2019

IARIW-HSE

Special IARIW-HSE Conference "Experiences and Future Challenges in Measuring Income and Wealth in CIS Countries and Eastern Europe" Moscow, Russia, September 17-18, 2019

Does Weather Sharpen Income Inequality in Russia?

Vladimir Otrachshenko
Olga Popova

Paper Prepared for the IARIW-HSE Conference
Moscow, Russia, September 17-18, 2019
Session 3B: Income Inequality
Time: 13:45 – 15:45, September 17

Does weather sharpen income inequality in Russia?

Vladimir Otrachshenko [a,b] (otrachshenko@ios-regensburg.de)

Olga Popova [a,c,b] (popova@ios-regensburg.de)

[a] Leibniz Institute for East and Southeast European Studies (IOS), Landshuter Str. 4, 93047 Regensburg, Germany

[b] Graduate School of Economics and Management, Ural Federal University, Gogolya Str. 25, 620000 Yekaterinburg, Russian Federation

[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

PRELIMINARY DRAFT

PLEASE DO NOT CITE AND/OR CIRCULATE WITHOUT THE AUTHORS' CONSENT

Abstract

This paper uses regional panel data from Russia to show the impact of extremely hot and cold temperatures and precipitation on income inequality. This is a first paper that offers a detailed analysis of extreme temperature effects other than health in an upper-middle-income country. We show that extremely hot temperatures increase inequality, and the impact is uneven between rich and poor regions. This suggests that the impacts of warming on inequality are not concentrated solely in the poorest populations, as conventionally believed in the literature. A detailed exploration of labor market channels behind the effects suggests that extremely hot temperature increases inequality through reducing the employment in private sector industries, increasing the unemployment, and increasing the lower-paid public sector employment. Extremely cold temperatures have no impact on income inequality and labor market. This has many important implications for the economic development, given that extreme weather events become more frequent and severe worldwide.

Keywords: inequality, extreme temperature, Russia, climate change

JEL codes: I14, I32, J31, Q54

Acknowledgements. The authors acknowledge the support from Russian Science Foundation grant no. 19-18-00262.

1. Introduction

Extreme heat harms economic growth and the poor countries suffer the most (Dell et al., 2012, 2009; Diffenbaugh and Burke, 2019; Herold et al., 2017; Horowitz, 2009; Tol et al., 2004). This is a widely documented finding at a country level. With a few exceptions, the subnational analyses of the impact of extreme temperatures on economic growth and income are rare (Dell et al., 2009; Hsiang and Deryugina, 2014; Park et al., 2018). Moreover, given that cross-country analysis typically includes diverse countries from all over the world, it becomes difficult to analyze channels behind the possible effects of extreme temperature on income. This paper contributes in this direction by analyzing the impact of extremely hot and cold temperatures, using the regional-level data from Russia and examining the channels behind the impacts of weather on economic growth and income inequality.

The scholarship on extreme temperatures and income distribution/income inequality remains thin. One of the pioneering studies in this area suggests that the impact of global warming on income distribution is not uniform across the world. Despite emitting less greenhouse gases, poor countries, given their geographic location on the globe and lower capacity to adapt, become poorer (Tol et al., 2004). A recent paper confirms this finding and suggests that global warming increases economic inequality worldwide by examining data on gross domestic product (GDP) per capita globally (Diffenbaugh and Burke, 2019). However, estimating the aggregate impacts of global warming on countries without accounting for regional, industrial, and income group specifics may lead to biased conclusions (Tol et al., 2004). (Dell et al., 2009) take a step in this direction and estimate the impact of extremely hot temperatures on economic growth both across countries and across regions in 12 countries in the Americas. The findings suggest that within-country impacts of hot temperature are weaker than the across-counties relationship, but the magnitude is still sizeable economically.

Generally, studies that use the regional-level panel data to identify the effects of hot and cold temperatures focus mostly on mortality. To date, such studies exist for USA, Russia, India, and Mexico (Burgess et al., 2017; Cohen and Dechezleprêtre, 2017; Deschênes and Greenstone, 2011; Deschênes and Moretti, 2009; Otrachshenko et al., 2018, 2017). The mechanism behind the temperature-mortality relationship is related to the physiological response of human body to heat or cold stress through thermoregulation. The findings generally suggest that hot temperatures increase mortality, and the magnitude of this impact may depend on the level of country's economic development, since people in developed countries have more income to cope with the consequences of weather.

The studies of other economic and social impacts of weather received less attention. Earlier literature finds that hot temperatures decrease labor productivity and induce the reallocation of time between indoor and outdoor work and leisure (Zivin and Neidell, 2014). This suggests that weather indicators may also affect the income distribution either directly or indirectly through the impact on labor supply. However, the studies of the income inequality-weather relationship are scarce and rarely go beyond examining the impact of weather on GDP and GDP growth. One such study analyzes the country level data from USA and find that as compared to a day with 15°C, each day with the average temperature above 30°C reduces annual income per capita by 0.065%, which is equivalent to about 20 USD (Hsiang and Deryugina, 2014). Another study combines household data from 52 countries and shows a negative within-country correlation between household wealth and hot temperature in hot countries, and documents that individuals performing agricultural or unskilled manual work, i.e. have occupations with greater exposure to warmer temperature, are more likely to be poor (Park et al., 2018).

We examine the distributional impacts of extreme temperature and precipitation shocks, using the 20-years panel data from the Russian regions. Specifically, we show how extremely hot (days with an average daily temperature above 25°C) and cold (days with an average daily temperature below 23°C) and precipitation reduce economic growth and affect income distribution in Russia. To account for the heterogeneity in economic performance between the Russian regions, we analyze the impact of weather on the population income shares in poor and rich regions separately. Finally, by focusing on employment relocation and wages in different industries, we identify the labor market channels behind the inequality-temperature relationship.

Several important findings stand out. First, the findings suggest that hot days considerably decrease economic growth. One hot day decreases the real regional GDP per capita by 0.2%. This finding is in line with the existing literature on the US data on the negative impacts of global warming for economic growth. Second, hot temperatures affect income distribution and reduce the inequality in poor regions, while rich regions are affected to a smaller extent. Third, cold temperatures mostly do not affect economic growth and inequality. At the same time, a larger amount of rainfall increases the share of poor population in rich regions. This might be explained by floods in rich regions that become more frequent. The analysis of labor market channels behind the effect suggests that the temperature-inequality relationship occurs primarily because of relocation from employment to unemployment and from changes in employment structure.

We contribute to the literature in several ways. First, we provide an in-depth analysis of the impact of extreme temperatures and precipitation for within an upper-middle income economy. Existing studies focus on the impact of global warming either in poor countries or in rich countries, while the analysis of middle-income economies that according to the recent classification of the World Bank, constitute about 50% of all countries in the world is still scarce.[1] Second, we detail and test channels through which extremely hot and cold temperatures may affect income distribution.

