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Extreme Temperature Shocks and Labor Market Heterogeneity: Regional Evidence from Korea*

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Abstract

While the economic consequences of global warming have received growing attention, relatively little is known about how extreme temperatures affect labor market outcomes. This paper fills that gap by examining the impact of extreme temperature shocks on the Korean labor market using daily regional data from June 1999 to February 2024 and a panel local projection framework. Despite its relatively small geographic size, Korea exhibits substantial regional diversity in both climate and labor market conditions, providing a unique setting to study bidirectional temperature shocks within the same country. We find that, on average, extreme cold has a significantly negative effect on labor market indicators, while the effects of extreme heat are limited. Second, the impacts vary substantially by job characteristics and season, but not by key socio-demographic traits. Third, the labor market effects of extreme temperatures have become more negative in recent years, consistent with the progression of global warming.

JEL classification: C33, E24, J3, Q54

Keywords: Climate change, Extreme Temperature, Labor Market Dynamics

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1 Introduction

Climate change is increasingly shaping the social and economic landscape across the globe. Among its various manifestations, extreme temperature events, i.e., both unseasonal heat and cold, have emerged as particularly critical forces with the potential to disrupt labor market dynamics. In addition to extreme weather events such as storms, floods, and droughts, abnormal temperatures are becoming more frequent with global warming and are now recognized as a major factor directly influencing labor outcomes. These climate shocks affect workers through various channels, including health, productivity, and employment stability. Their impact is particularly pronounced in climate-sensitive sectors, where the consequences of heatwaves or cold spells can be immediate and severe. Yet, in a rapidly evolving climate, it remains difficult to predict whether these effects will ultimately prove beneficial or detrimental to labor market performance.

This paper examines how extreme temperatures affect labor market outcomes in South Korea, with a particular focus on seasonal heterogeneity, time variation, and differences across employment types and sectors. Using daily temperature data from 16 metropolitan regions from June 1999 to February 2024, we construct region-specific measures of extreme heat and cold shocks and estimate their effects on key labor market indicators. Despite its relatively small geographic size, Korea exhibits substantial regional diversity in both climate and labor market conditions, providing a rare opportunity to study bidirectional temperature shocks within the same country. In particular, it has both two extreme seasons (summer and winter) and it is associated with large variations in the temperature in a year. For example, in 2024, the lowest average temperature was -3.9°C (25°F) in January while the hightest temperature was 33.3°C (92°F) degree in August in Seoul[1]: In addition, among about 240 countries, people exposed to hot and cold days as proportions of the total population ranks 30th, which confirms that Korea is well-exposed to all extreme temperatures.[2] Moreover, the pronounced seasonality in Korea creates a distinct setting in which to analyze seasonal heterogeneity in temperature effects.

[1] https://data.kma.go.kr/stcs/grnd/grndTaList.do

[2] Data is from OECD (Copernicus Climate Data Store (CDS) ERA5 hourly data on single levels (ERA5), the Thermal comfort indices (ERA5- HEAT), and Global Human Settlement Layer (GHSL) population grids) and we take the average between 1997 and 2023. Hot (resp. cold) days are the days with maximum (resp. minimum) temperature exceeding 35°C (resp. lower than 0°C). We add both measures to see how a country is exposed to both extremes.

Due to the relatively short time span of nationally representative labor market data, we employ a panel local projection framework using region-level labor statistics, such as employment and unemployment rates, to identify the dynamic effects of extreme temperatures. Our analysis reveals several important findings. First, when not accounting for seasonality, extreme cold tends to have more pronounced negative effects on the labor market than extreme heat. While extreme heat slightly reduces labor force participation, extreme cold significantly lowers employment and raises unemployment—though these effects are generally short-lived. Second, extreme heat increases the number of irregular and daily workers, while extreme cold decreases it. In contrast, regular workers respond in the opposite direction in the short term. Third, when disaggregated by season, the effects of temperature shocks vary substantially. Extreme heat in spring and fall increases employment, particularly among irregular and wage workers. In contrast, summer heat increases unemployment in the short run, and summer cold improves labor market outcomes. In winter, however, both extreme heat and cold reduce employment, especially among irregular workers. Interestingly, ex-ante heterogeneous characteristics of the workers, gender, education, and ages as examples, do not seem to generate heterogeneous responses to the extreme events.

To further explore the role of global warming, we also focus on the first 10 years (1999–2008) and the most recent 10 years (2015–2024) of our sample and repeat our empirical analysis.[3] We find that the impact of extreme temperature shocks has evolved over time; the positive effects of extreme heat observed in earlier years have diminished, while the negative effects of extreme cold have intensified. In particular, extreme heat in summer has recently started to exert statistically significant negative effects on employment. Meanwhile, fall cold increases employment, while both extreme heat and cold in winter continue to reduce labor market activity. This indicates that the extreme temperature shocks likely have more and more negative impacts on the labor market going forward.

We finally examine whether these effects differ across industries. Sector-level analysis again reveals substantial heterogeneity. For example, in spring, extreme heat raises employment in agriculture,

[3]Between 1999 and 2008, the average temperature in Korea was 12.5°C, compared to 13.28°C between 2015 and 2024, consistent with the broader trend of the global warming, according to the data from Korea Meteorological Administration Weather Data Service (`https://data.kma.go.kr/stcs/grnd/grndTaList.do?pgmNo=70`).

while in summer, both heat and cold negatively affect employment in the same sector. The financial and insurance sectors are also adversely affected by summer heat. In fall and winter, manufacturing shows consistently negative responses to extreme temperatures, while retail employment declines sharply in response to winter cold. Thus, our findings on heterogeneous effects altogether indicate that consideration of an appropriate dimension of heterogeneity may be important when introducing policy measures to protect workers against extreme climate (temperature, for instance) shocks.

This study contributes to a growing literature on the labor market impacts of climate change by providing the first comprehensive analysis of how extreme temperatures affect labor outcomes in South Korea. While much of the existing literature has focused on the aggregate economic effects of climate change, particularly on GDP growth or inflation (e.g., Dell et al. 2012; Burke et al. 2015; Bilal and Känzig 2024; Nath et al. 2024), there has been relatively little attention paid to direct labor market consequences. Recent studies (e.g., Zivin and Neidall 2014; Nguyen 2024) have begun to explore this connection in the U.S., and others have looked at broader climate or disaster shocks on employment globally (Jia et al. 2022; Leduc and Wilson 2023; Rode et al. 2023; Duprey et al. 2024; Xie 2024). To our knowledge, however, this is the first study to systematically investigate the impact of extreme temperatures on the labor market in South Korea and study comprehensively the potential heterogeneous effects across different types of workers. Given that income/wealth inequality has become an important issue in economics, recent development of heterogeneous agent New-Keynesian (HANK) model as an example, our findings on heterogeneous effects of the extreme temperature shock further adds to the literature by exploring additional dimension of inequality that workers can face. Moreover, the pronounced seasonal variation in Korea offers a unique context to uncover how these effects differ by season and industry.

The rest of the paper is organized as follows. Section 2 introduces data and empirical strategy. Section 3 presents our empirical findings and then Section 4 concludes.

2 Data and Methodology

2.1 Labor Market Data

The regional labor market variables used in this study are sourced from the Economically Active Population Survey conducted by the Statistics Departement of Korea. These include labor force participation rates, employment rates, unemployment rates, the number of employed individuals, unemployed individuals, wage workers, regular workers, and temporary or daily workers across 16 metropolitan cities and provinces.[4] The data are recorded on a monthly basis, spanning from June 1999 to February 2024, with the starting point aligned with the initial collection and recording of the survey data.

Industry-specific employment data are also obtained from the Economically Active Population Survey. Out of 21 major industry classifications, we consider eight key sectors: "Agriculture, Forestry, and Fishing," "Manufacturing," "Construction," "Wholesale and Retail Trade," "Transportation and Storage," "Accommodation and Food Services," "Finance and Insurance," and "Real Estate and Leasing." These data are recorded monthly and cover the period from January 2000 to February 2024.[5]

All labor market variables utilized in this paper are seasonally adjusted using the X-13ARIMA-SEATS methodology, developed by the U.S. Census Bureau.

2.2 Extreme Temperature Shocks

To construct extreme high- and low-temperature shock series, we first obtain daily average temperature data for 16 metropolitan cities and provinces in Korea, which span from May 1, 1989 to February 29, 2024 from the Korea Meteorological Administration's Weather Data Open Portal. The daily average temperature dataset contains three missing data points in our sample.[6] We address these gaps by imputing the absent observations using the average of the daily mean temperatures from the two days on

[4] Sejong City was excluded from the analysis because it was designated a special self-governing city in July 2012 and incorporated into the metropolitan dataset, resulting in an insufficient observation period for inclusion.

[5] Due to limited regional observations for industry-specific data, the sectoral-level analysis relies on nationwide labor market data by industry. The starting point of January 2000 was chosen to account for the 8th revision of the Standard Industrial Classification, which took effect that month.

[6] The three missing data points are: Incheon, October 16, 2011; Daegu, September 30, 2013; and Daegu, July 29, 2017.

either side of the missing date.

It is worthwhile to note that we adjust the months of the daily average temperature data to align with the survey periods of the labor market variables for our empirical analysis. The Economically Active Population Survey from which we employ labor market variables designates the week containing the 15th of each month as the reference period. If the 15th falls on a Sunday, the data for that month capture employment conditions up to the 15th, and any further changes in the remaining days in the month will be captured in the following month's survey.[7] Thus, to assess the impact of extreme temperatures on the labor market more precisely, it is necessary to realign the daily temperature data by defining a hypothetical month based on the labor market survey period. The extreme temperature shocks discussed in the next section are also computed after applying this monthly adjustment.

Next, we construct the extreme temperature shocks as follows. We count the number of days per month with unusually high or low temperatures, based on the historical monthly temperature distribution for each region. In particular, for a given month m in year t, extreme temperatures are determined by estimating the regional average temperature and standard deviation of month m over the previous 10 years (from $t-10$ to $t-1$).[8] A day in month m of year t is classified as an extreme high-temperature (resp. low-temperature) day if the deviation of its daily average temperature from the estimated monthly average exceeds (resp. is lower than) twice the standard deviation.

The number of extreme high- and low-temperature days is then aggregated monthly to construct measures of extreme high- and low-temperature shocks for 16 distinct regions over time. Figures 1 and 2 illustrate the time series of each extreme temperature shocks across seven selected metropolitan cities in Korea, including nation-wide shocks, from June 1999 to February 2024.[9] In each individual panel,

[7] For instance, since January 15, 2024 falls on a Monday, the reference period extends through Sunday, January 21. As a result, any changes in employment status occurring between January 22 and January 31, 2024 are excluded from the January survey result and instead captured in the February 2024 survey. Accordingly, when processing the daily temperature data, the period from January 22 to January 31, 2024, was treated as part of February 2024 for calculating means and standard deviations. At the same time, "January" data for the Economically Active Population Survey covers the period from December 18, 2023 to January 21, 2024.

[8] While there is no consensus regarding the size of the window for calculating the average temperature, this paper uses a 10-year window for analytical convenience. However, robustness checks indicate that using a 25-year period to compute extreme temperature shocks does not significantly alter their impact on the labor market. Some results from these robustness checks are presented in Appendix Figure B.1.

[9] For visual clarity, only seven metropolitan regions are shown; series constructed for the remaining 9 provinces are provided in Appendix Figure A.2.

the x-axis represents the months in our sample period, while the y-axis indicates the number of days with extreme temperatures in each month. Since our construction methodology updates the regional average temperature and associated standard deviation in each year, our shocks do not appear to exhibit a clear trend over time. However, we highlight heterogeneity across the regions, which motivates us to exploit the cross-section variations in the estimation.

