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JEL Classification: I14, K42, P52, Q54

Keywords: Violence, Gender Homicide, Extreme Temperatures, Russia

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Extreme Temperature and Extreme Violence across Age and Gender: Evidence from Russia

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Abstract

We examine the relationship between extreme temperatures and violent mortality across Russian regions, with implications for the social costs of climate change. We assess the unequal impact of temperature shocks across gender and age groups by exploring a dataset on temperature and violence in Russia, between the years 1989 and 2015. Hot days lead to an increase in both female and male victims, one hot day resulting in the loss of 1,579 person-years of life for men, and 642 for women. However, the likelihood of victimization during weekends rises noticeably for women, with women between 25 and 59 more victimized on weekends. Our results suggest that female victimization on hot days would be mitigated by increases in regional income and job opportunities, and on cold days, by decreasing the consumption of spirits.

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"For now, these hot days, is the mad blood stirring."

William Shakespeare, *Romeo and Juliet,* Act 3, Scene 1

1. Introduction

"[T]he prime time for murder is clear: summertime", states *The New York Times.* Heightened social interactions and the presence of biological and psychological triggers that prompt violence partially explain why, "in the summer months, the bad guys tend to be deadliest."[1] Global climate change is persistently debated in policy circles and in the media. Beyond the physical changes in the Earth's environment, it is important to examine possible changes in human behavior with social and economic consequences. Documenting the empirical link between rising temperatures and specific social consequences is a crucial, but demanding task. In spite of a growing body of research suggesting that climate change fosters conflict and warfare,[2] the literature has so far barely examined how uncomfortably high and low temperatures prompt violent and aggressive individual behavior, the most ubiquitous weather-behavior linkage put forward in biology and psychology.[3] Violent acts by individuals are hard to predict, so that any information that helps us reduce victimization is important.

This paper examines the impact of hot and cold days on violent mortality and its unequal incidence across gender and age groups by exploring a dataset on temperature and violence across 79 regions of the Russian Federation between 1989 and 2015. Russia has one of the

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[1] See Lehren and Baker (2009).

[2] See, for instance, Burke et al. (2009), and Hsiang et al. (2011). Weather shocks plausibly impact political stability. Burke and Leigh (2010) and Bruckner and Ciccone (2011) document that weather shocks appear to lead to democratization. Dell et al. (2012) show that adverse temperature shocks increase the probability of irregular leader transitions (i.e. coups).

[3] Anderson (1989, p. 74) first claimed the effects of climate on aggression is "not trivial in magnitude nor a simple by-product of aggression opportunity". The first comprehensive study of the impact of climate change on crime was presented by Ranson (2014), who analyzed US historical data, estimated the relationship between weather and crime, extrapolating long-term effects for different scenarios.

highest incidence rates of violence.[4] We draw on the cultural, geographic, and climatic diversity of the Russian Federation to estimate the likely impact of an additional high and low temperature day on violent acts. These are violent individual acts leading to death occurring in the course of daily life interactions, not driven by political or social unrest. The relevance of our results cannot be escaped, especially as the effects of change may become more acute, and, as suggested by other studies, the impact of hot days on mortality may be greater in developing countries.[5]

Though only the "tip of the iceberg", evaluating the impact on murders overcomes, in part, the underreporting of physical violence and associated consequences, including psychological violence, the latter being, naturally, also important.[6] We find that days with average temperatures above 25°C lead to an increase in both female and male victims, while days with lower temperatures do not affect violent mortality.[7] The likelihood of victimization during weekends, as opposed to workdays, rises noticeably for females, suggesting different contexts for the emergence of violence. Our results are consistent with the exposure model developed by criminologists, as explained below, which predicts that violence increases against women who spend more time at home, with potentially violent partners, such as during weekends. The findings also suggest that in regions that are poorer, less developed, and with higher consumption of spirits, the likelihood of female victimization during both hot and cold

[4] According to Soares and Naritomi (2010) Russia is burdened by the largest present value social cost of violence from reduced life expectancy as a share of GDP, immediately after Latin America and the Philippines. Our unique dataset allows us to examine violence perpetrated against women and against men across age groups, on weekdays, and on weekends.

[5] Burgess et al. (2017) repeat the exercise in Deschênes and Greenstone (2011) for India and find that an additional day with temperatures exceeding 36°C leads to a rise in the annual mortality rate in India that is about seven times higher than for the United States. These are computed relative to a day in the 22–24°C range.

[6] Cerqueira and Soares (2016) show results indicating that the total welfare cost of homicides in Brazil corresponds to about 78% of Gross Domestic Product, and the yearly welfare cost is about 2.3%.

[7] Deschênes and Greenstone (2011) document the relationship between daily temperatures and annual mortality rates, with both relationships exhibiting nonlinearities, with significant increases at the extremes of the temperature distribution. The estimates in Deschênes and Greenstone (2011) suggest that climate change will lead to an increase in the age adjusted US mortality rate of 3 percent by the end of the twenty-first century.

days is greater. This suggests that improving economic conditions may help to mitigate the harmful effects of temperature shocks.

The remainder of the paper is organized as follows. Section 2 discusses the relationship between violence and weather. Sections 3 and 4 describe the data and the methodology, respectively. Estimation results are presented in Section 5. Section 6 presents mitigation strategies, while Section 7 presents sensitivity checks. The last section offers conclusions.

2. Literature Review

2.1. Weather and Violence

Becker´s model, the canonical model of crime, implies a decrease in crime on hot days, if heat increases the cost of supply of crime.[8] But explaining violence requires going beyond strictly-rational explanations for violence, and admitting that violence is not purely instrumental; it may occur as an impulse, not just the result of a search for greater individual utility. External conditions, including weather conditions, have been shown to affect human judgment and facilitate aggression.[9] Experimental evidence strongly suggests that ambient temperatures impact the psychological propensity to commit violent criminal acts, as shown in Anderson (1989), and Baron and Bell (1976). If we address not just crime but violence, the mechanism present in standard models of criminal behavior is further distanced from motivations for domestic and workplace violence, even violence on public occasions and festivities. Benefits and deterrents are blurred, and documenting the direct relationship between temperatures and violence is a key first step.

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[8] In Becker (1968), an individual´s decision to commit a crime is based on rational consideration of the costs and benefits of the act. In this model, the weather is an input that affects the probability of successfully completing a crime and the probability of escaping undetected thereafter.
[9] See Ranson (2014), who refers to Card and Dahl (2011) and Baumeister and Heatherton (1996).

While novel to the economics literature, a considerable number of studies in psychology and physiology associate hot temperatures and aggressiveness.[10] In periods of hot ambient temperature, police officers tend to be more aggressive toward suspects, as pointed out in Vrij et al. (1994), strikes and job quits are more frequent (Simister and Cooper, 2005),[11] drivers sound their horn more often (Kenrick and MacFarlane 1986), and even baseball pitchers hit batters more often (Larrick et al., 2011; Reifman, Larrick, and Fein, 1991). Researchers such as Jacob et al. (2007) and Ranson (2014) have uncovered a positive association between hot weather and different types of crime. Further, Rotton and Cohn (2004) find that in air conditioned locations aggravated assaults are not as likely during hot weather.

There are three possible explanations for weather as a driver of aggression: biological, psychological, and, third, social. These explanations are naturally interrelated.[12] The biological explanation is summed up in Simister and Cooper (2005), who suggest that the human body reacts to both extremely cold and extremely hot temperatures by producing stress hormones, including adrenaline, noradrenaline, and testosterone. Also according to these authors, hot temperature increases the blood level of adrenaline and noradrenaline in both men and women, leading to the expansion of the blood vessels, increased heart rate and blood pressure, stimulated respiration, focused attention, and heightened anxiety. These same bodily effects are also present when the human body and human brain need to mobilize for action and possible aggression,

[10] For a detailed discussion see Anderson (1989), which is the major literature review on temperature and aggression. According to Anderson (1989), most field studies suggest that heat is associated with more aggression. “First, temperature effects are direct; they operate at the individual level. Second, temperature effects are important; they influence the most antisocial behaviors imaginable.” (Anderson 1989, p. 94). In addition, “[h]otter regions of the world yield more aggression; this is especially apparent when analyses are done within countries. Hotter years, quarters of years, seasons, months, and days all yield relatively more aggressive behaviors” (Anderson 1989, p. 93).

[11] In the 1960s, “U.S. government officials noted that riots were more likely to occur in warmer weather, and subsequent analysis confirmed this relationship” (Dell et al., 2014, p. 768, who refer to Carlsmith and Anderson, 1979; U.S. Riot Commission, 1968).

[12] According to Pakiam (1981), a multiple causation theory of crime prevails, whereby “anthropological-biological, socio-economic and physical environmental causes are possible, with a crime finally being triggered by appropriate psychological and physiological changes” (p.185).

during stressful or dangerous situations.[13] A third hormone, testosterone, is activated during hot weather, and ten times more so in men than in women. Moreover, the interaction of noradrenaline and testosterone fosters aggression (Kemper, 1990).

