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DOES WEATHER SHARPEN INCOME INEQUALITY IN RUSSIA?†

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Using subnational panel data, this paper analyzes how hot and cold extreme temperatures and precipitation affect economic activity and income distribution in Russia. We account for the intensity of exposure to extreme temperatures by analyzing the impacts of both single and consecutive days with extreme temperature, i.e., heat waves and cold spells, and examine several labor market channels behind those effects. We find that consecutive extremely hot days decrease regional GDP per capita but do not affect income inequality. Poor regions are affected by extreme temperatures relatively more than rich regions. These effects occur because of reallocation of labor from employment to unemployment, an increase in prices in poor regions, and to some extent because of changes in the industrial employment structure, while relative wages are not affected. Extremely cold days, both single and consecutive, as well as extreme precipitation have a limited impact on economic activity and income distribution.

JEL Codes: I3, J31, Q54

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1. Introduction

In a well cited study, Tol *et al.* (2004) suggest that global warming has a non-uniform impact on income distribution across the world, i.e., despite emitting fewer greenhouse gases, poor countries, given their geographic location on the globe and

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lower capacity to adapt, become poorer. Recently, Diffenbaugh and Burke (2019) examine the global data on gross domestic product (GDP) per capita and confirm this finding. With few exceptions, however, the subnational analyses of the impact of extreme temperatures on economic growth and income distribution remain overlooked (Dell *et al.*, 2009; Hsiang and Deryugina, 2014; Park *et al.*, 2018). This is unfortunate because estimating the aggregate impacts of global warming on countries without accounting for regional, industrial, and income group differences may lead to faulty conclusions (Tol *et al.*, 2004). Also, a cross-country analysis typically includes diverse countries from all over the world, and it is hard to analyze channels through which extreme temperatures affect income distribution.

This paper addresses these issues and contributes to the literature on income distribution and extreme weather events in several ways. First, and most importantly, using the subnational panel data from Russia, we analyze whether and how extreme temperature and precipitation shocks affect regional GDP per capita and income distribution, and examine several labor market channels behind those effects. Second, unlike other studies, we account for the intensity of extreme temperatures exposure by simultaneously examining the impacts of both single extreme temperature days and consecutive extreme temperature days (heat waves and cold spells), i.e., at least three days with the same extreme temperature.[1] Given that the frequency and intensity of extreme weather events will increase in the future, accounting for heat waves and cold spells is an important policy-relevant task for gaining a more precise estimation of global warming consequences (Intergovernmental Panel on Climate Change [IPCC], 2014).

Studies that use the regional-level panel data to identify the effects of hot and cold temperatures generally focus on mortality. To date, such studies exist for China, India, Mexico, Russia, and the USA (Deschênes and Moretti, 2009; Deschênes and Greenstone, 2011; Burgess *et al.*, 2017; Otrachshenko *et al.*, 2017; Otrachshenko *et al.*, 2018; Yu *et al.*, 2019; Banerjee and Maharaj, 2020; Cohen and Dechezleprêtre, 2021; Otrachshenko *et al.*, 2021).[2] The mechanism behind the temperature-mortality relationship is related to the physiological response of the 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 the country's economic development, since people in developed countries have more income to cope with the consequences of weather.

Earlier studies also find that hot temperatures reduce labor productivity, encourage the reallocation of time between indoor and outdoor work and leisure, and induce companies in industries with greater exposure to temperature risks to move to industries with a lower exposure (Dell *et al.*, 2009; Graff Zivin and Neidell, 2014; Park *et al.*, 2018; Zhang *et al.*, 2018; Otrachshenko and Nunes, 2021). This suggests that weather indicators may also affect the income distribution either

[1]We define an extremely hot day as one day with a mean temperature above 25°C and an extremely cold day as one day with a mean temperature below −23°C. Consecutive extremely hot/cold days are a sequence of at least three such days. These definitions are discussed in the data section.

[2]In a recent study, Hartwell *et al.* (2021b) also control for weather conditions in studying the causes of city-level pollution in Russia.

directly or indirectly through the impact on labor supply and labor demand. Numerous cross-country studies also document that extreme heat harms economic growth and that poor countries suffer the most (Tol *et al*., 2004; Dell *et al*., 2009; 2012; Horowitz, 2009; Herold *et al*., 2017; Diffenbaugh and Burke, 2019). Even so, the scholarship on extreme temperatures and income distribution remains scarce and most studies rarely go beyond analyzing the effects of temperature on GDP per capita or GDP growth.[3]

We examine the distributional impacts of extreme temperature and precipitation shocks, using the 20-years panel data from the Russian regions.[4] Within this time span we focus on the short- and medium-term effects of temperature and precipitation on economic activity and income distribution in Russia.[5] Specifically, we examine how single/consecutive days, both extremely hot and cold, and precipitation affect several indicators of income distribution, including GDP per capita, population income shares, poverty rate, Gini coefficient, and the $90^{th}/10^{th}$ income percentile ratio. To account for the heterogeneity in economic performance between the Russian regions, we analyze the impact of weather on inequality indicators in poor/rich and cold/hot regions separately. Finally, by focusing on unemployment, employment reallocation and wages in different industries, and migration we identify the labor market channels behind the inequality-temperature relationship.

Several important findings stand out. First, we find that consecutive hot days considerably decrease regional GDP per capita, while single hot days have no impact on GDP per capita. Specifically, each consecutive hot day in a sequence of at least three such days decreases the real regional GDP per capita by 0.19%. However, consecutive days have no impact on income inequality as measured by the Gini index or the 90–10 income percentile ratio. Second, while both poor and rich regions are vulnerable to global warming, poor regions are affected relatively more. Third, cold temperatures and extreme precipitation mostly do not affect GDP per capita and income distribution. The analysis of labor market channels behind the effect suggests that the temperature-inequality relationship occurs primarily because of reallocation of labor from employment to unemployment, increase in prices in poor regions, and to some extent because of changes in the employment structure in different sectors.

The remainder of the paper is organized as follows. In Section 2 we present the background on income inequality and weather conditions in Russia. Section 3 reviews the literature, presents our hypotheses, and proposes the channels through which extreme temperatures may affect regional GDP per capita and income distribution. Sections 4 and 5 present methodology and data, respectively. Section 6 discusses our main findings, and Section 7 concludes.

[3]In general, there is a flourishing literature on the impact of natural resources on income inequality. For a recent summary of this literature, see Hartwell *et al*. (2021a).

[4]We define income inequality as the extent to which income is unevenly distributed among a population within and between the regions. The terms “income inequality” and “income distribution” are used interchangeably throughout the paper.

[5]Dell *et al*. (2014) point out that one should distinguish between the short-term effects of *weather* and the long-term effects of *climate change*. While the analysis of weather effects on socioeconomic indicators is typically based on short- and medium-term data, the analysis of climate change data requires a longer time span to adequately capture possible adaptation and intensification effects.

2. Background

2.1. *Income Inequality in Russia*

Russia is an upper-middle-income economy with high but relatively stable income inequality. According to the OECD estimates in 2017, the Gini index, the most frequently used measure of income inequality, is 0.331 in Russia, which is slightly above the OECD average of 0.317 (OECD, 2019).[6] Academic studies of income inequality in Russia can generally be classified into two major groups: (i) the studies that describe the dynamics and causes of income inequality during and after the economic transition, using the Russian household and individual survey data (e.g., the Russia Longitudinal Monitoring Survey (RLMS) or the Russian Household Budget Survey), and (ii) the studies of interregional income inequality in Russia. Below we briefly review the most important findings in each of these two groups of studies.

The studies that use the Russian household data generally agree that wage and income inequality grew in Russia during the transition period before 2000 and has been relatively stable or decreasing thereafter (Brainerd, 1998; Commander *et al.*, 1999; Lokshin and Popkin, 1999; Jovanovic, 2001; Lehmann and Wadsworth, 2007; Gorodnichenko *et al.*, 2010; Lukiyanova and Oshchepkov, 2012; Calvo *et al.*, 2015; Dang *et al.*, 2020).[7] The major trend that led to a decrease in income inequality was a pro-poor growth, i.e., a relatively faster growth in the income of the poorest income groups as compared to the income of the richest groups (Lukiyanova and Oshchepkov, 2012; Dang *et al.*, 2020), and changing returns to employment in different economic sectors (Milanovic, 1999; Calvo *et al.*, 2015). Researchers also underscore that the Russian income inequality and poverty dynamics is a complex phenomenon. On the one hand, the share of persistently poor households is relatively low in Russia. However, the majority of the population has been moving in and out of poverty since the beginning of the 1990s until now, and the upward mobility of the poor along the income distribution is still very limited (Lokshin and Popkin, 1999; Lukiyanova and Oshchepkov, 2012; Dang *et al.*, 2020).

Studies of interregional inequality in Russia are still scarce (for reviews, see Gluschenko (2011) and Zubarevich (2015)). Regional-level studies emphasize that there is a substantial differentiation or even polarization between income distributions in the Russian regions (Fedorov, 2002; Gluschenko, 2011). Scholars generally agree that the major determinants of interregional income inequality in Russia are agglomeration effects and urbanization rates, openness, economic structure, and resource endowment, as well as geographic position (Fedorov, 2002; Gluschenko, 2011; Zubarevich, 2015; Zubarevich, 2019). However, the extent of regional income polarization in Russia and its obstacles for economic development are often exaggerated, since "except for the main oil- and gas-extracting regions and Moscow, at

[6]The estimates of the Russian State Statistical Service suggest that the Gini index has been relatively stable since 1995 at *circa* 0.4.