The reminder of the paper is organized as follows. In Section 2, we propose channels through which extreme temperatures may affect income distribution and economic growth. Sections 3 and 4 present methodology and data, respectively. Section 5 discusses our main findings, while Section 6 concludes.

2. Channels

Thermal stress has a direct impact on human health and functioning by inducing physiological adjustment through increased blood pressure, blood viscosity, heart rate, and bronchoconstriction (Basu and Samet, 2002). This reduces cognitive performance, work productivity, hours worked in industries with direct exposure to temperature, and leads to relocation of time from work to leisure (Cho, 2017; Goodman et al., 2018; Graff Zivin et al., 2018; Heal and Park, 2016; Kjellstrom et al., 2009; Zhang et al., 2018; Zivin and Neidell, 2014). In turn, thermal stress may increase income inequality through several labor market effects. First, lower productivity and work hours may lead to wage reductions, especially in sectors with greater exposure to outdoor temperature exposure, e.g. agriculture (Dell et al., 2012, 2009; Park et al., 2018). Second, it may lead to relocation of labor from sectors with greater exposure to temperature risks to sectors with lower exposure (Zhang et al., 2018). Finally, it may increase transitions from employment to unemployment (Graff Zivin et al., 2018; Zivin and Neidell, 2014). The specific behavioral responses to extreme temperatures depend on local labor market context and degree of exposure to heat or cold that a particular industry or occupation faces (Heal and Park, 2016; Kahn, 2016; Zivin and Neidell, 2014).

Unequal exposure to hot and cold temperatures may also lead to unequal sectoral development in poor and rich countries/regions, facilitating income inequality. In poor and middle-income countries, both agricultural and industrial output is contracting after hot temperatures, and both labor- and capital-intensive industries are affected (Dell et al., 2012; Hsiang, 2010; Zhang et al., 2018), while in rich countries, agricultural profits may grow as a result of global warming (Deschênes and Greenstone, 2007; Mendelsohn et al., 1994). Rich and cold regions therefore receive more benefits from global warming than poor and hot regions (Heal and Park, 2016; Park et al., 2018; Tol et al., 2004). On the other hand, recent studies suggest that on average, both rich and poor countries suffer from consequences of global warming, and the inequality grows globally (Burke et al., 2015; Dell et al., 2012; Hsiang and Deryugina, 2014).

[1] There are a few exceptions. (Zhang et al., 2018) analyze data on manufacturing firms in Chine, while (Dell et al., 2009) use data from 12 countries in the North and South America.

By directly affecting agricultural production, temperature extremes have an effect on food prices, and in turn, affect real income in both rich and poor countries (Kahn, 2016). Extreme temperatures also increase energy consumption and prices, reducing real incomes (Deschênes and Greenstone, 2011). Thus, not only labor income may be affected but overall income too. In the Russian case, according to the Federal Statistical Service, about 60% of individual income in 2017 is non-labor income and includes income from entrepreneurship (up to 8%), state benefits (up to 20%), property income (up to 5%), and remittances and other income sources (up to 26%).

To summarize, extreme temperatures may affect within-country economic growth and income inequality through several channels: (a) labor market adjustments via wage changes and labor relocation from one industry to another, (b) unequal industrial and agricultural development in rich and poor regions, and (c) effects on overall real income via energy and food price changes.

3. Methodology

In this section we present the econometric model to estimate the relationship between socioeconomic indicators and weather. Our model is as follows.

$$Y_{it} = \beta_0 + \beta_1 Bin_{it}^{below-23°C} + \beta_2 Bin_{it}^{above\ 25°C} + \delta_1 Bin_{it}^{Prec.10-20mm} + \delta_2 Bin_{it}^{Prec.\ above\ 20mm}$$
$$+\alpha_i + \gamma_t + \boldsymbol{\Phi}' Region * Trend + u_{it} \qquad (1)$$

where the subscripts i and t stand for a region and year, respectively. Y is the set of the socioeconomic indicators such as the natural logarithm of the real regional GDP per capita $\ln(GDP)$, unemployment rate, relative sectorial wages, the natural logarithm of the annual real income $\ln(Income)$, the share of individuals within a particular income group (i.e. lowest income, lower middle income, middle, upper middle, and high income groups), the share of individuals who live below the poverty threshold, and the sectorial share of employed. $Bin^{below-23°C}$ and $Bin^{above\ 25°C}$ stand for the number of days in a region i and year t on which the average daily temperature below -23°C and above 25°C, repectively. Days with temperature between -23°C and 25°C are used as a default category. $Bin^{Prec.10-20mm}$ and $Bin^{Prec.\ above\ 20mm}$ stand for the number of days with the mean daily precipitation between 10 mm and 20 mm and above 20 mm, respectively, while days with precipitation between 0 mm and 10 mm are used as a default category. The definition of extreme temperatures and precipitation is discussed in the next section.

α_i stands for the regional fixed effects, accounting for important unobserved regional specific time invariant characteristics that may affect regional socioeconomic indicators. For instance, these effects may account for the region-specific natural resource abundance, infrastructure, and access to rivers, seas, and oceans. γ_t is the time fixed effects that may account for economic reforms common across all regions. $Trend$ is a linear time trend. The interaction term $Region * Trend$ accounts is the set of region-specific linear time trends that affect socioeconomic indicators and may also correlate with climate, e.g. trends in sectoral location choices. u_{it} is a disturbance term while $\boldsymbol{\beta}$ and $\boldsymbol{\delta}$ are the vectors of the model parameters.

4. Data

We use regional panel data for Russia, a middle-income economy with substantial differences in regional economic development and a wide distribution of temperatures and precipitation between regions. Data are available for 79 regions of Russia and come from two main sources. The first source is the Federal State Statistical Service of Russia that provides regional-level data on GDP (1992-2015), unemployment (1995-2015), income shares and share of people in poverty (2000-2015), total monetary income per capita (2000-2015), as well as the distribution of wages (2005-2015) and employment (2000-2015) across industries. For each series, we use the longest available time span. For wages and employment data, industrial classification is presented according to the Russian Classification of Economic Activities (OKVED, Rev. 2), which is harmonized with the Classification of Economic Activities in the European Communities (NACE Rev. 2).[2]