A second link between heat and crime is psychological. Anderson (1989) suggests that violent crime and aggressive behavior during extreme temperatures are driven by an emotional or instinctive state of arousal of the nervous system. As stated by Anderson (1989, p. 77), "temperature-sensitive cells are connected directly (i.e. neurally) and indirectly (i.e. hormonally) to a variety of systems that control a variety of bodily and emotional functions". Anderson (1989) argues that both extremely hot and cold temperatures are uncomfortable for the human body, facilitating aggression. However, while the relationship between hot temperatures and violence is supported by early laboratory experiments, as in Baron and Bell (1976), findings related to cold temperatures are inconclusive.[14]

A third possible explanation for the relationship between heat and aggression is an increased frequency in social contacts (Anderson, 1989). As people spend more time outside, get together in larger numbers, and go on vacations, opportunities for violent interactions increase. However, Anderson (1987) and Rotton and Frey (1985) find no empirical support for the interactions-violence explanation. The impact of extreme temperatures on aggression and crime is not necessarily mediated by the frequency of social contacts.

[13] Cold temperature increases noradrenaline levels, not adrenaline, according to Frank et al. (1997) and Sramek et al. (2000). Noradrenaline is associated with higher anger levels (Simister and Cooper, 2005). It is a hormone that prevents heat loss by contracting blood vessels, reducing the heart rate, and increasing metabolism. Generally, hot temperatures are more closely related to hormone activation than cold temperatures, as warm clothes reduce the body stress stemming from the cold (Anderson, 1989). Also, cold temperatures are associated with natural obstacles to violent crime such as lower mobility due to drift or snow, closed doors and windows, etc. (Ranson, 2014; Vrij, Van Der Steen, and Koppelaar, 1994).

[14] This may stem from contradictory effects of neurotransmitters: while the increase in the level of serotonin during cold weather slows aggression down (Reis 1974), another neurotransmitter, acetylcholine, triggers aggression (Myers 1974). Any possible link between precipitation and crime has also been less evident in the criminology literature, as pointed out by Wright and Miller (2005). Jacob et al. (2007) employ a fixed effects panel specification and US data to find that higher temperatures increase both violent and property crime, but higher precipitation does not. Actually, precipitation is associated with a reduction in violent crime.

Early psychological studies suggest a positive correlation between hot temperatures and crime in the US (Anderson, 1987; Rotton and Frey, 1985, Ranson, 2014). Rotton and Frey (1985) find a positive correlation between hot temperatures and assaults, while Anderson (1987) suggests that this correlation is stronger for violent crimes against other persons - e.g. murders, rapes, and assaults, than for violent crimes against property - e.g. robbery, burglary, larceny theft, and motor vehicle theft. In a study using daily data of eleven eastern cities in the United States, Curriero et al. (2002) find higher mortality on very cold days and very hot days, with the negative impacts of hot days occurring primarily in northern cities.[15]

The circumstances behind violent acts differ widely, but it is reasonable to consider whether victimization falls more heavily on specific gender and age groups, and what may be the forces behind that inequality. Cerqueira and Soares (2016) point out that incorporating heterogeneities such as age and gender has important effects on the estimated welfare cost of deadly violence, leading to a 23% upwards correction in total costs.

2.2. Inequality Across Gender

Violence toward women is both a cause and a consequence of gender inequality. The unequal victimization of women is related to different issues, the first of which is the prevalence of domestic violence. Much of the violence that victimizes women occurs in the home, or in connection with close relationships. Multi-country studies show that 15% to 75% of all violence against women is perpetrated by a spouse or domestic partner (Garcia-Moreno et al., 2006; Hindin, Kishor, and Ansara, 2008; Hidrobo and Fernald, 2013; Aizer, 2010).[16] For Russia, Volkova et al. (2015) estimate that 70% to 80% of serious violent crimes, and 30% to 40% of

[15] Ranson (2014) also suggests that most crimes are significantly reduced during cold weather (at 0°F), with the exception of murders and vehicle thefts.

[16] Aizer (2010) exploits exogenous changes in the demand for female labor and shows that decreases in the wage gap reduce violence against women in the U.S. According to the recent report by the International Labor Organization (2016), the gender wage gap in Russia is 1.5 times greater than in the US and reaches almost 30%.

murders are committed in the family, with upwards of 10,000 women killed by their husbands or companions.

Second, domestic violence responds to different cues, all of which may be more prevalent at certain periods, such as weekends. Card and Dahl (2011) classify intra-family violence by men as "instrumental" or "expressive" behavior, the first with the aim of exercising control over partners and children and the second, a response that, in itself, provides utility or arises unintentionally in family arguments. Both triggers for violent behavior are more likely to occur during weekends, when family interactions increase, including the emotional cues leading to violent behavior. Gantz, Bradley, and Wang (2006) find that National Football League (NFL) game days are associated with higher rates of family violence in the home cities of NFL teams. Card and Dahl (2011) uncover a link between emotional cues associated with the results in games of professional football in the United States and domestic violence. They find that upset losses result in a 10% increase in the rate of at-home violence by men against their female partners. Other "cues", such as a history of violence, may be relevant. La Mattina (2017) shows how domestic violence increases in the wake of civil conflict, in tandem with reduced bargaining power for females. In Russia, arguably, there has been a particularly high historical incidence of violence, associated with the incidence of World War II, as well as the violent behavior of a long-lived totalitarian regime.

Third, economic difficulties may increase the incidence of domestic violence. Transfer programs in which income is accrued to the woman's budget have been shown to decrease the incidence of spousal abuse.[17] Fourth, excessive alcohol consumption is often associated with

[17] See Aizer (2010) and Bobonis et al. (2013). The latter found, for targeted transfer programs in Mexico, that beneficiary women are 40% less likely to be physically abused by their partners. Hidrobo and Fernald (2013) study Ecuador's cash transfer program and show that women with greater than primary school education benefit from a decrease in exposure to psychological violence, but for women with primary school education or less, the cash

male violent behavior, as suggested in Carpenter and Dobkin (2011) and Luca et al. (2015).[18] Fifth, examining direct victimization alone may underestimate the unequal effects of violence on women. Gender violence may affect labor market outcomes through mechanisms such as psychological costs, including depression and anxiety disorders, and diminished human capital acquisition, but also through physical health consequences and stigmatization, leading to lower probability of successful partnership.[19]

Several papers have estimated the effects of domestic violence on children, including poorer reading and math scores and misbehavior by children in troubled families - Carrell and Hoekstra (2010), and poorer health status of newborns - Aizer (2011). The consequences of these may also fall more heavily on women, as they bear an unequal burden as to caring for children. Cerqueira and Soares (2016) suggest that their computations underestimate the cost of violence, as they ignore morbidity as an outcome of violence, intangible costs associated with fear, and changes in habits to avoid victimization, some of which have a greater incidence among women.

2.3. Inequality Across Age

For different reasons, related or unrelated to gender, older individuals may suffer differential rates of victimization. Otrachshenko et al. (2017) investigate the impact of days with hot temperature on all mortality causes, as well as cardiovascular-caused mortality, and respiratory-caused mortality. They find that the adult, but not old, are the most affected, and people over 60 are relatively less affected (p. 295). This may suggest that violence victimizes the old more acutely. Using data from the 1990s, Soares and Naritomi (2010) find that the incidence

transfer significantly increases emotional violence in households where the woman's education is equal to or higher than her partner's.

[18] Carpenter and Dobkin (2011) suggest that regulating the minimum legal drinking age reduces alcohol consumption, mortality, and crime rates. Luca et al. (2015) find that state-level alcohol bans in India reduce male's alcohol consumption and result in lower rates of domestic violence against women.

[19] Sabia et al. (2013) study sexual violence in the US and find that due to adverse psychological and physical consequences, female victims participate in the labor force less and receive lower wages.

of violence in Latin America, noticeably in Colombia, Brazil, and Mexico, the most violent countries, is concentrated in prime age.[20] The same is true for the United States,[21] while Russia has a later age profile, with groups around 40-45 the most victimized. For all countries mentioned, except Russia, most violence is gang-related.

There is, however, evidence that older women may be especially targeted. Miguel (2005) finds that negative income shocks are associated with a large increase in the murder, by relatives, of elderly women, but not other population groups. Changes in the age profile of victims may be affected by the gender ratio. La Mattina (2017) finds that part of the higher incidence of domestic violence is driven by changes in the gender ratio over time and across localities. In Russia, the difference between male and female life expectancies may be a factor, as well as the evolution of relative health status between males and females, with the latter seeing their health degrading more rapidly over time.