[7]Recently, Novokmet *et al.* (2018) combine various sources of data on both income and wealth inequality in Russia and suggest that earlier studies substantially underestimate the extent of inequality in Russia during the transition. However, Kapeliushnikov (2020) raises a number of methodological concerns regarding the study by Novokmet *et al.* (2018).

one extreme, and a few underdeveloped republics, at the other extreme, there is no great difference estimated in per capita GDP between the levels of economic development of most Russian regions" (Zubarevich, 2015). Nevertheless, most scholars also agree that it is important to account for interregional income inequality when designing the economic policies in Russia.

2.2. *Weather and Climate in Russia*

As it is the most extensive territory globally, Russia includes almost all climatic zones and often faces both extremely hot and cold temperatures. The average temperatures range from −60°C and below in the eastern Siberia to +35°C and higher in the southern parts, while precipitation is relatively low.[8] According to the World Bank (2020), the coldest month in Russia is January, with average temperature −25.4°C and average precipitation 21.7 mm and the warmest month is July, with average temperature 15.4°C and average precipitation 63.6 mm.

The climate of Russia is predominantly continental with hot summers and cold winters. There is also a substantial diversity in climatic and weather conditions across the country. The European part of Russia, southern parts of Siberia, and the Far East have humid continental climate with mild to hot summers and cold winters. In the Southern European part, summers are very hot, and winters are cool to cold. In the Siberian part, summers are warm to hot, and winters are very cold.

Figure 1 shows the average number of hot days in Russia over the period 1995–2015. For illustration purposes, in this figure we show data for federal districts of Russia, an equivalent of the European NUTS2 classification, while the main analysis in this paper is based on data for 79 regions of Russia, an equivalent of the European NUTS3 classification (see the data section for details). As shown in Figure 1, there is a substantial variation in the number of hot days across regions of Russia. Generally, South, North Caucasian, Central, and Volga federal districts (geographically, Central and Southern European parts of Russia) experience a higher number of hot days than the rest of the country, though there is a non-zero number of hot days and frequent heat waves in all regions.

There is also an increasing trend in the number of hot days over time. As such, the average number of days above 25°C has doubled in Russia during the last 20 years (from 3.24 in 1995 to 6.76 in 2015). As compared to 1995, the growth in the number of hot days in 2015 is observed in Central, South, North Caucasian, Volga, and Siberian federal districts, while in North-West, Ural, and Far East there is on average no change in the number of hot days. Overall, according to recent reports, the annual average temperature growth over the period 1976–2019 in Russia is 0.47°C per 10 years, which is 2.5 times greater than the global annual temperature growth (0.18°C per 10 years) over the same period (Otrachshenko and Popova, 2019; Roshydromet, 2020).

[8]Oymyakon, a rural locality in the Sakha Republic in the eastern Siberia, frequently experiences average daily temperatures −50°C and minimal daily temperatures −60°C and below during the winter months.

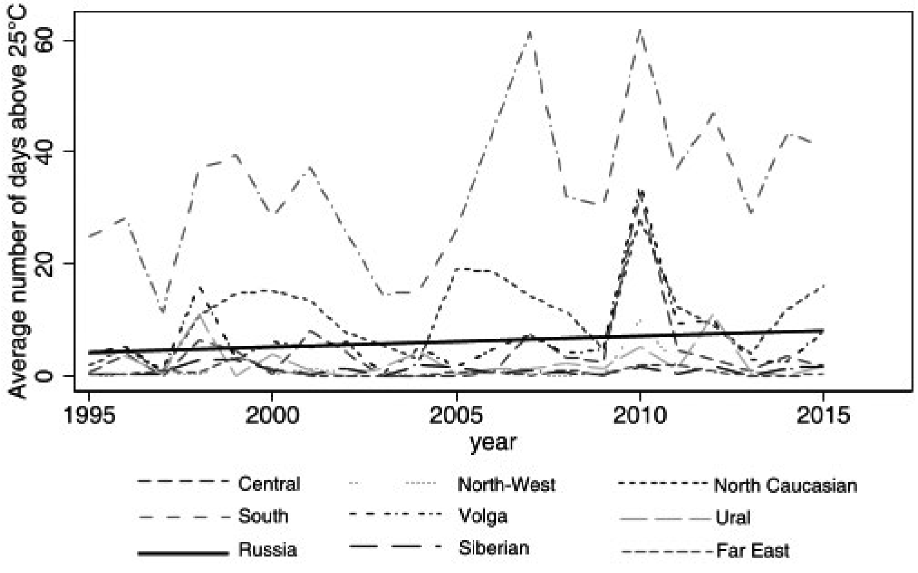

Figure 1. Variation in the total number of hot days in the Russian federal districts, 1995–2015

Notes: The total number of days with average daily temperature above 25°C are reported. Data are aggregated by the authors from the level of meteorological stations to the federal district level, an equivalent of the European NUTS2 classification. Main analysis in the paper is performed using data at a lower level of aggregation for 79 regions, an equivalent to the European NUTS3 classification (for details, see data section).

Source: Authors' compilation based on data from the Russian Federal State Service for Hydrometeorology and Environmental Monitoring.

Weather conditions also correlate with economic activity. Table 1 presents the average shares of employment in selected industries by federal districts. As shown in this table, federal districts with a greater number of hot days (Central, South, North Caucasian, and Volga) have relatively higher shares of employed in agriculture and relatively lower shares of employed in manufacturing (except for Volga federal district) than federal districts with a relatively lower number of hot days (North-West, Ural, Siberian, and Far East). The shares of employed in construction, trade, and services are similar across the country.

3. Previous Literature, Channels, and Hypotheses

Studies at a cross-county level suggest that extremely hot temperatures reduce economic growth (Tol *et al*., 2004; Dell *et al*., 2009; 2012; Horowitz, 2009; Herold *et al*., 2017; Diffenbaugh and Burke, 2019). Subnational studies on this topic are still scarce. An exception is Dell *et al*. (2009), who document the negative relationship between temperatures and economic growth across countries and across regions in 12 countries in the Americas. The authors suggest that within-country impacts of temperature are weaker than the across-countries effect, but the magnitude is still economically sizeable. Also, Hsiang and Deryugina (2014) analyze the subnational level data for the USA and find that single extremely hot days reduce

TABLE 1

Average Shares of Employment in Selected Industries by Federal District (2005–15), in % to Total Labor Force in the Federal District

	Agriculture	Mining	Manufacturing	Construction	Trade	Energy	Services
South	17.91	0.78	11.43	6.76	16.61	2.90	1.82
North Caucasian	19.06	0.80	11.18	7.21	14.14	2.49	1.83
Volga	12.97	0.93	19.16	7.29	16.39	2.71	1.60
Ural	8.35	4.28	17.90	8.06	15.30	3.28	1.58
Central	11.52	0.46	18.93	6.96	18.09	2.99	1.55
Siberian	11.63	2.71	11.39	6.90	15.27	3.21	1.70
Far East	3.42	5.31	7.31	7.81	15.14	5.74	1.68
North-West	8.75	1.81	16.18	7.37	15.79	3.56	1.90

Source: Authors' construction based on data from the Federal State Statistical Service of Russia.*Note*: The federal districts are ranked according to average number of days above 25°C in 2015 from the highest to the lowest.

annual income per capita. The impact of consecutive extreme days on economic growth and income distribution is not studied in the previous literature. However, a study on mortality suggests that while single extreme days, both hot and cold, may not be harmful, consecutive extreme days are indeed harmful and increase mortality (Otrachshenko *et al.*, 2018). This is because the exposure to extreme temperatures increases considerably during consecutive days. Therefore, we hypothesize that:

> **H1:** Extreme temperatures reduce regional GDP per capita and increase income inequality. Consecutive extreme days are more harmful than single days.

Another country-level finding in the literature is that extremely hot temperatures widen income disparities between poor and rich countries (Tol *et al.*, 2004; Horowitz, 2009; Dell *et al.*, 2012; Herold *et al.*, 2017). Despite emitting fewer greenhouse gases, poor countries become poorer, given their geographic location on the globe and lower capacity to adapt. Unequal exposure to hot and cold temperatures also leads to unequal sectorial development in poor and rich countries, exacerbating income inequality. In particular, in poor and middle-income countries both agricultural and industrial output contracts following hot temperatures, and both labor- and capital-intensive industries are affected (Hsiang, 2010; Dell *et al.*, 2012; Zhang *et al.*, 2018), while in rich countries agricultural profits may grow as a result of global warming (Mendelsohn *et al.*, 1994; Deschênes and Greenstone, 2007). Rich and cold regions therefore receive more benefits from global warming than do poor and hot regions (Tol *et al.*, 2004; Heal and Park, 2016; Park *et al.*, 2018). On the other hand, recent studies also suggest that on average, both rich and poor countries suffer from the consequences of global warming, and the inequality is growing globally (Dell *et al.*, 2012; Hsiang and Deryugina, 2014; Burke *et al.*, 2015). Therefore, we expect that extreme temperatures increase between-region income inequality.

> **H2:** Poor and hot regions suffer from extreme temperatures more than rich and cold regions do.

There are also several channels through which extreme temperatures may affect real income of the population. First, extremely hot temperatures affect agricultural production and food prices, and in turn affect real income in both rich and poor countries, though the impact may differ by climatic zone, crop types, and the country's engagement in international trade (Deschênes and Greenstone, 2007; Kahn, 2016; Lesk *et al.*, 2016). Moreover, extreme temperatures also increase energy consumption and prices, reducing real income of the population, and countries with different natural resource endowments might be affected by this channel differently (Deschênes and Greenstone, 2011). Therefore, we expect that:

> **H3:** Extreme temperatures reduce real income of the population by increasing consumption prices.

