Health Consequences of the Russian Weather

(Published in *Ecological Economics* 132, 2017)

https://doi.org/10.1016/j.ecolecon.2016.10.021

Vladimir Otrachshenko* [a,d]

*Corresponding author

[a] Nova School of Business and Economics, Campus de Campolide, 1099-032 Lisbon, Portugal. E-mail: vladotr@novasbe.pt

[d] Graduate School of Economics and Management, Ural Federal University, Mira 19, 620002 Yekaterinburg, Russian Federation

Olga Popova [b,c,d]

[b] Institute for East and Southeast European Studies (IOS), Landshuter Str. 4, 93047 Regensburg, Germany. E-mail: popova@ios-regensburg.de

[c] CERGE-EI, a joint workplace of Charles University and the Economics Institute of the Czech Academy of Sciences, Politickych veznu 7, 111 21 Prague, Czech Republic

[d] Graduate School of Economics and Management, Ural Federal University, Mira 19, 620002 Yekaterinburg, Russian Federation

Pavel Solomin [a]

[a] Nova School of Business and Economics, Campus de Campolide, 1099-032 Lisbon, Portugal. E-mail: p.o.solomin@gmail.com

Acknowledgements

The authors acknowledge the support from the Russian Science Foundation Grant No. 15-18-10014 "Projection of optimal socio-economic systems in turbulence of external and internal environment". All opinions expressed are those of the authors and have not been endorsed by the Russian Science Foundation. We are grateful to two anonymous referees, Maria A. Cunha e Sá, Richard Frensch, Vladimir Kozlov, Alexander Nepp, Luis C. Nunes, Renato Rosa, and Hans Wiesmeth for valuable comments and suggestions that helped improve the paper.

Health Consequences of the Russian Weather

Abstract

This paper examines and quantifies the impact of weather shocks on all-cause, cardiovascular-, and respiratory-cause mortality for different age groups in Russia. Using a regional panel data analysis from 1989 to 2014, we find that both hot and cold days cause an increase in all-cause and cause-specific mortality. On the other hand, days with extremely cold temperature (below -30°C) may have an opposite impact and reduce mortality. Overall, our findings suggest that the economic costs of all-cause mortality due to one day with hot and cold temperatures correspond to 10.25 million USD and 7.91 million USD or 0.28% and 0.22% of daily GDP in Russia, respectively. The results also suggest that regions frequently experiencing hot and cold temperatures have adapted to these temperatures.

Keywords: Health; Mortality; Temperature; Weather; Russia

JEL codes: C51; I12; J17; Q54

1. Introduction

It is conventionally agreed that growing anthropogenic emissions of greenhouse gases increase the number of extremely hot days globally (IPCC, 2014). To slow this process, governments implement greenhouse gas emission reduction policies. The important benefits of such policies are the human health improvements and the reduced mortality risks due to hot temperature, which lead to better educational attainments, higher labor productivity, and better economic performance.[1] Moreover, given the recent demographic transition in industrialized countries, that is, decreasing fertility and aging population, the health and mortality of the working age population is essential for economic development.

A growing body of empirical economic literature analyzes the impact of extreme weather events on mortality.[2] For instance, Deschênes and Moretti (2009), Barecca (2012), and Barreca et al. (2015) and (2016) find that extremely hot temperatures, above 90°Fahrenheit (°F), increase mortality in the United States, while Burgess et al. (2014) confirm this finding for India. Another study by Deschênes and Greenstone (2011) goes further and investigates the impact of the weather on the all-cause mortality of different age groups in the US. The authors find that besides the fact that extremely hot days increase mortality, the relationship differs among age groups.

The impact of extremely cold temperature on mortality has received less attention in the economic literature.[3] Deschênes and Moretti (2009) and Barecca (2012) argue that extremely cold temperature increases mortality in the U.S., and IPCC (2014) underscores that fewer extremely cold days worldwide will lead to modest reductions in mortality. However, it is worth noting that existing economic studies consider temperatures only above 0°F (ca. -17.78°C). This study contributes to the literature on the impact of cold and hot weather shocks

---

[1] See Azarnert (2006), Acemoglu and Johnson (2007), Burgess et al. (2014), Fioroni (2010), Galor and Weil (2000), Graff Zivin and Neidell (2014), Lorentzen et al. (2008), Maccini and Yang (2009), Senne (2014), Strittmatter and Sunde (2013), and Yang (2008).

[2] For comprehensive reviews, see Dell et al. (2014) and Graff Zivin and Neidell (2013).

[3] In fact, the definition of extremely cold temperature is study-specific and is based on the average daily minimum temperature in a given region.

on mortality, using data on Russia, a country with the unique range of average daily temperatures from -60°C to 35°C. According to the World Bank (2016), during the 1990-2012 period, the warmest and coldest months in Russia are July and January with the average monthly temperatures 15.1°C and -25.2°C, respectively.

The empirical findings provide interesting insights. First, days with cold (between -30°C and -25°C) and extremely cold (-30°C and below) temperatures may have different effects. In the former case mortality increases, while in the latter mortality may decrease, because individuals may show risk aversion behavior during the extremely cold days by wearing warmer clothes and/or staying indoors. Second, hot days (above 25°C) increase the total all-age mortality and the cardiovascular- and respiratory-cause all-age mortality. The total estimated cost of one day with hot (above 25°C) and cold (-30°C and -25°C) temperatures on the all-cause mortality of the working age population corresponds to 10.25 and 7.91 million USD or 0.28% and 0.22% of daily GDP in Russia, respectively. Finally, we find evidence of adaptation to hot and cold temperatures only in those regions that frequently experience these temperatures.

It is worth mentioning that climate change may have a greater impact on mortality than the impact of weather shocks estimated in this study. For instance, climate change might increase the incidence of vector borne diseases as well as the frequency of natural disasters, contributing to a larger number of fatalities (Deschênes and Greenstone, 2011; Kerry, 2005). These aspects are left for future research.

The rest of the paper is organized as follows. Section 2 discusses the mechanism of the weather impact on mortality. Sections 3 and 4 describe the data and the econometric model, respectively. Estimation results are presented in Section 5 while Section 6 provides the economic costs of days with cold and hot temperatures. Sections 7 and 8 discuss the adaptation of regions to hot and cold temperatures and the robustness of our results, respectively. The last section offers conclusions.

2. How does weather affect health?

Temperature and precipitation affect human health and mortality directly and indirectly (see Basu and Samet, 2002; Dell et al., 2014). Economic studies provide evidence to those effects based on countrywide regional data from the U.S. (Barreca, 2012; Barreca et al., 2015 and 2016; Deschênes and Moretti, 2009; Deschênes and Greenstone, 2011) and India (Burgess et al., 2014). The epidemiological literature uses case studies to assess the impact of weather in the Netherlands (Kunst et al., 1993), China (Pan et al., 1995), Great Britain (Aylin et al., 2001), and Portugal (Vasconcelos et al., 2013).

The literature reports that there are different channels of the direct impact of weather indicators on health and mortality. The first is due to natural disasters that directly contribute to deaths and injuries (Anttila-Hughes and Hsiang, 2013; Eisenberg and Warner, 2005; Yang, 2008). The second is due to thermal stress and thermoregulation (Anderson and Le Richie, 1970; Barreca et al., 2015 and 2016; Deschênes and Moretti, 2009; Keatinge et al., 1984 and 1986; Kunst et al., 1993; Martens, 1998; Pan et al., 1995; Schaanning et al., 1986). The second one is considered to be the most common channel, through which weather affects health and mortality.

A typical range of the comfortable temperature limits for a human body is from 68°F to 74°F (20-23.3°C) during the winter and from 73°F to 78°F (22.3-25.6°C) during the summer (Burroughs and Hansen, 2011). Temperatures exceeding those limits may increase mortality. Extreme temperatures may stress the cardiovascular, cerebrovascular, and respiratory systems. For instance, high temperature may cause a change in blood pressure, heart rate, and blood viscosity, leading to a circularity collapse that results in death (Martens, 1998).

While there are studies on the impact of extreme hot temperature and heat waves on mortality, there is little evidence in the economic literature regarding the impact of cold temperature. Epidemiological literature suggests that cold temperature may contribute to influenza, pulmonary infections through bronchoconstriction, and a change in cellular and humoral immunity (Martens, 1998). Barreca (2012) and Martnes (1998) mention that the impact of cold temperature on mortality may even have a greater impact on mortality than the impact of hot temperature. Since in our study temperature varies from -60°C to 30°C and above, we also compare whether the impact of hot temperature differs from that of cold.

Overall, temperatures exceeding the comfortable limits for human well-being, extreme cold and hot temperatures, induce physiological adjustment, including changes in blood pressure, blood viscosity, heart rate, and bronchoconstriction, leading to a greater risk of death due to cardiovascular and respiratory diseases.

The literature also pays particular attention to a "harvesting" effect. This means that high outdoor temperature increases the risk of death for those who would have died sooner even if temperature would have been within comfortable limits. This effect is especially important for extremely hot weather and less so for extremely cold (Deschenes and Moretti 2009; Braga et al. 2001). In particular, the "harvesting" effect explains higher mortality among the elderly during extremely hot days. Also, people with cardiovascular or respiratory diseases are more vulnerable to both extremes**.** As pointed out by Deschenes and Moretti (2009), the long-run consequences of the harvesting effect are equivocal. On the one hand, a short-run increase in mortality during extreme temperature days is offset by a decrease in mortality in subsequent days such that no long-run effect on mortality occurs. On the other hand, extreme temperature days may result in health complications that may lead to death in the long-run.

Weather also affects health and mortality indirectly through economic outcomes and pollution. For instance, temperature and precipitation affect economic growth, energy consumption, agricultural production, labor productivity, and pollution levels (Deschênes and Greenstone, 2011; Dell et al., 2012; Graff Zivin, and Neidell, 2013 and 2014). Those outcomes, in turn, may also affect health and mortality. Studies also document that weather change experienced by a mother during pregnancy affects subsequent outcomes of children, including health complications, infant mortality, nutrition, and schooling (Anttila-Hughes and Hsiang, 2013; Deschenes et al., 2009; Kudamatsu et al., 2012; Maccini and Yang, 2009).

3. Data

We use data on mortality from the Demographic Yearbook of Russia published by the Federal State Statistics Service of the Russian Federation[4] from 1989 to 2014. The data prior to 1998 are digitalized from hard copies. These data include all-cause, cardiovascular-, and respiratory-cause mortality in 79 regions of Russia. The regions are distinguished according to the administrative territorial division as of 2013.[5]

The cardiovascular- and respiratory-cause mortality is distinguished according to the 10th edition of the International Statistical Classification of Diseases and Related Health Problems (ICD) (codes I and J, respectively). The annual mortality rate is measured per 1,000 inhabitants. The all-cause, cardiovascular-, and respiratory-cause mortality data are disentangled for different age groups: all-age, infant, 1-9, 10-19, 20-29, 30-49, 50-59, 60-69, and 70 and above (70+) age groups. Table 1 presents the average annual mortality rate by age groups and causes of death. As shown in this table, mortality rate increases with age except the all-cause infant mortality which is higher when compared to other groups of young people. According to the Federal State Statistics Service of the Russian Federation, about 80.5% of infant deaths in 2014 were due to various external factors such as complications during perinatal and puerperium periods, and delivery, congenital malformations, deformations and chromosomal abnormalities.

---

[4] www.gks.ru

[5] According to the Constitution of the Russian Federation, there were 83 territorial units in 2013. However, there were the Nenets autonomous district (part of the Arkhangelsk oblast), the Khanty-Mansi autonomous district, and the Yamalo-Nenets autonomous district (both are parts of the Tyumen oblast), for which the data on mortality were not collected separately before 1999. To be consistent, we use the data of the Arkhangelsk and Tyumen oblasts that include information on those autonomous districts. Also, data on mortality and weather conditions are missing for the Chechen Republic. Therefore, our database contains the information for 79 territorial units out of 83.

Table 1: Average annual mortality rate by age groups and causes of death, 1989-2014

Age Groups	All-cause	Cardio-vascular	Respiratory
Infants	13.58	0.11	1.52
1-9	0.59	0.01	0.06
10-19	0.82	0.03	0.02
20-29	2.64	0.2	0.07
30-39	4.72	0.82	0.19
40-49	8.43	2.55	0.41
50-59	15.85	6.59	0.82
60-69	29.32	16.2	1.51
70+	83.8	61.09	3.15

Note: The annual mortality rate is measured per 1,000 inhabitants.
Source: Authors' calculations from the Federal State Statistics Service of the Russian Federation.