3. Data

We use annual data on violent mortality rates in 79 regions of the Russian Federation for the period from 1989 until 2015 from the Russian Federal State Statistics Service.[22] According to the International Statistical Classification of Diseases and Related Health Problems (ICD) by the World Health Organization, violent death is defined as a death from homicide and injury

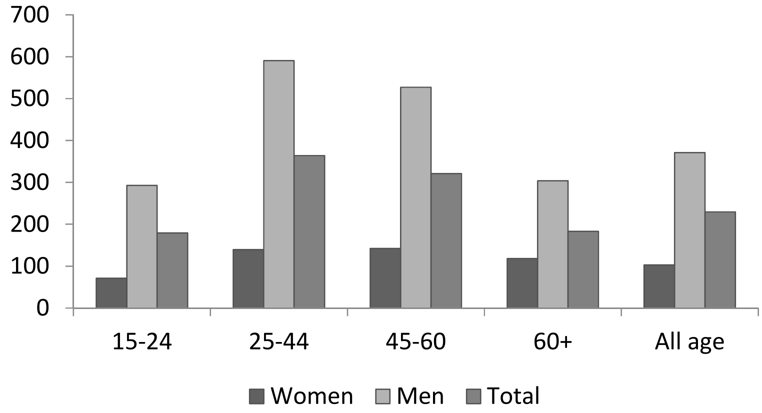
[20] Cerqueira and Soares (2016) explore data from Brazil and find that men in their 20s are about 10 times more exposed to homicide than women of similar age. Also, men in their 20s are three times more likely to be victims of homicide than men in their 40s. In Russia, men in their 20s are about five times more exposed than women of the same age, and as exposed as men in their 40s. These are authors' calculations based on the Russian Fertility and Mortality Database (RusFMD 2016).

[21] Levitt (1999) shows that changes in the age structure of population explain the increase in murder rates in the US. The author finds that a 1% increase in the share of young in the population increases the homicide rate by 0.41%.

[22] Our dataset includes all regions of the Russian Federation with the exception of autonomous districts that are included in larger territorial units, i.e. the Khanty-Mansi Autonomous District – Yugra and the Yamalo-Nenets Autonomous District, which are part of a larger Tyumen oblast, the Nenets Autonomous District, which is a part of the Arkhangelsk oblast. Also, data for the Chechen Republic are not available.

purposely inflicted by other persons, including legal execution.[23] Figure 1 presents the violent mortality rates per million of population across gender and age groups in 1989-2015.

Figure 1
Average Annual Violent Mortality Rate
Across Gender and Age groups
Per Million – Russia - 1989-2015.

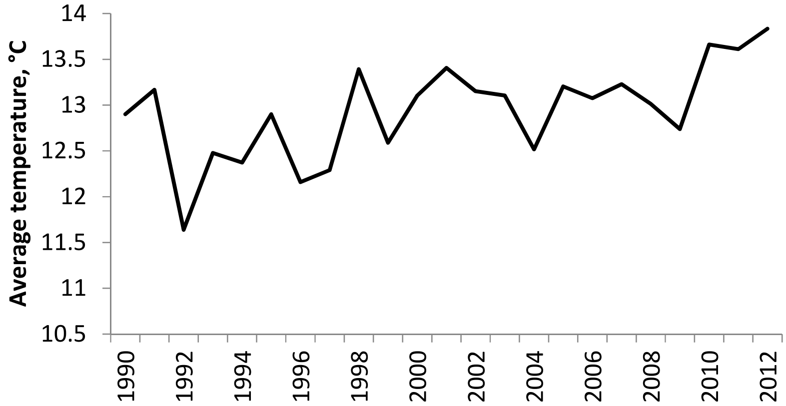


Source: Authors' computations based on data from the Federal Statistical Service of the Russian Federation. Violent mortality rate measured per million persons of the corresponding age group is presented.

According to the World Bank, the annual average temperature in Russia from 1990-2012 was -5.4°C. The warmest month is July, with the average monthly temperature 15.1°C, while the coldest month is January, with -25.2°C. As shown in Figure 2, the average summer temperature in Russia from 1990-2012 was about 13°C with an upward trend.

[23] The death penalty has been indefinitely suspended and not executed in Russia since 1996. According to archival data, in the period 1991-1996, 163 persons were executed; this is 0.07% of the total violent mortality in Russia during this period.

Figure 2
Average Monthly Temperature in June-August
Centigrade - Russia - 1990-2012



Source: Authors' construction based on data from the Climate Change Knowledge Portal of the World Bank.

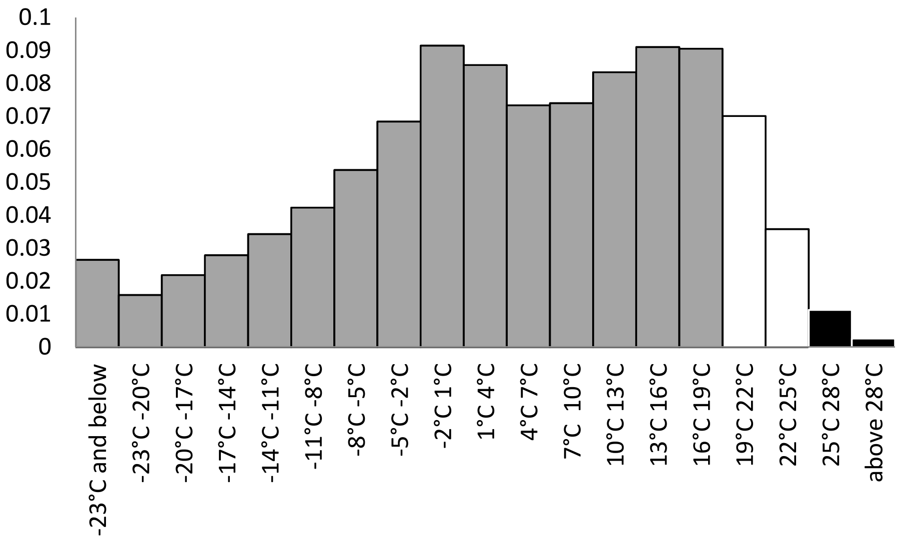
The data on average daily temperature and precipitation are collected from 518 meteorological ground stations and are weighted by an inverse distance square from the nearest population settlement within a 200 km radius. The settlements within a region are then weighted based on their population. Ground stations that are closer to settlements with a larger population thereby receive the largest weight. This approach gives us the weather experienced by an average person in a region (Hanigan, Hall, and Dear 2006; Dell, Jones, and Olken 2014).[24]

Figure 3 shows the distribution of days with a particular mean daily temperature in Russia from 1989 to 2015. As shown in this figure, the temperature spectrum is divided into 3-degree centigrade intervals. For the empirical analysis, these intervals are constructed for each region and each year. Each interval presents the frequency of days with a particular temperature within a region and year. In Figure 3 the white bars stand for the frequency of days with the (19°C, 22°C] and (22°C, 25°C] temperature ranges, which are the most comfortable temperature

[24] An alternative approach is to use the area-weighted weather data, which gives "the average weather experienced by a place" (Dell et al. 2014, p.751). As suggested by Dell et al. (2014), this approach is less preferred for countries with large scarcely populated regions, e.g. the US and Russia.

limits and used as default. The black bars stand for the frequency of days with the (25°C, 28°C] and above 28°C temperature ranges, showing the extremely hot temperature. Overall, only two thirds of the regions have experienced days above 28°C, and the average number of days with such temperature is 0.97 per year in our sample. Thus, in our analysis, we combine the days above 25°C into one interval.

Figure 3
Distribution of Days across Temperature Ranges
Russia - 1989-2015



Source: Authors' computations. *Notes:* The intervals in white, (19°C, 22°C] and (22°C, 25°C], the most comfortable temperature limits, are used as default. The intervals in black, (25°C, 28°C] and above 28°C, show the extremely hot temperature.

The data on mean daily precipitation within a region and a year are divided into terciles: [0 mm, 10 mm), [10 mm, 20mm), and between 20 mm and above. The precipitation interval [0 mm, 10 mm) is used as a default. In case of both temperature and precipitation, the numbers of days per year is standardized to 365 days.