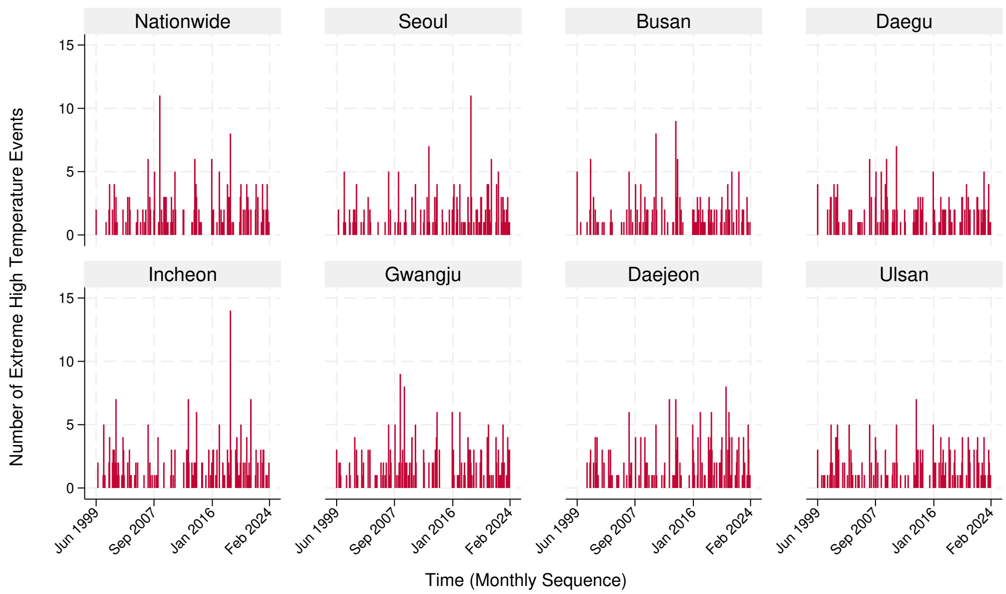


Figure 1: Extreme High Temperature Shocks in South Korean Metropolitan Cities, 1999–2024

This figure shows the time series of our baseline monthly extreme high temperature shocks for the period January 1999 – February 2024, based on previous 10-year's data used for the construction of the regional averages and standard deviations. Extreme temperature shocks are plotted for 7 metropolitan cities in Korea for brevity, and those for the remaining 9 provinces are provided in Appendix Figure A.1.

Extreme temperature shocks can be defined in various alternative ways. For instance, Shim et al. (2018) defined extreme temperatures by using the mean (M) and the standard deviation (S) of weather observations over the entire sample period, classifying a day as an extreme high-temperature day if its value exceeds $2S$ above the mean, or as an extreme low-temperature day if it falls below $-2S$. Results using this alternative definition of extreme temperature shocks are presented in Appendix Figure A.2. Under this approach, extreme high-temperature shocks exhibit a pronounced upward trend, while extreme low-temperature shocks show a more noticeable downward trend compared to the method de-

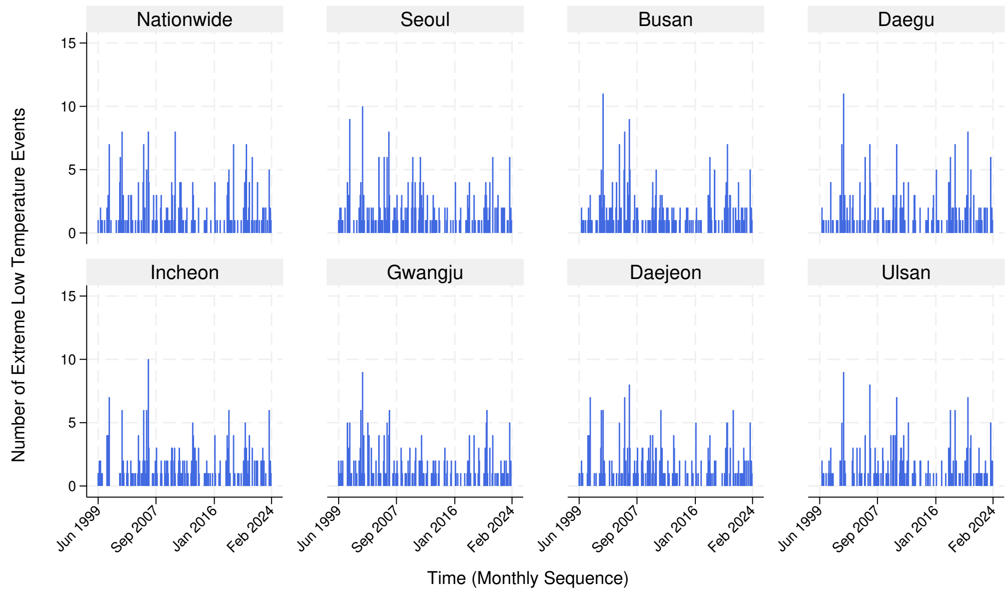


Figure 2: Extreme Low Temperature Shocks in South Korean Metropolitan Cities, 1999–2024

This figure shows the time series of our baseline monthly extreme low temperature shocks for the period January 1999 – February 2024, based on previous 10-year's data used for the construction of the regional averages and standard deviations. Extreme temperature shocks are plotted for 7 metropolitan cities in Korea for brevity, and those for the remaining 9 provinces are provided in Appendix Figure A.1.

scribed above. Nonetheless, considering that extreme temperature shocks are intended to measure how much current temperatures deviate from predictable values based on the past information, this alternative method has a key drawback; this combines past and future information. This misalignment with the information set used in the econometric models of this study could reduce the reliability of the estimation results.

Another possible approach involves defining extreme high and low temperature days as those falling at the top and bottom 10% of the temperature distribution throughout the sample period, and use the number of days with these extreme temperature for a given month. This method shares the limitation similar to the above-mentioned alternative methodology in the sense that it simultaneously uses both past and future information.

2.3 Methodology

2.3.1 Baseline Model

To estimate the dynamic effects of extreme temperatures on the labor market, we employ a panel local projection model, following Duprey et al. (2024) and Bilal and Känzig (2024). As noted in the previous section, we find substantial variations in the extreme temperature shocks in Korea at the regional level (see Figures 1 and 2). In addition, regional labor markets also exhibit differences in terms of industrial composition. Therefore, utilizing such variation would yield more efficient estimates, balancing out a relatively short time-series dimension of the labor market variables in Korea. In sum, the panel local projection model provides a concise yet flexible framework to exploit the cross-sectional variations in examining the effects of weather shocks, which can be easily modified to investigate possible heterogeneity as will be detailed below. Specifically, we construct the following model:

$$\begin{aligned}\Delta \ln Y_{i,t+h} &\equiv \ln Y_{i,t+h} - \ln Y_{i,t-1} \\ &= \alpha_h + \beta_h \text{Shock}_{i,t} + \sum_{j=1}^{J} \Delta \ln Y_{i,t-j} + D_i + D_y + D_m + \epsilon_{i,t+h}, \quad h = 0, \ldots, 12 \qquad (1)\end{aligned}$$

where $Y_{i,t+h}$ represents a labor market variable observed in region i at time $t+h$, while $\Delta \ln Y_{i,t,h}$ denotes the changes of Y_i after h periods since t. The term D_i captures region-specific fixed effects, controlling for unique characteristics that may influence the regional labor market. Additionally, D_y and D_m represent year-specific and month-specific fixed effects, respectively, introduced to account for common macroeconomic fluctuations and other factors that may affect regional labor markets uniformly. To capture the dynamic effects of labor market variables, we include lagged terms of the dependent variable ($\sum_{j=1}^{J} \Delta \ln Y_{i,t-j}$), specifically J lags of monthly growth rates, where J is set to 3. Finally, α_h and $\epsilon_{i,t+h}$ denote the intercept and the error term, respectively.

In the context of the local projection model, $\text{Shock}_{i,t}$ refers to the extreme high- or low-temperature shock in region i at time t. The coefficient β_h, hence, captures the effect on the dependent variable h periods after a unit increase in one of the extreme temperature shocks. The maximum of h in this model is set to 12 to cover the impact of the shock over a 12-month period following its occurrence.

2.3.2 Season-Dependent Model

The panel local projection model would estimate the average effect of extreme high and low temperatures on the labor market, regardless of the timing of such temperature shocks. However, the impact of the shocks may vary depending on when they occur. For instance, Nguyen (2024) showed that the response of the labor market to extreme high temperatures can differ depending on the season in which they occur, using the U.S. labor market data. Similarly, Burke et al. (2015) demonstrate that temperature variations can have distinct influences on GDP using a country-panel data, which hinges on the annual average temperature. In particular, they find that the annual average temperature of 13°C plays an important role as a threshold; regions with average temperatures lower than 13°C experience positive effects from temperature increases, while regions with higher average temperatures experience negative effects. Kim (2023) confirms that the same threshold exists in regions within Korea, where the responses of regional GDP to temperature varies along with the annual average temperature of 13°C. From the perspective of labor supply, these findings imply an inverted U-shaped relationship between temperature and labor supply decisions. For industries or occupations with significant outdoor working hours, temperatures falling below or rising above an optimal level may lead to reduced productivity and, consequently, a decline in labor supply (Zivin and Neidall 2014; Rode et al. 2023).

Building on the above discussion, we further investigate whether the impact of extreme temperature shocks on the labor market exhibits seasonality or not. Korea provides an ideal setting for the examination of seasonal heterogeneity, as the country has four distinct seasons around year. In 2024, for example, the average temperatures for winter and summer in Korea recorded 0.4°C and 25.6°C, respectively, deviating greatly from the threshold temperature of 13°C depending on season. Thus, we modify our baseline panel local projection model as follows:

$$\Delta \ln Y_{i,t+h} = \alpha_h + \sum_{j=1}^{J} \Delta \ln Y_{i,t-j} + D_i + D_y + D_m$$
$$+ \beta_{\text{spr},h} \times I_{\text{spr}} \times \text{Shock}_{i,t} + \beta_{\text{sum},h} \times I_{\text{sum}} \times \text{Shock}_{i,t}$$
$$+ \beta_{\text{fall},h} \times I_{\text{fall}} \times \text{Shock}_{i,t} + \beta_{\text{win},h} \times I_{\text{win}} \times \text{Shock}_{i,t}$$
$$+ \epsilon_{i,t+h}, \quad h = 0, \ldots, 12 \tag{2}$$

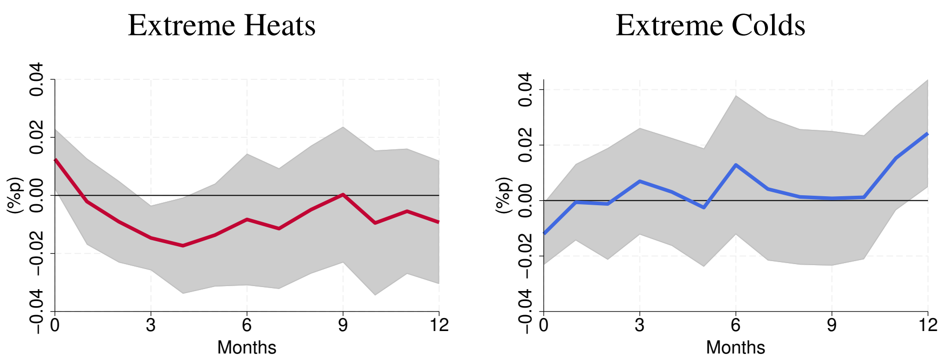
where I_{spr}, I_{sum}, I_{fall}, and I_{win} are seasonal dummy variables representing spring, summer, fall, and winter, respectively. In this study, spring is defined as March, April, and May; summer as June, July, and August; fall as September, October, and November; and winter as December, January, and February. Accordingly, the coefficients $\beta_{\text{spr},h}$, $\beta_{\text{sum},h}$, $\beta_{\text{fall},h}$, and $\beta_{\text{win},h}$ capture the effects on the dependent variable h periods after a one-day increase in extreme temperature shocks during spring, summer, fall, and winter, respectively.