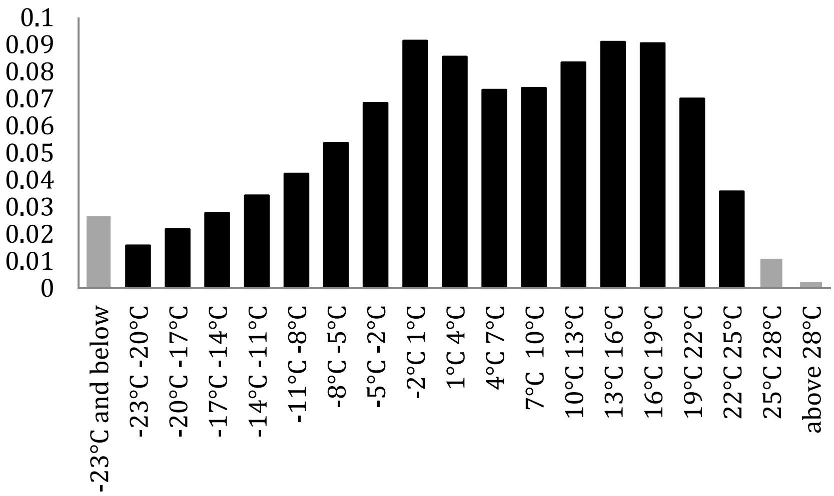
The second data source is the Federal State Service for Hydrometeorology and Environmental Monitoring that provides data on temperature and precipitation for 518 ground meteorological stations in Russia for the period 1989-2015. To aggregate the data to regional level we follow several steps. For each meteorological station, we first calculate daily average temperature and precipitation. Then for each administrative unit (city, town, or village) in the region, we locate the nearest meteorological station(s) within 200 km. To give the largest weight to a station that is closest to a specific administrative unit, inverse distance square is use as a weight. Finally, to aggregate data to a regional level, population weights are used according to the administrative units' population. This allows to measure temperature as an "a temperature felt by an average person in a region" as opposed to "a temperature felt by an average area in the region" (Dell et al., 2014).

Figure 1 shows the distribution of days with a specific average daily temperature in Russia from 1989 to 2015. In this figure, the temperature range is divided into several bins with a 3°C

[2] The following industries are distinguished in our sample: agriculture, hunting, forestry, and fishing; mining and quarrying; manufacturing; electricity, gas, and water supply; construction; wholesale and retail trade, repair of motor vehicles; accommodation and food service activities; transportation and communication, communication; real estate activities; education; human health and social work activities; activities of extraterritorial organizations and bodies; and other service activities.

step. Each temperature bin presents how many days with a specific temperature were in Russia in the years between 1989 and 2015. In Figure 1 the grey bars show extremely cold temperature (below -23°C) and extremely hot temperature (bins (25°C, 28°C] and above 28°C). In Russia, one third of the regions have not yet experienced days with the average temperature in 24 hours being above 28°C. In our sample, the average number of such days is 0.97 per year. Thus, we combine the days above 25°C into one temperature bin. For the empirical analysis, we construct temperature bins for each region and each year. As described in previous section, we use three bins in our model: below -23°C, above -23°C and below 25°C (the default bin), and above 25°C. Similarly, for precipitation, we calculate the number of days with average daily precipitation below 10 mm (the default bin), between 10 mm and 20 mm, and above 20 mm. The numbers of days per year is standardized to 365 days.

Figure 1: Distribution of days with a specific temperature range, 1989-2015.



Source: Authors' computations. *Notes:* Temperature bins include the number of days with a specific temperature in Russia between 1989-2015. The intervals in black are used as default. The intervals in grey, below -23°C, (25°C, 28°C], and above 28°C, show the extremely cold and hot temperatures.

The raw correlation between the number of hot days and the natural logarithm of GDP per capita is presented in Figure A1 in appendix.

5. Results

Following the existing literature, we first estimate Eq. (1) using the logarithm of GDP per capita a dependent variable. The results are shown in Table 1 and suggest that each extremely hot day reduces GDP per capita by 0.2%, as compared to a day with a temperature between -23°C and below 25°C. We further distinguish the results by income groups and find that an extremely hot day marginally increases the shares of the lowest and the middle-income groups, although the share of poor people and total real monetary income are not affected.

We also find that extremely an extremely cold day has no impact on GDP per capita, income distribution, and total real monetary income. This may be related to local regulations that are effective in helping to cope with the consequences of cold weather. For instance, there are official state requirements regarding the construction materials, the indoor working temperature, the allowed outdoor working cloths, and the outdoor working time based on different weather conditions.[3] In the case of extreme temperatures, a working day may even be canceled or shortened. Also, due to the specific climatic conditions, some regions introduce compensating wage differentials and allow for early retirement. For instance, in cold regions the official retirement age for males is 55 years old and for females 50 years old, while the general retirement age is 65 and 60, respectively.

A day with precipitation 10mm-20mm increases the middle-income share as compared to a day with average precipitation 0mm-10mm.

Table 1: Impact of day with extreme temperatures

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dep. Variables (in %):	Ln(GDP)	Lowest income group	Lower middle income group	Middle income group	Upper middle income group	High income group	Poverty rate	Ln(Inco-me)
-23°C and below	-0.000	0.002	-0.012	0.002	0.001	0.013	0.031	-0.000
	(0.001)	(0.002)	(0.017)	(0.002)	(0.001)	(0.031)	(0.028)	(0.000)
above 25°C	-0.002***	0.005*	-0.007	0.003*	-0.005	-0.062	-0.021	0.000
	(0.000)	(0.002)	(0.015)	(0.002)	(0.006)	(0.040)	(0.033)	(0.000)
10 mm 20 mm	-0.001	0.002	-0.037	0.007**	-0.002	-0.067	-0.010	0.000
	(0.001)	(0.004)	(0.026)	(0.003)	(0.004)	(0.074)	(0.073)	(0.001)
above 20 mm	0.001	0.010	-0.037	0.006	0.006	-0.001	0.072	0.000
	(0.001)	(0.009)	(0.054)	(0.008)	(0.006)	(0.155)	(0.216)	(0.001)
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional Linear Trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,649	1,653	1,653	1,653	1,653	1,653	1,651	1,254
R-squared	0.942	0.555	0.514	0.553	0.073	0.239	0.576	0.982

Note: 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 (-23°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.

To account for the heterogeneity in economic performance between the Russian regions, we further analyze the impact of weather on the population income shares in poor and rich regions separately. For that purpose, we divide Russian regions into those with above average real GDP

[3] For a detailed discussion, see Methodical Recommendations of the Federal State Service for Surveillance on Consumer Rights Protection and Human Wellbeing (2006).

during the studied period (rich regions) and those below average real GDP (poor regions). The list of resulting rich and poor regions in our sample is presented in Table A1 in appendix.

The results for poor and rich regions are shown in Table 2 and 3, respectively. As shown in Table 2, in poor regions, hot temperatures affect the distribution of income between 20% income groups. For instance, the lowest income group share increases by 0.006% due to one hot day, while the share of the middle-income group increases by 0.003% due to one hot day. While the impacts may seem small, these are the impact of one hot day, implying that with an increase in the number of hot days, the impacts will grow substantially. Also, a day with average precipitation of 10 mm to 20 mm increases the shares of middle- and upper-middle-income groups. This may be related to concentration of agriculture in those regions. Thus, an average level of precipitation may improve agricultural production and bring extra income to such regions.