4. Methodology

To examine the impact of weather on violent mortality, we follow the econometric approach suggested by Deschênes and Greenstone (2011), Burgess et al. (2017), and Otrachshenko et al. (2017) and (2018). The econometric model is estimated for each gender separately and is as follows:

$$Violence_{rt} = \beta_0 + \sum_{j=1}^{J=17} \beta_j \, TempBin_{rt} + \sum_{k=1}^{K=3} \delta_k \, PrecBin_{rt} + \boldsymbol{\alpha_r} + \boldsymbol{\gamma_t} + \boldsymbol{\Phi'\alpha_r} * Trend + \varepsilon_{rt} \quad (1)$$

where the subscripts *r* and *t* stand for a region and year, respectively. $Violence_{rt}$ is violent mortality rate per million persons in a region *r* and year *t*. The temperature spectrum is divided into 3-degree centigrade intervals, yielding 17 intervals with a particular temperature: below -23°C, (-23°C, -20°C], (-20°C, -17°C], (-17°C, -14°C], (-14°C, -11°C], (-11°C, -8°C], (-8°C, -5°C], (-5°C, -2°C], (-2°C, 1°C], (1°C, 4°C], (4°C, 7°C], (7°C, 10°C], (10°C, 13°C], (13°C, 16°C], (16°C, 19°C], (19°C, 25°C], and above 25°C. $TempBin_{rt}$ stands for the number of days in a region *r* and year *t* in which the mean daily temperature fell in the *j-th* of the 17 intervals. The temperature interval (19°C, 25°C] is used as a default. Similarly, $PrecBin_{rt}$ stands for the number of days in a region *r* and year *t* in which the mean daily precipitation fell in the *n-th* of the 3 intervals: [0 mm, 10 mm), [10 mm, 20mm), and between 20 mm and above. The precipitation interval [0 mm, 10 mm) is used as a default.

$\boldsymbol{\alpha_r}$ are regional fixed effects. The fixed effects estimation controls for region-specific time invariant unobserved factors that may affect regional violent mortality rate, e.g. the region-specific quality of medical facilities or characteristics of regional penitentiary system. $\boldsymbol{\gamma_t}$ are time fixed effects that control for time varying factors common across all regions, e.g. the health sector or law enforcement reforms. *Trend* is a linear time trend. The interaction term $\boldsymbol{\alpha_r}$ *

$\boldsymbol{Trend}$ accounts for any region-specific linear time trends that may affect violent mortality rate and also correlate with climate, e.g. trends in regional criminal environment. $\boldsymbol{\varepsilon_{rt}}$ is a stochastic disturbance term while $\boldsymbol{\beta}, \boldsymbol{\delta}, \textbf{and } \boldsymbol{\Phi}$ are the vectors of the model parameters. Standard errors are clustered at a regional level and are robust to heteroskedasticity. We discriminate the impact across gender and age groups and across work days and weekends. Relevant population weights are used for all regressions. We also compute years of life lost by a victim that are due to the impact of one hot day (above 25°C). That is, how many years a victim would live if she/he were not murdered.

We provide several sensitivity checks. First, we estimate Eq. (1) for the post-transition period (2000-2015) only. Second, we include the lagged violence rate in Eq. (1), since it might be the case that in regions with high current violence rates, we should expect high violence rates in the next year. Finally, we split the above 25°C temperature bin into the 25-28°C and above 28°C temperature bins to investigate whether the impact on violence is greater for higher temperatures.

5. Estimation Results

In this section we present all results from Eq. 1. All regressions are weighted by the corresponding population and robust standard errors are clustered at a regional level.

Table 1 presents the impact of one day with a particular range on violence against both genders. We find that, indeed, one day with an average temperature above 25°C is associated with a higher prevalence of extreme violence, while days with an average temperature lower than 25°C have no impact. This is true in the case of the total number of victims as well as female or male victims.

Table 1
Impact of Temperature on Total Homicide
By Gender

	Both Genders			Females			Males		
	Coeff.		S.E.	Coeff.		S.E.	Coeff.		S.E.
-23°C and below	-0.29		0.50	-0.01		0.22	-0.51		0.82
-23°C -20°C	-0.65		0.61	-0.30		0.35	-1.02		0.94
-20°C -17°C	-0.50		0.84	-0.14		0.37	-0.88		1.38
-17°C -14°C	0.10		0.66	0.02		0.28	0.30		1.10
-14°C -11°C	-1.02		0.90	-0.47		0.39	-1.55		1.48
-11°C -8°C	-0.44		0.36	-0.24		0.18	-0.60		0.58
-8°C -5°C	-0.31		0.51	0.00		0.22	-0.61		0.85
-5°C -2°C	-0.42		0.55	-0.21		0.23	-0.62		0.93
-2°C 1°C	0.03		0.40	0.03		0.16	0.07		0.68
1°C 4°C	-0.50		0.47	-0.11		0.18	-0.94		0.80
4°C 7°C	-0.38		0.42	-0.23		0.17	-0.55		0.71
7°C 10°C	-0.30		0.43	-0.10		0.17	-0.51		0.72
10°C 13°C	-0.27		0.35	-0.02		0.15	-0.56		0.58
13°C 16°C	0.08		0.21	0.04		0.10	0.12		0.34
16°C 19°C	-0.08		0.26	-0.07		0.11	-0.09		0.44
above 25°C	0.60	***	0.15	0.32	***	0.07	0.91	***	0.27
10 mm 20 mm	-0.47		0.36	-0.12		0.16	-0.90		0.61
20 mm 100 mm	0.82		1.12	0.35		0.49	1.40		1.87
Time Fixed Effects	Yes			Yes			Yes		
Reg. Fixed Effects	Yes			Yes			Yes		
Reg. Linear Trends	Yes			Yes			Yes		
Nr. Of Obs.	2,120			2,120			2,122		
Rsq-within	0.76			0.75			0.74		

Notes: *** stands for a 1% significance level. Coeff. and S.E. stand for coefficients and robust standard errors that are clustered at a regional level. All regressions are weighted by the corresponding population. The temperature interval (19°C, 25°C] and the precipitation interval [0 mm, 10 mm) are used as defaults.

As shown in Table 1, during a day with temperature above 25°C the number of victims of both genders increases by 0.60 persons per million inhabitants.[25] The number of female and male victims increases by 0.32 and 0.91, respectively. In relative terms, those impacts correspond to

[25] It is worth mentioning that this impact might be compensated by 0.36% increase in the regional GDP per capita (see Appendix A for details).

0.26%, 0.31%, and 0.245% increase in the number of total, female, and male victims, respectively.[26]

5.1. Impacts across Age and Gender

We then discriminate the impact of one day with temperatures above 25°C across age and gender groups. We distinguish four age groups: young (15-24 y.o.), adult (25-44 y.o.), mature (45-59 y.o.), and old (above 60 y.o.). As shown in Table 2, one day with such temperature ranges is significantly associated with more violence against females and males across all age groups, with the exception of young females. Quantitatively, the impact of extreme weather is greater for males than for females, with young and mature males affected the most.[27] Nevertheless, as detailed in footnote 25, in relative terms the likelihood of victimization among females is greater – 0.9%, 0.88%, and 1% for adults, mature, and old, respectively, when compared to male counterparts – respectively 0.35%, 0.24%, and 0.41%, that is, between one third and one half of female rates.

IPCC (2014) points out that studies with attention to the impact of cold temperature on human behavior (i.e. health) remain overlooked. To fill this gap, we also test the impact of cold temperatures on violence. As shown in Table 1, we find no evidence of the impact of cold temperatures. In line with this result, we also find no impact of cold temperatures on males and females by age groups (see Table 3). This is an interesting finding, suggesting that global warming has two dangerous implications for human well-being: the number of victims may

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[26] The likelihood of being a victim is computed as follows: for both genders is 0.26%=(0.6*100)/229.55, for females is 0.31%=(0.32*100/102.89), and for males is 0.245%=(0.91*100/371.08). The numbers in a denominator are taken from Figure 1, while the numbers in a numerator are taken from Table 1. All other computations are done in the same way.

[27] An article in *The New York Times* mentions the lower association of females with violence, both as victims and as perpetrators, together with the greater likelihood of being victimized by someone they know, a partner, or a family member (Lehren and Baker 2009).

increase due not only due to an increasing number of hot days, but also to a decreasing number of cold days.

Table 2
Impact of One Day With Temperatures Above 25°C
By Gender and Age Group

	Both Genders			Females			Males		
	Coeff.		S.E.	Coeff.		S.E.	Coeff.		S.E.
All Ages	0.60	***	0.15	0.32	***	0.07	0.91	***	0.27
Young (15-24)	0.44	**	0.16	0.06		0.09	0.80	***	0.27
Adult (25-44)	0.76	***	0.23	0.46	***	0.13	1.06	**	0.42
Mature (45-59)	1.19	***	0.30	0.55	***	0.16	1.93	***	0.52
Old (60+)	0.48	***	0.16	0.36	**	0.13	0.74	**	0.31

Notes: The estimated coefficients on the above 25°C bin for a particular age and gender group are from Eq (1). Coeff. and S.E. stand for coefficients and robust standard errors that are clustered at a regional level. *** and ** stand for 1% and 5% significance levels, respectively. Each regression includes all temperature and precipitation bins, regional and year fixed effects, and regional time trends, and is weighted by the corresponding population. Full results are available from the authors upon request.