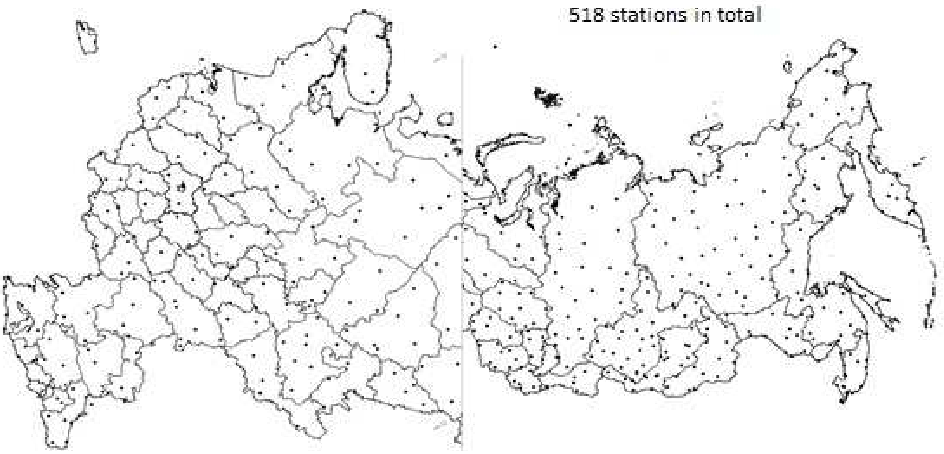
The weather data are taken from the Federal State Service of the Russian Federation for Hydrometeorology and Environmental Monitoring. These data are collected from 518 ground stations, representing the average daily temperature and precipitation level (see Figure 1). The weather data are taken from ground stations that are located within a 200 kilometer radius of each administrative area's (e.g. city, town, village) centroid in a given region. If there are several ground stations within the centroid of each administrative area, these stations are weighted by an inverse distance square. Thus, the meteorological station closest to a particular administrative area is given the largest weight.

To aggregate the weather data at a regional level, they are weighted by the administrative areas' population they represent. Thus, administrative areas with the largest population are given the largest weight in a particular region.[6] The aggregation using the population-weighted weather data as opposed to the area-weighted weather data is recommended by Dell et al. (2014) for such countries as the United States and Russia, which have geographically large territorial units with low population density. As a result, we receive "the average weather experienced by a person in the administrative area, not the average weather experienced by a place" (Dell et al., 2014, p.751).

---

[6] For a detailed discussion on the methods of the weather data aggregation, see Hanigan et al. (2006).

Figure 1: Map of ground stations in Russia



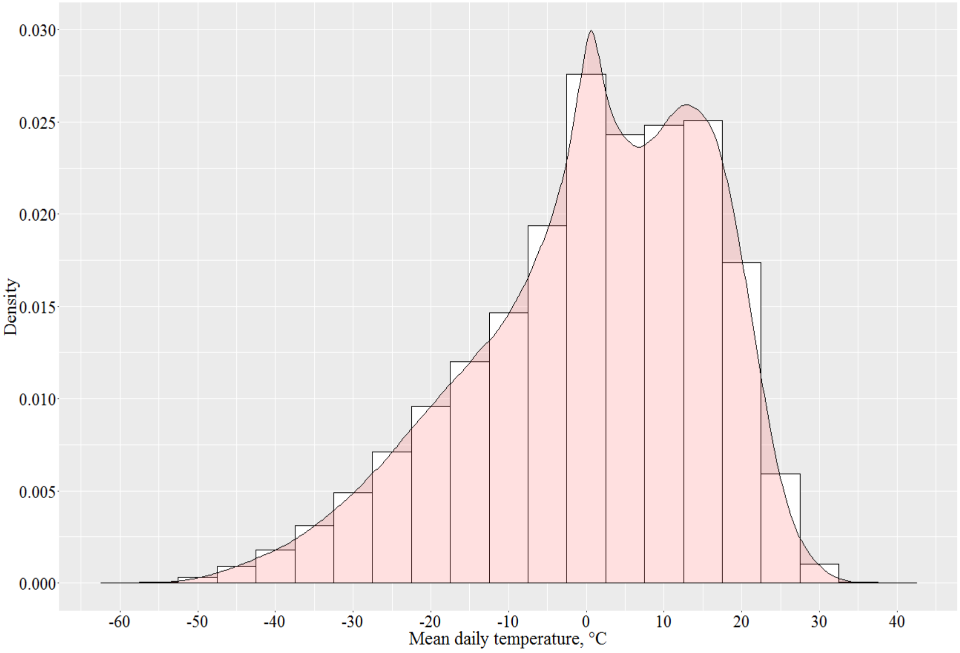
Source: Authors' construction using the R-software program.

Following Deschênes and Greenstone (2011) and Burgess et al. (2014), for each year and region we construct the 13 temperature bins. The temperature is measured in degrees Celsius (°C). The temperature bins are divided into the following temperature ranges: -30°C and below, (-30°C, -25°C], (-25°C, -20°C], (-20°C, -15°C], (-15°C, -10°C], (-10°C, -5°C], (-5°C, 0°C], (0°C, 5°C], (5°C, 10°C], (10°C, 15°C], (15°C, 20°C], (20°C, 25°C], and above 25°C.[7] For instance, all days within a particular year and region with the mean daily temperature 10°C fall into the bin (5°C, 10°C]. The 5°C step for the temperature bins is chosen based on the distribution of days with the corresponding average daily temperature from 1989 to 2014. This distribution is shown in Figure 2.

---

[7] The interpretation of parentheses and brackets is as follows. For instance, the (-30°C,-25°C] bin does not include -30°C but includes -25°C. All other temperature bins are interpreted accordingly.

Figure 2: Distribution of days with a specific temperature

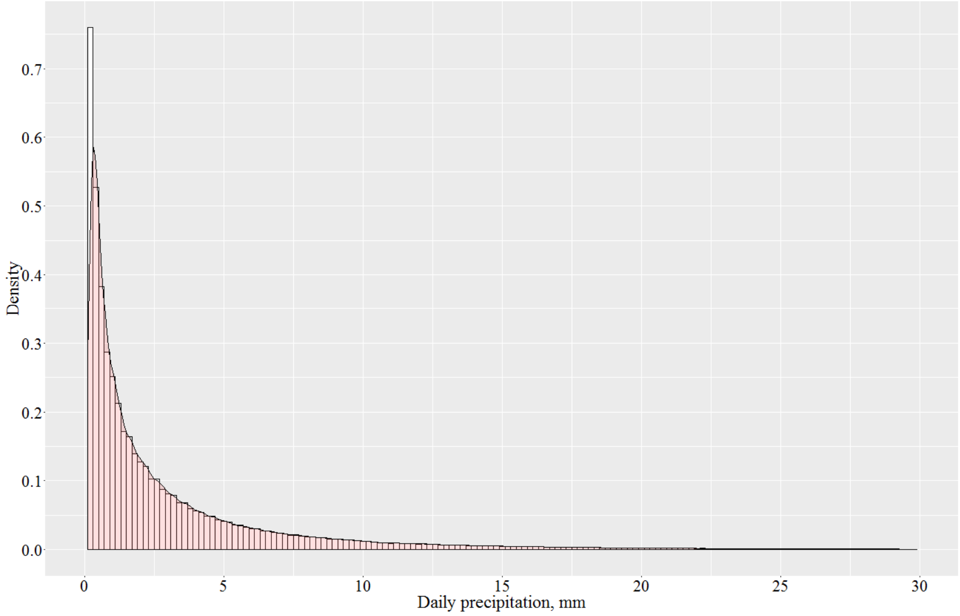


Source: Authors' construction.

In contrast to the literature, in this study we use a wider temperature range, from -60°C to above 30°C. We consider days with the temperature -30°C and below as extremely cold and days with the temperature above 25°C as hot. As shown in Figure 2, the distribution is skewed to the right with the long left tail and short right tail. This indicates that the number of extremely cold days is greater than the number of hot days. The mode of distribution is in between 0°C and 15°C. About two thirds of regions in our sample experience the days with temperature below -30°C in the covered period. However, only one third of regions in our sample experience days with temperature above 30°C between 1989 and 2014. Thus, we decide to merge days with temperature above 25°C into one bin.

The distribution of days with a specific precipitation level is shown in Figure 3. Following Burgess et al. (2014), we divide the distribution of days with a specific precipitation level measured in millimeters (mm) in a year *t* into tertiles. In our case the precipitation range in the lower tertile is [0 mm, 10 mm), the range in the middle tertile is [10 mm, 20mm), while the range in in the upper tertile is between 20 mm and above. Since there are too many days with zero amount of rainfall, these were excluded from Figure 3. Even after the exclusion of those days, we still observe that the distribution is skewed to zero with long thin tail to the right, indicating the number of days with the extreme amount of rainfall is low. In case of both temperature and precipitation, we standardized the numbers of days per year to 365 days.

Figure 3: Distribution of days with a specific level of precipitation



Note: Days with 0mm amount of precipitation level are not included.
Source: Authors' construction.

4. Econometric Model

In this section we present the econometric model to estimate the relationship between mortality and weather. Following Deschênes and Greenstone (2011) and Burgess et al. (2014), our model is:

$$ln(Mortality_{rt}) = \beta_0 + \sum_{j=1}^{J=13} \beta_j \, Bin_{rt}^{Temp} + \sum_{n=1}^{N=3} \delta_n \, Bin_{rt}^{Prec} + \alpha_r + \gamma_t + \boldsymbol{\Phi}' Region * Trend + u_{rt} \quad (1)$$

where the subscripts *r* and *t* stand for a region and year, respectively. $Mortality_{rt}$ stands for mortality rate. Bin_{rt}^{Temp} 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 13 bins. The temperature bin (20°C, 25°C] is used as a default. Bin_{rt}^{Prec} 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 bins. The precipitation bin [0 mm, 10 mm) is used as a default. The definition of temperature and precipitation bins is discussed in the previous section.

α_r stands for the regional fixed effects. Using panel data analysis with the fixed effects, we control for all of the potentially important unobserved regional specific time invariant variables that may affect regional mortality rate. For instance, these fixed effects may account for the region-specific supply of doctors and medical facilities. γ_t stands for the time fixed effects. For instance, the time fixed effects may account for the health sector reforms that are common across all regions.

To control for regional linear time trends, we include the interaction term, $Region * Trend$, where *Region* is a set of dummy variables and equals one for a region *r* and 0 otherwise while *Trend* is a linear time trend. This interaction term controls for any region-specific trends that may affect the outcome of interest and might correlate with climate. u_{rt} is a disturbance term while $\boldsymbol{\beta}, \boldsymbol{\delta}, \text{and } \boldsymbol{\Phi}$ are the vectors of the model parameters. Robust standard errors are clustered at a regional level. All regressions are weighted by the relevant population.

In contrast to Barreca et al. (2015) and (2016), we do not include explanatory variables such as age categories in Eq.1, since we analyze mortality for different age groups separately rather than all-age mortality. Also, Dell et al. (2014) recommend to include any additional economic explanatory variables based only on a strong argument, and point out that the inclusion of explanatory variables may lead to an over-controlling problem and bias the results. For instance, as discussed by Dell et al. (2014), such variables as national income or investment are potentially endogenous, since they are affected by the weather data directly and indirectly.

4.1. Economic Costs of Hot and Cold Days

To estimate the economic costs of hot and cold days for the working age population, we follow the approach suggested by Leal et al. (2006) and Kontsevaya et al. (2013). These economic costs represent a present value of the forgone earnings of individuals affected by a mortality risk and are estimated as follows:

$$EC_{trg} = \sum_{t=1}^{T} \frac{1}{(1+i_r)^t} * D_{ig} * W_r * LFP_r \tag{2}$$

where the subscript *t* and *r* stand for time and a region, respectively, while *g* stands for an age-specific group (i.e. 20-29 years old; 30-39 years old; 40-49 years old; and 50-59 years old). *T* stands for years left until the retirement age. *T* equals 30 years for the 20-29 age group, 20 years for the 30-39 age group, 10 years for the 40-49 age group, and 5 for the 50-59 age group.[8] *EC* stands for the present value of economic costs of one extra hot or cold day (with the average daily temperature above 25°C or between -30°C and -25°C, respectively). *D* is the estimated number of deaths due to one extra hot or cold day. The estimated number of deaths due to all-cause, cardiovascular-, and respiratory-cause diseases is based on the average age specific mortality and population over the covered period. Then, the average number of deaths is multiplied by the age specific coefficients on the above 25°C or between -30°C and -25°C temperature bins (see Tables A1-A3 in the appendix). *W* is the average regional yearly earnings per capita in 2014, and *LFP* is a regional labor force participation rate in 2014. To calculate the present value of the future economic costs, we use a discount factor, *i*, that corresponds to the regional consumer price index in 2014.[9]

It is also worth mentioning that the estimated economic costs from Eq. 2 should be considered as the lower bound estimates. First, in calculating those costs, we use the upper age limit of each age group. Thus, a share

---

[8] In 2014, the female retirement age in the Russian Federation was 55 years old, and the male retirement age was 60 years old. Also, some cold regions have early retirement age (50 years old for females and 55 years old for males). For simplicity, to calculate the economic cost, we use 60 years old as the retirement age. In the case of the 50-59 group, we multiply Eq.2 by the share of population aged 50-55 in the 50-59 group such that this group has 5 years left until retirement.