3 Empirical Results

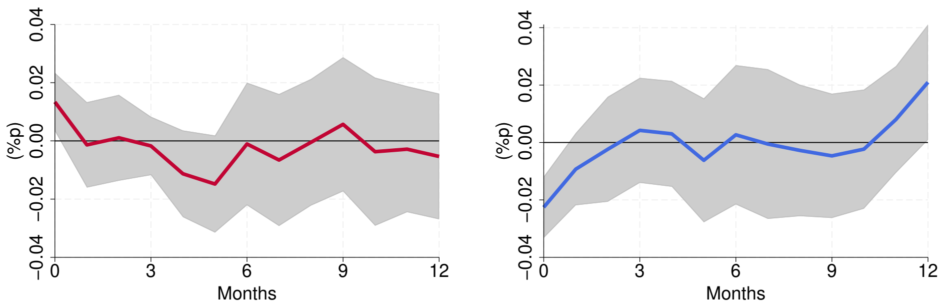
This section presents our empirical findings. We first analyze the average labor responses and then examine if there are heterogeneous effects across seasons, employment type and socio-demographic characteristics, time, and industries.

3.1 Average Response of Labor Market

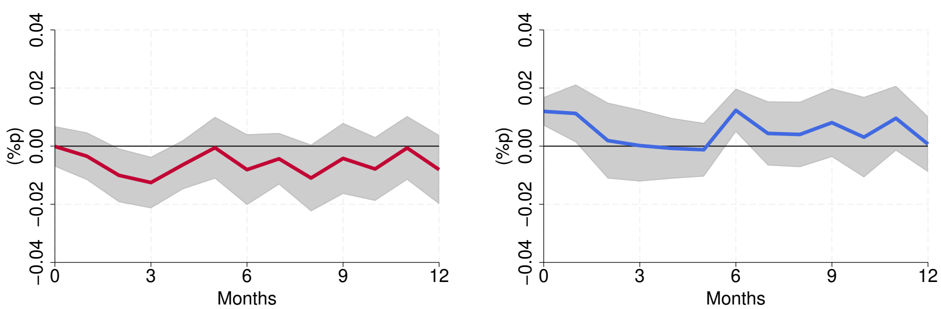
We first examine the overall dynamic effects of extreme temperature shocks on the labor market, by estimating the impulse responses using the baseline model (equation (1)). Figure 3 illustrates the responses of key labor market variables—namely, the labor force participation rate, employment rate, and unemployment rate—to extreme temperature shocks. In this figure, red (resp. blue) line represents the average response of the dependent variables to the extreme high (resp. low) temperature shock after h periods and gray area indicates 95% confidence interval. On average, extreme high-temperature



(i) labor force participation rate



(ii) employment rate



(iii) unemployment rate

Figure 3: Average Responses to Extreme Temperature Shocks

Notes: This figure plots the impulse responses of the key labor market variables from the baseline model, i.e., equation (1). The red and blue lines represent the responses to extreme high and low temperature shocks, respectively. The shaded areas correspond to 95% confidence intervals.

shocks do not appear to have a significant negative impact on the labor market. Rather, unemployment decreases slightly after 3 months, indicating that such a shock can be good for the labor market. In contrast, extreme low-temperature shocks lead to a short-term decline in the employment rate (typically within three months) and an increase in the unemployment rate, suggesting overall negative effects on the labor market.

3.2 Heterogeneous Effects of Extreme Temperature Shocks

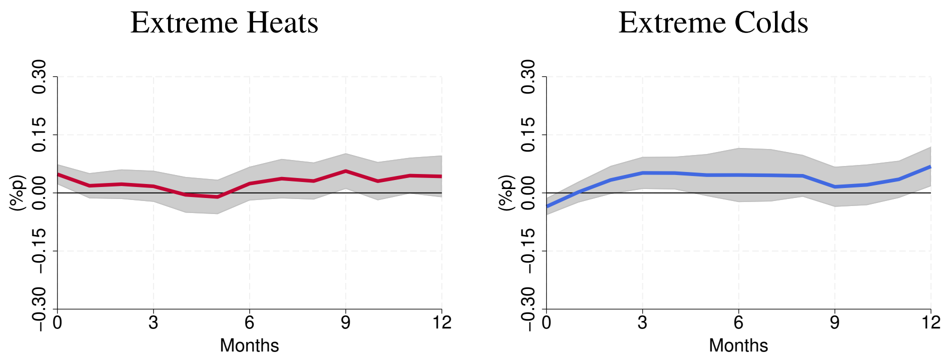
In the previous section, we analyze the *average* response of the labor market to extreme temperature shocks. This section extends the baseline analysis to investigate potential heterogeneity in responses to the extreme temperature shocks. In particular, considering that workplaces and/or workers have different characteristics that can be potentially affected by such shocks (see Rode et al. (2023), as an example), we first explore if the shocks have heterogeneous effects on workers depending on their job and demographic characteristics. We also examine if there exists seasonal heterogeneity in the responses of the labor market to the extreme temperature shocks, in the spirit of Nguyen (2024).

3.2.1 Employment Types

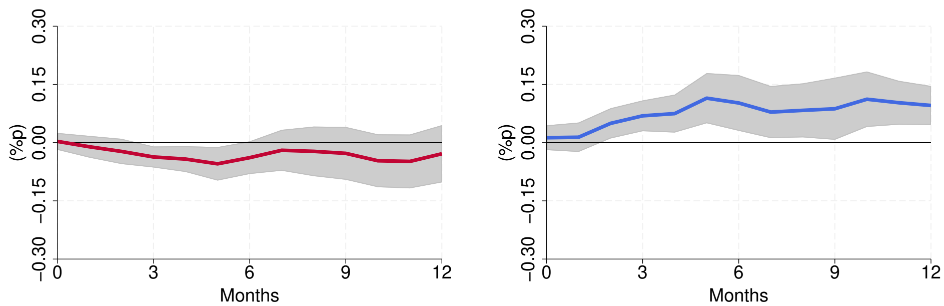
We first consider potential heterogeneous effects across job characteristics. In particular, we consider i) non-wage workers, who are defined as employed individuals but not wage workers, ii) regular workers, who are full-time worker, and iii) temporary and daily workers, who are employed on a part-time or day-to-day contract basis. Given the pronounced segmentation of the Korean labor market between regular and non-regular employment, it is important to examine whether the impacts of temperature shocks vary by job quality. For instance, according to Statistics Korea, the average monthly labor income of regular workers was approximately $2,500 in 2023, compared to just $1,400 for non-regular workers, illustrating a stark disparity that highlights the dual structure of the labor market.

Figure 4 presents the estimated dynamic effects of extreme temperature shocks on the number of workers by employment type.[10] Overall, any effects on all of the worker counts tend to dissipate after

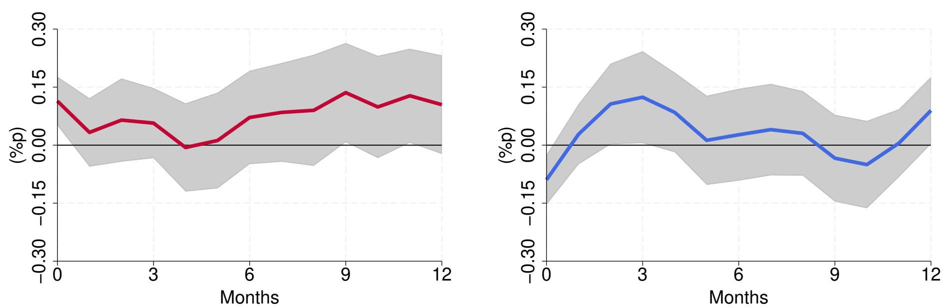
[10]When disaggregated by employment type, the number of workers is the only available statistic in the Korean labor



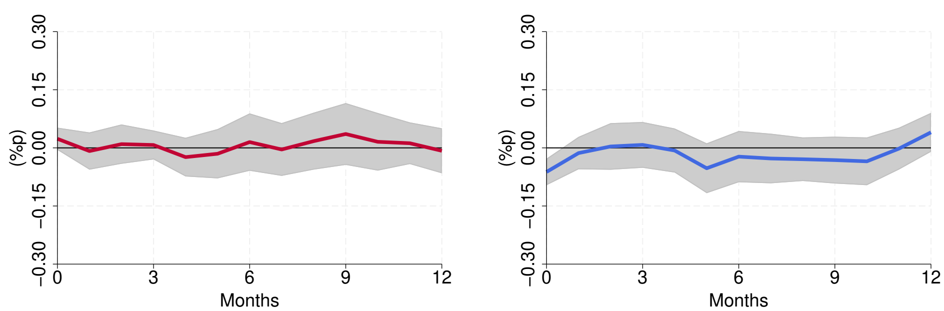
(i) number of wage workers



(ii) number of regular workers



(iii) number of temporary/daily workers



(iv) number of non-wage workers

Figure 4: Responses of the Number of Workers by Employment Type

Notes: This figure plots the impulse responses of the number of workers by employment type from the baseline model, i.e., equation (1). The red and blue lines represent the responses to extreme high and low temperature shocks, respectively. The shaded areas correspond to 95% confidence intervals.

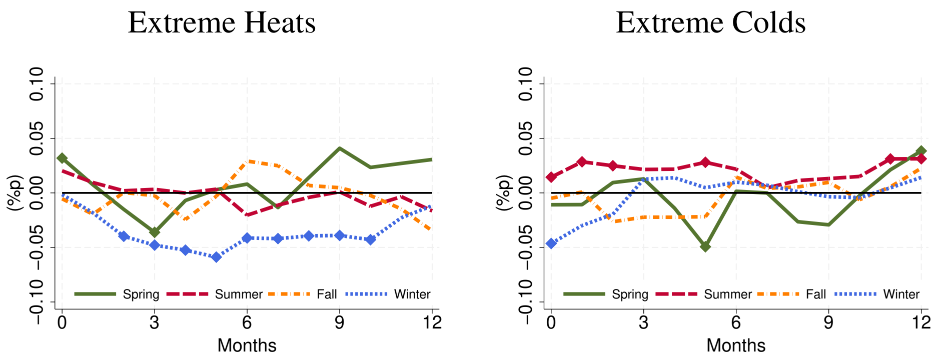
approximately six months, indicating limited long-term impacts. However, the number of temporary and daily workers increases by approximately 0.1 percentage points immediately after an extreme high temperature shock, while the number of wage workers rises by roughly 0.05 percentage points only. On the contrary, the numbers of temporary and daily workers and non-wage workers decline by around 0.1 and 0.05 percentage points, respectively, following an extreme cold shock. Conversely, the number of regular workers exhibits a long-term increase following the extreme low temperature shock. This suggests that, overall, extreme low temperature shocks have a relatively positive impact on the labor market by increasing the number of regular workers, which are usually considered to be high-quality jobs.

3.2.2 Seasonal Variations

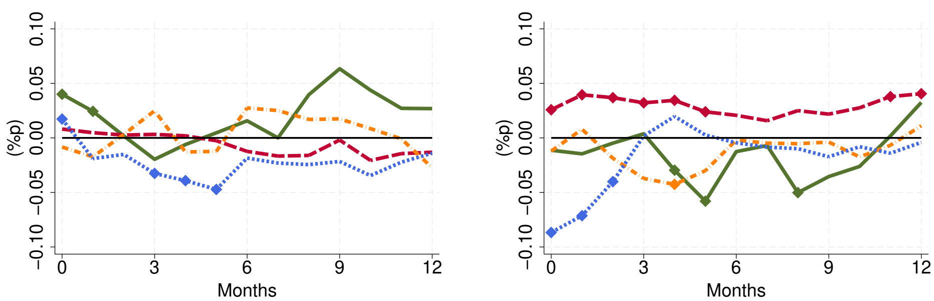
The analysis to estimate the average effects of extreme temperature shocks on the labor market has a limitation in that it may not fully capture the potential seasonal variations in the labor market effects of extreme temperatures, as demonstrated by Nguyen (2024) using the U.S. data. To address this concern, this section employs a state-dependent panel local projection model, i.e., equation (2), to study if the effects of extreme high- and low-temperature shocks on the labor market are different across seasons. Figures 5 and 6 present the impulse responses of the key labor market variables and the number of works by employment type to extreme high- and low-temperature shocks for each season. In each figure, green solid, red dashed, yellow dash-dotted and blue dotted lines represent the responses in spring, summer, fall, and winter, respectively. Impulse responses that are significant at the 95% confidence level are noted with diamond markers.