Table 3
Impact of One Day With Temperatures Below - 23°C
By Gender and Age Group

	Both Genders		Females		Males	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
All Ages	-0.29	0.50	-0.01	0.22	-0.51	0.82
Young (15-24)	-0.41	0.41	-0.05	0.16	-0.76	0.71
Adult (25-44)	-0.47	0.73	-0.13	0.31	-0.69	1.20
Mature (45-59)	-0.83	0.94	-0.20	0.44	-1.44	1.54
Old (60+)	-0.32	0.47	0.05	0.30	-0.91	0.89

Notes: The estimated coefficients on the below -23°C bin for a particular age and gender group are from Eq (1). Coeff. and S.E. stand for coefficients and robust standard errors that are clustered at a regional level. Each regression includes all temperature and precipitation bins, regional and year fixed effects, and regional time trends, and is weighted by the corresponding population. Full results are available from the authors upon request.

5.2. Years of Life Lost by a Victim

According to McCollister et al. (2010), the total social costs of criminal acts consist of tangible and intangible costs. In the case of murders, tangible costs include victim costs (a present value of life time earnings), criminal system costs (i.e. police protection cost, legal and adjudication costs, and the convicted perpetrators' correction costs), and crime carrier costs (productivity losses associated with perpetrators of crimes). Intangible costs include corrected risk-of-homicide costs that are willingness to pay to prevent violence. According to McCollister et al. (2010), the total social costs of one murder in the US are about 9 million USD in 2008 prices.

We compute years of life lost by a victim that are due to the impact of one hot day (above 25°C). That is, how many years a victim would live if she/he were not murdered. This measure is equivalent to victim costs suggested by McCollister et al. (2010) and contributes 8.2% to the total social costs (McCollister et al. 2010). Our estimates should be considered as a lower bound of the total social costs. The results are in Table 4, in which columns 1-3 correspond to the estimated number of deaths of females, males, and both genders based on the impact of one day with temperature above 25°C (hot) from Table 2. Columns 4-6 stand for the years of life lost by a victim of a particular age group. Those columns are based on the statistics of the World Health Organization (WHO) (2016) on life expectancy of particular age groups. Columns 7-9 stand for the total number years of life lost due to the impact of one hot day.

Table 4 shows that the greatest number of victims associated with one day above 25°C is among adult and mature females and males - 10 and 8 female victims, and 23 and 25 male victims, respectively. The greatest total number of years lost is observed among the adult females and males, which is the most economically active and reproductive age group. Overall, we find that the total number of years lost among all age groups is 642 and 1,579 for females and males, respectively. We also compute the average number of years lost per victim. According to our results, if not killed, a female victim would live additional 26.75 years, while a male victim would live 25.06 years more. Thus, even though there are more males than females among the victims at all age groups, except for the elderly, females have a greater cost in terms of years lost *per se*.

Table 4
Estimated Number of Victims of One Day With Temperatures Above 25°C
By Gender and Age Group

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Estimated Number of Deaths			**Years of Life Lost**			**Person-Years of Life Lost**		
Age Groups	Female	Male	Both Genders	Female	Male	Both Genders	Female	Male	Both Genders
Young (15-24)	1*	9	9	57.2	45.8	51.5	57.2*	412.20	463.50
Adult (25-44)	10	23	33	38.6	29.2	33.9	386	672	1,118.70
Mature (45-59)	8	25	33	25.3	18.2	21.8	202	455.00	718
Old (above 60)	6	6	12	17.2	12.4	14.8	54	40.18	177.60
Total	24	63	87				642	1,579	2,478
Years of Life Lost per Death							26.75	25.06	28.48

Notes: * is based on non-significant coefficient. Columns (1)-(3) are computed by multiplying the estimated impact of one day above 25°C from Table 2 by the average regional population of each gender and age group during the 1989-2015 period. Columns (4)-(6) stand for the number of years of life lost by each gender and age group computed as a difference between life expectancy and the upper age limit of a particular age group. (7)-(9) are computed by multiplying columns (1)-(3) and (4)-(6).

We compare our estimates with those provided by Deschenes and Moretti (2009). Those authors examine the impact of one cold day (below 30°F or -1°C) on the mortality of each gender of specific age groups. They find that a death associated with the impact of a cold day corresponds to 11.5 and 10.6 years of life lost *per se* for females and males, respectively. One possible explanation for why our estimates are about two and half times greater is that violence is most likely to be unexpected and exogenous to a victim, while mortality due to cold days can be expected and prevented by risk aversion behavior. For instance, to prevent the adverse impact of cold weather on own health, individuals stay at home, use heaters, wear warm clothing, and use medicines, thereby reducing the risk of death during cold days, while in the case of violence, risk aversion behavior might not help to reduce the risk of being victimized. Also, the impact of hot days on mortality is typically greater than the impact of cold days (Deschênes and Greenstone, 2011).

5.3. Work Days versus Weekends

The circumstances of violence may differ between work days and weekends. The article in *The New York Times* mentioned above indicates how, when the overall number of homicides falls, a greater share of homicides occur on weekends (Lehren and Baker, 2009). We therefore examine the impact of temperature during work days and weekends separately.

We find that both males and females are more likely to fall victim in response to temperature shocks during weekends, with victimization rates about ten times greater than those during work days for adult females and about two times greater for mature males. The impact of temperature on female victimization is significant and positive for adult, mature, and old females during both work days and weekends (see Tables 5 and 6). As for men, the coefficient is significantly different from zero for all age groups.

Even though males are quantitatively more victimized than females, in relative terms, the likelihood of being a victim during a weekend is greater for females than for males. For instance, one weekend day above 25°C increases the likelihood of being a victim among adult and mature females by 1% and 1.17%, respectively, while among male counterparts this likelihood is 0.37% and 1.06%, respectively. This finding may be explained by high rates of domestic violence. According to the United Nations report on Russia (United Nations, 2006, p.9), "…14,000 females were killed annually by their husbands". Given the scarcity of official statistics on domestic violence in Russia, this explanation remains merely suggestive. Note that we do not find any results related to the impact of work and weekend days with temperature below -23°C on homicide for either gender.

Table 5
Impact of a Work Day with Temperatures above 25°C
By Gender and Age Group

	Both Genders			Females			Males		
	Coeff.		S.E.	Coeff.		S.E.	Coeff.		S.E.
All Ages	0.75	***	0.18	0.37	***	0.09	1.18	***	0.31
Young (15-24)	0.74	***	0.21	0.02		0.13	1.41	***	0.37
Adult (25-44)	0.94	***	0.29	0.53	***	0.18	1.37	**	0.53
Mature (45-59)	1.34	***	0.35	0.59	**	0.23	2.22	***	0.58
Old (60+)	0.60	**	0.21	0.46	**	0.18	0.91	**	0.41

Notes: The estimated coefficients on the above 25°C bin for a particular age and gender group are from Eq (1). Coeff. and S.E. stand for coefficients and robust standard errors that are clustered at a regional level. *** and ** stand for 1% and 5% significance levels, respectively. Each regression includes all temperature and precipitation bins, regional and year fixed effects, and regional time trends, and is weighted by the corresponding population. Full results are available from the authors upon request.

Table 6
Impact of a Weekend Day with Temperatures above 25°C
By Gender and Age Group

	Both Genders			Females			Males		
	Coeff.		S.E.	Coeff.		S.E.	Coeff.		S.E.
All Ages	1.48	**	1.55	0.89	***	0.25	2.13	**	0.93
Young (15-24)	0.69		0.45	0.31		0.23	1.02		0.79
Adult (25-44)	1.82	**	0.83	1.40	***	0.39	2.20		1.43
Mature (45-59)	3.50	***	1.02	1.66	***	0.61	5.60	***	1.71
Old (60+)	1.04	**	0.49	0.63		0.40	1.91	*	1.04

Notes: The estimated coefficients on the above 25°C bin for a particular age and gender group are from Eq (1). Coeff. and S.E. stand for coefficients and robust standard errors that are clustered at a regional level. *** and ** stand for 1% and 5% significance levels, respectively. Each regression includes all temperature and precipitation bins, regional and year fixed effects, and regional time trends, and is weighted by the corresponding population. Full results are available from the authors upon request.

5.4. Relative Impacts on Age and Gender

While in the section above we tested for the impact of temperature shocks on violence for different gender and age groups, we now test for the existence of a differential impact for specific gender and age groups. In this way, we can assess which groups are more vulnerable, in relative terms. In the tables below, each cell presents a difference between two figures, the first being the estimated impact on the category identified in the row, and the second the same for the category identified in the column. The number in parentheses is the p-value of the test of the difference, with a lower value associated with a statistically significant difference denoted by a shaded cell.

Table 7 shows that older females are significantly more victimized than young females, those between 15 and 24 y.o., In addition, there is no significant difference in victimization of females older than 25 y.o. As for males, those between 45 and 59 y.o. are the most likely, and those between 15 and 44 y.o. and over 60 y.o. are less likely to fall victims of violence. Thus, two very different profiles emerge, with adult and older females and middle aged men, relatively more victimized, when intra-gender comparisons are at stake.