[9] The use of the consumer price index as a discount factor in the calculation of the present value of economic costs is suggested by Leal et al. (2006) for the European Union countries and Kontsevaya et al. (2013) for Russia.

of individuals in each age group may have a greater number of years left until the retirement age. Second, according to Russian legislation, individuals are allowed to work after retirement, while in our calculations, we assume that once an individual retires, he/she stops working. Finally, the estimated costs do not account for a possible increase in the retirement age, which is discussed among the Russian authorities.

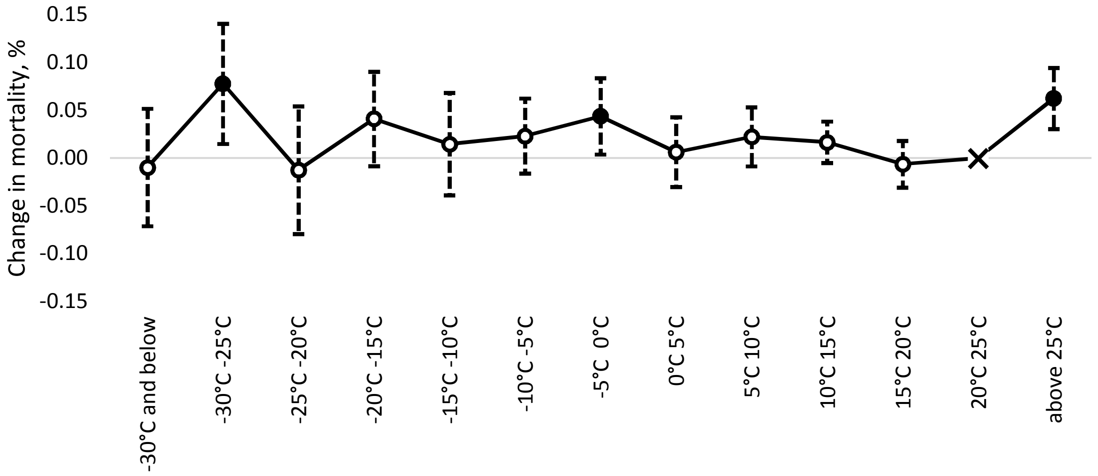
5. Estimation Results

In this section we present and discuss estimation results. The section is divided into five parts: the impact of weather (i) on all-cause mortality, (ii) on cardiovascular-cause mortality, (iii) on respiratory-cause mortality, in (iv) we discuss the impact of days with extremely cold and hot temperatures on mortality, and finally, in (v) we estimate the impact of cold and hot days during work days and weekends. Note that the temperature bin coefficients are interpreted with respect to the temperature bin between 20°C and 25°C, while the bin coefficients for precipitation are interpreted with respect to the precipitation bin between 0 mm and 10 mm. Hereinafter, these bins are referred to as the default bins. The significance of the estimated coefficients is presented at a 10% significance level.

5.1. All-cause Mortality

The results for the impact of weather on all-cause all-age mortality are shown in Figure 4. Hereinafter, “all-cause” and “total mortality” are used interchangeably. As shown in this figure, the solid circles stand for the statistically significant impacts at a 10% significance level and the empty circles stand for the non-significant ones. The dashed line stands for a 90% confidence interval. The default bin is indicated by the cross. The detailed estimation results are presented in Table A1 in the appendix.

Figure 4: The impact of one day with a specific temperature on the total all-age mortality



Notes: The solid circles stand for statistically significant impact, while the empty circles stand for non-significant. The dashed line stands for a 90% confidence interval. The default bin is indicated by the cross. Robust standard errors are clustered at a regional level. The regression is weighted by regional population.

In Figure 4 we see the significant positive impact of an additional day with the temperatures below 0°C on the total all-age mortality. An additional day per year with temperatures between (-5°C, 0°C] and (-30°C, -25°C] increases the total all-age mortality by 0.04% and 0.08%, respectively. Epidemiological literature suggests that such cold-related mortality can be due to arterial thrombosis, coronary spasms, low immunity, and reduced resistance to respiratory infections (Keatinge et al., 1997).

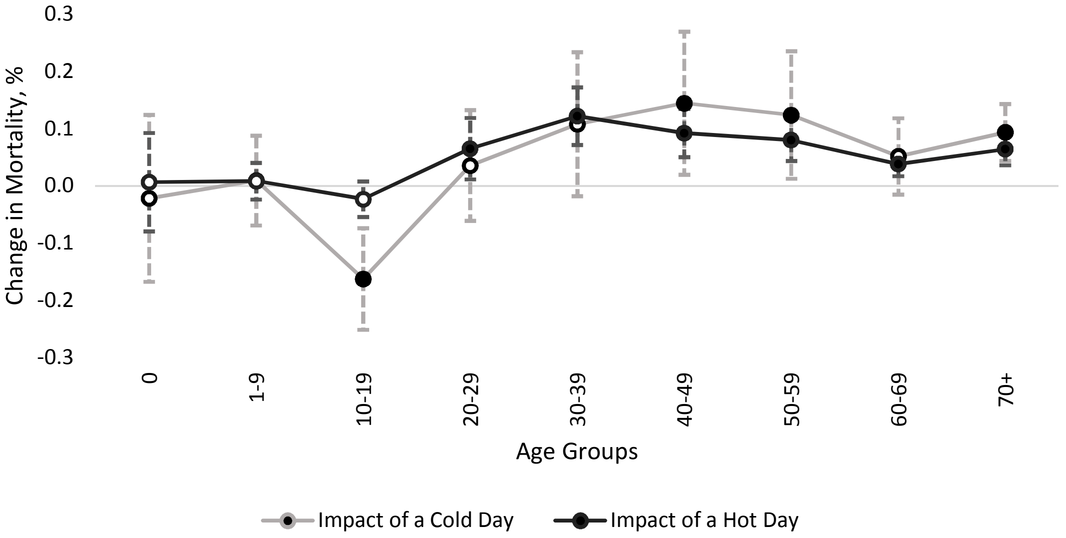
Regarding hot days, as shown in Figure 4, an additional day with temperature above 25°C in a year increases the total all-age mortality by 0.06%, relative to the default bin. This impact is considerable, even though slightly lower when compared to other studies. For instance, Deschênes and Greenstone (2011) find that the impact of one additional extremely hot day (above 90°F or ca. 32.2°C) on the all-age total mortality is 0.11% for the US, while Burgess et al. (2014) find the impact of one day with temperature above 97°F (ca. 36.1°C) to be about 0.75% for rural areas and 0.37% for urban areas in India.[10]

---

[10] Note that our study differs from Deschênes and Greenstone (2011) and Burgess et al. (2014) in two ways. First, the range of temperatures in our study is wider (from -30°C and below to above 25°C). Second, our default temperature bin is in the range between 20°C and 25°C. Deschênes and Greenstone (2011) use temperature bins from 10°F (ca. – 12.2°C) and below to above 90°F (ca. 32.2°C) with the ten-degree steps and 50-60°F (ca. 10-15.5°C) as a default bin. Burgess et

Next, we discuss the results regarding the all-cause mortality by age groups. The results on cold and hot days for each age group are in Figure 5. The grey line corresponds to the impact of a day with cold temperature (between -30°C and -25°C) on the mortality of a particular age group, while the black line corresponds to the impact of a day with hot temperature (above 25°C). The solid black circles stand for the statistically significant impact at a 10% significance level. As shown in this figure, an additional day in a year with cold temperature increases the all-cause mortality of the 40-49, 50-59, and 70+ year olds by 0.14%, 0.12%, and 0.09%, respectively. At the same time, a one day with this temperature reduces mortality of the 10-19 years old. We offer a possible explanation to this impact in the next subsection**.**

Figure 5: The impact of one day with (-30°C,-25°C] and above 25°C temperatures on the total mortality by age groups



Notes: The grey line corresponds to the impact of a day with cold temperature (-30°C and -25°C) on the mortality of a particular age group, while the black line corresponds to the impact of a day with hot temperature (above 25°C). The solid black circles stand for statistically significant impact, while the empty circle stands for non-significant. The dashed line stands for a 90% confidence interval. Robust standard errors are clustered at a regional level. All regressions are weighted by the regional population of a specific age group.

Regarding hot temperature, one extra hot day (above 25°C) in a year increases the mortality of the 20-29, 30-39, 40-49, 50-59, 60-69, and 70+ age groups by 0.07%, 0.12%, 0.09%, 0.08%, 0.04%, and 0.06% respectively,

---

al. (2014) use temperature bins in a range between 70°F (ca. 21.1°C) and below and above 97°F (ca. 36.1°C) with the three-degree step and 70-72°F (ca. 21.1-22.2°C) as a default bin.

when compared to the default bin. Importantly, in relative terms, the impact of hot days on the 30-39 year olds is greater than the impact on any other age group. This is an important policy-relevant finding, indicating that the most productive age group is more vulnerable to hot weather in terms of relative risk.

Note that we do not find sufficient evidence on the impact of weather on infant mortality. This is not surprising since any changes in the health of infants, whose thermoregulatory functions are not mature, warn for immediate attention and timely medical treatment. This mitigates the impact of weather on infant mortality. Deschênes and Greenstone (2011) also do not find the impact of weather on infant mortality in the US, except for the extremely hot days. Burgess et al. (2014) argue that infants are not affected by extremely hot weather in urban areas in India. Regarding the elderly (70 and above), we find that this age group is vulnerable to any temperature change, supporting the harvesting effect (see Table A1).

Regarding the impact of precipitation on mortality, our findings are consistent with Deschênes and Greenstone (2011). We do not find the relationship between precipitation and mortality of most age group. except for the 1-9 and 20-29 year olds. One extra day of rainfall between 10mm and 20mm reduces the mortality of the 1-9 year olds by 0.09% with respect to the default bin (bin with 0mm and 10mm amount of rainfall). This finding may be explained by the fact that higher precipitation level associated with humidity is more comfortable for human health, especially during extremely hot days, as documented by Kunst et al. (1993). There is also the marginal impact of one extra day of rainfall between 20mm and above on the mortality of the 20-29 year olds.

5.2. Cardiovascular-cause Mortality

According to the World Health Organization, cardiovascular-cause mortality is the most important cause of death worldwide, representing 31% of total mortality in 2012 (WHO, 2015). In Russia, this situation is even more critical, accounting for 53% of total mortality in 2012.[11]

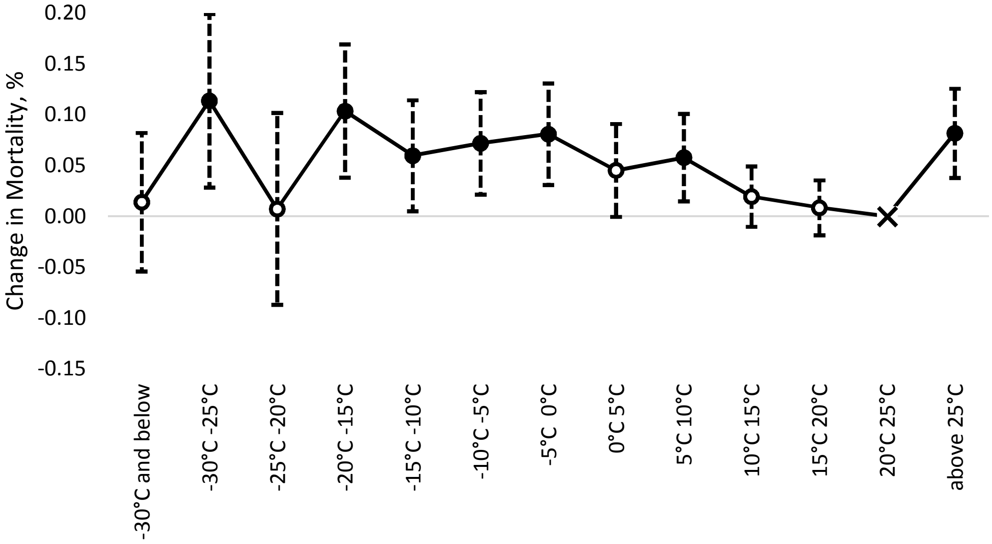
---

[11] See the Federal State Statistics Service of the Russian Federation at www.gks.ru.

The estimation results on the impact of different temperature bins on the cardiovascular-cause all-age mortality and on the impact of cold and hot days on the cardiovascular mortality of each age group are shown in Figures 6 and 7, respectively (for details, also see Table A2 in the appendix).

As shown in Figure 6, the coefficients on the bins with lower temperature have a positive sign and are statistically significant at a 10% significance level. This means that low temperature increases the cardiovascular-cause all-age mortality. In relative terms, the impact of the (-30°C, -25°C] temperature bin on mortality is greater than the impact of the (above 25°C] temperature bin with respect to the default bin (0.11% vs 0.08%, respectively).