Table 2: Poor regions

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Variables (in %):	Lowest income group	Lower middle income group	Middle income group	Upper middle income group	High income group	Poverty rate
-23°C and below	0.004	0.020	0.004	0.001	-0.001	-0.030
	(0.003)	(0.021)	(0.003)	(0.001)	(0.050)	(0.037)
above 25°C	0.006*	0.014	0.003*	0.001	-0.041	-0.058
	(0.003)	(0.018)	(0.002)	(0.000)	(0.052)	(0.055)
10 mm 20 mm	0.008	-0.015	0.010**	0.002*	-0.048	-0.085
	(0.006)	(0.035)	(0.004)	(0.001)	(0.088)	(0.111)
above 20 mm	0.011	0.037	0.003	0.002	-0.018	-0.308
	(0.013)	(0.062)	(0.009)	(0.002)	(0.213)	(0.392)
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Regional Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Regional Linear Trends	Yes	Yes	Yes	Yes	Yes	Yes
Observations	818	818	818	818	818	818
R-squared	0.562	0.582	0.685	0.520	0.230	0.624

Note: 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 (-23°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 3 shows the results for rich regions. Interestingly, a hot day decreases the share of high-income group, contributing to lower inequality. At the same time, a day with strong precipitation (above 20 mm) substantially increases poverty rate, contributing to higher inequality. Thus, both poor and rich regions are vulnerable to extreme temperature and precipitation.

Table 3: Rich regions

Dep. Variables (in %):	(1) Lowest income group	(2) Lower middle income group	(3) Middle income group	(4) Upper middle income group	(5) High income group	(6) Poverty rate
-23°C and below	0.001	-0.046*	-0.000	-0.001	0.037	0.091***
	(0.003)	(0.024)	(0.002)	(0.002)	(0.041)	(0.029)
above 25°C	0.005	-0.034	0.009	-0.028	-0.221**	0.026
	(0.004)	(0.033)	(0.009)	(0.030)	(0.098)	(0.046)
10 mm 20 mm	-0.004	-0.032	0.005	-0.010	-0.105	0.035
	(0.005)	(0.037)	(0.005)	(0.012)	(0.137)	(0.098)
above 20 mm	0.011	-0.096	0.013	0.015	0.013	0.574***
	(0.013)	(0.091)	(0.016)	(0.015)	(0.259)	(0.191)
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Regional Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Regional Linear Trends	Yes	Yes	Yes	Yes	Yes	Yes
Observations	814	814	814	814	814	812
R-squared	0.566	0.497	0.522	0.0913	0.280	0.504

Note: 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 (-23°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.

As discussed in Section 2, hot days may contribute to income inequality through the relocation of time away from work. As shown in Table 4, a hot day increases unemployment by 2.3% through affecting primarily poor regions. This may explain the negative effect of hot days on GDP per capita.

Table 4: The impact of weather on unemployment

Dep. Variables (in %):	All regions Unemployment	Poor regions Unemployment	Rich regions Unemployment
-23°C and below	0.005	0.019	-0.009
	(0.007)	(0.012)	(0.008)
above 25°C	0.023**	0.036**	-0.011
	(0.010)	(0.014)	(0.011)
10 mm 20 mm	-0.019	-0.018	-0.029**
	(0.015)	(0.029)	(0.014)
20 mm 100 mm	0.007	-0.008	0.001
	(0.042)	(0.069)	(0.043)
Time Fixed Effects	Yes	Yes	Yes
Regional Fixed Effects	Yes	Yes	Yes
Regional Linear Trends	Yes	Yes	Yes
Observations	1,873	941	932
R-squared	0.672	0.655	0.747

Note: 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 (-23°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.

If a region faces hot or cold temperature frequently, this may lead to some adaptation to such weather. To show whether this is the case, we disentangle the regions according to mean number of hot/cold days. A region is defined as "hot" if the number of days with an average temperature above 25°C is above the sample mean number of such days. Similarly, a region is defined as "cold" if the number of days with an average temperature below -23°C is above the sample mean number of such days. The regions' classification into "hot" and "cold" is shown in Table A1 in appendix.

The results are shown in Tables 5 and suggest that the impact of extremely hot days concentrates in relatively hotter regions. This implies that regions not only do not adapt to the impact of hot temperatures, but it worsens the income distribution in those regions. The impact goes through increasing unemployment and decreasing GDP per capita and real income.

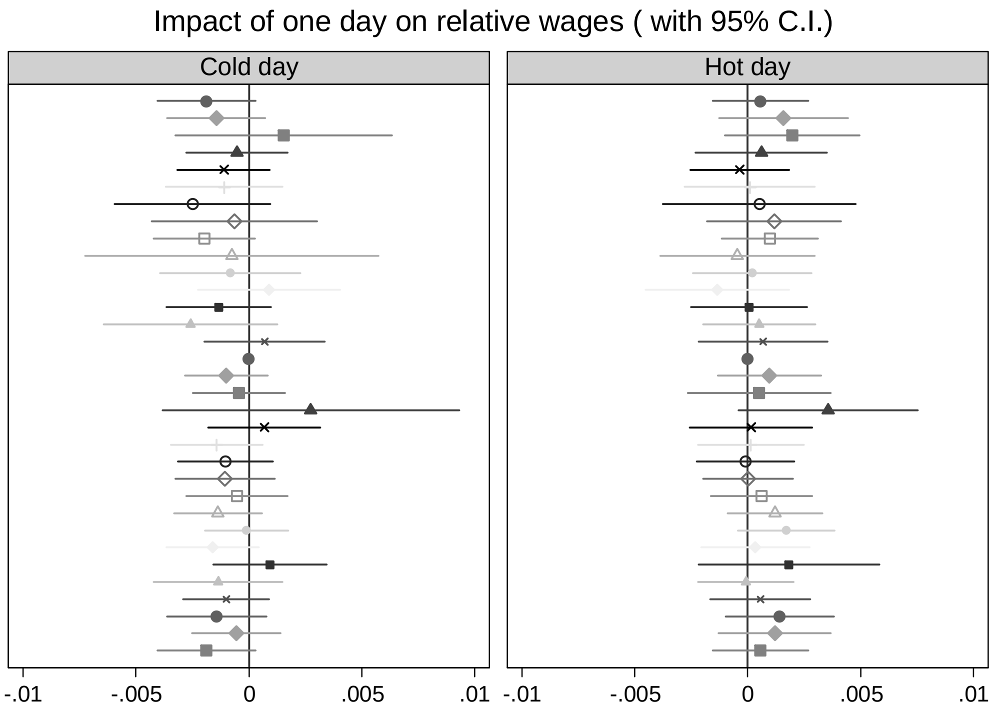
Table 5: Hot vs Cold Regions

Dep. Variables:	All regions Ln(GDP)	Hot regions Ln(GDP)	Cold regions Ln(GDP)	All regions Unempl.	Hot regions Unempl.	Cold regions Unempl.	All regions ln(Inco-me)	Hot regions ln(Inco-me)	Cold regions ln(Inco-me)
-23°C and below	-0.000	-0.000	-0.001	0.005	0.004	0.004	-0.000	-0.002**	0.000
	(0.001)	(0.001)	(0.001)	(0.007)	(0.017)	(0.009)	(0.000)	(0.001)	(0.000)
above 25°C	-0.002***	-0.002***	-0.002	0.023**	0.036**	0.018	0.000	-0.001*	0.000
	(0.000)	(0.001)	(0.001)	(0.010)	(0.015)	(0.020)	(0.000)	(0.000)	(0.001)
10 mm 20 mm	-0.001	-0.002*	-0.000	-0.019	-0.020	-0.020	0.000	0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.015)	(0.026)	(0.019)	(0.001)	(0.001)	(0.001)
20 mm 100 mm	0.001	0.001	0.001	0.007	-0.077	0.080	0.000	0.002	-0.001
	(0.001)	(0.002)	(0.002)	(0.042)	(0.072)	(0.062)	(0.001)	(0.001)	(0.002)
Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional Linear Trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,649	809	840	1,873	941	955	1,254	614	640
R-squared	0.942	0.949	0.939	0.672	0.655	0.702	0.982	0.983	0.981

Note: 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 (-23°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.