At an individual level, 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, and hours worked in industries with direct exposure to temperature, and leads to reallocation of time from work to leisure (Kjellstrom *et al.*, 2009; Graff Zivin and Neidell, 2014; Heal and Park, 2016; Cho, 2017; Graff Zivin *et al.*, 2018; Zhang *et al.*, 2018; Park *et al.*, 2020). Recently, Park *et al.* (2018) combine household data from 52 countries and show a negative within-country correlation between household wealth and hot temperature in hot countries, documenting that individuals performing agricultural or unskilled manual work (i.e., those in occupations with greater exposure to warmer temperature) are more likely to be poor.

Based on previous literature, we can disentangle several labor market channels through which thermal stress may increase interregional income inequality. First, thermal stress may increase transitions from employment to unemployment due to low productivity and health reasons (Graff Zivin and Neidell, 2014; Graff Zivin *et al.*, 2018). Second, lower productivity and work hours as a result of extreme temperatures may lead to wage reductions, especially in sectors with a greater exposure to ambient temperatures, e.g., agriculture (Dell *et al.*, 2009; 2012; Park *et al.*, 2018). Third, thermal stress may lead to the reallocation of labor from sectors with a greater exposure to temperature risks to sectors with a lower exposure (Zhang *et al.*, 2018). Finally, exposure to extreme temperatures increases migration (Deschênes and Moretti, 2009; Mueller *et al.*, 2020). 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 (Graff Zivin and Neidell, 2014; Heal and Park, 2016; Kahn, 2016). Thus, we test the following hypotheses:

H4a: Extreme temperatures lead to the reallocation of labor from employment to unemployment;

H4b: Extreme temperatures increase wage differentials between industries having a different exposure;

H4c: Extreme temperatures lead to the reallocation of labor from industries with a greater exposure to industries with a lower exposure;

H4d: Extreme temperatures lead to the reallocation of labor force from regions with a greater exposure to temperature risks to regions with a lower exposure.

In sum, extreme temperatures may affect regional GDP per capita and income inequality through several channels: (a) unequal industrial and agricultural development in rich and poor regions, (b) effects on overall real income per capita via consumption price changes, and (c) labor market adjustments via wage changes, labor reallocation between industries and/or between regions with a different exposure, and transitions from employment to unemployment.

4. Methodology

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

$$
\begin{aligned}
(1) \qquad & Y_{it} = \beta_0 + \beta_1 Consec.\, Bin_{it}^{below-23^\circ\mathrm{C}} + \beta_2 Bin_{it}^{below-23^\circ\mathrm{C}} + \beta_3 Bin_{it}^{above25^\circ\mathrm{C}} \\
& + \beta_4 Consec.\, Bin_{it}^{above25^\circ\mathrm{C}} + \delta_1 Bin_{it}^{Prec.10-20\ \mathrm{mm}} + \delta_2 Bin_{it}^{Prec.above20\ \mathrm{mm}} \\
& + \alpha_i + \gamma_t + \mathbf{\Phi}' Region * Trend + u_{it}
\end{aligned}
$$

where the subscripts i and t stand for a region and year, respectively. Y_{it} is the set of income distribution indicators such as the natural logarithm of the real regional GDP per capita $\ln(GDP_{it})$, 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, Gini coefficient, and the $90^{th}/10^{th}$ income percentile ratio. $Bin_{it}^{below-23^\circ C}$ and $Bin_{it}^{above25^\circ C}$ stand for the number of single days in a region i and year t in which the average daily temperature is below -23°C (extremely cold) and above 25°C (extremely hot), respectively. Coefficients on $Bin_{it}^{below-23^\circ C}$ and $Bin_{it}^{above25^\circ C}$ are interpreted as the impact of one day with extreme temperature compared to a day in the default bin. Days with temperature between −23°C and 25°C are used as a default category.

$Consec.\, Bin_{it}^{below-23^\circ C}$ and $Consec.\, Bin_{it}^{above25^\circ C}$ are the number of days in spells of at least three consecutive days with the average daily temperature below -23°C and above 25°C, respectively. Coefficients on $Consec.\, Bin_{it}^{below-23^\circ C}$ and $Consec.\, Bin_{it}^{above25^\circ C}$ are interpreted as the impact of one day in a spell of at least three consecutive days with extreme temperature compared to a day in the default bin. Note that in Eq. (1) a day with a specific temperature range can fall into only one temperature bin. That is, a day in the consecutive bin, i.e., $Consec.\, Bin_{it}^{above25^\circ C}$, is excluded from $Bin_{it}^{above25^\circ C}$, and similarly for consecutive and single cold days. The sum of single and consecutive days in each year equals 365.

$Bin_{it}^{Prec.10-20\ mm}$ and $Bin_{it}^{Prec.above20\ mm}$ stand for the number of days with the mean daily precipitation between 10 and 20 and above 20 mm, respectively, while days with precipitation between 0 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 unobserved regional specific time invariant characteristics that may affect regional income distribution. 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 $Region * Trend$ is the set of region-specific linear time trends that affect income inequality and may also correlate with climate, e.g., trends in industrial location choices, government spending, or private investments.[9] The combination of region fixed effects, time fixed effects, and region-specific trends allows disentangling the effects of temperature and

[9]In robustness checks, we also include the model with linear and quadratic trends. The results are robust to such modification (see Table 3).

precipitation from possible sources of omitted variable bias (Dell *et al*., 2014). u_{it} is a disturbance term, while β and δ are the vectors of the model parameters. Eq. (1) is estimated using fixed effects with robust standard errors clustered at a regional level.[10]

The approach that we use is a reduced-form panel approach. This approach allows estimating the total causal impact of temperature and precipitation with relatively few assumptions for identification (Dell *et al*., 2014). To identify the impact of temperature and precipitation on socioeconomic indicators, Eq. (1) should include only temperature and precipitation variables, regional and time fixed effects as well as regional trends, and exclude any additional economic controls (Dell *et al*., 2014). Including any additional economic controls in Eq. (1) causes an over-controlling problem, since most economic indicators are themselves influenced by weather conditions directly or indirectly (Dell *et al*., 2014).

As specified above, we first analyze a set of income distribution indicators. We then test several channels through which extreme weather may affect income inequality. For this, we estimate Eq. (1) also for several other socioeconomic indicators, including a change in the value of the fixed consumption basket, relative wages in different economic sectors, the share of employed in different economic sectors, unemployment rate, and migration rate. To account for the heterogeneity in economic performance between the Russian regions, we analyze the impact of weather on inequality indicators in poor/rich and cold/hot regions separately.

5. 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, which provides regional-level data on various indicators of income and economic activity. In the analysis we use data on the annual real GDP per capita, five income quintile groups, the share of people in poverty, Gini coefficient, and the $90^{th}/10^{th}$ income percentile ratio, unemployment and migration rates, and the distribution of wages and employment across industries. The definitions and measurement units of all variables used in the analysis are presented in Table A1 in the online appendix. 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).[11]

[10] In robustness checks, we also estimate the model with standard errors adjusted for heteroskedasticity and autocorrelation (see Table S3 in the online appendix). The results are robust to such modification.

[11] 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.

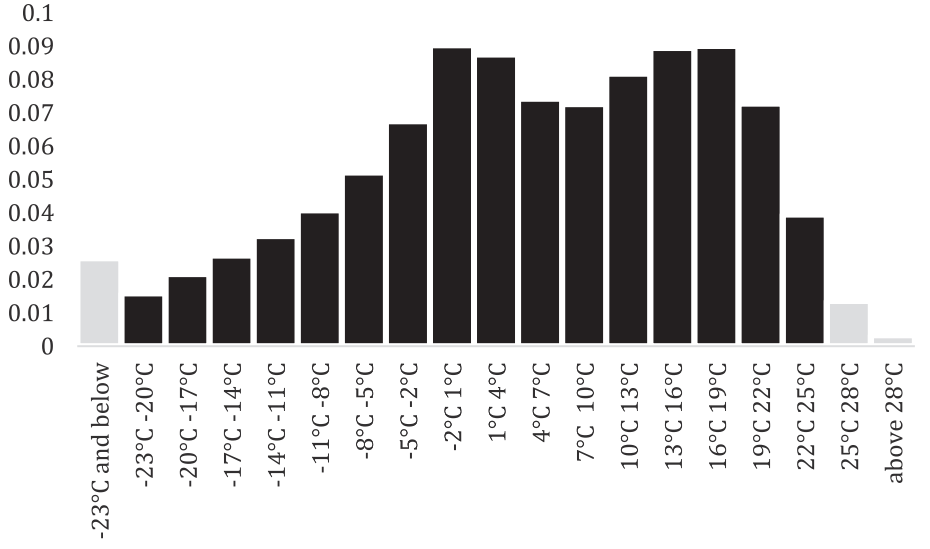

Figure 2. Distribution of days with a specific temperature range, 1995–2015

Notes: Temperature bins include the number of days with a specific temperature in Russia from 1995–2015. 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 hottemperatures.

Source: Authors' computations.

Descriptive statistics for economic variables used in the analysis are presented in Table A2 in the online appendix.