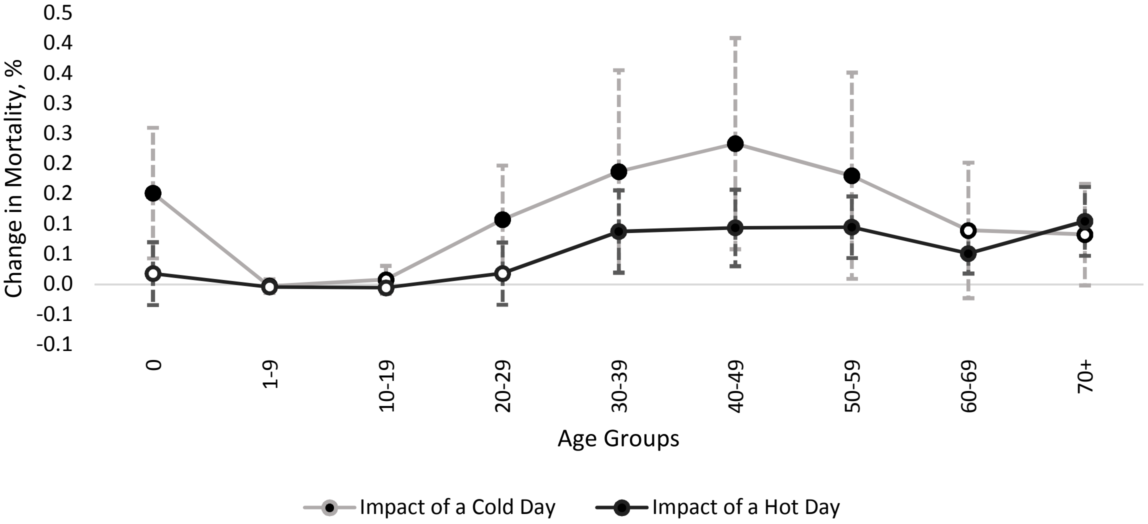
Figure 6: The impact of one day with a specific temperature on the all-age cardiovascular-cause mortality



Notes: The solid circles stand for statistically significant impact, while the empty circles stand for non-significant. The dashed line stands for a 90% confidence interval. The default bin is indicated by the cross. Robust standard errors are clustered at a regional level. The regression is weighted by regional population.

In Figure 7 we see the results on the impact of cold and hot days for each age group. As shown in this figure, days with cold temperature (i.e. between -30°C and -25°C) increase mortality of all age groups, except for the 1-9 and 10-19 year olds. In fact, in relative terms, the greatest impacts on mortality occur for the working age groups (0.18% for the 30-39 and 50-59 year olds and 0.23% for the 40-49 year olds for one extra day). The rise in the cardiovascular-cause mortality during the cold weather is important evidence for policy makers. It implies that cold-protective regulatory measures, housing conditions, and the risk aversion behavior of inhabitants might not be effective enough in reducing mortality during the cold weather.

Figure 7: The impact of one day with (-30°C,-25°C] and above 25°C temperatures on the cardiovascular-cause mortality by age groups



Notes: The grey line corresponds to the impact of a day with cold temperature (-30°C and -25°C) on the mortality of a particular age group, while the black line corresponds to the impact of a day with hot temperature (above 25°C). The solid black circles stand for statistically significant impact, while the empty circles stand for non-significant. The dashed line stands for a 90% confidence interval. Robust standard errors are clustered at a regional level. All regressions are weighted by the regional population of a specific age group.

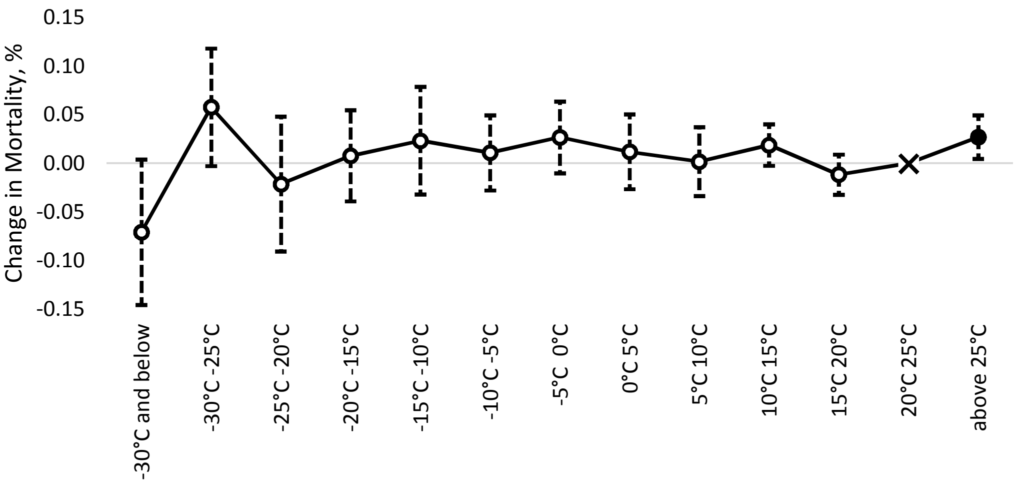
Concerning hot temperature, we find evidence of an increase in the cardiovascular-cause mortality of the 30-39, 40-49, 50-59, 60-69, and 70+ age groups. It is interesting that in relative terms, the greatest impact is found for the group of the 30 and 39 year olds following the 40 and 49 year olds, corresponding to a 0.84% and 0.6% rise in mortality for each additional day above 25°C with respect to the default bin. This is an important result since those age groups are also considered to be most productive and economically active. An increase in mortality of those age groups raises the dependency ratio, and reduces income tax payments and social security system contributions.

Regarding the amount of rainfall, we do not find any evidence of its impact on cardiovascular-cause mortality of any age group, except for the 20-29 age group**.**

5.3. Respiratory-cause Mortality

The results for the respiratory-cause all-age mortality are in Figure 8 (for details, see also Table A3 in the appendix). We find that only hot temperature (above 25°C) increases the respiratory-cause mortality. For each extra day in a year mortality increases by 0.03% when compared to the default bin. Epidemiological literature suggests that the heat-related respiratory-cause mortality can be due to thermal stress, susceptibility to pneumonia, and the inhalation of irritants present in hot and dry air. Moreover, the incubation period of respiratory diseases is very short and the likelihood of complications related to them is very high. This process is aggravated by the high temperature of environment (see Kunst et al. 1993).

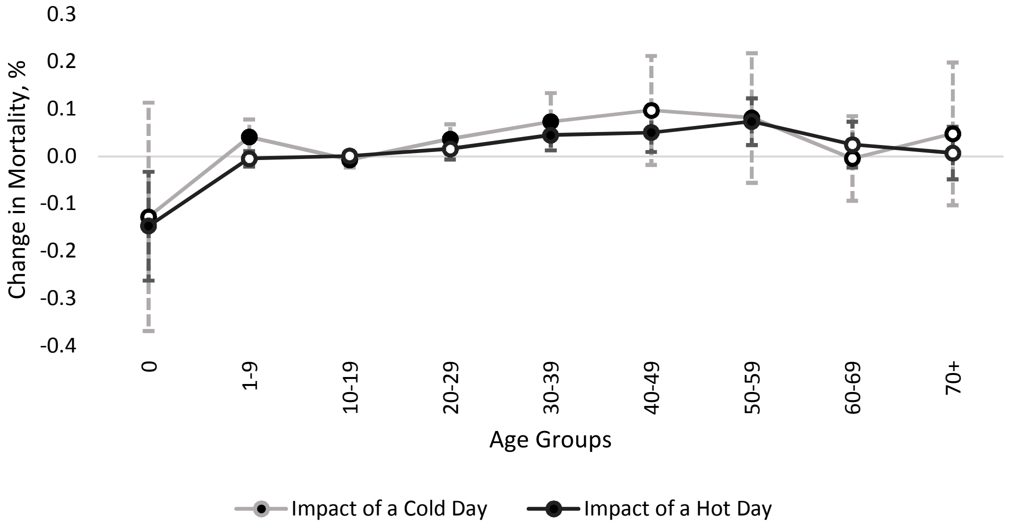
Figure 8: The impact of temperature on the all-age respiratory-cause mortality



Notes: The solid circles stand for statistically significant impact, while the empty circles stand for non-significant. The dashed line stands for a 90% confidence interval. The default bin is indicated by the cross. Robust standard errors are clustered at a regional level. The regression is weighted by regional population.

The results for the impact of cold and hot temperatures on the respiratory-cause mortality for different age groups are in Figure 9. The children of age 1 to 9 are vulnerable to cold temperature (i.e. between -30°C and -25°C)**.** For instance, one extra day with temperature between -30°C and -25°C increases their mortality by 0.04% when compared to the default bin. This can be explained by the fact that the children of age 1 to 9 still have an immature immunity. Moreover, children of this age start attending educational institutions such as kindergarten and primary school, where the likelihood to be infected increases. Also, one extra day with temperature between -30°C and -25° increases mortality of the 20-29 and 30-39 year olds by 0.04% and 0.07%, respectively.

Figure 9: The impact of one day with (-30°C,-25°C] and above 25°C temperatures on the respiratory-cause mortality by age groups



Notes: The grey line corresponds to the impact of a day with cold temperature (-30°C and -25°C) on the mortality of a particular age group, while the black line corresponds to the impact of a day with an extremely hot temperature (above 25°C). The solid black circles stand for statistically significant impact, while the empty circles stand for non-significant. The dashed line stands for a 90% confidence interval. Robust standard errors are clustered at a regional level. All regressions are weighted by the regional population of a specific age group.

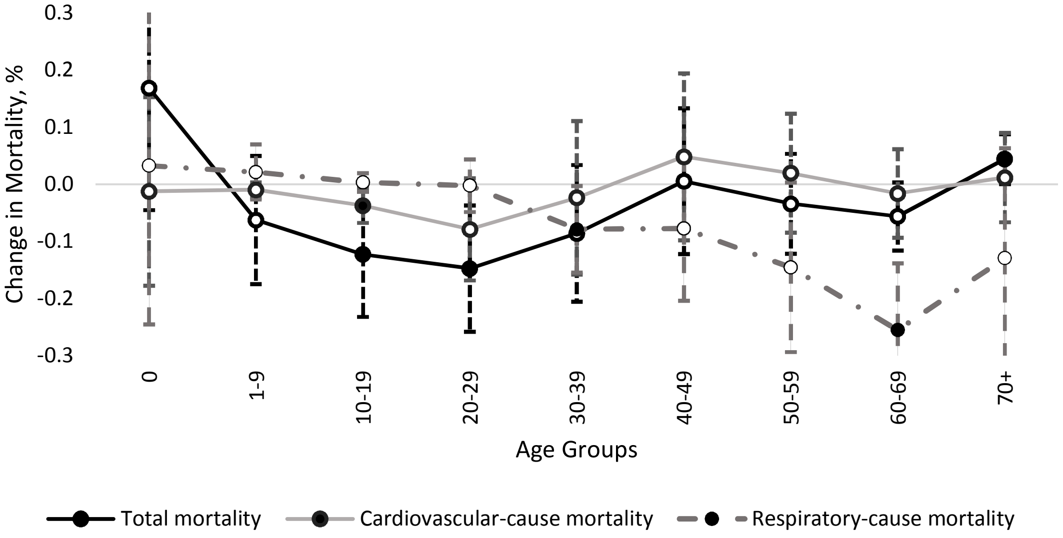
In Figure 9 we also see the impact of hot temperature for people of age 30-39, 40-49, and 50-59. For instance, one extra day with such temperature increases the mortality of those age groups by 0.04%, 0.05%, and 0.07%, respectively, when compared to the default bin.

Concerning precipitation, we do not find the impact of precipitation on the mortality of any age group except the 20-29 group, for whom one day with an amount of rainfall between 20mm and above increases mortality by 0.22% with respect to the default category.

5.4. Extremely Cold and Hot Temperatures and Mortality

As shown in previous sections, cold and hot days increase the total, cardiovascular-, and respiratory-cause all-age mortality. However, we also find that extremely cold days (below -30°C) may reduce mortality. As shown in Figure 10, an additional day in a year with the extremely cold temperature reduces the total mortality of the 10-19 and 20-29 year olds by 0.12% and 0.15%, respectively. We also find that this temperature reduces the cardiovascular-cause mortality of age 10-19 and the respiratory-cause mortality of age 30-39 and 60-69. One possible explanation of these results is that extremely cold weather might cause people to stay indoors. Such behavior results in fewer fatalities from traffic accidents, as suggested by Eisenberg and Warner (2005), or reduces the spread of communicable diseases via less contact. Although these results are suggestive, they provide interesting insights, since earlier economic studies did not consider temperatures colder than 0°F (ca. -17.8°C) and assumed that colder temperatures have only a harmful effect for human health.