Table 7
Differential Daily Impact of Temperatures above 25°C
Across Age Group, for Each Gender

	Female			Male		
	15-24	25-44	45-59	15-24	25-44	45-59
Adult (25-44)	0.46-0.06 (0.01)			1.06-0.80 (0.55)		
Mature (45-59)	0.55-0.06 (0.00)	0.55-0.46 (0.49)		1.93-0.80 (0.02)	1.93-1.06 (0.00)	
Old (60+)	0.36-0.06 (0.07)	0.74-0.46 (0.46)	0.74-0.55 (0.16)	0.74-0.80 (0.99)	0.74-1.06 (0.50)	0.74-1.93 (0.00)

Notes: The null hypothesis is H_0: $\beta_i^{\text{above 25°C}} - \beta_j^{\text{above 25°C}} = 0$ where i and j correspond to a particular age group and $i \neq j$. This hypothesis represents whether the impact of one day with temperatures above 25°C is the same across different age groups for a particular gender. Each cell presents a difference between two figures, the first being the estimated impact on the category identified in the row, and the second the same for the category identified in the column. P-values of the tests are in parentheses, where shaded cells stand for a statistically significant difference.

Table 8 reports the tests for significant differences in victimization across genders, for each age group. We find that young men, between 15 and 24 y.o., and mature men, between 45 and 59 y.o., are significantly more victimized than females of the same age cohort. These results are consistent with the results in Table 7, with mature men relatively more victimized across age groups and relative to women, and young men also relatively more victimized than women, though significantly less victimized than mature men. The mirror image is adult and older women being as victimized as their male cohorts, and thus relatively more vulnerable than young and mature women.

Table 8
Differential Daily Impact of Temperatures above 25°C
Across Genders, for Each Age Group

		Female			
		15-24	25-44	45-59	60+
Male	Young (15-24)	0.80-0.06 (0.02)			
	Adult (25-44)		1.06-0.46 (0.24)		
	Mature (45-59)			1.93-0.55 (0.01)	
	Old (60+)				0.74-0.36 (0.21)

Notes: The null hypothesis is H_0: $\beta_i^{\text{above 25°C}} - \beta_j^{\text{above 25°C}} = 0$ where i and j correspond to a particular gender group and $i \neq j$. This hypothesis represents whether the impact of one day with temperatures above 25°C is the same between genders of the given age group. Each cell presents a difference between two figures, the first being the estimated impact on the category identified in the row, and the second the same for the category identified in the column. P-values of the tests are in parentheses, where shaded cells stand for a statistically significant difference.

Table 9 reports the tests for differential effects between weekend and week days, for the same gender and age groups. We find that adult and mature females, that is, women between 25 and 59 y.o., are significantly more victimized during weekend days. Men between 45 and 59 y.o. are also more victimized on weekends. These results also deserve a reading in tandem with results in Tables 7 and 8. The higher victimization of adult and mature women may be suggestive of the presence of domestic violence. The fact that a relatively more victimized group age-wise, women over 60, does not exhibit significant differences between weekend and week days does not dispute that interpretation, as older women are more likely to be retired and thus be equally present in the domestic environment on weekends and work days.

Table 9
Differential Daily Impact of Temperatures above 25°C
Weekends and Work Days – Across Age and Gender

		Female				Male			
		Work Day				Work Day			
		15-24	25-44	45-59	60+	15-24	25-44	45-59	60+
Weekend Day	Young (15-24)	0.31-0.02 (0.25)				1.02-1.41 (0.56)			
	Adult (25-44)		1.40-0.94 (0.01)				2.20-1.37 (0.46)		
	Mature (45-59)			1.66-0.59 (0.00)				5.60-2.22 (0.01)	
	Old (60+)				0.63-0.46 (0.61)				1.91-0.91 (0.2)

Notes: The null hypothesis is H_0: $\beta_i^{\text{above 25°C}} - \beta_j^{\text{above 25°C}} = 0$ where i corresponds to weekend day while j corresponds to work day. This hypothesis represents whether the impact of one day with temperatures above 25°C is the same between weekend day and work day of a given gender and age group. Each cell presents a difference between two figures, the first being the estimated impact on the category identified in the row, and the second the same for the category identified in the column. P-values of the tests are in parentheses, where shaded cells stand for a statistically significant difference.

6. Mitigation Mechanisms

We now test possible mitigation mechanisms by introducing in our baseline specification interaction terms between extreme temperature days and a set of regional socioeconomic indicators.[28] This approach has been used by Sekhri and Storeygard (2014), who examine the mechanisms behind the impact of rainfall on dowry deaths, by Rocha and Soares (2015), who investigate the mechanisms explaining the impact of rainfall on birth outcomes, and by Cattaneo and Peri (2016), who study the mechanisms mitigating the effect of temperature and precipitation on emigration rates. Table 10 presents our main results for total and gender specific mortality, for the three possible mitigation channels considered, namely: the real monthly wage, in thousands of Rubles, the rate of unemployment, and the consumption of vodka per capita. We find that a higher regional real wage reduces the number on female victims on hot days, with no impact on male victimizations. A real

[28] We are here limited to the post-1995 period, as data on socioeconomic characteristics are available only after that date.

monthly regional wage of 19,667 Rubles a month – about 412 USD, in 2015 prices, fully counters the effect of high temperatures on violence over females. The average monthly regional wage is only about 11,000 Rubles (about 230 USD, in 2015 prices, in the period of study), suggesting that the overwhelming majority of households does not come close to the above threshold. Cold days increase the number of victims of both genders' victimization,[29] but again this is countered by higher real wages, with a real wage above 17,500 Rubles (about 366 USD, in 2015 prices) and 14,900 Rubles (about 312 USD, in 2015 prices), respectively countering female and male victimization.[30] Higher regional unemployment reinforces the negative impact of hot days on female victimization, with no effect on male victimization. Finally, vodka consumption raises the impact of weather shocks on violence, though only on cold days,[31] and the effect is present for both genders, though quantitatively more significant for males. In sum, in poorer, less developed regions the number of female victims decreases with higher real wages and more job opportunities on hot days, and decreases with vodka consumption on cold days. On cold days the number of male victims decreases with higher wages and lower vodka consumption.

[29] Similarly, Cattaneo and Peri (2016) find a significant effect of temperature only when the interaction terms of temperature with economic conditions are included.
[30] The estimated real monthly wage is computed as follows: 1.40 - 0.08*(Real wage/1,000)=0. The estimates are taken from Table 10.
[31] We also tested the regional beer consumption per capita as a mitigation channel instead of the regional vodka consumption per capita. The results are similar. Yet, the magnitude of the interaction terms is about 1.5 times lower for females and is 1.2 time lower for males when compared to vodka consumption (for females 0.78 vs. 0.45 and for males 2.48 vs.2.10). This means that vodka consumption has a greater reinforcement effect than beer consumption.

Table 10
Testing for Mitigating Mechanisms

		Total			Female			Male		
		Coeff.		S.E.	Coeff.		S.E.	Coeff.		S.E.
Real Wage	Above 25°C	0.96	*	0.50	0.59	**	0.22	1.35		0.87
	Real wage*Above 25°C	-0.04		0.04	-0.03	*	0.01	-0.04		0.06
	Below -23°C	3.24	***	0.99	1.40	***	0.39	5.22	**	1.71
	Real wage*Below -23°C	-0.21	***	0.03	-0.08	**	0.03	-0.35	**	0.12
Unemployment	Above 25°C	0.03		0.30	-0.02		0.14	0.12		0.52
	Unemployment*Above 25°C	0.05	*	0.03	0.03	**	0.01	0.07		0.05
	Below -23°C	-0.24		0.54	0.02		0.27	-0.52		0.90
	Unemployment*Below -23°C	0.06		0.04	0.03		0.02	0.09		0.07
Vodka Consumption	Above 25°C	-0.97		1.93	-0.21		0.94	-1.79		3.26
	Vodka Consumption*Above 25°C	-0.33		0.40	-0.11		0.19	-0.57		0.68
	Below -23°C	5.97	*	3.49	3.36	*	1.77	9.20		5.67
	Vodka Consumption *Below -23°C	1.55	**	0.75	0.78	*	0.39	2.48	**	1.21

Notes: ***, **, and * stand for a 1%, 5%, and 10% significance levels. Coeff. and S.E. stand for coefficients and robust standard errors that are clustered at a regional level. All regressions are weighted by the corresponding population. The temperature interval (19°C, 25°C] and the precipitation interval [0 mm, 10 mm) are used as defaults. All models include all temperature and precipitation bins as in a baseline model, time and regional fixed effects, linear regional trends, socioeconomic conditions, and their interaction terms with all temperature and precipitation bins.

