and none statistically significant. There are thus two imperfect but consistent pieces of evidence that non-economic factors could explain some of the temperature-violence relationship. The first is that a known psychologically-dependent outcome, suicide, responds in a strikingly similarly way to changes in temperature. We view the extent of this similarity as unlikely if suicide did not share some underlying commonalities in terms of mechanism with these other forms of violence. The second is that the effect of temperature on all types of violence that we measure is immediate – i.e., that it occurs in the same month as the temperature shock – which is inconsistent with the most obvious income-related stories in which temperature reduces agricultural output, given that the period in which crops are sensitive to temperature is temporally disjoint from the period in which harvest income is realized. Again, each of these pieces of evidence on their own might not be convincing, but together they suggest a substantial

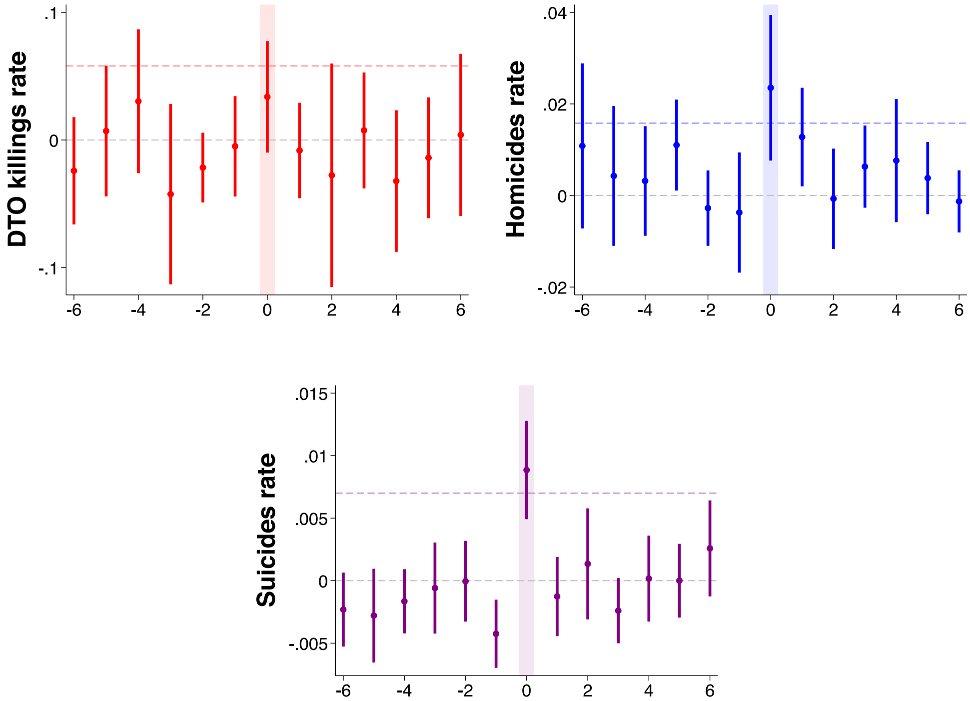

Fig. 6. Temporal distribution of estimates *Notes:* This figure shows regression estimates β_{t+k} from Eq. 4.

role for non-economic factors in explaining how both intergroup and interpersonal violence in Mexico respond to changes in temperature.

8. Conclusion

Using municipality-by-month variation in temperature, we find significant contemporaneous effects of temperature on DTO killings, homicides, and suicides in Mexico. Estimated effects are economically meaningful for each outcome, and imply that temperature can induce large additional increase in violence on top of already high baseline levels of both DTO killings and homicides. This is the first study to our knowledge to find such a similar relationship across a spectrum of violence outcomes in a single setting, and our estimated effects are surprisingly consistent with existing estimates in the literature from other contexts.

Using a variety of approaches and data, we assess whether non-economic factors are contributing to the results. A constellation of evidence, including the limited influence of a cash transfer program as well as comparison with economically-motivated non-violent DTO crimes, indicate that economic factors can at best only partially explain the observed relationship between temperature and violence or mitigate what we argue is a psychological channel. We present two pieces of more direct evidence that suggest a role for non-economic factors in explaining the temperature-violence link for group- and interpersonal violence: the substantial similarity between how these outcomes respond to temperature and how suicide responds to temperature, and the immediacy of the response of these variables to changes in temperature.

We draw two tentative policy implications from our findings. The first is that, at least in this particular setting, standard economic interventions might not be an effective tool for shaping how violence responds to changes in climate. Second, our results are equally pessimistic on the role for adaptation in shaping this response, with neither higher average income levels nor specific interventions that alter how individuals experience climate (i.e., air conditioning) appearing to affect how violence responds to temperature. More speculatively, reducing future temperature increases through emissions mitigation, rather than trying to induce adaptation through policy intervention (or hoping that it will occur on its own), thus unfortunately may be the most fruitful strategy in this setting for limiting the violent consequences of future climate change.

Declaration of Competing Interest

None

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jebo.2019.10.021.

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