Figure 10: The impact of one day with extremely cold temperature (below -30°C) on mortality by age groups



Notes: The solid black circles stand for statistically significant impact, while the empty circles stand for non-significant. The dashed line stands for a 90% confidence interval. Robust standard errors are clustered at a regional level. All regressions are weighted by the regional population of a specific age group.

Our results are consistent with epidemiological case studies that underscore that extremely cold temperatures may prevent excess mortality. For instance, Donaldson et al. (1998a and 1998b) conduct the case studies in

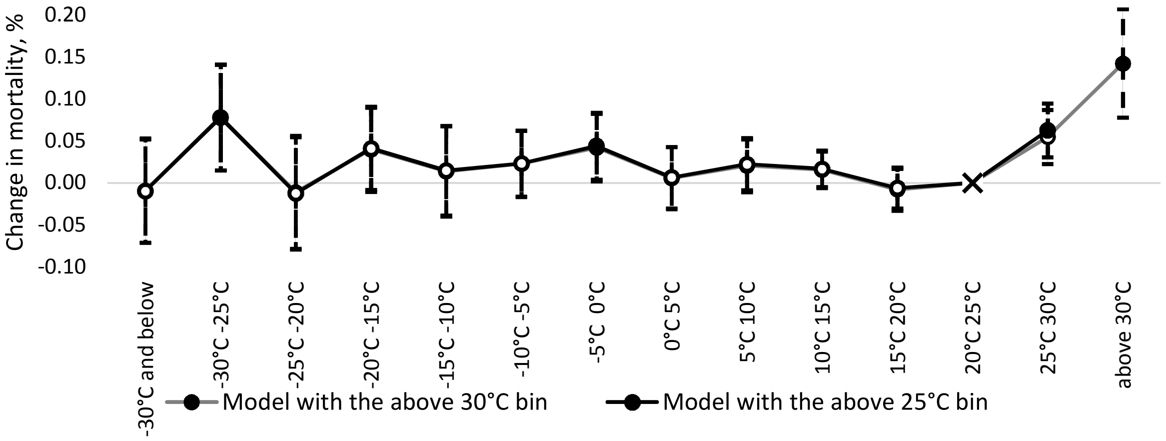
Yekaterinburg (Eastern side of the Ural Mountains) and Yakutsk (Eastern part of Siberia), the two Russian cities with -6.8°C and -26.6°C mean temperatures during winter, respectively. The authors find that cold weather does not increase the mortality of the local population because inhabitants show risk aversion behavior by wearing warmer clothes, practicing physical activities, and/or staying at home on cold days. There are also preventive official regulations that forbid outdoor working activities and attendance of school during extremely cold days.

To analyze the impact of extremely hot temperature (above 30°C), we redefine the hot temperature bin (i.e. above 25°C) into the (25°C, 30°C] and above 30°C bins, even though only one third of regions in Russia experience this extremely hot temperature, as discussed in the Data section. The findings suggest that this modification does not change our results since the impact of all temperature bins on the total all-age mortality remains the same as in our main model specification (see Figure 11).[12] As shown in Figure 11, one extra hot day above 30°C increases the total mortality by 0.14%. Even though this finding is similar to Deschênes and Greenstone (2011), it should be interpreted with caution, since only few regions experience this temperature. This also suggests that our main model presents the lower bound estimates for the impact of hot temperature (i.e. above 25°C) on mortality in Russia. The impact of extremely hot days on mortality in Russia can be addressed in future, when more regions will experience these days.

Figure 11: Comparison of the models with different specification of hot temperature bins

---

[12] Results also remain the same in the case of cardiovascular- and respiratory-cause mortality and are available upon request.

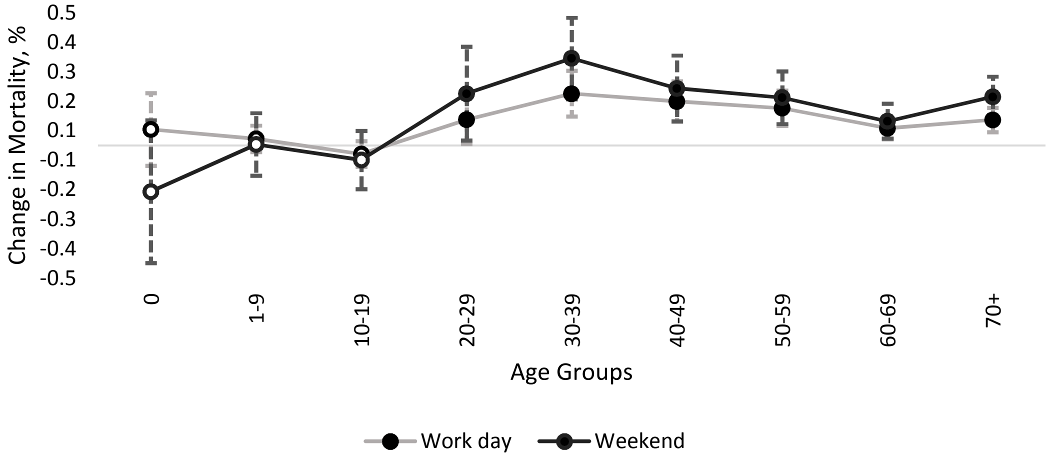


Notes: The impact of one day with a specific temperature on the total all-age mortality is presented. The solid circles stand for statistically significant impact, while the empty circles stand for non-significant. The dashed line stands for a 90% confidence interval. The default bin is indicated by the cross. Robust standard errors are clustered at a regional level. The regression is weighted by regional population.

5.5. Work Days vs. Weekends

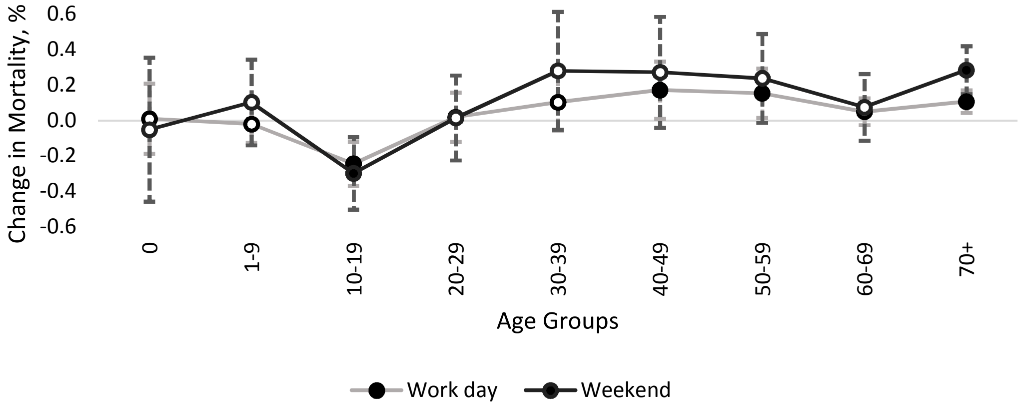
The impact of temperature on mortality might be different during work days and weekends, especially for the working age population. There are several reasons for these possible differences. First, workplaces typically have air conditioning that helps mitigate the weather impact, yet it is not common to have air conditioning at home in Russia. Second, during the summer people often spend weekends outside (i.e. picnics, fishing, among other outdoor activities). Third, there might be other behavioral aspects that is, for instance, drinking more alcohol during the weekend. These reasons increase the likelihood of being affected by hot temperatures. Thus, we estimate models for work days and weekends separately. The results for the impact of hot and cold days on the total mortality by age groups are presented in Figures 12 and 13, respectively.

Figure 12: The impact of a work day and weekend hot temperature on the total mortality by age groups



Note: The impact of a day with the temperature above 25°C is presented. The default temperature bin is from 20°C to 25°C. The solid circles stand for statistically significant impact, while the empty circles stand for non-significant. The dashed line stands for a 90% confidence interval. The default bin is indicated by the cross. Robust standard errors are clustered at a regional level. The population weight of a specific age group is applied.

Figure 13: The impact of a work day and weekend cold temperature on the total mortality by age groups



Note: The impact of a day with the temperature between -25°C and -30°C is presented. The default temperature bin is from 20°C to 25°C. The solid circles stand for statistically significant impact, while the empty circles stand for non-significant. The dashed line stands for a 90% confidence interval. The default bin is indicated by the cross. Robust standard errors are clustered at a regional level. The population weight of a specific age group is applied.

As shown in Figures 12 and 13, the impact of a weekend hot and cold temperature on the total mortality of the working age and retired population is greater than that of work days, confirming our previous explanations.

However, in both figures, the confidence intervals of the impact of a work day and weekend overlap for all age groups, showing that those impacts are not statistically different.

6. Economic Costs of Hot and Cold Days

There is a global increase in anthropogenic greenhouse gas emissions, due to which the number of extremely hot days is expected to grow and the number of extremely cold days is expected to decrease (IPCC, 2014). In this section we estimate the number of deaths due to hot and cold days by age groups, except for young people.[13] Then we evaluate the economic costs of those days for the working age population. These costs stand for a present value of the forgone earnings of an individual affected by a mortality risk, as described in the Econometric Model section. The estimated economic costs attributed to hot days can be used for conducting a cost-benefit analysis of the greenhouse gas reduction policies while the costs attributed to cold days can be used to assess the potential economic gains due to lower exposure to cold temperatures.

The results for one extra day above 25°C are shown in Table 2. The largest estimated number of deaths is computed for the 70+ year olds for the all-cause and cardiovascular-cause.

Table 2: The estimated economic cost of one day above 25°C

Age Groups	Estimated Number of Deaths			Economic Cost in USD (millions)		
	All-cause	Cardio-vascular	Respiratory	All-cause	Cardio-vascular	Respiratory
20-29	41	1*	0*	1.32	0.03*	0.01*
30-39	126	16	2	3.79	0.5	0.05
40-49	158	48	4	3.53	1.08	0.10
50-59	227	106	10	1.61	0.78	0.07
60-69	160	111	6*			
70+	593	721	4*			
Total	1,305	1,002	16	10.25	2.36	0.22

Notes: * corresponds to non-significant coefficients from Tables A1-A3. The total number of deaths and economic costs (see the row 'Total') are computed by summing up the respective estimates of a specific age group that are based on statistically significant coefficients from Tables A1-A3. Exchange rate is 1 USD=58.57 Russian Rubles (31 December 2014).

---

[13] Note that we do not calculate the number of deaths due to hot and cold days for infants and young people of age 1-9 and 10-19 since the impact of hot and cold weather on those age groups is either marginally significant or not statistically significant.

Overall, the total estimated number of deaths due to cardiovascular diseases is considerably greater than due to respiratory diseases for all age groups. As shown in Table 2, the estimated numbers of deaths due to cardiovascular and respiratory diseases associated with one day of hot temperature account for 78% of the all-cause number of deaths. This is supported by the national statistics discussed above.

In the next columns, we see the associated economic cost for each type of mortality in USD in 2014 prices (in millions). The total estimated impact of one day with hot temperature on the all-cause mortality of working age population corresponds to 10.25 million USD or 0.28% of GDP per day in Russia.[14] This is a considerable impact since the Russian governmental expenditures on medicine were 25.05 million USD per day in 2014, and the one day impact corresponds to 40.2% of those expenditures.

Next, we compute the economic cost associated with one extra day with the average daily temperature between -30°C and -25°C. The results are shown in Table 3. The estimated numbers of deaths due to cardiovascular and respiratory diseases associated with one day of cold temperature account for 26% of the all-cause number of deaths.

The total estimated impact of one day with cold temperature on the all-cause mortality of the working age population corresponds to 7.91 million USD or 0.22% of GDP per day in Russia. This impact corresponds to 31.58% of daily governmental expenditures on medicine.

---

[14] To calculate GDP per day, we divide the annual GDP by 365 days.

Table 3: The estimated economic cost of one day between -30°C and -25°C

Age Groups	Estimated Number of Deaths			Economic Cost in USD (millions)		
	All-cause	Cardio-vascular	Respiratory	All-cause	Cardio-vascular	Respiratory
20-29	23*	5	1*	0.76*	0.17	0.02*
30-39	116*	33	3	3.48*	1.01	0.09
40-49	246	122	9	5.49	2.76	0.19
50-59	340	212	12	2.42	1.52	0.08
60-69	200*	199*	0*			
70+	890	576*	19*			
Total	1,476	367	12	7.91	5.46	0.36

Notes: * corresponds to non-significant coefficients from Tables A1-A3. The total number of deaths and economic costs (see the row 'Total') are computed by summing up the respective estimates of a specific age group that are based on statistically significant coefficients from Tables A1-A3. Exchange rate is 1 USD=58.57 Russian Rubles (31 December 2014).