Results from Figures 5 and 6 are in line with Nguyen (2024); the labor market responds quite differently depending on the season in which the extreme temperature shocks hit the economy. Key observations can be summarized as follows. First, in seasons with mild temperature (spring and fall), the impact of extreme temperatures on the labor market tends to be relatively limited, though extreme high temperatures often exert a positive influence. This positive effect manifests primarily through an

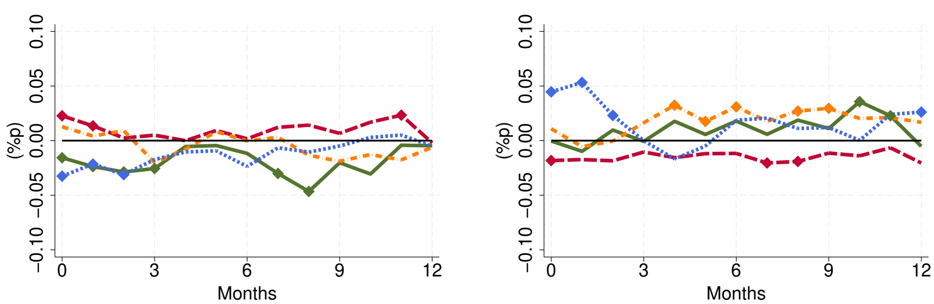
market data.



(i) labor force participation rate



(ii) employment rate



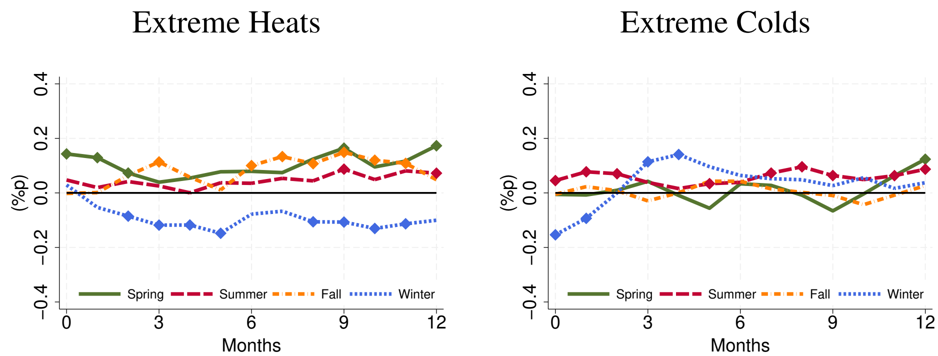
(iii) unemployment rate

Figure 5: Seasonal Heterogeneity in the Responses of Key Labor Variables

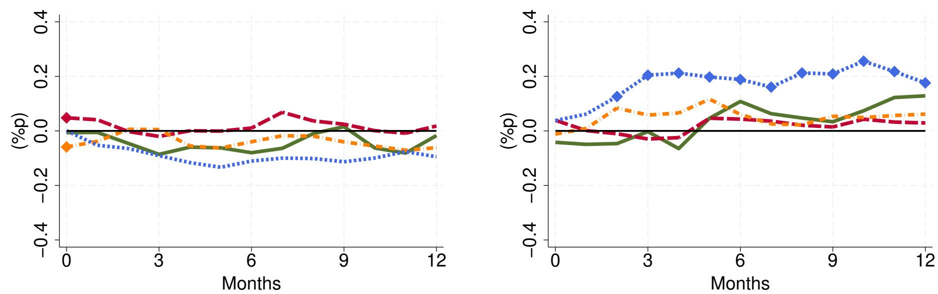
Notes: This figure plots the impulse responses of the key labor market variables from equation (2). The right and left columns report responses to extreme high- and low-temperature shocks. The green solid, red dashed, yellow dash-dotted and blue dotted lines represent the responses of spring, summer, fall and winter, respectively. Statistical significance at the 95% confidence level are noted with diamond markers.

increase in the number of temporary and daily workers, which subsequently drives a rise in the overall number of wage workers in these seasons.

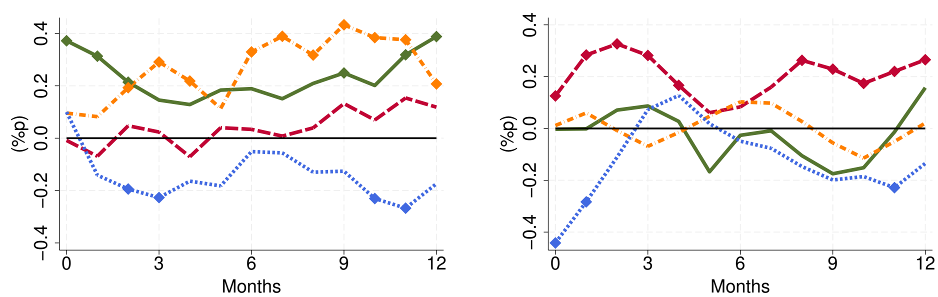
Second, extreme low temperatures in summer tend to stimulate the labor market, by boosting employment but reducing unemployment rate. This contrasts the impacts of extreme high temperatures in summer, which show little notable impact beyond a short-term spike in the unemployment rate,



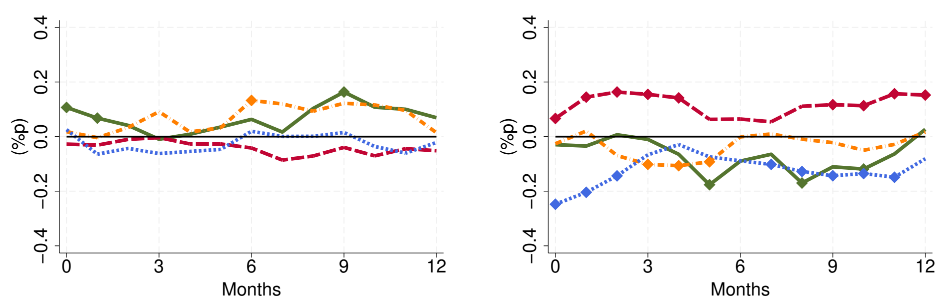
(i) number of wage workers



(ii) number of regular workers



(iii) number of temporary/daily workers



(iv) number of non-wage workers

Figure 6: Seasonal Heterogeneity in the Responses of the Number of Workers by Employment Type

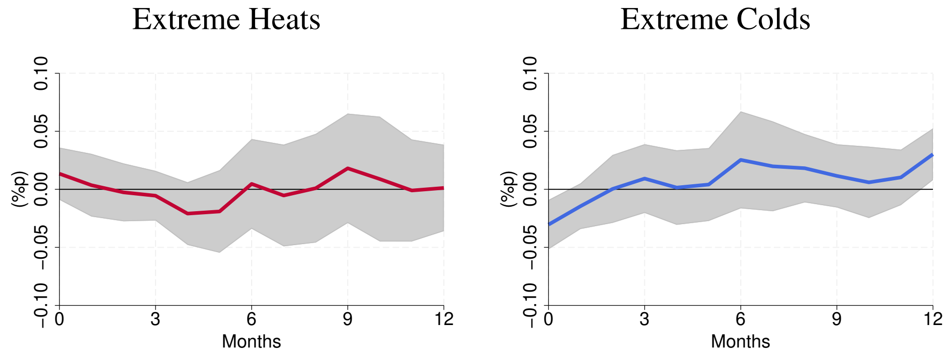
Notes: This figure plots the impulse responses of the number of workers by employment type from equation (2). The right and left columns report responses to extreme high- and low-temperature shocks. The green solid, red dashed, yellow dash-dotted and blue dotted lines represent the responses of spring, summer, fall and winter, respectively. Statistical significance at the 95% confidence level are noted with diamond markers.

lasting approximately two months. The positive effect of the extreme low temperature in summer is particularly pronounced in the increased numbers of temporary, daily, and non-wage workers, a pattern consistent with findings by Zivin and Neidall (2014); they argue that in typically high-temperature conditions, an extreme low-temperature event can reduce the average temperature, potentially enhancing labor supply.

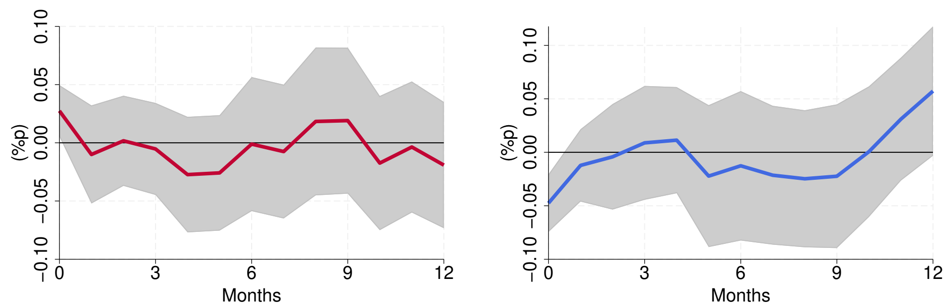
Third, extreme low temperatures in winter produce a starkly different outcome, exerting a markedly negative effect on the labor market. Compared to other seasons, nearly all labor market variables respond significantly negatively in winter, underscoring the heightened sensitivity of the labor market to extreme low temperatures during this season. When broken down by employment type, the number of temporary and daily workers goes down far more substantially than that of regular workers, revealing a differential impact across worker categories. This can be seen as the inverse of the summer low-temperature effect: In winter, extreme low temperatures result in severe cold, amplifying the adverse consequences for the labor market. These findings lend support to the earlier hypothesis of an inverted U-shaped relationship between temperature and labor supply, where temperatures deviating from an optimal level, either by falling below or rising above the optimum, lead to reduced productivity and labor supply, ultimately harming the labor market. Interestingly, unlike in summer, extreme high temperatures in winter also tend to negatively affect labor market variables, though the impact is less severe than that of extreme low temperatures. Overall, extreme temperature events in winter appear to have a more consistently detrimental impact on the labor market compared to other seasons, highlighting the season's unique vulnerability to temperature shocks.

3.2.3 Socio-demographic Characteristics

Previous analyses show that the effects of the extreme temperature shocks are heterogeneous depending on (i) worker type and (ii) season. In this section, we further analyze if additional dimension of heterogeneity, socio-demographic heterogeneity in particular, matters. In doing so, we consider i) gender (male vs. female), ii) age (young (aged 15$\sim$ 29) vs. middle (aged 30$\sim$ 49) vs. old (aged 50$\sim$)), and iii) education level (high shool graduate or below vs. college graduate or above). Results are presented in Figures 7 to 9.