The second data source is the Federal State Service for Hydrometeorology and Environmental Monitoring, which 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, as suggested in previous studies (Hanigan *et al*., 2006; Dell *et al*., 2014). 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 a radius of 200 km.[12] To give the greatest weight to a station that is closest to a specific administrative unit, inverse distance square is used as a weight. Finally, to aggregate data to a regional level, population weights are used according to the administrative units' population. This allows measuring temperature as "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 2 shows the distribution of days with a specific average daily temperature in Russia from 1995 to 2015. In this figure the temperature range is divided into several bins with a 3°C step. Each temperature bin presents how many days there were with a specific temperature in Russia in the years between 1995 and 2015. In Figure 2 the gray bars show extremely cold temperature (below −23°C)

[12]This station can also be outside of the region where the administrative unit is located.

and extremely hot temperature (bins (25°C, 28°C] and above 28°C). One third of the regions in Russia 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 1.19 per year. We therefore combine the days above 25°C into a single temperature bin.

The justification for our definition of an extremely cold day (a day with the average temperature below −23°C) and of an extremely hot day (a day with the average temperature above 25°C) derives from several arguments. First, the literature suggests that comfortable ambient temperature limits for human body are 22–26°C in summer and 20–24°C in winter (Burroughs and Hansen, 2011). When the temperature exceeds these limits, there is thermal stress on the human body. For instance, with a temperature over 24°C mental work capacity is reduced (Burroughs and Hansen, 2011), mortality increases, leading to substantial years of life lost (Deschênes and Moretti, 2009), and labor productivity is reduced (Graff Zivin and Neidell, 2014; Zhang *et al*., 2018). All these effects may lead to changes in earnings and income distribution. Regarding the low temperature cut-off points, there is no universal definition in the literature, as this may depend on a particular region. In our case, temperatures below −23°C and above 25°C are experienced by all regions of Russia, and yet can be considered as extremely cold/hot. On average, in our sample we have 5.95 days with temperature above 25°C and 9.79 days with temperature below −23°C. Finally, the same definition of extremely hot and cold days is also used in previous research on the effects of weather in Russia (Otrachshenko *et al*., 2018; 2021).

For the empirical analysis, we construct temperature bins for each region and each year. As described in the previous section, we use the following bins in our model: below −23°C, above −23°C and below 25°C (the default bin), and above 25°C. We also construct bins for consecutive cold days (at least three days with average temperature below −23°C) and for consecutive hot days (at least three days with average temperature above 25°C). In the literature there is no universal definition of how many days with the same temperature should appear in a sequence to recognize this sequence as a heat wave or a cold spell. In this paper we follow the definition of consecutive days suggested by Otrachshenko *et al*. (2018). Bins of single and consecutive days do not overlap, i.e., days that are included in consecutive bins are not counted in single day bins.

Similarly, for precipitation we calculate the number of days with average daily precipitation below 10 mm (the default bin), between 10 and 20, and above 20 mm. The numbers of days per year is standardized to 365 days.

6. Results

In this section we first discuss the impact of single and consecutive hot and cold days as well as precipitation on different indicators of regional income distribution, including the regional GDP per capita, income quintile groups, the share of poor people, Gini coefficient, and the $90^{th}/10^{th}$ income percentile ratio. To account for heterogeneity of weather effects, the results are then presented for poor and rich regions, and for hot and cold regions.[13] Finally, we test and discuss the

[13]The definition of this clustering between regions is presented below.

channels through which extreme temperatures affect the regional income distribution, including a change in the monetary value of a fixed commodity basket, and several labor market channels, as discussed above.

6.1. *Main Results*

Table 2 shows the impact of single and consecutive hot and cold days on the regional GDP per capita and the indicators of income distribution.[14] As shown in column (1) in Table 2, each consecutive hot day reduces GDP per capita by 0.19% when compared to a single day with the temperature range between −23°C and 25°C. This means that a year with 10 additional consecutive hot days reduces GDP per capita by almost 2 percent, which is an economically sizeable impact. Another important finding is that single hot days do not affect GDP per capita. This result underscores the importance of accounting for consecutive days such as heat waves and cold spells that represent the intensity of extreme events. According to our findings, GDP losses occur only in case of heat waves, but not due to increases in the number of single hot days. Extremely cold days, both single and consecutive, also do not affect GDP per capita.

The results on GDP per capita are generally consistent with previous studies on different countries. The closest study to which we may compare ours is Park (2016), who suggests that a single extremely hot day decreases total income per capita in the US by 0.048 percent. Also, Zhang *et al*. (2018) show that a single extremely hot day decreases manufacturing output in China by 0.45 percent. However, both Park (2016) and Zhang *et al*. (2018) do not account for the intensity of extreme temperature days (consecutive days), which is an important methodological contribution of our study. Thus, the comparison of findings by Park (2016) and Zhang *et al*. (2018) with our study is provided only for a reference.

We further distinguish the results by income quintile groups and find that a single extremely hot day increases the shares of the lowest and the middle-income groups, although the share of people who live below the poverty threshold (Poverty), Gini, and the $90^{th}/10^{th}$ income percentile ratio are not affected. Also, a day with precipitation of 10–20 mm increases the middle-income share as compared to a day with average precipitation 0–10 mm.

A notable finding is that regarding GDP per capita, consecutive hot days have an impact, while for income shares, only the impact of single hot days is significant. The difference in the results for GDP per capita and income shares may be explained by different mechanisms behind these results. The results on GDP per capita may reflect the production-side effects. For enterprises, single hot days may have no impact on the activity, while consecutive days (heat waves) may require an adjustment in economic activities that is difficult to achieve in the short run. In other words, enterprises may fail to adapt to heat waves in the short run, and this is reflected in the negative impact of consecutive days on GDP per capita. In the case of income shares, the individual-level effects may prevail. The burgeoning literature on the adverse impact of single hot days on mortality, health, and labor

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

TABLE 2
THE IMPACT OF DAYS WITH EXTREME TEMPERATURE ON REAL GDP PER CAPITA AND INCOME DISTRIBUTION INDICATORS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dep. Variables:	Ln(real GDP per capita)	Lowest income group	Lower middle income group	Middle income group	Upper middle income group	High income group	Poverty	Gini	The 90th/10th income percentile ratio
Consecutive below −23°C	−0.0002	0.0012	−0.0009	0.0016	0.0024	0.0332	0.0367	−0.0001	−0.0067
	(0.0007)	(0.0027)	(0.0147)	(0.0025)	(0.0020)	(0.0511)	(0.0403)	(0.0001)	(0.0292)
Below −23°C	−0.0007	0.0040	−0.0077	0.0034	−0.0024	−0.1161	−0.0388	−0.0001	−0.0234
	(0.0011)	(0.0041)	(0.0279)	(0.0032)	(0.0035)	(0.1152)	(0.0881)	(0.0002)	(0.0416)
Above 25°C	0.0018	0.0225***	−0.0041	0.0119**	−0.0226	−0.4057	0.1839	−0.0002	−0.0355
	(0.0018)	(0.0071)	(0.0484)	(0.0050)	(0.0258)	(0.2489)	(0.2128)	(0.0004)	(0.1079)
Consecutive above 25°C	−0.0019***	0.0008	−0.0107	0.0013	−0.0019	0.0237	−0.0378	−0.0001	0.0062
	(0.0005)	(0.0020)	(0.0158)	(0.0015)	(0.0026)	(0.0444)	(0.0526)	(0.0001)	(0.0203)
10–20 mm	−0.0009	0.0015	−0.0377	0.0073**	−0.0024	−0.0621	−0.0068	−0.0004***	−0.0148
	(0.0007)	(0.0039)	(0.0261)	(0.0030)	(0.0044)	(0.0743)	(0.0727)	(0.001)	(0.0315)
20–100 mm	0.0009	0.0092	−0.0375	0.0053	0.0063	0.0121	0.0758	−0.0006*	−0.1062**
	(0.0015)	(0.0089)	(0.0532)	(0.0079)	(0.0061)	(0.1583)	(0.2154)	(0.0003)	(0.0513)
Observations	1,656	1,649	1,649	1,649	1,649	1,649	1,647	1,649	1,649
R-squared	0.943	0.555	0.514	0.553	0.074	0.240	0.576	0.626	0.373

Notes: The period of analysis for GDP, Gini, and the 90th to 10th income percentile ratio is 1995–2015, while for population income groups and the share of people in poverty is 2000–15. Robust standard errors clustered at a regional level are in parentheses. All regressions include a regional linear trend, and region and year fixed effects. The temperature bin (−23°C, 25°C) and the precipitation bin (0, 10 mm) are used as the default bins. ***, **, * stand for 1%, 5%, and 10% significance levels, respectively.