7. Adaptation to Cold and Hot Days

A key question in analyzing the impact of extreme temperatures on mortality is whether individuals adapt to temperature changes. According to the IPCC (2007, p.6), adaptation is "an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities". Following this definition, adaptation to extreme temperature means that its impact is less harmful in regions that experience this temperature more frequently. This adaptation may occur due to technological advances that help to cope with extreme temperature, e.g. installation of air conditioners to protect against heat (Barreca et al. 2015 and 2016) or building houses from cold-resistant materials to protect against cold.

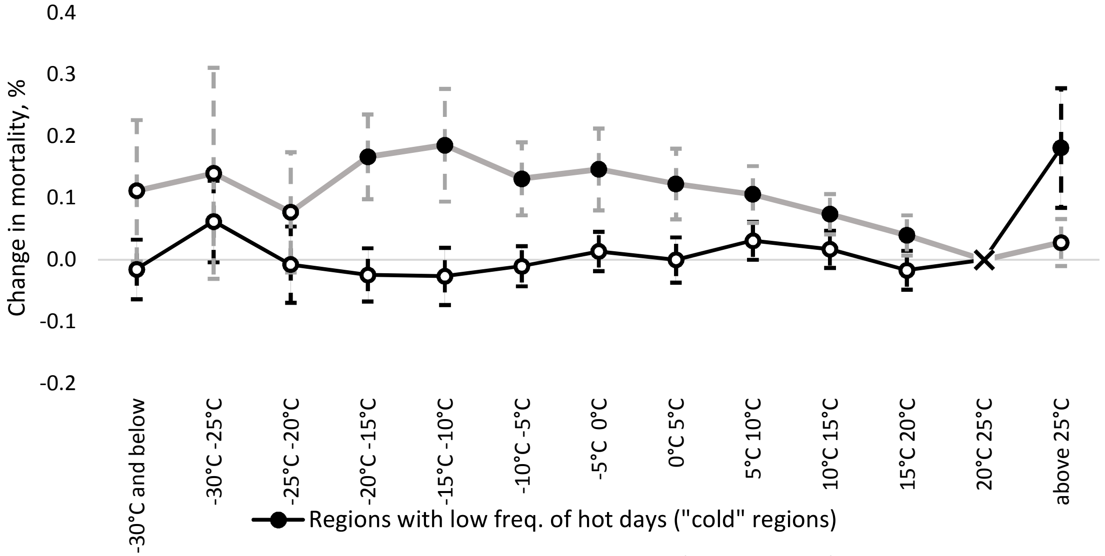
To illustrate adaptation to hot temperature, we split our sample in half based on the frequency of days above 25°C.[15] Figure 14 presents the results for regions with high and low frequencies of days with hot temperature. As shown in this figure, an additional day with hot temperature in regions with low frequency of such days increases mortality (black line), while other temperature ranges have no statistically significant impact on the total all-age mortality. Contrarily, in regions with high frequency of hot days, an additional hot day does not

---

[15] We thank an anonymous referee for suggesting this approach to study adaptation.

affect mortality (grey line). This may suggest that those regions have adapted to hot temperature, for instance, by installing air conditioners. However, population in those regions still remains vulnerable to lower temperatures, indicating that cold-protective measures (e.g., housing conditions) might not be effective enough.

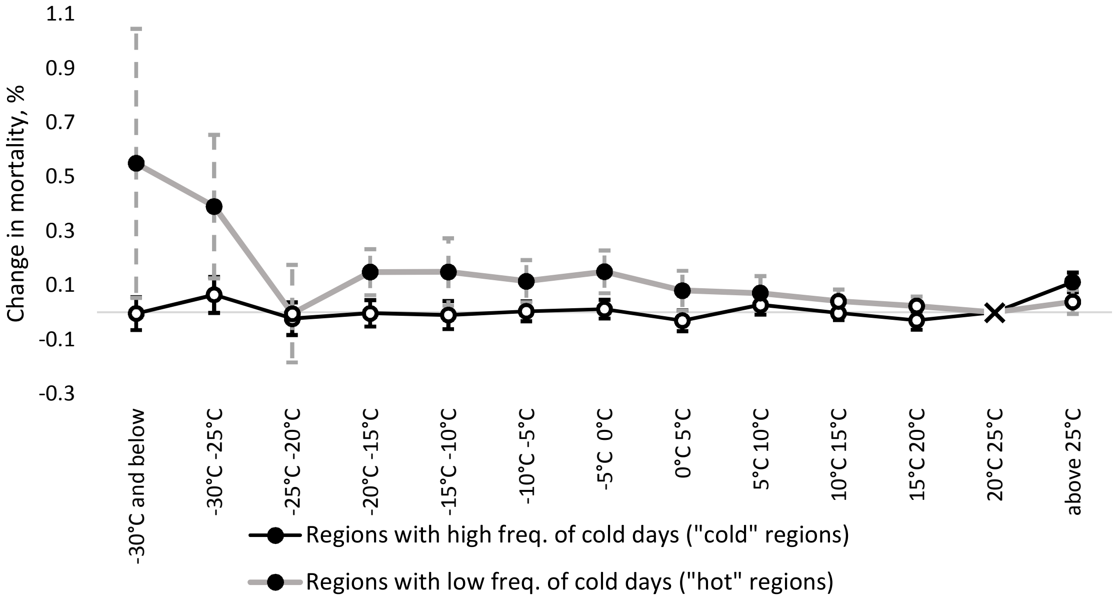
Figure 14: The impact of one day with a specific temperature for regions with high and low frequency of days above 25°C



Note: The solid circles stand for statistically significant impact, while the empty circles stand for non-significant. The dashed line stands for a 90% confidence interval. The default bin is indicated by the cross. Robust standard errors are clustered at a regional level. The regional population weights are applied.

To examine adaptation to cold temperature, we split our original sample in half based on the frequency of days below -25°C. Figure 15 presents the results for regions with high and low frequencies of cold temperatures. As shown in this figure, an additional day with the extremely cold temperature in regions with low frequency of such days increases mortality. Also, temperatures below 5°C have a statistically significant impact and increase mortality in these regions. In contrast, in regions with high frequency of cold days, an additional cold day does not affect mortality. This may suggest that regions that experience cold temperatures more frequently have adapted to this extreme, for instance, by using heaters. So, we may conclude that hot temperature is harmful for cold regions.

Figure 15: The impact of one day with a specific temperature for regions with high and low frequency of days below -25°C



Note: The solid circles stand for statistically significant impact, while the empty circles stand for non-significant. The dashed line stands for a 90% confidence interval. The default bin is indicated by the cross. Robust standard errors are clustered at a regional level. The regional population weights are applied.

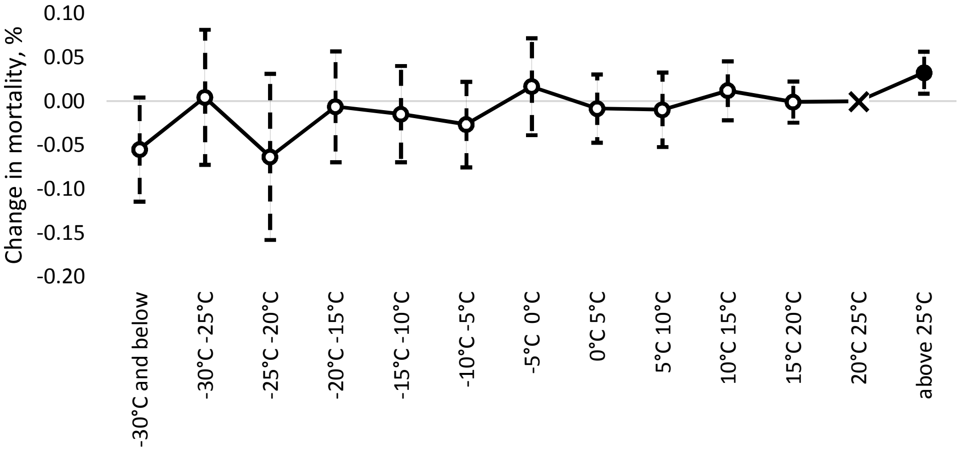
Given Figures 14-15, we observe that there is adaptation to hot temperatures in “hot” regions and adaptation to cold temperatures in “cold” regions. Overall, our findings suggest that if a region experiences both temperatures (hot or cold) less frequently, those temperatures have a harmful impact on mortality in that region.

8. Robustness Check

In this section we discuss the robustness of our results. Several alternative specifications are suggested. First, it might be the case that time trends in health and economic outcomes in certain regions correlate with climate. To alleviate this concern and check that the model adequately controls for time trends, we estimate a ‘placebo’ model that includes one year ahead of temperature bins in addition to contemporary ones. If the model accounts for such time trends accurately, then no information is left unexplained in the current mortality that correlates with the future period temperature bins.

The results are presented in Figure 16. As shown, none of the estimated coefficients on one year ahead temperature bins are statistically significant, except for the marginal significance of the coefficient on the hot temperature bin, which is also close to zero in magnitude. Thus, we may conclude that the model estimated in the previous section accounts for regional time trends adequately.

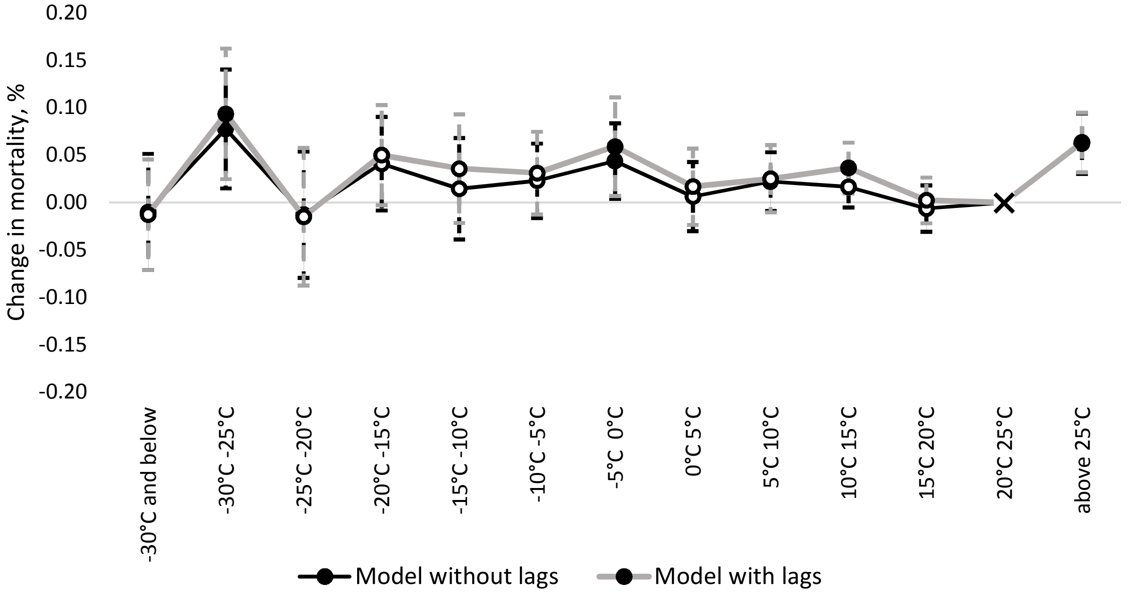
Figure 16: Impact of one year ahead temperature bins on the total all-age mortality in the 'placebo' model



Note: The solid circles stand for statistically significant impact, while the empty circles stand for non-significant. The dashed line stands for a 90% confidence interval. The default bin is indicated by the cross. Besides one year ahead temperature bins, the model also includes the current temperature bins. Robust standard errors are clustered at a regional level. The regional population weights are applied.

Another concern is whether the model accounts for the end-of-year harvesting effects. It might be the case that cold temperatures in December of the current year affect mortality in January of the next year. If so, the impact of cold days in December is underestimated. To address this issue, we estimate a model that includes one year lags of temperature bins in addition to contemporary ones. The results are presented in Figure 17**.** As shown, the impacts of the current period temperature bins from models with and without lags and their confidence intervals overlap. This suggests that after controlling for the lagged temperature bins, the impacts of all bins from both models are statistically the same. This means that our model adequately addresses the issue with the cold weather harvesting effects.

Figure 17: The impact of one day with a specific temperature on the total all-age mortality in models with and without lagged temperature bins



Note: The model with lagged temperature bins also include the temperature bins of the current year. The solid circles stand for statistically significant impact, while the empty circles stand for non-significant. The dashed line stands for a 90% confidence interval. The default bin is indicated by the cross. Robust standard errors are clustered at a regional level. The regional population weights are applied.

9. Conclusion

This study contributes to the literature on the impact of cold and hot weather shocks on mortality, using the regional panel data from Russia, an upper-middle-income country with vast interior climatic variations. The empirical findings suggest that days with cold temperature in a range between -30°C and 0°C increase mortality, especially of the population above 40 years old. We also find that days with hot temperature increase mortality considerably for most age groups. The impacts of days with cold and hot temperature are pronounced in the case of the cardiovascular-cause mortality, which remains a main cause of mortality in Russia. The results also suggest that regions frequently experiencing hot and cold temperatures have adapted to these temperatures.