(i) male

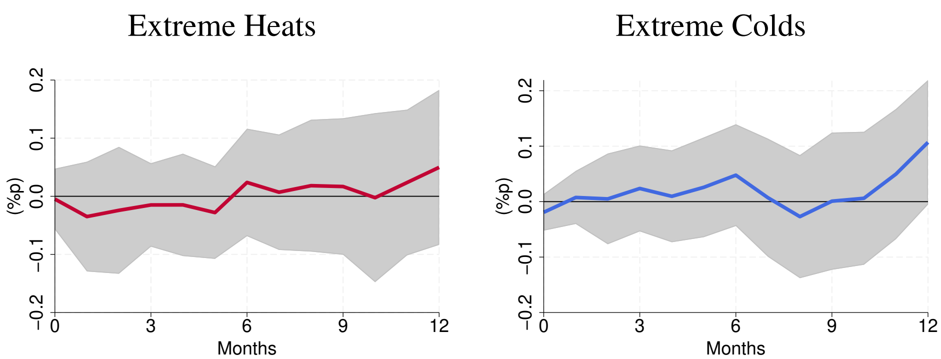


(ii) female

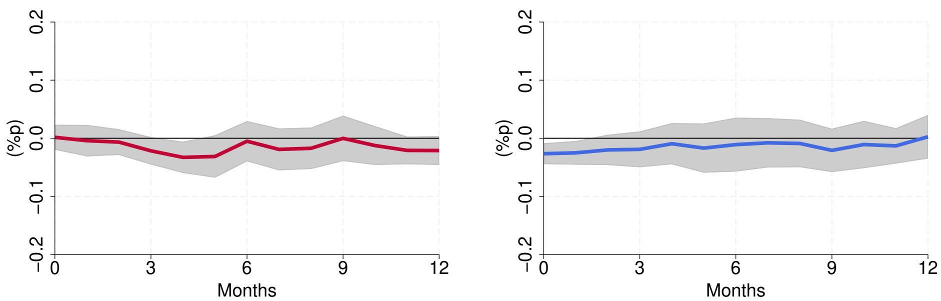
Figure 7: Responses of the Number of Workers by Gender

Notes: This figure plots the impulse responses of the number of workers by gender from the baseline model, i.e., equation (1). The red and blue lines represent the responses to extreme high and low temperature shocks, respectively. The shaded areas correspond to 95% confidence intervals.

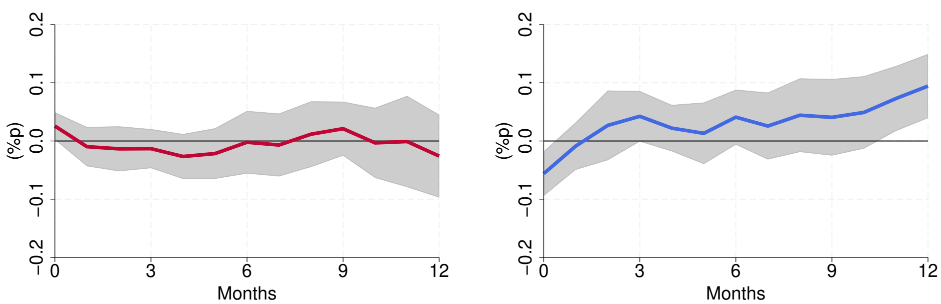
Interestingly, we find not much significant heterogeneity across workers when considering their key demographic characteristics. Across all gender and age groups, we find that extreme cold-temperature shocks tends to have a short-term negative impact, while the effects of extreme hot temperatures are muted. One noticeable observation is that the extreme low-temperature shock increases employment of workers with higher education (right low panel of Figure 9), while the number of workers of the other group falls temporarily after the impact. Together with findings on heterogeneous effects by worker type (full vs. part-time), these observations indicate that future theories need to consider ex-post heterogeneity rather than ex-ante heterogeneity across workers when developing a model to study how extreme events affect workers differently.



(i) young (aged 15∼ 29)



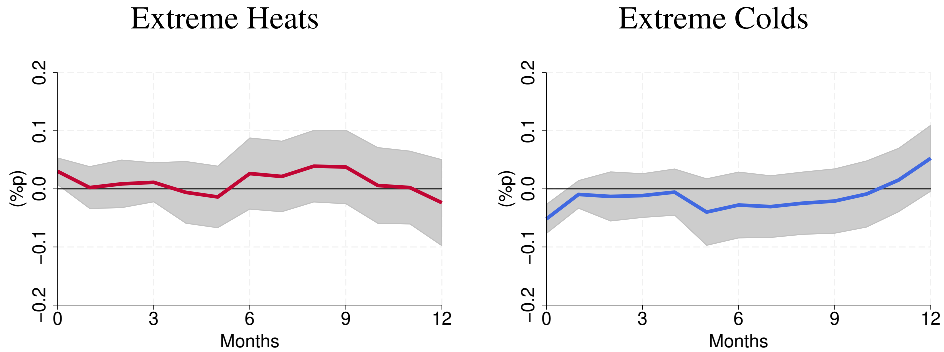
(ii) middle (aged 30∼ 49)



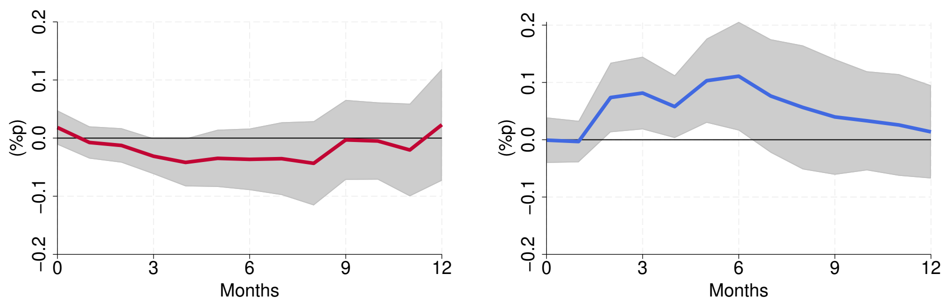
(iii) old (aged 50∼)

Figure 8: Responses of the Number of Workers by Age Group

Notes: This figure plots the impulse responses of the number of workers by age group from the baseline model, i.e., equation (1). The red and blue lines represent the responses to extreme high and low temperature shocks, respectively. The shaded areas correspond to 95% confidence intervals.



(i) high school graduate or below



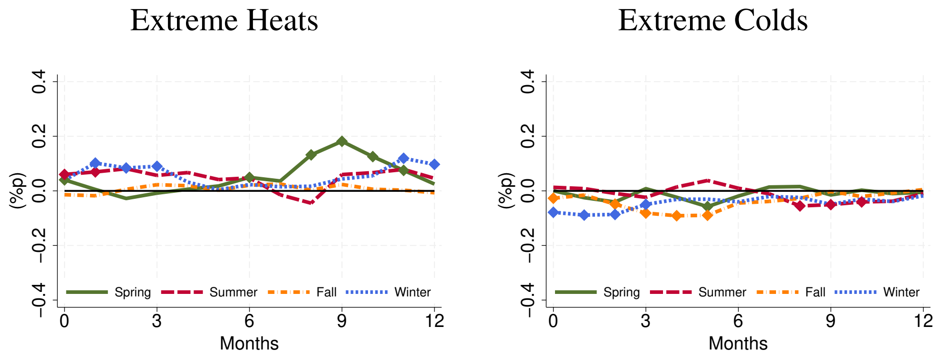
(ii) college graduate or above

Figure 9: Responses of the Number of Workers by Education Levels

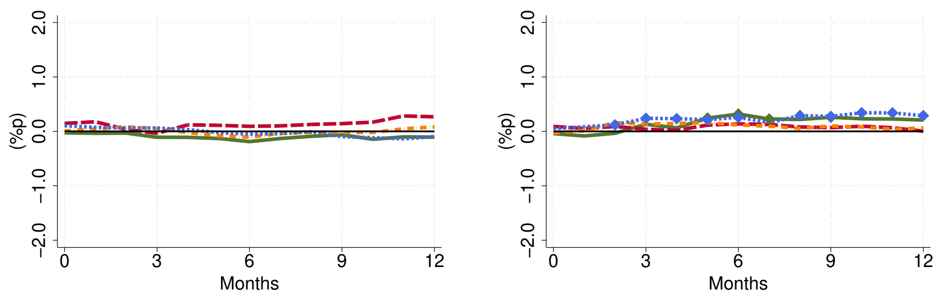
Notes: This figure plots the impulse responses of the number of workers by education from the baseline model, i.e., equation (1). The red and blue lines represent the responses to extreme high and low temperature shocks, respectively. The shaded areas correspond to 95% confidence intervals.

3.3 Impacts of Global Warming

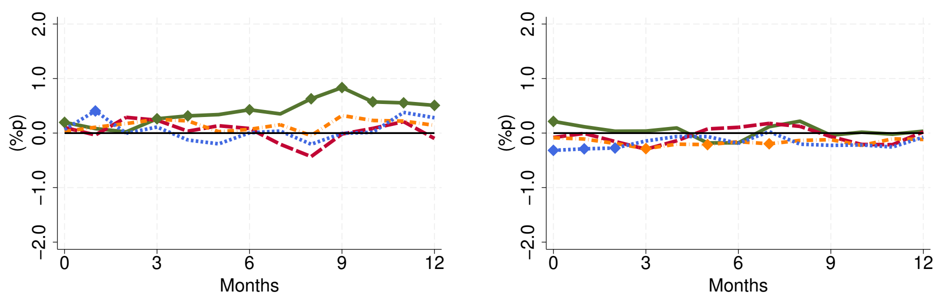
One of the key findings from the previous sections is that the level of temperature at the time of extreme high- or low-temperature events plays a critical role in determining the direction, magnitude, and significance of the impulse responses. Similar conclusions have been drawn in the previous literature, such as Burke et al. (2015) and Kim (2023), which demonstrate that the effects of temperature fluctuations on the economy can vary depending on an annual average temperature threshold of 13°C. Moreover, these findings indicate that if average temperatures are gradually rising due to global warming, the impact of extreme temperature shocks may also vary across different sample periods. For example, Kim et al. (2022) employed a Smooth Transition Vector Autoregressive model to show that extreme climate shocks had little significant impact on macroeconomic variables such as industrial production, unemployment rates, and inflation in the 1960s but when the sample period extends to 2019, extreme climate



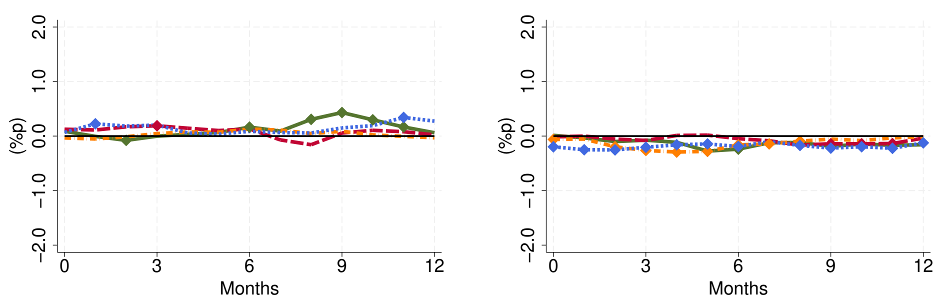
(i) employment rate



(ii) number of regular workers



(iii) number of temporary/daily workers

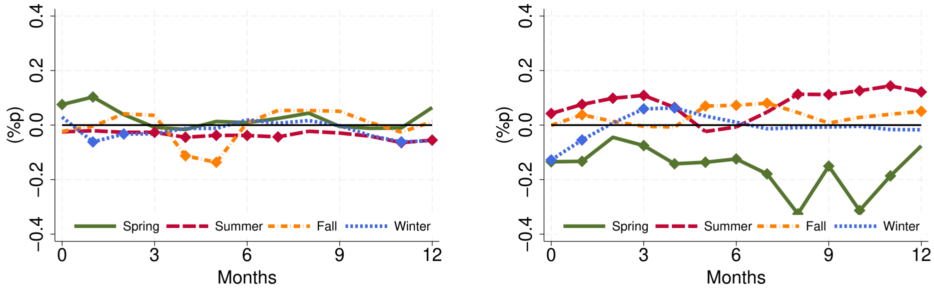


(iv) number of non-wage workers

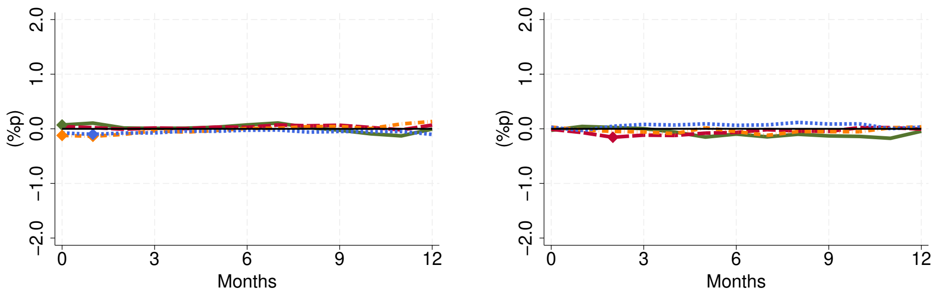
Figure 10: Responses in the First 10 Years (June 1999–June 2008)

Notes: This figure plots the impulse responses of the number of workers by employment type from equation (2) for the period from June 1999 to June 2008. The right and left columns report responses to extreme high- and low-temperature shocks. The green solid, red dashed, yellow dash-dotted and blue dotted lines represent the responses of spring, summer, fall and winter, respectively. Statistical significance at the 95% confidence level are noted with diamond markers.