TABLE 3
Robustness Checks

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dep. Variables:	ln(GDP) Baseline model	ln(GDP) with lag of ln(GDP)	ln(GDP) without transition period (2000–2015)	Poverty (2000–2015)	Gini (2000–2015)	The 90th/10th income percentile ratio (2000–2015)	ln(GDP) with above 28°C	Ln(GDP) with linear and quadratic trends
lag ln(GDP)	–	0.5679***	–	–	–	–	–	–
		(0.0280)						
Consecutive below −23°C	−0.0002	−0.0005	−0.0002	0.0721	0.0001	0.0085	−0.0001	−0.0003
	(0.0007)	(0.0007)	(0.0006)	(0.0438)	(0.0001)	(0.0254)	(0.0007)	(0.0008)
Below −23°C	−0.0007	0.0004	−0.0009	−0.0983	−0.0002	−0.0205	−0.0006	−0.0005
	(0.0011)	(0.0009)	(0.0012)	(0.0795)	(0.0002)	(0.0401)	(0.0010)	(0.0009)
Above 25°C	0.0018	0.0025	0.0020	0.2435	0.0003	−0.0203	–	0.0016
	(0.0018)	(0.0017)	(0.0015)	(0.1773)	(0.0004)	(0.1181)		(0.0018)
Consecutive above 25°C	−0.0019***	−0.0014***	−0.0013***	−0.0493	−0.0001	0.0134	–	−0.0017***
	(0.0005)	(0.0004)	(0.0004)	(0.0404)	(0.0001)	(0.0208)		(0.0005)
above 28°C	–	–	–	–	–	–	−0.0119***	–
							(0.0042)	
Consecutive above 28°C	–	–	–	–	–	–	−0.0005	–
							(0.0006)	
10–20 mm	−0.0009	−0.0005	−0.0001	0.0409	−0.0002	0.0012	−0.0007	−0.0005
	(0.0007)	(0.0006)	(0.0007)	(0.0622)	(0.0001)	(0.0351)	(0.0007)	(0.0007)
20–100 mm	0.0009	−0.0003	0.0002	0.1241	−0.0002	−0.0968	0.0011	0.0008
	(0.0015)	(0.0011)	(0.0013)	(0.1338)	(0.0003)	(0.0628)	(0.0015)	(0.0016)
Observations	1,656	1,577	1,264	1,262	1,264	1,264	1,656	1,656
R-squared	0.943	0.965	0.953	0.653	0.677	0.391	0.943	0.959

Notes: Robust standard errors clustered at a regional level are in parentheses. All regressions include a regional linear trend, and region and year fixed effects. The temperature bin (−23°C, 25°C) and the precipitation bin (0, 10 mm) are used as the default bins. Columns (1), (2), and (7) refer to the results obtained on a sample 1995–2015. *** stands for 1% significance level.

productivity supports this argument (Deschênes and Moretti, 2009; Deschênes and Greenstone, 2011; Graff Zivin and Neidell, 2014; Otrachshenko *et al*., 2017). While an individual may face difficulties in adjusting to a single hot day, which may come unexpectedly, she/he may adjust her/his behavior and labor-market activity to adapt to consecutive hot days.

Regarding extremely cold temperatures, we find that neither single nor consecutive days affect income distribution indicators. We therefore find support for Hypothesis 1 in the case of extremely hot days, but not in case of extremely cold days. 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 outdoor work clothing allowed, and the outdoor work time based on different weather conditions.[15] In the case of extreme temperatures, usually cold days, a working day may be shortened or even canceled. Also, due to the specific climate conditions, some regions introduce compensating wage differentials and allow for early retirement. For instance, in cold regions the official retirement age for men is 60 years old and for women 55 years old, while the general retirement age is 65 and 60, respectively.

To check the robustness of our results we provide several model modifications (see Table 3 and Tables S1 and S2 in the online appendix). First, we include the lag of ln(GDP per capita) in Eq. (1). Note, however, that since past economic performance is also affected by weather, this may lead to over-controlling and endogeneity problems. The results suggest that the impact of consecutive hot days remains statistically significant even after controlling for past economic performance. Second, the period of economic transition from plan to market is characterized by falling GDP in Russia. To exclude the possibility that the transition period may drive our results, we estimate Eq. (1) without the transition period, i.e., using the post-transition period sample (2000–15). The impact of consecutive hot days on GDP per capita remains statistically significant and the effect is not statistically different from the one in the baseline model. Similarly, the effects of single and consecutive hot and cold days remain insignificant if we use the post-transition period sample for poverty share, Gini, and the $90^{th}/10^{th}$ income percentile ratio.

In Table 3 we also provide the results with a different definition of extremely hot temperature bins, using above 28°C instead of above 25°C. The results suggest that the impact of a single hot day above 28°C on GDP per capita is similar to the impact of one consecutive day above 25°C, while a consecutive day above 28°C has no effect. However, these results should be interpreted with caution since one third of the regions in our sample do not experience temperature above 28°C.

Also, to check that the effects of weather are contemporaneous and not driven by past weather, we include the lags of temperature and precipitation in Eq. (1). The results available in Table S1 in the online appendix show that the lags of weather indicators do not affect current income distribution. Finally, in Table S2 in the online appendix, we provide the results for a model with intermediate 3-degree temperature bins and a model with an alternative definition of consecutive hot days. Main results are also robust to these model modifications.

[15]For a detailed discussion, see the methodical recommendations of the Russian Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing (2007).

6.2. *Results for Poor and Rich Regions*

To account for the heterogeneity in economic performance between the Russian regions and to test Hypothesis 2, we analyze the impact of extreme weather on the population income shares in poor and rich regions separately. For that purpose, we divide the Russian regions into those with above the average real GDP per capita during the period studied ("rich" regions) and those below the average real GDP per capita ("poor" regions). The list of resulting rich and poor regions in our sample is in Table A3 in the online appendix.

The results for poor and rich regions are shown in Tables 4 and 5, respectively. As shown in Table 4, in poor regions consecutive hot days affect real GDP per capita with the same magnitude as in the overall sample, that is, each day in a spell of at least three consecutive days above 25°C decreases real GDP per capita by 0.19%. Hot temperatures also affect the distribution of income between 20 percent income groups. A single hot day leads to an increase in the lowest income group share by 0.0167 percent and a decrease in the highest income group share by 0.376 percent, though the latter effect is only marginally statistically significant. Also, the share of the middle-income group increases by 0.003 percent due to one consecutive hot day, while a day with the average precipitation of 10 to 20 mm increases the income of the middle-income group. These effects may be related to the concentration of agriculture in those regions. As shown in Table A2 in the online appendix, the share of employed in agriculture in poor regions is relatively higher than in rich regions and in the overall sample. Thus, hot weather and the amount of precipitation may provide an additional opportunity for agricultural production and bring extra income to poor regions. As a result, this may reduce income inequality. This finding is also supported by a negative coefficient of the impact of a single hot day on the Gini coefficient, although the impact is economically small. Also, consecutive hot days decrease the ratio of the richest 10 percent and poorest 10 percent of the income distribution, signaling a decrease in income inequality in poor regions.

Table 5 shows the results for rich regions. Consecutive hot days decrease real GDP per capita also in rich regions. The effect is not statistically different from the one for poor regions and the overall sample, though only marginally statistically significant. Interestingly, a single hot day increases the income share of lowest- and middle-income groups, by 0.0465 percent and 0.0299 percent, respectively, also contributing to lower inequality. At the same time, one consecutive hot day reduces the share of the lower middle-income group by 0.0515 percent, though the effect is only marginally statistically significant, while the Gini and $90^{th}/10^{th}$ income percentile ratio are not affected. A potential explanation for these findings is that individuals in the poorest and the second poorest group are employed in sectors with different exposures to hot temperature. Both results are also similar in absolute magnitude, implying that a decrease in the share of the second poorest group is to some extent reflected in an increase in the share of the poorest group. These results underscore that the impact of hot temperatures is pro-poor, since an increase in the share of the poorest income group and a decrease in the share of the second poorest group (marginally significant), while being income equalizing, leads to poorer outcomes. Moreover, consecutive cold days and days with a large

TABLE 4
The Impact of Days with Extreme Temperature on Real GDP Per Capita and Income Distribution Indicators (Poor Regions)

Dep. Variables (in %):	(1) Ln(real GDP per capita)	(2) Lowest income group	(3) Lower middle income group	(4) Middle income group	(5) Upper middle income group	(6) High income group	(7) Poverty	(8) Gini	(9) The 90th/10th income percentile ratio
Consecutive below −23°C	0.0000	0.0022	−0.0037	0.0045	0.0011	−0.0313	−0.0481	−0.0002	0.0228
	(0.0007)	(0.0053)	(0.0159)	(0.0051)	(0.0014)	(0.0954)	(0.0605)	(0.0002)	(0.0596)
Below −23°C	−0.0013	0.0079	0.0814*	0.0037	0.0001	−0.0074	−0.0287	−0.0001	−0.0430
	(0.0011)	(0.0100)	(0.0416)	(0.0081)	(0.0023)	(0.2009)	(0.2295)	(0.0004)	(0.0925)
Above 25°C	0.0015	0.0167**	−0.0161	0.0081	0.0019	−0.3763*	0.1829	−0.0001	0.1301**
	(0.0023)	(0.0074)	(0.0574)	(0.0052)	(0.0013)	(0.2223)	(0.2853)	(0.0004)	(0.0553)
Consecutive above 25°C	−0.0019***	0.0034	0.0157	0.0027*	0.0004	0.0121	−0.0517	−0.0002**	−0.0308**
	(0.0006)	(0.0025)	(0.0186)	(0.0013)	(0.0004)	(0.0575)	(0.0794)	(0.0001)	(0.0222)
10–20 mm	−0.0024**	0.0049	−0.0261	0.0088**	0.0017	−0.1162	−0.1054	−0.0006***	−0.0436
	(0.0011)	(0.0067)	(0.0346)	(0.0042)	(0.0011)	(0.1110)	(0.1127)	(0.002)	(0.0320)
20–100 mm	−0.0005	0.0093	0.0173	0.0023	0.0013	0.1189	−0.2753	−0.0007	−0.0839
	(0.0019)	(0.0124)	(0.0620)	(0.0088)	(0.0019)	(0.2405)	(0.3784)	(0.0005)	(0.0726)
Observations	840	835	835	835	835	835	835	835	835
R-squared	0.940	0.569	0.584	0.694	0.527	0.241	0.622	0.587	0.327

Notes: The period of analysis for GDP, Gini, and the 90th to 10th income percentile ratio is 1995–2015, while for population income groups and the share of people in poverty is 2000–15. Robust standard errors clustered at a regional level are in parentheses. All regressions include a regional linear trend, and region and year fixed effects. The temperature bin (−23°C, 25°C) and the precipitation bin (0, 10 mm) are used as the default bins. ***, **, * stand for 1%, 5%, and 10% significance levels, respectively.