To understand the labor market channels behind the temperature-inequality relationship, we analyze the impact of temperature extremes on relative wages in different industries and on the shares of employed in different industries. As discussed in Section 2, temperature extremes may lead to relocation of time from work to leisure and from work to unemployment. This reduces hours worked in specific sectors and reduces wages. Alternatively, as a part of adaptation strategy, individuals and firms may relocate labor from industries more exposed to extreme temperature to industries less exposed to extreme temperature. Figure 2 shows the impact of hot and cold days on wages in different industries. As evident from this figure, there is no statistically significant impact on all industries.[4] We can therefore rule out the wage channel behind the temperature-inequality relationship.

Figure 2: The impact of hot and cold days on relative wages in different industries

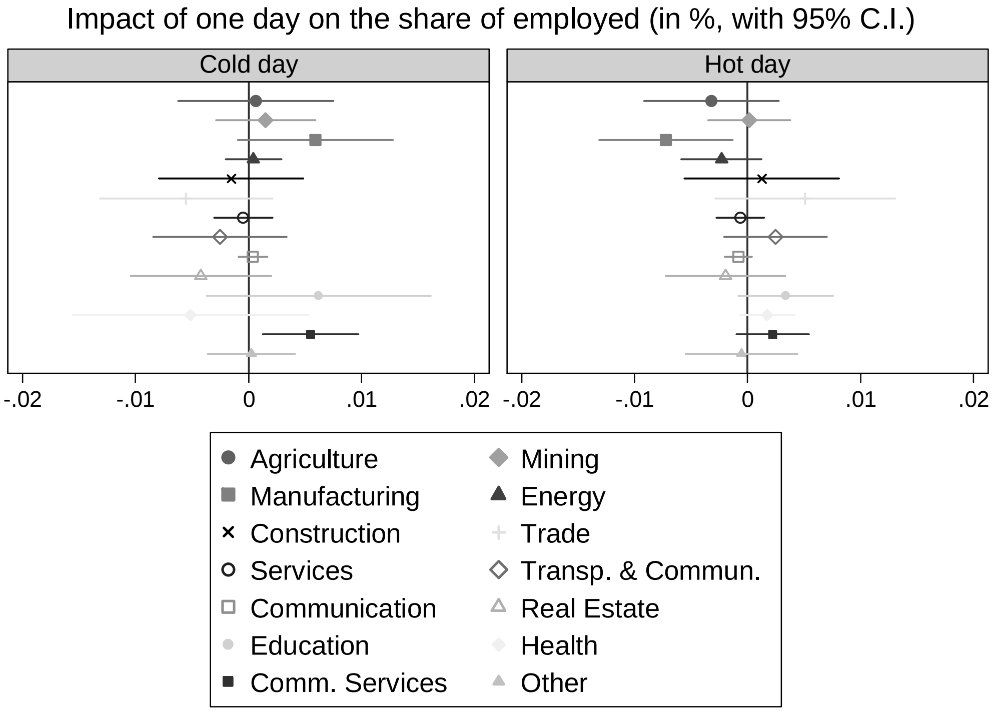


Source: Authors' estimation based on data from the Russian State Statistical Service. Note: The impact is measured for 32 industries according to the extended Russian Classification of Economic Activities. The industries are: (1) agricultural, hunting, and forestry; (2) fishing and aquaculture; (3) extraction of crude petroleum and natural gas; (4) mining, (5) manufacturing of food and tobacco; (6) manufacturing of textiles; (7) manufacturing of leather and related products; (8) manufacture of wood and related products; (9) manufacturing of paper and paper products; (10) manufacturing of coke, refined petroleum products, and nuclear materials; (11) manufacturing of chemical and chemical products; (12) manufacturing of rubber and plastic products; (13) manufacturing of non-metallic mineral products; (14) manufacturing of electronic and optical products; (15) manufacturing of motor vehicles and equipment; (16) other manufacturing (jewelry, sport goods, musical instruments, etc.); (17) electricity, gas, and water supply; (18) construction; (19) wholesale and retail trade and repair of motor vehicles and motorcycles; (20) wholesale trade; (21) retail trade and repair; (22) accommodation and food service activities; (23) transport; (24) communication; (25) financial service activities; (26) real estate activities; (27) programming and broadcasting activities; (28) scientific research and development; (29) national security; (30) education; (31) human health activities; and (32) social services and utilities. The category "other manufacturing" is used as a default to calculate relative wages.

[4] This results hold for the impact of hot and cold temperatures and for the impact of precipitation, and also when we disentangle the regions into rich and poor. The results for rich and poor regions are available upon request.

We then focus on the impact of extreme temperatures on employment structure. The results are presented in Figure 3. As shown in this figure, on average, one hot day decreases the share of employed in manufacturing and has no impact on employment in other industries and marginally increases the share of employment in public sector (education, health, and communal services), while one cold day increases the share of employed in communal services. We may conclude that as a part of adaptation strategy, the individual relocate from industries more exposed to the impact of temperature (private sector) to industries less exposed to the impact of temperature (public sector). Precipitation has no effect on the employment shares in different industries (see Figure A2 in appendix).

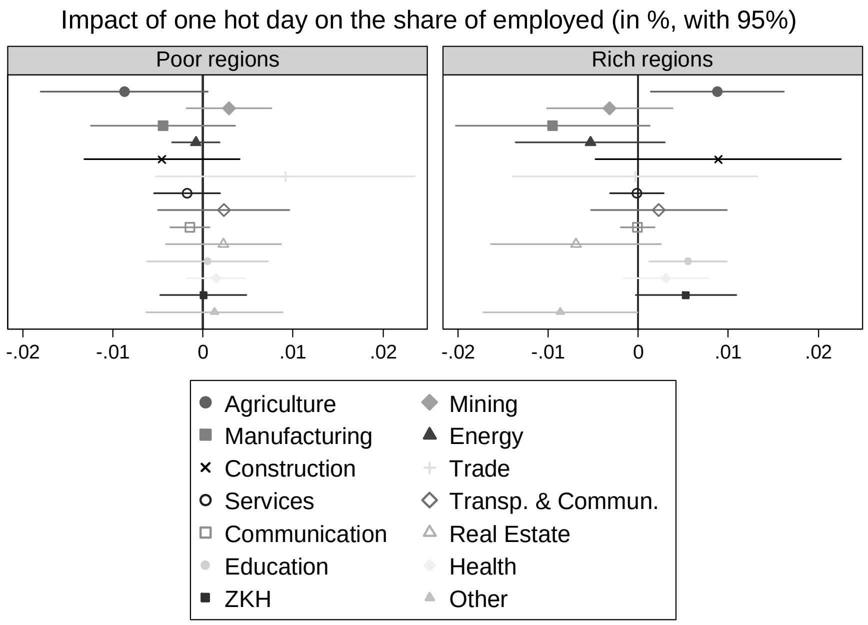
Figure 3. The impact of one cold and one hot day on the share of employed in different industries.