Next, we test mitigation mechanisms by age for each gender. The results are presented in Table B1 for hot days and in Table B2 for cold days, respectively (see Appendix b). As shown in Table B1, the impact of hot days on victimization among mature and old females might be mitigated by increasing the real monthly wage and by reducing unemployment in a region. However, improving the quality of life will not reduce male victimization of any age group. Also, we do not find mitigation/reinforcement effect during hot days due to alcohol consumption of both genders.[32] Concerning the impact of cold days on the victimization of both genders, we find that this impact might be mitigated in all age groups by increasing the real wage, while reducing unemployment decreases victims among

32 It would be interesting to test mitigation mechanisms related to alcohol consumption during weekends and weekdays, but information regarding the weekly breakdown of alcohol consumption is not available.

young females only (see Table B2). Spirits consumption also reinforces the impact of cold days among old females and young and adult males.

7. Sensitivity Check

To check that our results are robust, the following steps are undertaken. First, until 2000, Russia was in a transition period from the communist to market economy that was characterized by institutional development, economic reforms, political changes, and changes in social life. To check the robustness of our results we estimate Eq. (1) for the post-transition period (2000-2015) only, and then compare the coefficients with the original model (1). As shown in Table C1 in the appendix, in the models with (1) and without (2) a transition period, the coefficients on the above 25°C temperature bin are statistically significant. Even though the magnitude of coefficients in both models differs slightly, the confidence intervals of the estimates overlap, suggesting that they are not statistically different from each other.

Second, it might be the case that in regions with high current violence rates, we should expect high violence rates in the next year. For that purpose, we include the lagged violence rate in Eq. (1). Model (3) shows that the coefficient on the above 25°C temperature bin is statistically significant. Comparing two models with (3) and without (1) the lagged variable, we find that in the model with the lagged violence rate the estimated coefficient is smaller when compared to the original model. However, the confidence intervals of both estimates overlap. As suggested in the economy-climate change literature review by Dell et al. (2014), one should be careful in using endogenous variables in analysis since doing so may lead to biased estimates. This is exactly the case, since the lagged violence also depends on the weather of the previous period. Thus, if the lagged dependent variable is included, the current impact of weather is underestimated.

As stated above, only two thirds of regions are affected by the temperature above 28°C and the annual average number of days with such temperature range is 0.97. It would be interesting to split the above 25°C temperature bin into the 25-28°C and above 28°C temperature bins to analyze whether the impact on violence is greater for higher temperatures. As shown in Table C1, in model (4) with above 28°C temperature bin, the impact of such temperature range is greater than the impact of the above 25°C temperature bin, even though not statistically different. This suggests that the estimates in this study should be considered as lower bounds and if the number of days with higher temperature (i.e. above 28°C) increases, the impact of climate change on violence will be greater.

8. Conclusion

The importance of climate change is hard to exaggerate. However, precise estimates of the social consequences of high temperatures are rare. We rely on heretofore unused data from a novel Russian dataset covering three decades of information on temperatures and violent mortality to estimate the impact of hot and cold temperatures on violence. We uncover that most victimization occurs on weekends, for individuals aged between 45 and 59 years old. Males are more often victimized, especially men between 45 and 59 years old, but females are significantly more victimized on weekends, a result highly suggestive of the incidence of domestic violence.

The consistent relevance of economic conditions, including earnings and unemployment, as intermediating factors for the impact of weather on violence against females (and not males) suggests that we are capturing an important social mechanism that mediates how temperature translates into violence. Overall, our findings suggest that lower incomes, higher unemployment, and more widespread vodka consumption increase the impact of extreme temperatures on violence, namely violence against females. We show that the intensity and type of social interactions, which vary across age and gender, and between work and weekdays, are important factors determining the social cost of temperature shocks.

The importance of these results cannot be overstated, especially as the effects of climate change may become more acute.

Our findings might be interesting to policy makers in other regions and countries. First, we find that female victimization due to both hot and cold temperature shocks might be mitigated by improving quality of life and job opportunities in a region. However, those mechanisms may not reduce male victimization. Also, regulating spirits consumption may help to mitigate the harmful impact of weather shocks, though only cold ones. The increasing relevance of climate change, and the vulnerability of developing countries to its effects, calls for further work on the social determinants of victimhood and the gender and age inequalities it generates.

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Appendix A.

To compute by how much the real regional Gross Domestic Product (GDP) per capita should increase to mitigate/compensate the impact of one hot day on violence, the following steps are undertaken. First, we introduce in Eq. (1) regional economic indicators such as unemployment rate and log of real regional GDP per capita. Note that as discussed by Dell et al. (2014), including additional economic variables in Eq. (1) may lead to the over-controlling problem since most economic variables are themselves influenced by weather. We estimate such a model for illustration purposes only to compare the impact of one hot day with a possible impact of economic variables on violence. Also, regional economic data are available only since 1995. Thus, to make models with and without economic indicators comparable, we estimate both models for the 1995-2015 period. The results are in Table A1 (Models 2 and 3). As shown, both models have quantitatively and statistically the same coefficients on temperature and precipitation bins. Regarding the regional economic indicators, only the coefficient on log of GDP is statistically significant.

Second, we calculate the marginal rate of substitution between log of GDP per capita and the above 25°C temperature bin. That is, by how much should GDP per capita increase in order to mitigate/compensate the impact of one hot day on violence. The information regarding the coefficients is taken from Model 3 in Table A1 and the calculation is as follows:

$$\frac{\Delta Violence}{\Delta \ln(GDP)}\Delta \ln(GDP) + \frac{\Delta Violence}{\Delta TempBin^{above\ 25°C}}\Delta TempBin^{above\ 25°C} = 0$$

$$-83.97 * \Delta \ln(GDP) + 0.30 * \Delta TempBin^{above\ 25°C} = 0$$

$$\frac{\Delta \ln(GDP)}{\Delta TempBin^{above\ 25°C}} = \frac{0.30}{83.97} = 0.0036$$

As shown, the impact of one hot day might be compensated by a 0.36% increase in the regional GDP per capita. This finding indicates the importance of the impact of hot days on violent behavior.

Table A1
Model with and without Economic Indicators.

	(1) Baseline Model			(2) Model without Econ. Variables			(3) Model with Econ. Variables		
	Coeff.		S.E.	Coeff.		S.E.	Coeff.		S.E.
Ln(GDP)	-		-	-		-	-83.97	***	38.81
Unemployment	-		-	-		-	0.23		1.28
-23°C and below	-0.29		0.50	0.11		0.36	0.06		0.41
-23°C -20°C	-0.65		0.61	-0.62		0.52	-0.41		0.51
-20°C -17°C	-0.50		0.84	-0.47		0.65	-0.59		0.66
-17°C -14°C	0.10		0.66	0.14		0.48	0.12		0.52
-14°C -11°C	-1.02		0.90	-0.08		0.51	-0.06		0.52
-11°C -8°C	-0.44		0.36	0.16		0.27	0.10		0.31
-8°C -5°C	-0.31		0.51	0.35		0.27	0.34		0.28
-5°C -2°C	-0.42		0.55	-0.15		0.45	-0.21		0.48
-2°C 1°C	0.03		0.40	0.20		0.33	0.20		0.34
1°C 4°C	-0.50		0.47	-0.03		0.34	-0.10		0.39
4°C 7°C	-0.38		0.42	-0.33		0.36	-0.36		0.36
7°C 10°C	-0.30		0.43	-0.18		0.32	-0.19		0.32
10°C 13°C	-0.27		0.35	-0.25		0.33	-0.29		0.34
13°C 16°C	0.08		0.21	-0.08		0.21	-0.09		0.21
16°C 19°C	-0.08		0.26	-0.16		0.25	-0.19		0.18
above 25°C	0.60	***	0.15	0.42	***	0.14	0.30	*	0.18
10 mm 20 mm	-0.47		0.36	-0.35		0.23	-0.24		0.24
20 mm 100 mm	0.82		1.12	0.18		0.92	-0.10		0.90
Time Fixed Effects	Yes			Yes			Yes		
Reg. Fixed Effects	Yes			Yes			Yes		
Reg. Linear Trends	Yes			Yes			Yes		
Nr. Of Obs.	2,120			1,675			1,636		
Rsq-within	0.76			0.84			0.85		

Notes: The impact of temperature on total (both genders) homicide is presented in (1)-(3). ***, **, and * stand for 1%, 5%, and 10% significance levels. Coeff., S.E., and Reg. stand for coefficients, robust standard errors that are clustered at a regional level, and regions, respectively. All regressions are weighted by the corresponding population. The temperature interval (19°C, 25°C] and the precipitation interval [0 mm, 10 mm) are used as defaults. (1) Model from Table 1. (2)-(3) Models without and with economic indicators based on the 1995-2015 period data, respectively.

Appendix B.