TABLE 5
The Impact of Days with Extreme Temperature on Real GDP Per Capita and Income Distribution Indicators (Rich Regions)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dep. Variables (in %):	Ln(real GDP per capita)	Lowest income group	Lower middle income group	Middle income group	Upper middle income group	High income group	Poverty	Gini	The 90th/10th income percentile ratio
Consecutive below −23°C	−0.0002	−0.0007	−0.0260	−0.0020	0.0006	0.0906	0.1259**	0.0001	−0.0174
	(0.0011)	(0.0030)	(0.0227)	(0.0022)	(0.0020)	(0.0594)	(0.0465)	(0.0002)	(0.0294)
Below −23°C	−0.0000	0.0025	−0.0355	0.0032	−0.0034	−0.1644	−0.0743	−0.0002	−0.0090
	(0.0015)	(0.0039)	(0.0362)	(0.0033)	(0.0057)	(0.1393)	(0.0866)	(0.0002)	(0.0411)
Above 25°C	−0.0001	0.0465***	0.0192	0.0299**	−0.0676	−0.5800	0.2446	−0.0005	−0.3793
	(0.0029)	(0.0159)	(0.1095)	(0.0120)	(0.0764)	(0.6420)	(0.1856)	(0.0010)	(0.3140)
Consecutive above 25°C	−0.0015*	−0.0059	−0.0515*	−0.0009	−0.0151	−0.0204	−0.0173	0.0001	0.0706
	(0.0009)	(0.0036)	(0.0272)	(0.0061)	(0.0161)	(0.0912)	(0.0541)	(0.0002)	(0.0446)
10–20 mm	0.0012	−0.0034	−0.0344	0.0046	−0.0078	0.0005	0.0793	−0.0002	0.0043
	(0.0008)	(0.0052)	(0.0393)	(0.0040)	(0.0102)	(0.0989)	(0.0919)	(0.002)	(0.0543)
20–100 mm	0.0013	0.0087	−0.0981	0.0107	0.0087	−0.1271	0.5016**	−0.0005	−0.1370*
	(0.0024)	(0.0130)	(0.0908)	(0.0158)	(0.0114)	(0.2106)	(0.2016)	(0.0005)	(0.0792)
Observations	816	814	814	814	814	814	812	814	814
R-squared	0.934	0.557	0.495	0.516	0.091	0.278	0.514	0.679	0.435

Notes: The period of analysis for GDP, Gini, and the 90th to 10th income percentile ratio is 1995–2015, while for population income groups and the share of people in poverty is 2000–15. Robust standard errors clustered at a regional level are in parentheses. All regressions include a regional linear trend, and region and year fixed effects. The temperature bin (−23°C, 25°C) and the precipitation bin (0, 10 mm) are used as the default bins. ***, **, * stand for 1%, 5%, and 10% significance levels, respectively.

TABLE 6
Hot vs. Cold Regions

Dep. Variables:	All regions	Hot regions	Cold regions
	Ln(real GDP per capita)	Ln(real GDP per capita)	Ln(real GDP per capita)
Consecutive below −23°C	−0.0002	0.0012	−0.0009
	(0.0007)	(0.0008)	(0.0008)
Below −23°C	−0.0007	−0.0033*	0.0003
	(0.0011)	(0.0018)	(0.0011)
Above 25°C	0.0018	0.0004	0.0001
	(0.0018)	(0.0018)	(0.0040)
Consecutive above 25°C	−0.0019***	−0.0020***	−0.0019
	(0.0005)	(0.0006)	(0.0013)
10–20 mm	−0.0009	−0.0014	−0.0000
	(0.0007)	(0.0011)	(0.0010)
20–100 mm	0.0009	0.0018	0.0008
	(0.0015)	(0.0022)	(0.0020)
Observations	1,656	816	840
R-squared	0.943	0.950	0.939

Notes: The period of analysis for GDP is 1995–2015. Robust standard errors clustered at a regional level are in parentheses. All regressions include a regional linear trend, and region and year fixed effects. The temperature bin (−23°C, 25°C) and the precipitation bin (0, 10 mm) are used as the default bins. *** and * stand for 1% and 10% significance levels, respectively.

amount of precipitation (above 20 mm) also substantially increase the poverty rate. Thus, rich regions are also sensitive to extreme temperature and precipitation.

If a region often faces hot or cold temperature, this may lead to some adaptation to the weather. To show whether this is the case, we also disentangle the regions according to the 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 above 25°C is below the sample mean number of such days. The regions' classifications into "hot" and "cold" are shown in Table A3 in online appendix.

The results for hot and cold regions are reported in Table 6 and suggest that the impact of consecutive extremely hot days concentrates in relatively hot regions. This implies that not only do regions fail to adapt to the impact of hot temperature, but temperature also decreases GDP per capita in these regions.

6.3. *Channels*

To understand the channels behind the temperature-inequality relationship, we analyze the impact of temperature extremes on changes in the monetary value of a fixed commodity basket, unemployment, relative wages in different industries, the shares of employed in different industries, and migration rate.

As shown in Table 7, the change in the monetary value of a fixed commodity basket rises by 0.04 percent for each consecutive hot day as well as by 0.14% for each day with a large amount of precipitation. The effects are observed in poor regions, but not in rich regions. In line with Hypothesis 3, this suggests that in poor regions extreme temperature and precipitation induce changes in prices that may contribute to income inequality by reducing real income.

TABLE 7
The Impact of Weather on Prices

	All regions	Poor regions	Rich regions
	Change in the value of fixed basket	Change in the value of fixed basket	Change in the value of fixed basket
Consecutive below −23°C	0.0000	0.0001	−0.0001
	(0.0002)	(0.0002)	(0.0002)
Below −23°C	0.0003	0.0004	0.0004
	(0.0002)	(0.0005)	(0.0003)
Above 25°C	0.0000	−0.0003	0.0017
	(0.0007)	(0.0009)	(0.0013)
Consecutive above 25°C	0.0004**	0.0005**	−0.0000
	(0.002)	(0.0002)	(0.0003)
10–20 mm	−0.0000	0.0002	−0.0001
	(0.0003)	(0.0004)	(0.0004)
20–100 mm	0.0014**	0.0015**	0.0014
	(0.0006)	(0.0007)	(0.0010)
Observations	1,106	560	546
R-squared	0.649	0.657	0.661

Notes: The period of analysis is 2001–15. Robust standard errors clustered at a regional level are in parentheses. All regressions include a regional linear trend, and region and year fixed effects. The temperature bin (−23°C, 25°C) and the precipitation bin (0, 10 mm) are used as the default bins. ** stands for 5% significance level.

As discussed in Section 3, temperature extremes may also lead to the reallocation of time from work to leisure and from work to unemployment. This reduces hours worked in specific sectors and reduces wages. As shown in Table 8, one consecutive hot day increases unemployment by 0.0219 percent through affecting primarily poor and hot regions. Moreover, one day with moderate precipitation may reduce unemployment by 0.0277 percent in rich regions, suggesting that although rich regions might be resistant to extreme hot/cold days, they are vulnerable to drought. We therefore find support for Hypothesis 4a.

Figure 3 shows the impact of single/consecutive hot and cold days on relative wages in different industries. As revealed in this figure, there is no statistically significant impact in most industries.[16] Moreover, we do not observe the impact of precipitation (i.e., between 10–20 and above 20 mm), even after disentangling the regions into rich and poor.[17] We therefore do not find support for Hypothesis 4b and can rule out the wage channel behind the temperature-inequality relationship.

[16]A single hot day affects the relative wage differentials in the following industries: (3) extraction of crude petroleum and natural gas, (14) metallurgy and related products, (15) manufacturing of electronic and optical products, (20) wholesale trade, (31) human health activities, and (32) social services and utilities.

[17]The results for the impact of precipitation on relative wages are presented in Figure S1 in the online appendix. The results of the impact of single/consecutive hot and cold temperatures on relative wages in rich and poor regions are available upon request. In rich regions, a single hot day affects the relative wage differentials in industries (3) extraction of crude petroleum and natural gas, (5) manufacturing of food and tobacco, (15) manufacturing of electronic and optical products, (16) manufacturing of motor vehicles and equipment, (18) construction, (24) communication, (25) financial service activities, (27) programming and broadcasting activities, and (31) human health activities.

TABLE 8
The Impact of Weather on Unemployment

	All regions	Poor regions	Rich regions	Hot regions	Cold regions
Consecutive below −23°C	0.0104	0.0130	0.0024	0.0011	0.0150
	(0.0096)	(0.0175)	(0.0115)	(0.0178)	(0.0118)
Below −23°C	−0.0155	0.0156	−0.0235	0.0238	−0.0328
	(0.0172)	(0.0360)	(0.0186)	(0.0352)	(0.0199)
Above 25°C	−0.0505	−0.0390	−0.0186	−0.0357	−0.0438
	(0.0468)	(0.0589)	(0.0622)	(0.0530)	(0.0991)
Consecutive above 25°C	0.0219**	0.0282*	−0.0061	0.0275*	0.0283
	(0.0107)	(0.0142)	(0.0122)	(0.0137)	(0.0253)
10–20 mm	−0.0212	−0.0231	−0.0277**	−0.0238	−0.0205
	(0.0150)	(0.0282)	(0.0137)	(0.0244)	(0.0187)
20–100 mm	0.0169	0.0015	0.0139	−0.0518	0.0798
	(0.0417)	(0.0656)	(0.0440)	(0.0688)	(0.0621)
Observations	1,883	953	930	928	955
R-squared	0.650	0.611	0.753	0.613	0.702

Notes: The period of analysis is 1995–2015. Dependent variable is unemployment rate in percent. Robust standard errors clustered at a regional level are in parentheses. All regressions include a regional linear trend, and region and year fixed effects. The temperature bin (−23°C, 25°C) and the precipitation bin (0, 10 mm) are used as the default bins. ** and * stand for 5% and 10% significance levels, respectively.