Source: Authors' estimation based on data from the Russian State Statistical Service. Note: The impact is measured for 14 industries according to the Russian Classification of Economic Activities.

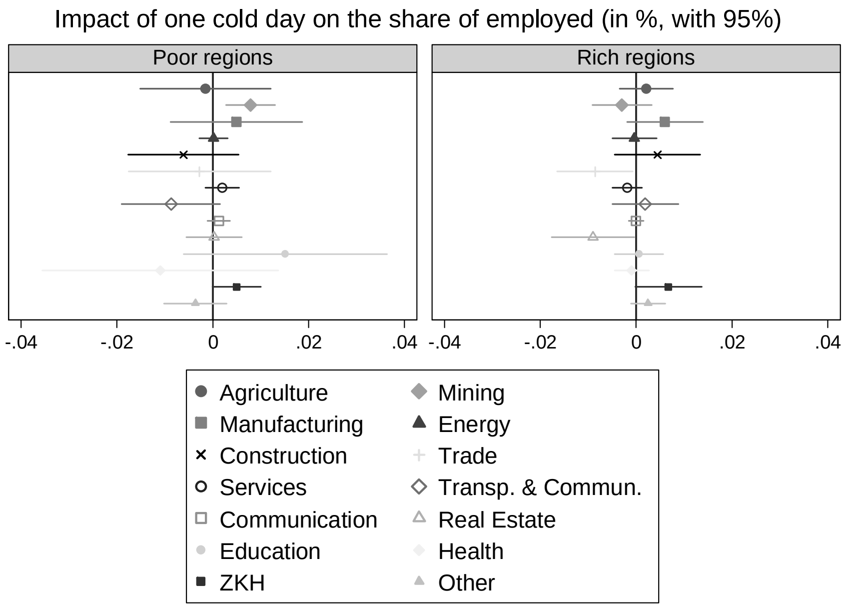
When we disentangle the regions into rich and poor, several interesting findings stand out (see Figures 4 and 5 for the impact of one hot and one cold day, respectively). Both hot and cold days affect the employment structure. As shown in Figure 4, in poor regions, one hot day reduces the share of employed in agriculture, while in rich regions, the shares of employed in agriculture, education, and communal services grow. One cold day increases the shares of employed communal services in both poor and rich regions (see Figure 5). Precipitation increases the share of employed in manufacturing in poor regions and the share of employed in health services in rich regions.[5]

Figure 4. The impact of one hot day on the share of employed in different industries in poor and rich regions.



Source: Authors' estimation based on data from the Russian State Statistical Service. Note: The impact is measured for 14 industries according to the Russian Classification of Economic Activities.

Figure 5. The impact of one cold day on the share of employed in different industries in poor and rich regions.



Source: Authors' estimation based on data from the Russian State Statistical Service. Note: The impact is measured for 14 industries according to the Russian Classification of Economic Activities.

[5] The results are available upon request.

Summarizing the findings, our analysis suggests that major channels behind the temperature-inequality relationship are changes in employment structure in different regions and transition from employment to unemployment. Although both rich and poor regions suffer from the impact of extreme temperatures, poor regions are affected relatively more. The findings suggest extremely hot days substantially decrease GDP per capita and increase unemployment, and one specific strategy for coping with the impact of extreme temperatures is the relocation of labor from private sector to more secure public sector. Overall, the relevance of our results cannot be escaped, especially as the effects of extreme temperatures may become more acute due to global warming.

6. Conclusion

Extreme weather events become more frequent and acute worldwide. In this paper, we document that extreme temperature and precipitation have important consequences for income inequality and economic growth in Russia. Using a subnational-level panel on Russia, we find that hot temperatures facilitate uneven development of poor and rich regions. While both poor and rich regions are vulnerable to global warming, poor regions are affected relatively more due to their specialization on economic activities that have more exposure to changing temperatures. Richer regions may have more resources to adapt and have economic structure that is less exposed to the impact of temperature. We also find that cold temperatures have little effect on income distribution in Russia. The paper also suggests that unemployment increases and relocation of labor from private to public sector are among the major forces that reduce economic growth and increase inequality as a result of extremely hot days.

References

Basu, R., Samet, J.M., 2002. Relation between elevated ambient temperature and mortality: A review of the epidemiologic evidence. Epidemiologic Reviews 24, 190–202. doi:10.1093/epirev/mxf007

Burgess, R., Deschenes, O., Donaldson, D., Greenstone, M., 2017. Weather, climate change and death in India. mimeo.

Burke, M., Hsiang, S.M., Miguel, E., 2015. Global non-linear effect of temperature on economic production. Nature 527, 235–239. doi:10.1038/nature15725

Cho, H., 2017. The effects of summer heat on academic achievement: A cohort analysis. Journal of Environmental Economics and Management 83, 185–196. doi:10.1016/j.jeem.2017.03.005

Cohen, F., Dechezleprêtre, A., 2017. Mortality, temperature, and public health provision: Evidence from Mexico. mimeo.

Dell, M., Jones, B.F., Olken, B.A., 2014. What do we learn from the weather ? The new climate–economy literature. Journal of Economic Literature 52, 740–798. doi:10.3386/w19578

Dell, M., Jones, B.F., Olken, B.A., 2012. Temperature shocks and economic growth: Evidence from the last half century. American Economic Journal: Macroeconomics 4, 66–95. doi:10.1257/mac.4.3.66

Dell, M., Jones, B.F., Olken, B.A., 2009. Temperature and income: Reconciling new cross-sectional and panel estimates. American Economic Review 99, 198–204. doi:10.1257/aer.99.2.198

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, 152–185. doi:10.1257/app.3.4.152

Deschênes, O., Greenstone, M., 2007. The economic impacts of climate change: Evidence from agricultural output and random fluctuations in weather. American Economic Review 97, 354–385. doi:10.1257/aer.97.1.354

Deschênes, O., Moretti, E., 2009. Extreme weather events, mortality, and migration. The Review of Economics and Statistics 91, 659–681.