Table B1
Testing for Mitigating Mechanisms
Across Gender and Age Groups
Days Above 25°C

			Female			Male		
			Est.		S.E.	Est.		S.E.
Real Wage	Young (15-24)	(above 25°C)	0.28		0.23	1.02		0.66
		Real Wage*(above 25°C)	-0.01		0.02	-0.03		0.05
	Adult (25-44)	(above 25°C)	0.70	**	0.32	2.01		1.41
		Real Wage*(above 25°C)	-0.03		0.02	-0.08		0.10
	Mature (45-59)	(above 25°C)	0.82	**	0.35	2.53	*	1.36
		Real Wage*(above 25°C)	-0.04	*	0.02	-0.05		0.10
	Old (60+)	(above 25°C)	0.84	**	0.31	0.63		0.71
		Real Wage*(above 25°C)	-0.03	*	0.02	-0.03		0.05
Unemployment	Young (15-24)	(above 25°C)	-0.23		0.20	0.31		0.43
		Unemployment*(above 25°C)	0.04	**	0.02	0.03		0.03
	Adult (25-44)	(above 25°C)	0.08		0.22	-0.51		0.98
		Unemployment *(above 25°C)	0.02		0.02	0.14		0.10
	Mature (45-59)	(above 25°C)	-0.33		0.29	1.26		0.92
		Unemployment *(above 25°C)	0.07	***	0.02	0.06		0.08
	Old (60+)	(above 25°C)	0.06		0.25	0.04		0.57
		Unemployment *(above 25°C)	0.04		0.03	0.02		0.05
Vodka Consumption	Young (15-24)	(above 25°C)	-0.55		1.39	-3.45		3.46
		Vodka Consumption*(above 25°C)	-0.15		0.29	-0.90		0.72
	Adult (25-44)	(above 25°C)	0.18		1.39	-2.40		5.63
		Vodka Consumption *(above 25°C)	-0.07		0.29	-0.77		1.20
	Mature (45-59)	(above 25°C)	-0.09		1.65	-0.27		4.95
		Vodka Consumption *(above 25°C)	-0.09		0.35	-0.43		1.02
	Old (60+)	(above 25°C)	-0.17		1.54	-2.35		3.38
		Vodka Consumption *(above 25°C)	-0.09		0.32	-0.53		0.70

Notes: ***, **, and * stand for 1%, 5%, and 10% significance levels. Coeff. and S.E. stand for coefficients and robust standard errors that are clustered at a regional level. All regressions are weighted by the corresponding population. The temperature interval (19°C, 25°C] and the precipitation interval [0 mm, 10 mm) are used as defaults. All models include all temperature and precipitation bins as in a baseline model, time and regional fixed effects, linear regional trends, socioeconomic conditions, and their interaction terms with all temperature and precipitation bins.

Table B2
Testing for Mitigating Mechanisms
Across Gender and Age Groups
Days Below - 23°C

			Female			Male		
			Est.		S.E.	Est.		S.E.
Real Wage	Young (15-24)	(below -23°C)	1.19	***	0.40	4.04	***	1.34
		Real Wage*(below -23°C)	-0.08	***	0.02	-0.28	**	0.10
	Adult (25-44)	(below -23°C)	1.89	***	0.57	8.24	***	2.78
		Real Wage*(below -23°C)	-0.10	**	0.04	-0.55	**	0.20
	Mature (45-59)	(below -23°C)	1.31	**	0.66	6.99	**	2.78
		Real Wage*(below -23°C)	-0.08	*	0.04	-0.47	**	0.21
	Old (60+)	(below -23°C)	1.81	**	0.63	5.16	**	1.96
		Real Wage*(below -23°C)	-0.10	**	0.04	-0.39	***	0.13
Unemployment	Young (15-24)	(below -23°C)	-0.17		0.22	-0.43		0.89
		Unemployment*(below -23°C)	0.04	*	0.02	0.06		0.06
	Adult (25-44)	(below -23°C)	0.38		0.42	-0.94		1.48
		Unemployment*(below -23°C)	0.01		0.03	0.17		0.12
	Mature (45-59)	(below -23°C)	-0.17		0.60	-0.34		1.46
		Unemployment*(below -23°C)	0.04		0.05	0.07		0.12
	Old (60+)	(below -23°C)	-0.01		0.41	-0.17		0.86
		Unemployment*(below -23°C)	0.05		0.04	-0.01		0.10
Vodka Consumption	Young (15-24)	(below -23°C)	0.86		1.94	6.01		4.10
		Vodka Consumption*(below -23°C)	0.23		0.44	1.55	*	0.84
	Adult (25-44)	(below -23°C)	4.31		2.68	18.36	*	9.96
		Vodka Consumption *(below -23°C)	0.99		0.60	4.78	**	2.16
	Mature (45-59)	(below -23°C)	3.56		2.49	3.75		8.88
		Vodka Consumption *(below -23°C)	0.84		0.52	1.36		1.87
	Old (60+)	(below -23°C)	5.91	*	3.41	4.33		7.82
		Vodka Consumption *(below -23°C)	1.34	*	0.77	1.41		1.73

Notes: ***, **, and * stand for 1%, 5%, and 10% significance levels. Coeff. and S.E. stand for coefficients and robust standard errors that are clustered at a regional level. All regressions are weighted by the corresponding population. The temperature interval (19°C, 25°C] and the precipitation interval [0 mm, 10 mm) are used as defaults. All models include all temperature and precipitation bins as in a baseline model, time and regional fixed effects, linear regional trends, socioeconomic conditions, and their interaction terms with all temperature and precipitation bins.

Appendix C.

Table C1: Comparison of the Models.

	(1) Baseline Model			(2) Model with Post-transition Period			(3) Model with the Lagged Violence			(4) Model with above 28°C Temperature Bin		
	Coeff.		S.E.	Coeff.		S.E.	Coeff.		S.E.	Coeff.		S.E.
Lagged Violence	-		-	-		-	0.76	***	0.02	-		-
-23°C and below	-0.29		0.50	-0.56		0.37	-0.01		0.21	-0.30		0.50
-23°C -20°C	-0.65		0.61	-0.17		0.29	-0.36		0.23	-0.65		0.61
-20°C -17°C	-0.50		0.84	-0.79		0.70	-0.49		0.42	-0.51		0.85
-17°C -14°C	0.10		0.66	-0.03		0.39	-0.02		0.41	0.10		0.66
-14°C -11°C	-1.02		0.90	0.15		0.30	-0.38		0.32	-1.02		0.91
-11°C -8°C	-0.44		0.36	0.18		0.31	-0.19		0.25	-0.44		0.36
-8°C -5°C	-0.31		0.51	0.19		0.24	-0.14		0.22	-0.32		0.52
-5°C -2°C	-0.42		0.55	0.09		0.31	-0.29		0.29	-0.42		0.56
-2°C 1°C	0.03		0.40	0.38	*	0.23	-0.07		0.25	0.03		0.41
1°C 4°C	-0.50		0.47	0.26		0.21	-0.39		0.23	-0.50		0.47
4°C 7°C	-0.38		0.42	0.24		0.18	-0.34		0.23	-0.39		0.43
7°C 10°C	-0.30		0.43	0.23		0.16	-0.38	*	0.20	-0.30	*	0.43
10°C 13°C	-0.27		0.35	0.33	**	0.15	-0.13		0.18	-0.27		0.35
13°C 16°C	0.08		0.21	0.20		0.15	-0.13		0.12	0.07		0.21
16°C 19°C	-0.08		0.26	-0.12		0.15	-0.02		0.13	-0.08		0.26
above 25°C	0.60	***	0.15	0.43	***	0.11	0.30	***	0.09	0.58	***	0.17
above 28°C	-		-	-		-	-		-	0.62	*	0.36
10 mm 20 mm	-0.47		0.36	-0.09		0.19	-0.20		0.18	-0.47		0.36
20 mm 100 mm	0.82		1.12	-0.38		0.60	0.21		0.46	0.81		1.12
Time Fixed Effects	Yes			Yes			Yes			Yes		
Reg. Fixed Effects	Yes			Yes			Yes			Yes		
Reg. Linear Trends	Yes			Yes			Yes			Yes		
Nr. Of Obs.	2,120			1,263			2,040			2,120		
Rsq-within	0.76			0.94			0.92			0.76		

Notes: The impact of temperature on total (both genders) homicide is presented in (1)-(4). ***, **, and * stand for 1%, 5%, and 10% significance levels. Coeff., S.E., and Reg. stand for coefficients, robust standard errors that are clustered at a regional level, and regions, respectively. All regressions are weighted by the corresponding population. The temperature interval (19°C, 25°C] and the precipitation interval [0 mm, 10 mm) are used as defaults. (1) is the model from Table 1. (2) is the model without transition period based on the 2000-2015 period data. (3) is the model with the lagged violence. (4) is the model with the temperature bin above 28°C.