Alternatively, as a part of an adaptation strategy, the reallocation of labor may occur from industries that are more exposed to weather extremes to industries that are less exposed to such extremes. We thus focus on the impact of extreme temperatures on the employment structure. That is, we would like to understand whether the share of employed in different industries is affected by weather extremes. The results for major industries are presented in Figure 4. Full regression results for this figure are also presented in Table S4 in the online appendix. The results suggest that a consecutive hot day marginally decreases the share of employed in manufacturing. This result is consistent with the recent findings of Zhang *et al*. (2018), who show that in China both labor- and capital-intensive manufacturing firms are strongly affected by hot days due to the reduction in productivity. Consecutive hot days also marginally increase the share of employed in trade. Interestingly, one single and each consecutive cold day increase the share of employed in manufacturing and in mining, respectively. This result can 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 indoor working temperature, the outdoor work clothing allowed, and the outdoor work time based on different weather conditions.[18] Thus, we find only partial evidence to support Hypothesis 4c that as part of adaptation strategy, labor force may relocate from industries more exposed to the impact of temperature to industries less exposed to the impact of temperature. Precipitation has no effect on the employment shares in different industries (see Figure S2 in the online appendix).

[18]For a detailed discussion, see the methodical recommendations of the Russian Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing (2007).

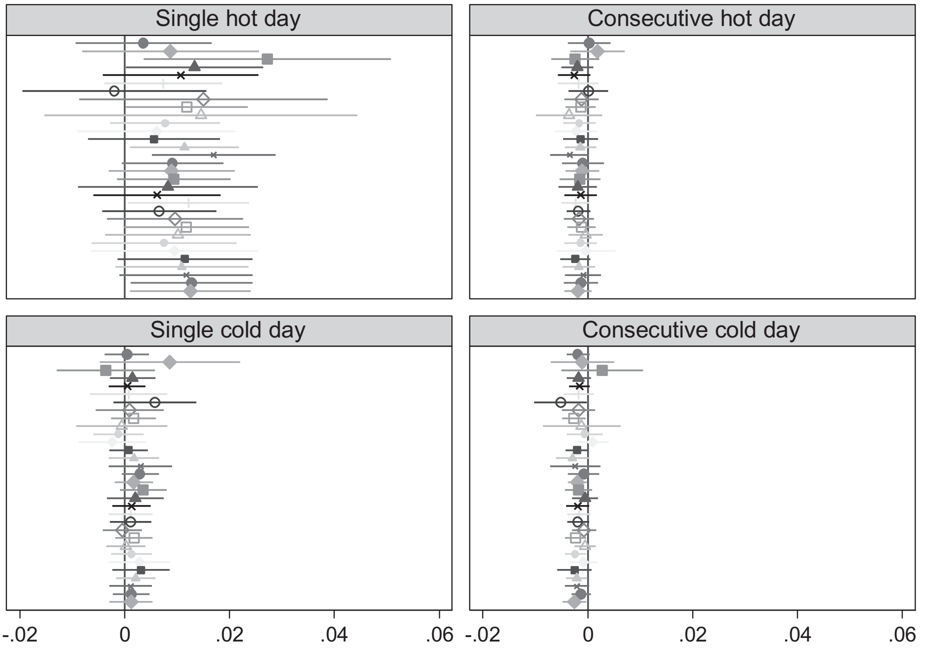

Figure 3. The impact of single/consecutive hot and cold days on relative wages in different industries (with 95% C.I.)

Notes: The period of analysis is 2005–2015. The impact is measured for 32 industries according to the extended Russian Classification of Economic Activities. The results are from separate regressions for each industry (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) metallurgy and related products; (15) manufacturing of electronic and optical products; (16) manufacturing of motor vehicles and equipment; (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.).

Source: Authors' estimations based on data from the Russian State Statistical Service.

We then disentangle the results on the impact of extreme temperatures for rich and poor regions (see Figures 5 and 6 for the impact of hot and cold days, respectively). The respective regression results are presented in the online appendix in Table S5 for poor regions and in Table S6 for rich regions. Since poor regions are relatively more specialized in agriculture as compared to rich regions (see Table A2), we expect that consecutive hot days will decrease the share of employed in agriculture in those regions. As shown in Figure 5, the estimated effect of a consecutive hot day on the share of employed in agriculture in poor regions is indeed negative, in line with our hypothesis, though not statistically significant (significant at 15 percent). This might be related to the relatively short sample period that we

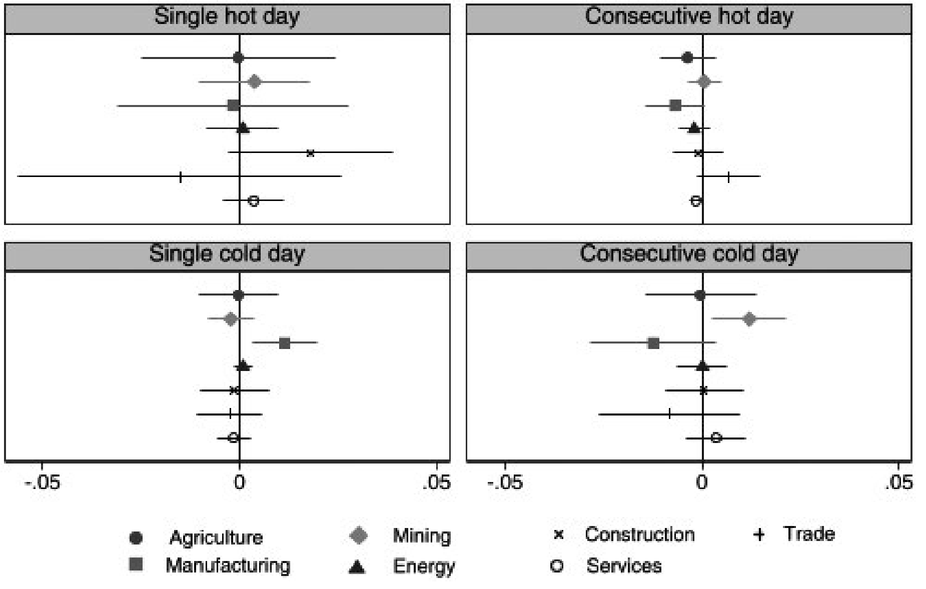

Figure 4. The impact of single and consecutive cold and hot days on the share of employed in different industries (with 95% C.I.)

Notes: The period of analysis is 2005–15. The impact is measured for 14 industries according to the Russian Classification of Economic Activities. The results are from separate regressions for each industry. Full regression results are presented in Table S4 in the online appendix.

Source: Authors' estimation.

analyze. In rich regions consecutive hot days decrease the share of employed in manufacturing, though the effect is only marginally statistically significant. Single hot days have no impact on employment shares in either poor or rich regions, except for a marginally significant decrease in the share of employed in trade in rich regions.

Cold days affect the shares of employed in mining and manufacturing in poor and rich regions (see Figure 6). Consecutive cold days similarly increase the share of employed in manufacturing in both rich and poor regions, while the effect of consecutive days on mining differs between rich and poor regions. In rich regions, the share of employed in mining decreases, which can possibly be explained by reallocation of labor from mining, a sector that can be relatively more exposed to cold temperature to manufacturing, a sector relatively less exposed to cold temperature. In contrast, in poor regions, the share of employed in mining increases due to consecutive cold days. The suggestive explanation for this is that poor regions are also more likely to be hot (see Table A3 for classification). Thus, consecutive cold temperatures are faced by poor regions relatively less often. Also, these differences between poor and rich regions can possibly be related to different types of mining activities in those regions, which we cannot disentangle.

Precipitation increases the share of employed in manufacturing, decreases the share of employed in construction in poor regions, and does not affect the shares

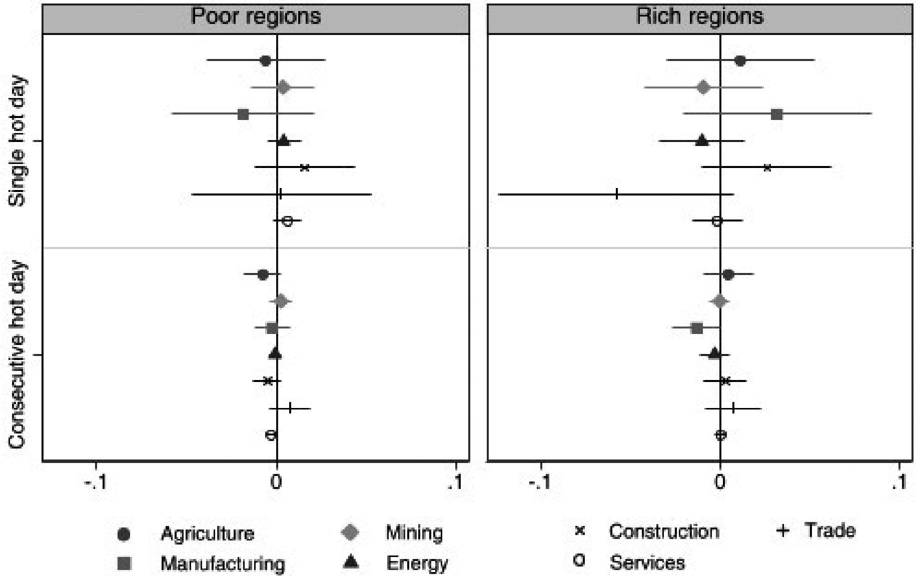

Figure 5. The impact of hot days on the share of employed in different industries in poor and rich regions (with 95% C.I.).