Several remarks are in order. First, IPCC (2014) underscores that there is insufficient evidence regarding the impact of cold temperature on human health. This study fills this gap in the case of Russia and opens a further discussion regarding the effect of cold temperatures on health outcomes. Although cold temperature increases mortality, days with extremely cold temperature (below -30°C) may have an opposite impact and reduce mortality. These results suggest an interesting avenue for future research, underscoring that the impact of cold temperature can be equivocal. This should be tested in other Northern countries, e.g., Canada or Scandinavian countries that also experience such extremes.

Second, studying the impact and economic costs of days with cold temperature is particularly relevant given the global increase in the number of hot days and decrease in the number of cold days**.** Our findings suggest that lower exposure to cold days has a potential to partially mitigate the economic harm from hot days since the estimated economic cost of a day with hot temperature is 10.25 million USD, while the estimated economic cost of a cold day is 7.91 million USD. These results can be used for a cost-benefit analysis of the greenhouse reduction policies in Russia. Finally, future research may also contribute to more detailed analysis of adaptation to cold and hot weather. For instance, it would be interesting to examine how fast adaptation to hot temperature may occur in cold regions.

References

Acemoglu, D., Johnson, S., 2007. Disease and development: the effect of life expectancy on economic growth. Journal of Political Economy 115(6), 925-985.

Anderson, T.W., Le Riche, W.H., 1970. Cold weather and myocardial infarction. Lancet 1, 291-296.

Anttila-Hughes, J., Hsiang, S. M., 2013. Destruction, disinvestment, and death: Economic and human losses following environmental disaster, mimeo.

Aylin, P., Morris, S., Wakefield, J., Grossinho, A., Jarup, L., and P. Elliott, 2001. Temperature, housing, deprivation and their relationship to excess winter mortality in Great Britain, 1986-1996. International Journal of Epidemiology 30, 1100-1108.

Azarnert, L.V., 2006. Child mortality, fertility, and human capital accumulation. Journal of Population Economics 19, 285-297.

Barreca, A. I., 2012. Climate, humidity, and mortality in the United States. Journal of Environmental Economics and Management 63, 19-34.

Barreca, A. I., Clay, K., Deschênes, O., Greenstone, M., and J. S. Shapiro, 2016. Adapting to climate change: The remarkable decline in the U.S. temperature-mortality relationship over the 20th century. Journal of Political Economy 124(1), 105-159.

Barreca, A. I., Clay, K., Deschênes, O., Greenstone, M., and J. S. Shapiro, 2015. Convergence in adaptation to climate change: Evidence from high temperatures and mortality, 1900-2004. American Economic Review 105(5), 247-251.

Basu, R., Samet, J. M., 2002. Relation between elevated ambient temperature and mortality: A review of the epidemiologic evidence. Epidemiologic Review 24, 190-202.

Braga, A., Ferreira, L., Zanobetti, A., and J. Schwartz, 2001. The time course of weather-related deaths. Epidemiology 12(6), 662-667.

Burgess, R., Deschenes, O., Donaldson, D., and M. Greenstone, 2014. The unequal effects of weather and climate change: Evidence from mortality in India, mimeo.

Dell, M., Jones, B. F., and B. A. Olken, 2014. What do we learn from the weather? The new climate – economy literature. Journal of Economic Literature 52(3), 740-798.

Dell, M., Jones, B. F., and B. A. Olken, 2012. Temperature shocks and economic growth: Evidence from the last half century. American Economic Journal: Macroeconomics 4(3), 66-95.

Deschênes, O., Greenstone, M., 2011. Climate change, mortality, and adaptation: Evidence from annual fluctuations in weather in the US. American Economic Journal: Applied Economics 3(4), 152-185.

Deschênes, O., Greenstone, M., and J. Guryan, 2009. Climate change and birth weight. American Economic Review 99 (2), 211-217.

Deschênes, O., Moretti, E., 2009. Extreme weather events, mortality, and migration. Review of Economics and Statistics 91(4), 659-681.

Donaldson, G.C., Tchernjavskii, V.E., Ermakov, S.P., Bucher, K., and W. R. Keatinge, 1998a. Winter mortality and cold stress in Yekaterinburg, Russia: Interview survey. BMJ 316, 514-518.

Donaldson, G.C., Ermakov, S.P., Komarov, Y.M., McDonald, C.P., and W. R. Keatinge, 1998b. Cold related mortalities and protection against cold in Yakutsk, eastern Siberia: observation and interview study. BMJ 317, 978-982.

Eisenberg, D., Warner, K. E., 2005. Effects of snowfalls on motor vehicle collisions, injuries, and fatalities. American Journal of Public Health 95(1), 120-124.

Emanuel, K., 2005. Increasing destructiveness of tropical cyclones over the past 30 years. Nature 436, 686-688.

Fioroni, T., 2010. Child mortality and fertility: Public vs. private education. Journal of Population Economics 23, 73-97.

Galor, O., Weil, D. N., 2000. Population, technology, and growth: From Malthusian stagnation to the demographic transition and beyond. American Economic Review 90(4), 806-828.

Graff Zivin, J., Neidell, M. J., 2014. Temperature and the allocation of time: Implications for climate change. Journal of Labor Economics 32(1), 1-26.

Graff Zivin, J., Neidell, M. J., 2013. Environment, health, and human capital. Journal of Economic Literature 51(3), 689-730.

IPCC, 2014. Climate change 2014: Synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.)]. IPCC, Geneva, Switzerland.

IPCC, 2007. Climate change 2007: Impacts, adaptation and vulnerability. Working group II contribution to the fourth assessment report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (Eds.), Cambridge University Press, Cambridge, UK.

Hanigan, I., Hall, G., and K.B.G. Dear, 2006. A comparison of methods for calculating population exposure estimates of daily weather for health research. International Journal of Health Geographics 5(38). Available at: http://www.ij-healthgeographics.com/content/5/1/38

Keatinge, W.R., Coleshaw, S. R. K., Cotter, F., Mattock, M., Murphy, M., and R. Chelliah, 1984. Increases in platelet and red cell counts, blood viscosity, and arterial pressure during mild surface cooling: Factors in mortality from coronary and cerebral thrombosis in winter. British Medical Journal 289, 1405-1408.

Keatinge, W.R., Coleshaw, S. R. K., Easton, J.C., Cotter, F., Mattock, M., and R. Chelliah, 1986. Increased platelet and red cell counts, blood viscosity and plasma cholesterol levels during heat stress, and mortality from coronary and cerebral thrombosis. American Journal of Medicine 81, 795-800.

Keatinge, W.R., Donaldson, G.C., Bucher, K., Jendritsky, G., Cordioli, E., Martinelli, M., Dardanoni, L., Katsouyanni, K., Kunst, A. E., Mackenbach, J.P., McDonald, C., Näyha, S., and I. Vuori, 1997. Cold exposure and winter mortality from ischemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe. The Lancet 349, 1341-1346.

Kontsevaya, A., Kalinina, A., and R. Oganov, 2013. Economic burden of cardiovascular diseases in the Russian Federation. Value in Health Regional Issues 2, 199-204.

Kunst, A. E., Looman, C. W. N., and J. P. Mackenbach, 1993. Outdoor air temperature and mortality in the Netherlands: A time-series analysis. American Journal of Epidemiology 137(3), 331-341.

Leal, J., Luengo-Fernandez, R., Gray, A., Petersen, S., and M. Rayner, 2006. Economic burden of cardiovascular diseases in the enlarged European Union. European Heart Journal 27, 1610-1619.

Lorentzen, P., McMillan, J., and Wacziarg, R., 2008. Death and development. Journal of Economic Growth 13, 81-124.

Maccini, S., Yang, D., 2009. Under the weather: Health, schooling, and economic consequences of early-life rainfall. American Economic Review 99(3), 1006-1026.

Martens, W. J. M., 1998. Climate change, thermal stress and mortality changes. Social Science and Medicine 46(3), 331-344.

Pan, W. H., Li, L., and M. Tsai, 1995. Temperature extremes and mortality from coronary heart disease and cerebral infarction in elderly Chinese. Lancet 345(8946), 353-355.

Schaanning, J., Finsen, H., and I. Lereim, 1986. Effects of cold air inhalation combined with prolonged submaximal exercise on airway function in healthy young males. European Journal of Respiratory Diseases 68, 74-77.

Senne, J.-N., 2014. Death and schooling decisions over the short and long run in rural Madagascar. Journal of Population Economics 27, 497-528.

Strittmatter, A., Sunde, U., 2013. Health and economic development – evidence from the introduction of public health care. Journal of Population Economics 26, 1549-1584.

Vasconcelos, J., Freire, E., Almendra, R., Silva, G. L., and P. Santana, 2013. The impact of winter cold weather on acute myocardial infarctions in Portugal. Environmental Pollution 183, 14-18.

World Bank, 2016. Average monthly temperature and rainfall for Russia from 1990-2012. Climate Change Knowledge Portal, The World Bank Group. Available at:

http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisCCode=RUS. Accessed July 15, 2016.

World Health Organization (WHO), 2015. Cardiovascular diseases (CVDs). Fact sheet Nr. 317. Available at: http://www.who.int/mediacentre/factsheets/fs317/en/ Accessed February 15, 2016.

Yang, D., 2008. Coping with disaster: The impact of hurricanes on international financial flows, 1970-2002. B.E. Journal of Economic Analysis and Policy 8(1), Article 13.

Appendix

Table A1: The impact of weather on the all-cause mortality by age group

Dep. Variable ln(Mortality)	All-age	Infant(<1)	1-9	10-19	20-29	30-39	40-49	50-59	60-69	70+
	Age Groups									
Bin -30C° and below	-0.0001 (0.0004)	0.0017 (0.0012)	-0.0006 (0.0007)	-0.0012 * (0.0007)	-0.0015 ** (0.0007)	-0.0009 (0.0007)	0.0001 (0.0008)	-0.0003 (0.0005)	-0.0006 (0.0004)	0.0004 (0.0003)
Bin -30C°-25C°	0.0008 ** (0.0004)	-0.0002 (0.0009)	0.0001 (0.0005)	-0.0016 *** (0.0005)	0.0004 (0.0006)	0.0011 (0.0008)	0.0014 * (0.0008)	0.0012 * (0.0007)	0.00005 (0.0004)	0.0009 *** (0.0003)
Bin -25C°-20C°	-0.0001 (0.0004)	-0.0006 (0.0008)	-0.0002 (0.0004)	-0.0016 ** (0.0006)	-0.0012 * (0.0006)	-0.0003 (0.0005)	-0.0005 (0.0005)	-0.0002 (0.0005)	-0.0008 * (0.0004)	0.0008 ** (0.0004)
Bin -20C°-15C°	0.0004 (0.0003)	-0.0006 (0.0006)	0.0000 (0.0004)	-0.0009 * (0.005)	-0.0005 (0.0004)	-0.0002 (0.000)	-0.0001 (0.0005)	-0.0002 (0.0004)	0.0001 (0.0003)	0.0010 *** (0.0003)
Bin -15C°-10C°	0.0001 (0.0003)	-0.0000 (0.0005)	-0.0007 * (0.0003)	-0.0014 *** (0.005)	-0.0004 (0.0004)	0.0002 (0.0005)	0.0004 (0.0006)	-0.0001 (0.0004)	-0.0003 (0.0003)	0.0007 *** (0.0002)
Bin -10C° -5C°	0.0002 (0.0002)	-0.0007 (0.0004)	-0.0004 (0.0003)	-0.0009 ** (0.0004)	0.0001 (0.0003)	-0.0001 (0.0003)	0.0001 (0.0003)	0.0001 (0.0003)	0.0000 (0.0002)	0.0006 *** (0.0002)
Bin 0C° -5C°	0.0004 * (0.0002)	-0.0001 (0.0004)	-0.0003 (0.0003)	-0.0005 (0.0004)	0.0001 (0.0003)	0.0004 (0.0003)	0.0005 (0.0003)	0.0005 * (0.0003)	0.0001 (0.0002)	0.0007 ** (0.0002)
Bin 0C° +5C°	0.0001 (0.0002)	-0.0006 (0.0004)	-0.0004 * (0.0002)	-0.0006 * (0.0003)	-0.0003 (0.0004)	0.0000 (0.0003)	-0.0001 (0.0003)	0.0001 (0.0003)	0.0001 (0.0002)	0.0004 ** (0.0002)
Bin +5C°+10C°	0.0002 (0.0002)	-0.0010 ** (0.0005)	-0.0004 * (0.0002)	-0.0006 ** (0.0003)	-0.0001 (0.0003)	0.0004 (0.0003)	0.0004 (0.0003)	0.0004 * (0.0002)	0.0001 (0.0002)	0.0005 ** (0.0001)
Bin +10C° +15C°	0.0001 (0.0001)	-0.0001 (0.0003)	-0.0001 (0.0002)	-0.0003 * (0.0002)	0.0000 (0.0002)	0.0001 (0.0003)	0.0002 (0.0002)	0.0003 (0.0002)	0.0001 (0.0001)	0.0003 ** (0.0001)
Bin +15C° +20C°	-0.0001 (0.0001)	-0.0010 ** (0.0004)	-0.0002 (0.0002)	-0.0004 ** (0.0002)	0.0002 (0.0003)	0.0001 (0.0003)	0.0000 (0.0002)	0.0000 (0.0002)	-0.0003 * (0.0001)	0.0000 (0.0001)
Bin +25C° ° and above	0.0006 ** (0.0002)	0.0001 (0.0005)	0.0001 (0.0002)	-0.0002 (0.0002)	0.0007 ** (0.0003)	0.0012 *** (0.0003)	0.0009 *** (0.0003)	0.0008 *** (0.0002)	0.0004 *** (0.0001)	0.0006 *** (0.0002)
Bin 10mm 20mm	-0.0003 (0.0004)	0.0009 (0.0008)	-0.0009 ** (0.004)	-0.0001 (0.0004)	-0.0006 (0.0006)	-0.0002 (0.0005)	-0.0010 (0.0006)	-0.0005 (0.0005)	0.0000 (0.0003)	0.0002 (0.0003)
Bin 20mm 100mm	0.0009 (0.0008)	-0.0026 (0.0021)	0.0008 (0.0010)	0.0010 (0.0011)	0.0026 * (0.0014)	0.0012 (0.0014)	0.0001 (0.0013)	0.0004 (0.0008)	0.0006 (0.0008)	0.0001 (0.0004)
R-sq.^{within}	0.917	0.927	0.814	0.756	0.845	0.846	0.883	0.925	0.955	0.937
Nr. of obs.	2047	2047	2047	2047	2047	2047	2047	2047	2047	2047