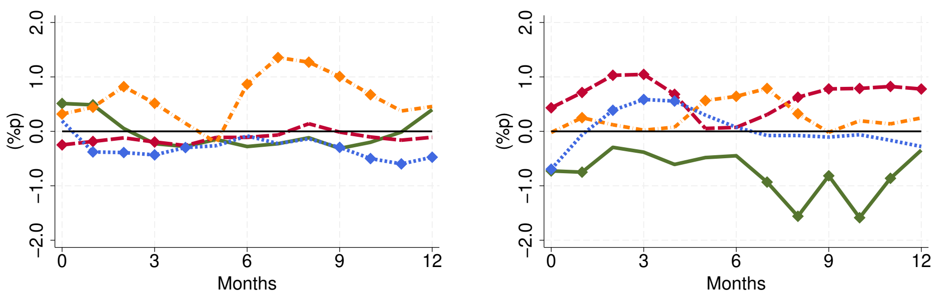
Extreme Heats Extreme Colds



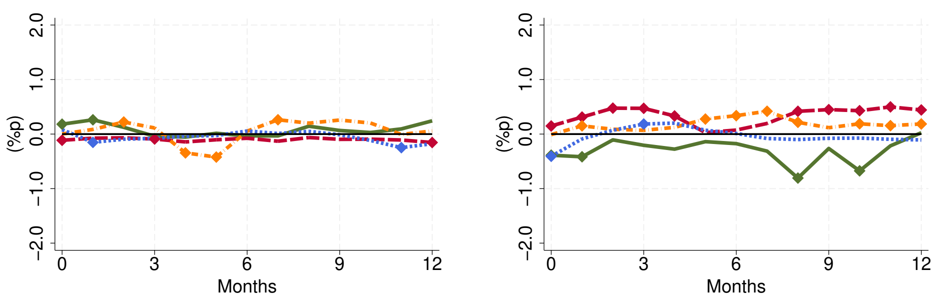
(i) employment rate



(ii) number of regular workers



(iii) number of temporary/daily workers



(iv) number of non-wage workers

Figure 11: Responses in the Last 10 Years (February 2015–February 2024)

Notes: This figure plots the impulse responses of the number of workers by employment type from equation (2) for the period from February 2015 to February 2024. The right and left columns report responses to extreme high- and low-temperature shocks. The green solid, red dashed, yellow dash-dotted and blue dotted lines represent the responses of spring, summer, fall and winter, respectively. Statistical significance at the 95% confidence level are noted with diamond markers.

shocks significantly reduce industrial production, increased unemployment rates, and raised consumer price indices, exerting a notable negative effect in the U.S.

Therefore, this section extends the seasonal analysis in Section 3.2.2 and examine the effects of extreme temperature shocks in two subperiods, i.e., the first 10 years from June 1999 to June 2008, and the last 10 years from February 2015 to February 2024, using equation (2).[11] According to the official statistics, between 1999 and 2008, the average temperature in Korea was 12.5°C but it went up to 13.28°C between 2015 and 2024, indicating that the average temperature in Korea has been on an increasing trend. The results are presented in Figures 10 and 11.

Our subsample analysis reveals that the effects of extreme temperature shocks vary considerably over time. In particular, clear differences emerge between the first 10 years of the sample (June 1999 – June 2008) and the most recent 10 years (February 2015 – February 2024), across all seasons and in response to both extreme high- and low-temperature shocks. Notably, in the later period, the labor market appears to benefit significantly from unusually low temperatures during the summer, while the positive effects previously associated with extreme heat tend to dissipate across seasons. Furthermore, the responses of regular workers to both types of shocks become notably muted, while non-regular workers have become disproportionately more exposed to the extreme temperatures.

For example, extreme high-temperature shocks in summer, which previously had little impact, now show a negative effect on nearly all labor market variables in the last 10 years, particularly in the first 2–3 months following the shock, whereas the positive effects of extreme low-temperature shocks have grown more significant and larger in magnitude. Similarly, in the fall season, the first 10 years saw extreme low temperatures significantly reducing the employment rate and increasing the unemployment rate, thus exerting a negative impact on the labor market. Yet, when the analysis focuses on the last 10 years, these same shocks appear to increase the employment rate and the number of workers, suggesting that cooler temperatures now stimulate the labor market compared to earlier periods.

In spring, during the first 10 years, extreme high-temperature shocks generally induced significant

[11] Here we present the sub-sample analysis results that account for seasonal heterogeneity, in order to fully exploit any differential impacts due to base temperature. Results without seasonal disaggregation are presented in Appendix Figures C.1 and Figure C.2, where we find that the seasonal effects reported in the main text remain largely unchanged.

positive responses in the labor market over the long term. However, in the most recent 10 years, this effect has largely diminished, leaving only short-term responses, while the negative effects of extreme low-temperature shocks have become more pronounced in this season.

In winter, the last 10 years exhibit a more pronounced tendency for both types of extreme temperature shocks to have negative effects. In particular, extreme high temperatures in winter now appear to have a significantly long-term adverse impact on the number of temporary and daily workers.

Taken together, these results illustrated in Figures 10 and 11, underscore how the labor market's sensitivity to extreme temperature events has evolved over time, likely influenced by rising average temperatures, adaptation efforts to those, as well as changing economic conditions. They also highlight the importance of employing more recent sample when examining the impact of climate variability on the labor market.[12] Notably, the negative effects of extreme temperatures on the labor market appear to become increasingly pronounced across all four seasons, suggesting that as climate warming continues, the labor market may face even greater challenges in the future. In addition, our finding that non-regular workers are primarily hit by the extreme temperature has an important implication for policy intervention going forward.[13]

3.4 Sector-Level Analysis

Since industries differ in their exposure to the physical risks of climate change, extreme temperature shocks are likely to have heterogeneous effects across sectors. Moreover, because industrial composition varies by region, a comprehensive analysis of labor market impacts would ideally rely on regional, industry-specific employment data. However, in Korea, monthly regional employment data disaggregated by industry are not available, making it infeasible to apply the same panel analysis used in earlier sections. As a result, this section employs national-level, industry-specific employment data and adopts

[12] Chung et al. (2024) also find that the impact of extreme climate events on the real economy and inflation has increased, particularly since 2010, which aligns with the findings of this study.

[13] It is worthwhile to note that this shift could be driven by a number of factors including the intensifying effects of climate change itself. In other words, during the analysis period, as climate warming progressed, firms may have adopted new technologies and machinery to reduce carbon emissions in response to government regulations. Such changes in production technology could lead to variations in labor demand in response to the same extreme temperature shocks, which is not explicitly taken into account in our analysis.

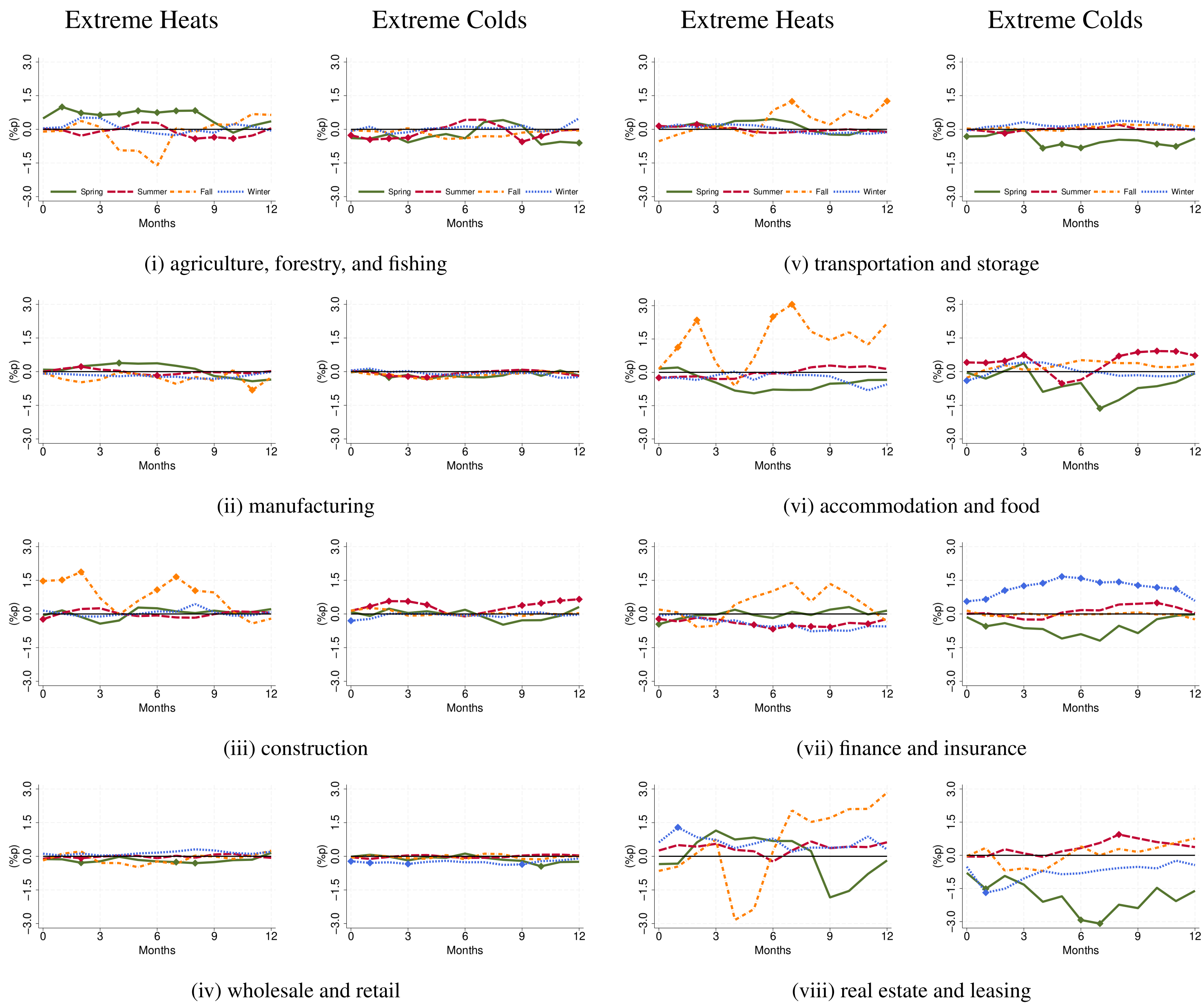


Figure 12: Seasonal Employment Response by Industry (February 2015–February 2024)

Notes: This figure plots the impulse responses of the number of workers by industry from equation (2) for the period from February 2015 to February 2024. The green solid, red dashed, yellow dash-dotted and blue dotted lines represent the responses of spring, summer, fall and winter, respectively. Statistical significance at the 95% confidence level are noted with diamond markers.

a standard local projection approach, which is an aggregate form of equation (2). To ensure policy relevance and reflect recent labor market dynamics, the analysis focuses on the most recent 10 years of the sample period and account for seasonal heterogeneity.[14]

The impulse response functions for extreme temperature shocks by season and industry are presented in Figure 12, with the main findings summarized as follows. First, in spring, extreme high-temperature shocks have a notable positive effect on agriculture, forestry, and fishing, while extreme low temperatures negatively affect the finance and insurance as well as real estate and leasing sectors. Second, in summer, extreme high temperatures have a negative effect on multiple industries, with particularly strong responses in agriculture, forestry, and fishing, construction, accommodation and food services, and finance and insurance. In contrast, extreme low temperatures have a significantly positive effect on construction but a negative impact on agriculture, forestry, and fishing. Third, in fall, most industries show no significant effects, though extreme high-temperature shocks lead to a substantial positive effect on construction. However, manufacturing exhibits a negative response to both extreme high- and low-temperature shocks. Last, in winter, extreme low-temperature shocks have a notable negative effect on wholesale and retail trade as well as real estate and leasing, while employment in finance and insurance increases significantly.[15]

In summary, extreme high temperatures in the hot summer and extreme low temperatures in the cold winter can more severely affect workers' conditions. In particular, industries with significant outdoor labor, such as agriculture, forestry, and fishing, construction, and accommodation and food services, as well as industries where demand for goods and services decreases due to temperature extremes, such as wholesale and retail trade and real estate, are primarily affected. Related, Zivin and Neidall (2014) found that in the U.S., when temperatures exceed 30°C, each additional degree reduces labor

[14]Results that do not incorporate seasonal variation are shown in Appendix Figures D.1 and D.2. The effects are generally modest, likely because seasonal differences—highlighted in earlier sections—play a significant role in shaping labor market responses to extreme temperatures.