Notes: The period of analysis is 2005–15. The impact is measured for 14 industries according to the Russian Classification of Economic Activities. The results are from separate regressions for each industry. Full regression results are presented in Table S5 and S6 in the online appendix.

Source: Authors' estimations.

of employed in different sectors in rich regions (see Tables S5 and S6 in the online appendix).

Another possible adaptation strategy is migration. To reduce the impact of extreme temperatures, individuals may migrate from places that are more exposed to extreme temperatures to places that are less exposed to such temperatures (Hypothesis 4d). As shown in Table 9, a single hot day indeed increases the net migration rate in rich and cold regions, where net migration rate is the difference between the number of immigrated and the number of emigrated per 10,000 of population. This is in contrast with Hypothesis 4d, as exposure to hot days is generally low in cold regions. However, in Russia natural resources extraction is mostly concentrated in colder regions and wages there are on average higher than in the rest of the country. Table A2 also shows that the shares of employed in the mining and the energy sectors is relatively higher in rich and cold regions as compared to poor and hot regions, and according to Table A3, rich regions are also more likely to be cold. Thus, cold regions may attract both internal and international migrants from other regions (i.e., hot regions). A consecutive hot day and a day with a large amount of precipitation decrease the net migration rate in cold regions. This may suggest that single hot days make cold regions more attractive for immigrants by improving living conditions and increasing employment opportunities in industries that are more suitable for warmer weather conditions such as agriculture,

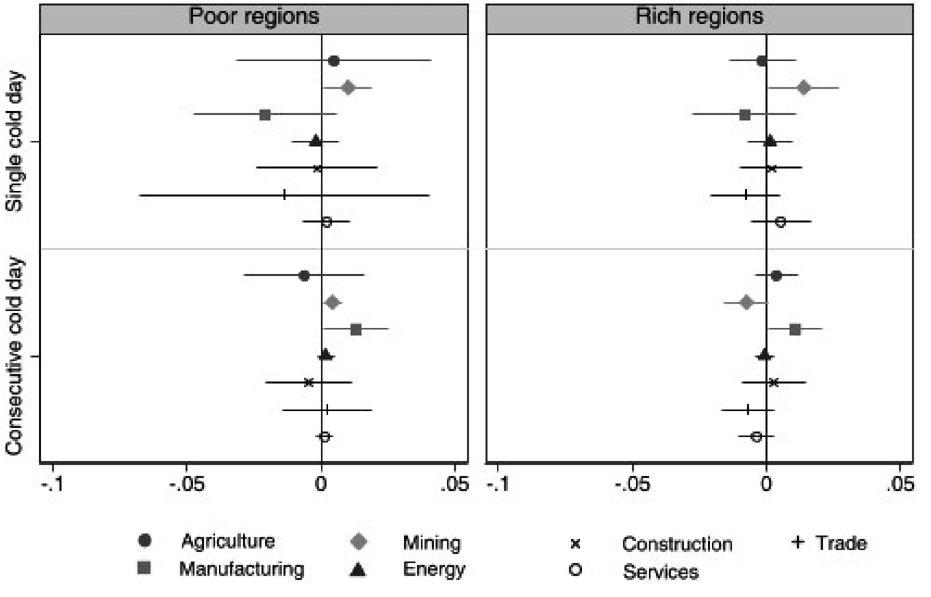

Figure 6. The impact of cold days on the share of employed in different industries in poor and rich regions (with 95% C.I.)

Notes: The period of analysis is 2005–15. The impact is measured for 14 industries according to the Russian Classification of Economic Activities. The results are from separate regressions for each industry. Full regression results are presented in Table S5 and S6 in the online appendix.

Source: Authors' estimations.

TABLE 9

The Impact of Weather on the Net Migration Rate

	(1)	(2)	(3)	(4)	(5)
	All regions	Poor regions	Rich regions	Cold regions	Hot regions
Consecutive below −23°C	−0.3690	−0.0293	−0.4795	−0.4607	0.1382
	(0.3234)	(0.2448)	(0.4617)	(0.3693)	(0.2283)
Below −23°C	0.5230	0.0896	0.7287	0.5057	0.8385
	(0.6319)	(0.8239)	(0.8054)	(0.7464)	(1.1897)
Above 25°C	−0.2127	−2.1238	2.4174**	3.0811**	−1.7517
	(1.7315)	(2.9471)	(1.0898)	(1.4229)	(2.3435)
Consecutive above 25°C	0.1454	0.2168	−0.1154	−1.0366*	0.2635
	(0.1953)	(0.2761)	(0.2362)	(0.5136)	(0.2019)
10–20 mm	−0.8680	−2.0229	0.4822	0.2024	−1.8761
	(0.9466)	(1.8500)	(0.4289)	(0.3720)	(1.8650)
20–100 mm	−0.1770	0.4599	−1.2907	−2.0778**	1.4880
	(1.1980)	(1.7686)	(1.1941)	(0.9734)	(1.5544)
Observations	1,659	840	819	840	819
R-squared	0.325	0.173	0.652	0.659	0.178

Notes: The period of analysis is 1995–2015. Dependent variable is net migration rate per 10,000 of population, which equals the difference between the rates of immigration to a region and emigration from a region. Robust standard errors clustered at a regional level are in parentheses. All regressions include a regional linear trend, and region and year fixed effects. The temperature bin (−23°C, 25°C) and the precipitation bin (0, 10 mm) are used as the default bins. ** and * stand for 5% and 10% significance levels, respectively.

construction, and services, while consecutive hot and rainy days may make those regions less comfortable for living and induce emigration to other regions.

Summarizing the findings, our analysis suggests that the major channels behind the temperature-inequality relationship are changes in prices (i.e., changes in the monetary value of a fixed consumption basket), employment structure in different regions (to some extent), transition from employment to unemployment, and migration. Although both rich and poor regions suffer from the impact of extreme temperatures, poor regions are affected relatively more, especially through the fall in GDP, increase in prices, and increase in unemployment.

7. Conclusion

In this paper we document that extreme temperature and precipitation have several important consequences for regional GDP per capita and income distribution in Russia. Given that the intensity of extreme weather events is expected to grow in the future, our paper also provides an important methodological contribution by accounting for both single and consecutive extremely hot and cold days. Using a subnational-level panel we find that consecutive hot days reduce GDP per capita, while single hot days induce pro-poor income redistribution through increasing the shares of income earned by poorer population groups. Extreme temperatures also lead to uneven development of poor and rich regions. We find that while both poor and rich regions are vulnerable to global warming, poor regions are affected relatively more, and this is reflected in the fall in GDP per capita, increase in prices, and increase in unemployment as a result of consecutive hot days. Also, poor regions are relatively more specialized in economic activities that are more vulnerable to changing weather conditions, e.g., agriculture. However, we do not find strong empirical support that hot days result in changes in the share of employed in agriculture in poor regions.

Another important finding is that extremely cold days, both single and consecutive, have little effect on income distribution. This result has two key implications. On the one hand, given the relatively large number of cold days in Russia as compared to other countries globally, this brings an advantage in economic development, since cold days create a potential to mitigate the economic harm from hot days. As our findings suggest, given their economic structure, relatively cold regions also have the potential to attract internal and international migrants. On the other hand, with global warming the number of extremely cold days decreases while extremely hot days and substantial floods become more frequent. In this situation, understanding those channels becomes crucial for designing the labor market policies to support development and reduce the exposure to global warming.

This study opens several avenues for future research. First, it would be interesting to show how different the short- and medium- term effects of weather are from the long-term effects of climate change. Given the relatively short time period of our analysis, we focus only on the short- and medium-term effects of weather, since the analysis for the effects of climate change requires a long time span to adequately capture both the adaptation to extreme weather events and their increasing intensity (Dell *et al.*, 2014). The relationship between GDP and climate change is also more complex than the relationship between GDP and weather fluctuations, since economic activity and a reduction/increase in carbon emissions may also affect climate change, leading to potential endogeneity in the economy-climate relationship.

To complement our analysis of the channels behind the effects of weather on GDP and income distribution indicators, future research could also employ firm- and individual-level data. Graf Zivin and Neidell (2014) for the US and Zhang *et al*. (2018) for China provide first steps in this direction. Another potential direction for future studies is to analyze the differential effects of extreme temperatures on labor and non-labor income. For example, the effect of temperature on remittances may partially depend on the temperature in a host country, and this effect may differ from the effect of temperature on labor income in the home country. Finally, future research may also provide a thorough analysis of reallocation of time from full time to part time, and from work to leisure because of exposure to extreme temperatures. Such substitution may occur between seasons, but also within a day. Graff Zivin and Neidell (2014) employ time use survey to analyze the impact of extreme temperatures on reallocation of time in the US, but similar studies for other parts of the world remain scarce.

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