Diffenbaugh, N.S., Burke, M., 2019. Global warming has increased global economic inequality. Proceedings of the National Academy of Sciences of the United States of America 116, 9808–9813. doi:10.1073/pnas.1816020116

Goodman, J., Hurwitz, M., Park, J., Smith, J., 2018. Heat and Learning. SSRN Electronic Journal. doi:10.2139/ssrn.3180724

Graff Zivin, J., Hsiang, S.M., Neidell, M., 2018. Temperature and human capital in the short and long run. Journal of the Association of Environmental and Resource Economists 5, 77–105. doi:10.1086/694177

Heal, G., Park, J., 2016. Reflections-temperature stress and the direct impact of climate change: A review of an emerging literature. Review of Environmental Economics and Policy 10, 347–362. doi:10.1093/reep/rew007

Herold, N., Alexander, L., Green, D., Donat, M., 2017. Greater increases in temperature extremes in low versus high income countries. Environmental Research Letters 12. doi:10.1088/1748-9326/aa5c43

Horowitz, J.K., 2009. The income-temperature relationship in a cross-section of countries and its implications for predicting the effects of global warming. Environmental and Resource Economics 44, 475–493. doi:10.1007/s10640-009-9296-2

Hsiang, S., Deryugina, T., 2014. Does the environment still matter? Daily temperature and income in the United States. National Bureau of Economic Research working paper series 20750, 1.

Hsiang, S.M., 2010. Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America. Proceedings of the National Academy of Sciences of the United States of America 107, 15367–15372. doi:10.1073/pnas.1009510107

Kahn, M.E., 2016. The climate change adaptation literature. Review of Environmental Economics and Policy 10, 166–178. doi:10.1093/reep/rev023

Kjellstrom, T., Kovats, R.S., Lloyd, S.J., Holt, T., Tol, R.S.J., 2009. The direct impact of climate change on regional labor productivity. Archives of Environmental and Occupational Health 64, 217–227. doi:10.1080/19338240903352776

Mendelsohn, R., Nordhaus, W.D., Shaw, D., 1994. The impact of global warming on agriculture: a Ricardian analysis. American Economic Review 84, 753–771.

Otrachshenko, V., Popova, O., Solomin, P., 2018. Misfortunes never come singly: Consecutive weather shocks and mortality in Russia. Economics and Human Biology 31, 249–258. doi:10.1016/j.ehb.2018.08.008

Otrachshenko, V., Popova, O., Solomin, P., 2017. Health consequences of the Russian weather. Ecological Economics 132, 290–306. doi:10.1016/j.ecolecon.2016.10.021

Park, J., Bangalore, M., Hallegatte, S., Sandhoefner, E., 2018. Households and heat stress: Estimating the distributional consequences of climate change. Environment and Development Economics 23, 349–368. doi:10.1017/S1355770X1800013X

Tol, R.S.J., Downing, T.E., Kuik, O.J., Smith, J.B., 2004. Distributional aspects of climate change impacts. Global Environmental Change 14, 259–272. doi:10.1016/j.gloenvcha.2004.04.007

Zhang, P., Deschenes, O., Meng, K., Zhang, J., 2018. Temperature effects on productivity and factor reallocation: Evidence from a half million chinese manufacturing plants. Journal of Environmental Economics and Management 88, 1–17. doi:10.1016/j.jeem.2017.11.001

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

Appendix

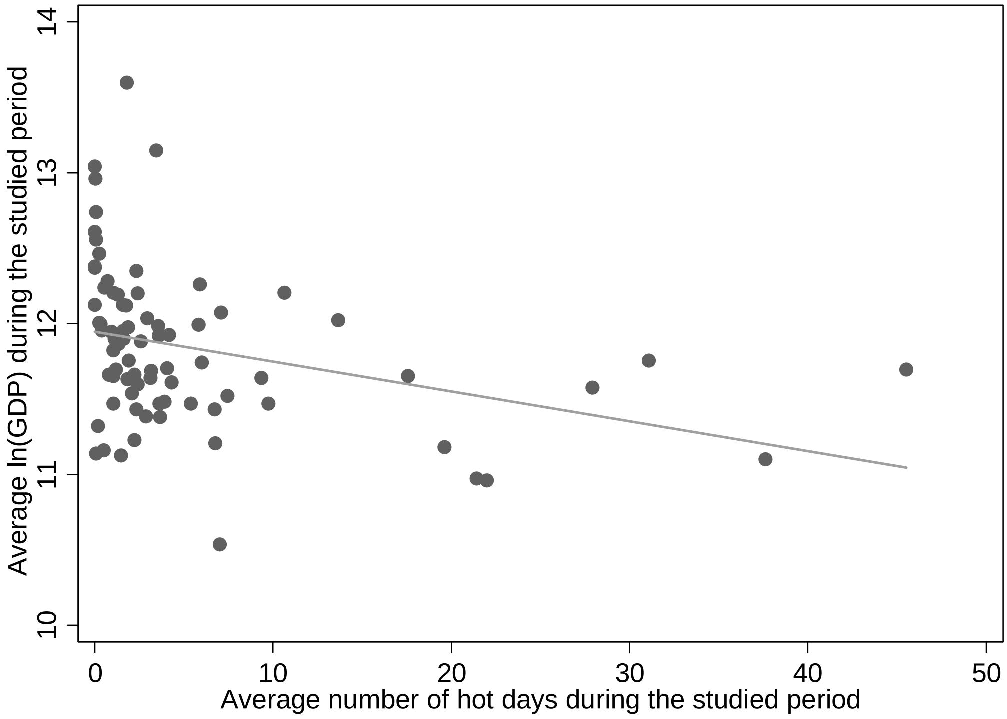
Table A1. Regions classification

Oblast	Region name	Econ. Classification	Temp. Classification
Ивановская область	Ivanovkaja oblast	Poor	Cold
Тверская область	Tverskaja oblast	Poor	Cold
Калужская область	Kaluzhskaja oblast	Poor	Cold
Кировская область	Kirivskaja oblast	Poor	Cold
Костромская область	Kostromskaja oblast	Poor	Cold
Псковская область	Pskovskaja oblast	Poor	Cold
Смоленская область	Smolenskaja oblast	Poor	Cold
Забайкальский край	Zabaykalskiy kraj	Poor	Cold
Республика Бурятия	Republic of Burjatija	Poor	Cold
Кабардино-Балкарская Республика	Kabardino-Balkarskaja Republic	Poor	Cold
Республика Алтай	Republic of Altay	Poor	Cold
Карачаево-Черкесская Республика	Karachaevo-Cherkesskaja Republic	Poor	Cold
Республика Тыва	Republic of Tyva	Poor	Cold
Еврейская автономная область	Jewish autonomous okrug	Poor	Cold
Алтайский край	Altajsky kraj	Poor	Hot
Краснодарский край	Krasnodarsky kraj	Poor	Hot
Ставропольский край	Stavropolsky kraj	Poor	Hot
Астраханская область	Astrahanskaja oblast	Poor	Hot
Брянская область	Brjanskaja oblast	Poor	Hot
Владимирская область	Vladimirskaja oblast	Poor	Hot
Волгоградская область	Volgogradkaja oblast	Poor	Hot
Воронежская область	Voronezhskaja oblast	Poor	Hot
Республика Ингушетия	Republic of Ingishetija	Poor	Hot
Курганская область	Kurganskaja oblast	Poor	Hot
Курская область	Kurskaja oblast	Poor	Hot
Орловская область	Orlovskaja oblast	Poor	Hot
Пензенская область	Penzenskaja oblast	Poor	Hot
Ростовская область	Rostovskaja oblast	Poor	Hot
Рязанская область	Rjazanskaja oblast	Poor	Hot
Саратовская область	Saratovskaja oblast	Poor	Hot
Тамбовская область	Tambovskaja oblast	Poor	Hot
Тульская область	Tulskaja oblast	Poor	Hot
Ульяновская область	Uljanovskaja oblast	Poor	Hot
Республика Адыгея	Republic of Adygeja	Poor	Hot
Республика Дагестан	Dagestan Republic	Poor	Hot
Республика Калмыкия	Republic of Kalmykija	Poor	Hot
Республика Марий Эл	Mariy El Republic	Poor	Hot
Республика Мордовия	Mordovija	Poor	Hot
Республика Северная Осетия-Алания	Severnaja Osetija-Alnija Republic	Poor	Hot
Чеченская Республика	Chechen Republic	Poor	Hot