[15]This pronounced effect in the finance and insurance sector is observed when using data from the last 10 years but not when using data from the first 10 years (2000–2009). This pattern holds even when excluding the COVID-19 period, suggesting that it is not driven by the unique circumstances of that period. However, considering the increasing frequency and persistence of extreme temperature events in recent years, this effect may be related to the growing importance of the insurance industry in response to disasters. Further analysis using detailed occupational and sub-industry data is needed to better understand this phenomenon, but due to the lack of such data, this is left for future research.

hours in climate-sensitive industries by up to one hour, and outdoor leisure activities decrease during both high and low temperatures, a finding consistent with the direction of the effects observed here. In contrast, relatively mild seasons of spring and fall appear to have a limited overall impact on the labor market, likely because extreme temperature shocks in these seasons do not significantly alter working conditions or demand relative to baseline temperatures.

4 Conclusion

This paper examined how extreme temperature shocks—both heat and cold—affected labor market outcomes in South Korea, a country with pronounced seasonal variation and increasing exposure to climate extremes. Using a panel local projection framework and daily regional temperature data spanning 25 years, we found that extreme cold has consistently negative effects on employment outcomes, while the impact of extreme heat was more nuanced, varying across seasons, employment types, and sectors. In particular, irregular jobs and industries requiring significant outdoor labor exhibited stronger responses, with winter showing the most notable impacts.

Importantly, our analysis revealed that the labor market effects of extreme temperatures had become more adverse over time, particularly for non-regular workers, consistent with the progression of global warming. This time-varying pattern highlighted the growing relevance of climate adaptation policies that were responsive not only to average conditions but also to the increasing frequency and intensity of climate shocks. By identifying key seasonal and sectoral heterogeneities, this study offered insights into which segments of the labor market were most exposed and potentially most in need of policy attention with climate change.

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A Extreme Temperature Shock Series

A.1 Extreme Temperature Shocks of 9 Korean Provinces

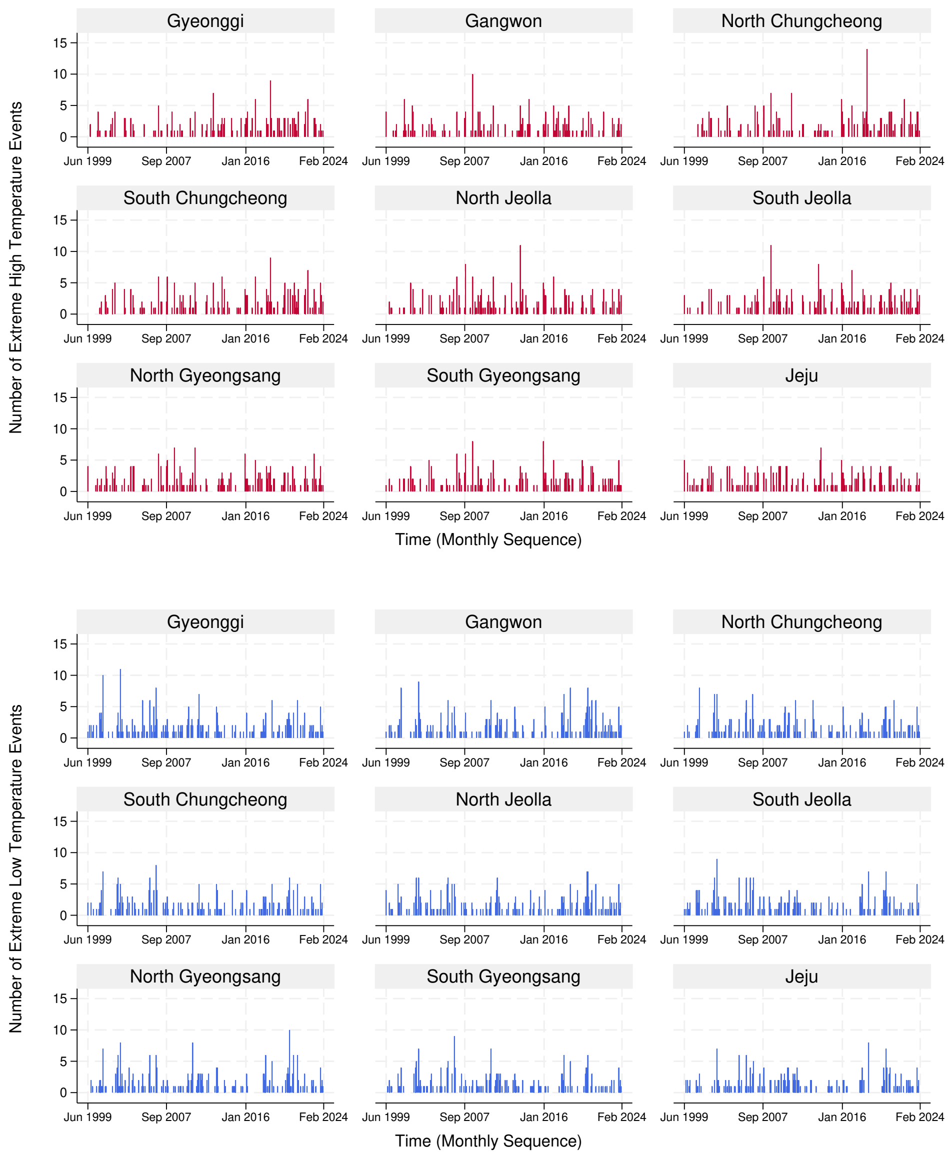

Figure A.1: Extreme Temperature Shocks of 9 Korean Provinces

This figure shows the time series of our baseline monthly extreme high- and low-temperature shocks for the period January 1999 – February 2024, based on previous 10-year's data used for the construction of the regional averages and standard deviations. Plotted series are for 9 provinces in Korea.

A.2 Extreme Temperature Shocks Based on the Full Sample Mean

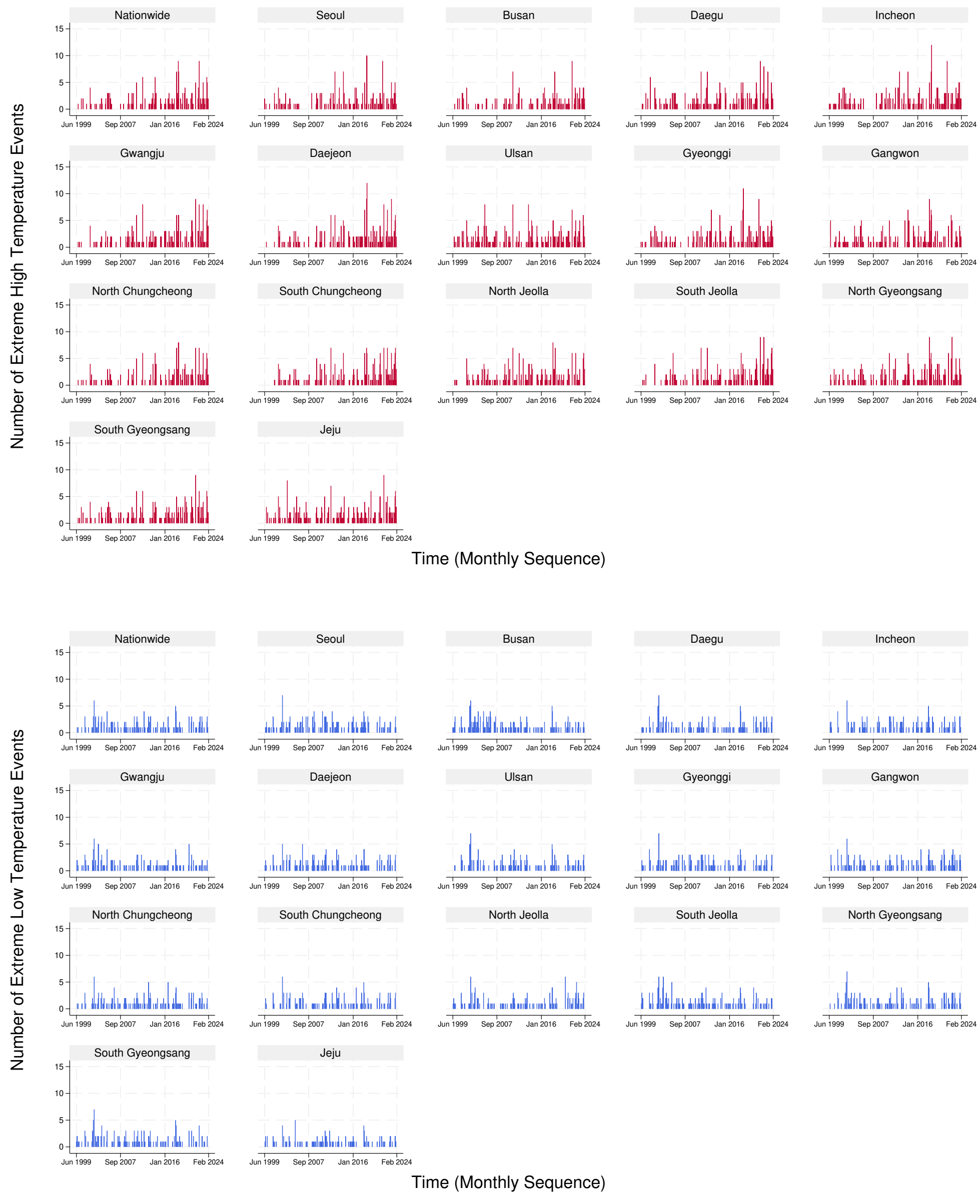

Figure A.2: National and Regional Extreme Temperature Shocks (Based on Full-Sample Mean)

This figure shows the time series of alternative monthly extreme high- and low-temperature shocks for the period January 1999 – February 2024, using the temperature mean and standard deviations obtained from the full sample period.

B Responses Using Alternative Extreme Temperature Shocks

Instead of the baseline extreme temperature shocks based on the monthly means of the preceding 10 years, we employ shocks constructed using the monthly means from the preceding 25 years.