Notes. Robust standard errors clustered at a regional level are in parentheses. All regressions include a regional linear trend, region and year fixed effects. The temperature bin (20°C, 25°C] and the precipitation bin [0 mm, 10 mm) are used as the default bins. The regional population weights are applied. ***, **, * stand for 1%, 5%, and 10% significance levels, respectively.

Table A2: The impact of weather on the cardiovascular-cause mortality by age groups

Dep. Variable	Age Groups									
ln(Mortality)	All-age	Infant(<1)	1-9	10-19	20-29	30-39	40-49	50-59	60-69	70+
Bin -30C° and below	0.0001 (0.0004)	-0.0001 (0.0010)	-0.0001 (0.0001)	-0.0004 ** (0.0002)	-0.0008 (0.0006)	-0.0002 (0.0008)	0.0005 (0.0009)	0.0002 (0.0006)	-0.0002 (0.0005)	0.0001 (0.0005)
Bin -30C° -25C°	0.0011 ** (0.0004)	0.0015 ** (0.006)	0.0000 (0.0001)	0.0001 (0.0001)	0.0011 * (0.0005)	0.0018 * (0.0010)	0.0023 ** (0.0008)	0.0018 * (0.0010)	0.0009 (0.0007)	0.0008 (0.0005)
Bin -25C° -20C°	0.0001 (0.0006)	0.0001 (0.0007)	0.0001 (0.0001)	-0.0001 (0.0006)	0.0005 (0.0005)	0.0008 (0.0006)	0.0004 (0.0006)	0.0003 (0.0005)	-0.0006 (0.0007)	0.0002 (0.0005)
Bin -20C° -15C°	0.0010 ** (0.0004)	0.0004 (0.0007)	0.0001 (0.0001)	-0.0001 (0.005)	0.0002 (0.0003)	0.0004 (0.0005)	0.0007 (0.0006)	0.0006 (0.0005)	0.0007 * (0.0004)	0.0011 ** (0.0004)
Bin -15C° -10C°	0.0006 * (0.0003)	-0.0003 (0.0006)	0.0000 (0.0001)	0.0000 (0.001)	0.0006 ** (0.0003)	0.0010 (0.0005)	0.0011 * (0.0006)	0.0006 (0.0004)	0.0001 (0.0004)	0.0007 ** (0.0003)
Bin -10C° -5C°	0.0007 ** (0.0003)	-0.0002 (0.0005)	0.0000 (0.0001)	0.0000 (0.0001)	0.0004 ** (0.0002)	0.0003 (0.0003)	0.0006 (0.0004)	0.0007 ** (0.0003)	0.0005 (0.0003)	0.0007 ** (0.0003)
Bin 0C° -5C°	0.0008 ** (0.0003)	-0.0001 (0.0005)	0.0000 (0.0001)	0.0000 (0.0001)	0.0005 ** (0.0002)	0.0008 ** (0.0003)	0.0009 ** (0.0004)	0.0009 *** (0.0003)	0.0004 (0.0003)	0.0009 *** (0.0003)
Bin 0C° +5C°	0.0001 (0.0002)	0.0000 (0.0005)	0.0000 (0.0001)	0.0000 (0.0001)	0.0002 (0.0002)	0.0006 * (0.0003)	0.0004 (0.0004)	0.0008 ** (0.0003)	0.0005 * (0.0003)	0.0004 (0.0003)
Bin +5C° +10C°	0.0006 ** (0.0003)	-0.0000 (0.0004)	0.0000 (0.0001)	0.0001 (0.0001)	0.0005 ** (0.0002)	0.0009 ** (0.0003)	0.0009 *** (0.0003)	0.0010 *** (0.0003)	0.0004 (0.0003)	0.0006 ** (0.0003)
Bin +10C° +15C°	0.0002 (0.0002)	0.0003 (0.0003)	0.0000 (0.0001)	0.0000 (0.0001)	0.0002 (0.0002)	0.0003 (0.0003)	0.0004 (0.0003)	0.0005 ** (0.0002)	0.0002 (0.0002)	0.0001 (0.0002)
Bin +15C° +20C°	0.0001 (0.0002)	0.0000 (0.0003)	0.0000 (0.0001)	-0.0001 (0.0001)	0.0003 (0.0002)	0.0003 (0.0003)	0.0003 (0.0003)	0.0001 (0.0002)	-0.0002 (0.0002)	0.0001 (0.0002)
Bin +25C° ° and above	0.0008 *** (0.0003)	0.0002 (0.0003)	0.0000 (0.0001)	-0.0001 (0.0001)	0.0002 (0.0003)	0.0009 ** (0.0004)	0.0009 ** (0.0004)	0.0009 *** (0.0003)	0.0005 ** (0.0002)	0.0010 *** (0.0003)
Bin 10mm 20mm	0.0002 (0.0004)	0.0004 (0.0006)	0.0000 (0.001)	-0.0001 (0.0001)	-0.0004 * (0.0002)	-0.0001 (0.0005)	-0.0003 (0.0006)	0.0000 (0.0006)	0.0001 (0.0004)	0.0006 (0.0005)
Bin 20mm 100mm	0.0009 (0.0010)	0.0003 (0.0002)	0.0002 (0.0002)	0.0003 (0.0003)	0.0022 ** (0.0009)	0.0011 (0.0013)	0.0005 (0.0014)	0.0001 (0.0013)	0.0012 (0.0012)	0.0000 (0.0009)
R-sq.^{within}	0.884	0.232	0.314	0.276	0.568	0.746	0.834	0.902	0.941	0.824
Nr. of obs.	2043	2043	2043	2043	2043	2043	2043	2043	2043	2043

Notes. Robust standard errors clustered at a regional level are in parentheses. All regressions include a regional linear trend, region and year fixed effects. The temperature bin (20°C, 25°C] and the precipitation bin [0 mm, 10 mm) are used as the default bins. The regional population weights are applied. ***, **, * stand for 1%, 5%, and 10% significance levels, respectively.

Table A3: The impact of weather on the respiratory-cause mortality by age groups

Dep. Variable	Age Groups									
ln(Mortality)	All-age	Infant(<1)	1-9	10-19	20-29	30-39	40-49	50-59	60-69	70+
Bin -30C° and below	-0.0007	0.0003	0.0002	0.0000	0.0000	-0.0008 *	-0.0008	-0.0014	-0.0025 ***	-0.0013
	(0.0004)	(0.0015)	(0.0003)	(0.0001)	(0.0003)	(0.0005)	(0.0009)	(0.0009)	(0.0007)	(0.0012)
Bin -30C° -25C°	0.0006	-0.0013	0.0004 *	-0.0001	0.0004 *	0.0007 **	0.0010	0.0008	0.0000	0.0005
	(0.0004)	(0.0015)	(0.0002)	(0.0001)	(0.0005)	(0.0004)	(0.0007)	(0.0008)	(0.0005)	(0.0009)
Bin -25C° -20C°	-0.0002	-0.0012	0.0001	0.0001	0.0001	-0.0005	-0.0008	-0.0003	-0.0015 **	0.0002
	(0.0004)	(0.0015)	(0.0002)	(0.0001)	(0.0002)	(0.0004)	(0.0005)	(0.0006)	(0.0007)	(0.0011)
Bin -20C° -15C°	0.0001	-0.0026 **	0.0001	0.0000	-0.0002	-0.0004 *	-0.0006	-0.0006	-0.0003	0.0011 *
	(0.0003)	(0.0012)	(0.0002)	(0.0001)	(0.0002)	(0.0002)	(0.0004)	(0.0004)	(0.0005)	(0.0006)
Bin -15C° -10C°	0.0002	-0.0014	0.0000	0.0000	0.0001	0.0004	0.0003	-0.0001	-0.0006	0.0003
	(0.0003)	(0.0010)	(0.0001)	(0.001)	(0.0001)	(0.0003)	(0.0006)	(0.0005)	(0.0005)	(0.0007)
Bin -10C° -5C°	0.0001	-0.0017	0.0000	0.0000	0.0000	-0.0001	0.0000	-0.0002	-0.0003	0.0004
	(0.0002)	(0.0009)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0003)	(0.0003)	(0.0004)	(0.0005)
Bin 0C° -5C°	0.0003	-0.0019 **	0.0000	0.0000	0.0000	0.0000	0.0002	0.0002	-0.0001	0.0009
	(0.0002)	(0.0008)	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0003)	(0.0003)	(0.0004)	(0.0006)
Bin 0C° +5C°	0.0001	-0.0014 *	0.0001	-0.0001	0.0002	-0.0001	-0.0004	-0.0005	0.0001	0.0010 *
	(0.0002)	(0.0007)	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0003)	(0.0003)	(0.0004)	(0.0005)
Bin +5C° +10C°	0.0000	-0.0013	0.0000	0.0000	0.0005 **	0.0001	0.0001	0.0000	-0.0002	0.0001
	(0.0002)	(0.0008)	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0003)	(0.0003)	(0.0006)
Bin +10C° +15C°	0.0002	-0.0003	0.0000	0.0000	0.0002	0.0000	-0.0002	0.0000	0.0002	0.0007
	(0.0001)	(0.0005)	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0003)
Bin +15C° +20C°	-0.0001	-0.0006	0.0000	0.0000	0.0003	-0.0001	-0.0003 *	-0.0002	-0.0003	0.0000
	(0.0001)	(0.0005)	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0003)
Bin +25C° ° and above	0.0003 **	-0.0015 **	0.0000	0.0002	0.0002	0.0004 **	0.0005 **	0.0007 **	0.0003	0.0001
	(0.0001)	(0.0007)	(0.0001)	(0.0001)	(0.0003)	(0.0002)	(0.0002)	(0.0003)	(0.0003)	(0.0003)
Bin 10mm 20mm	-0.0004	0.0000	-0.0002	-0.0002	-0.0004 *	-0.0004	-0.0006	-0.0009	0.0003	-0.0004
	(0.0005)	(0.0013)	(0.002)	(0.0002)	(0.0002)	(0.0003)	(0.0006)	(0.0007)	(0.0009)	(0.0011)
Bin 20mm 100mm	-0.0006	0.0012	0.0003	0.0003	0.0022 **	0.0004	-0.0003	0.0004	-0.0002	-0.0026
	(0.0007)	(0.0003)	(0.0006)	(0.0003)	(0.0009)	(0.0006)	(0.0012)	(0.0011)	(0.0010)	(0.0015)
R-sq.^{within}	0.705	0.863	0.590	0.567	0.568	0.758	0.742	0.766	0.843	0.796
Nr. of obs.	2043	2043	2043	2043	2043	2043	2043	2043	2043	2043

Notes. Robust standard errors clustered at a regional level are in parentheses. All regressions include a regional linear trend, region and year fixed effects. The temperature bin (20°C, 25°C] and the precipitation bin [0 mm, 10 mm) are used as the default bins. The regional population weights are applied. ***, **, * stand for 1%, 5%, and 10% significance levels, respectively.