Чувашская Республика	Chuvash Republic	Poor	Hot
Красноярский край	Krasnojarsky kraj	Rich	Cold
Приморский край	Primosky kraj	Rich	Cold
Амурская область	Amurskaja oblast	Rich	Cold
Архангельская область	Arhangelskaja oblast	Rich	Cold
Вологодская область	Vologodskaja oblast	Rich	Cold
Иркутская область	Irkutskaja oblast	Rich	Cold
Калининградская область	Kaliningradskaja oblast	Rich	Cold
Камчатский край	Kamchatskiy kraj	Rich	Cold
Кемеровская область	Kemerovskaja oblast	Rich	Cold
Ленинградская область	Leningradskaja oblast	Rich	Cold
Магаданская область	Magadaskaja oblast	Rich	Cold
Мурманская область	Murmaskaja oblast	Rich	Cold
Новгородская область	Novgorodskaja oblast	Rich	Cold
Новосибирская область	Novosibirskaja oblast	Rich	Cold
Пермский край	Permskiy kraj	Rich	Cold
Сахалинская область	Sahalinskaja oblast	Rich	Cold
Свердловская область	Sverdlovskaja oblast	Rich	Cold
Томская область	Tomskaja oblast	Rich	Cold
Тюменская область	Tyumenskaja oblast	Rich	Cold
Челябинская область	Chljabinskaja oblast	Rich	Cold
Чукотский автономный округ	Chukotskiy autonomous region	Rich	Cold
Ярославская область	Jaroskavkaja oblast	Rich	Cold
Республика Карелия	Republic of Karelija	Rich	Cold
Республика Коми	Komi Republic	Rich	Cold
Республика Хакасия	Republic of Khakasija	Rich	Cold
Республика Саха (Якутия)	Republic of Saha	Rich	Cold
Хабаровский край	Habarovsky kraj	Rich	Hot
Белгородская область	Belgorodskaja oblast	Rich	Hot
Нижегородская область	Nizhegorodskaja oblast	Rich	Hot
Самарская область	Samarskaja oblast	Rich	Hot
г. Санкт-Петербург	Saint-Petersburg	Rich	Hot
Липецкая область	Lipecskaja oblast	Rich	Hot
г. Москва	Moscow	Rich	Hot
Московская область	Moscow oblast	Rich	Hot
Омская область	Omskaja oblast	Rich	Hot
Оренургская область	Orenburgskaja oblast	Rich	Hot
Республика Башкортостан	Bashkortostan Republic	Rich	Hot
Республика Татарстан	Tatarstan Republic	Rich	Hot
Удмуртская область	Udmurtskaja oblast	Rich	Hot

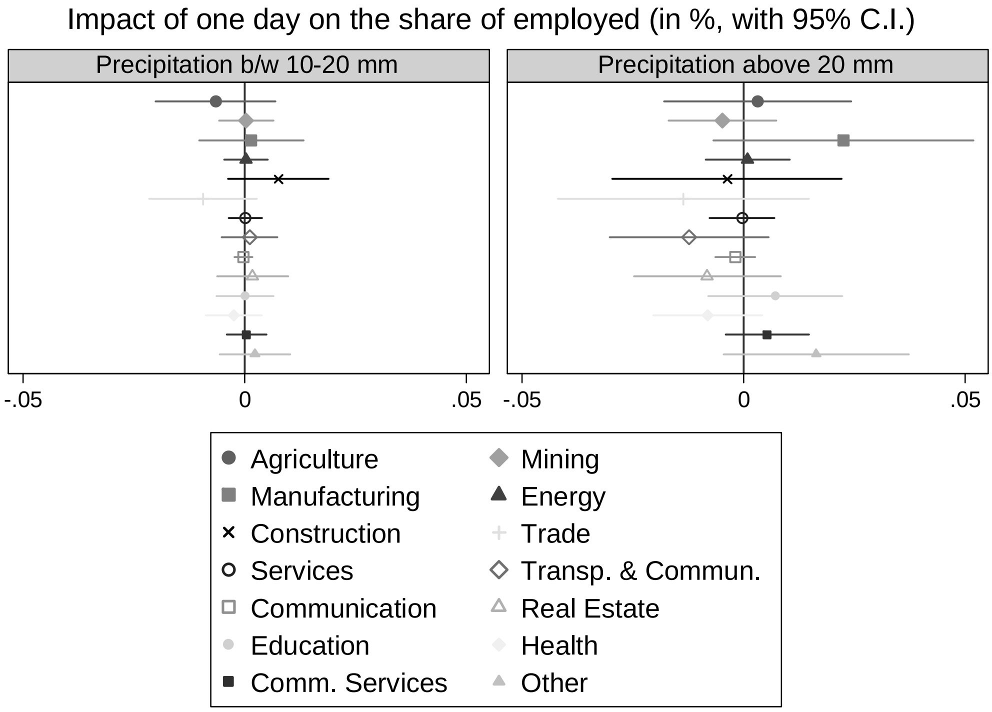
Source: Authors' construction. *Note.* The regions are divided into "rich" and "poor" according to the average real GDP during the studied period. "Rich" regions are those with average real GDP above the sample mean, and "poor" are those below the sample mean. The regions are divided into "hot" and "cold" according to the frequency of hot (cold) extremes in the studied period. "Hot" regions are those in which average daily temperature above 25°C occurs more frequently than mean in the sample, and "cold" regions are those in which average daily temperature below -23°C occurs more frequently than mean in the sample.

Figure A1. The correlation between the number of days above 25C and ln(GDP)



Source: The authors' construction.

Figure A2. The impact of precipitation on the share of employed in different industries



Source: Authors' estimation based on data from the Russian State Statistical Service. Note: The impact is measured for 14 industries according to the Russian Classification of Economic Activities.