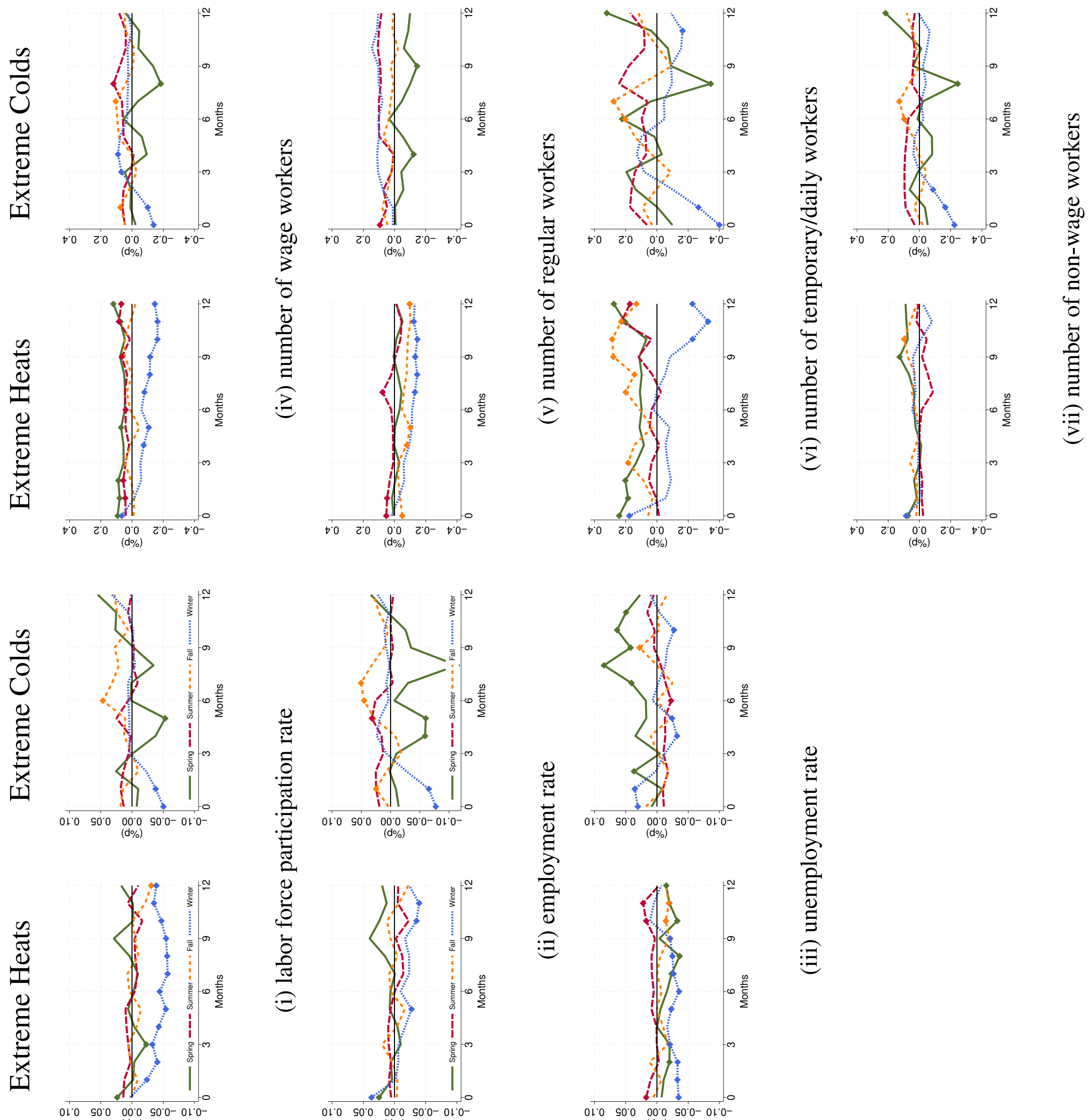

Figure B.1: Seasonal Responses to Extreme Temperature Shocks Based on a 25-Year Benchmark

Notes: This figure plots the responses from equation (2), using alternative shocks series which are based on the sample means and standard deviations from the preceding 25 years. The green solid, red dashed, yellow dash-dotted and blue dotted lines represent the responses of spring, summer, fall and winter, respectively. Diamond Markers denote statistical significance at the 95% confidence level.

C Subsample Analysis of the Average Model

C.1 Average Effects in the First 10-Year Period (June 1996–June 2008)

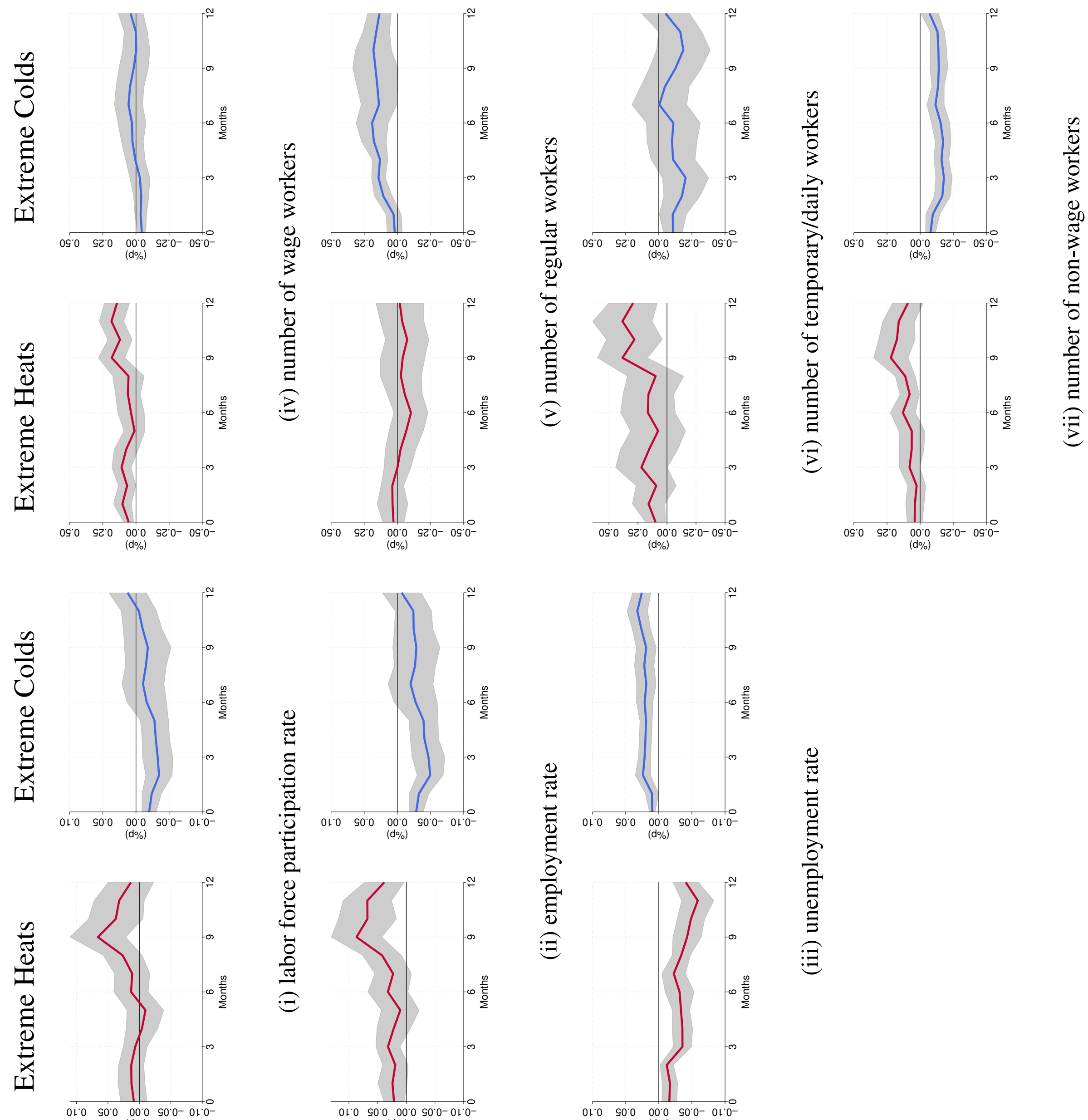

Figure C.1: Average Effects in the First 10-Year Period (June 1996–June 2008)

Notes: This figure plots the average impulse responses from the baseline model, i.e., equation (1) for the period from June 1996 to June 2008. The red and blue lines represent the responses to extreme high and low temperature shocks, respectively. The shaded areas correspond to 95% confidence intervals.

C.2 Average Effects in the Last 10-Year Period (February 2015–February 2024)

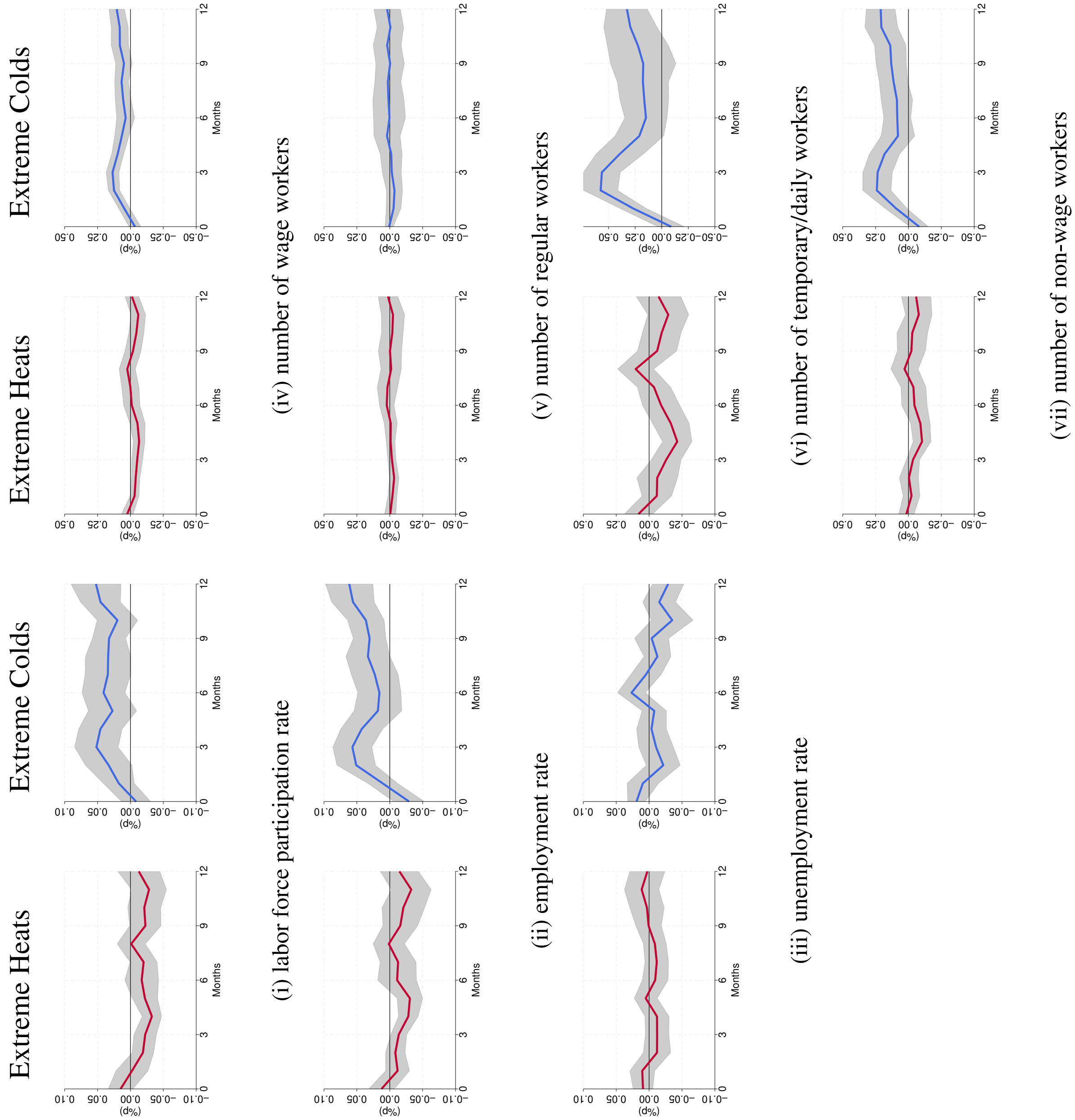

Figure C.2: Average Effects in the Last 10-Year Period (February 2015–February 2024)

Notes: This figure plots the average impulse responses from the baseline model, i.e., equation (1) for the period from February 2015 to February 2024. The red and blue lines represent the responses to extreme high and low temperature shocks, respectively. The shaded areas correspond to 95% confidence intervals.

D Effects on Employment by Industry: Robustness Checks

D.1 January 2000–January 2009

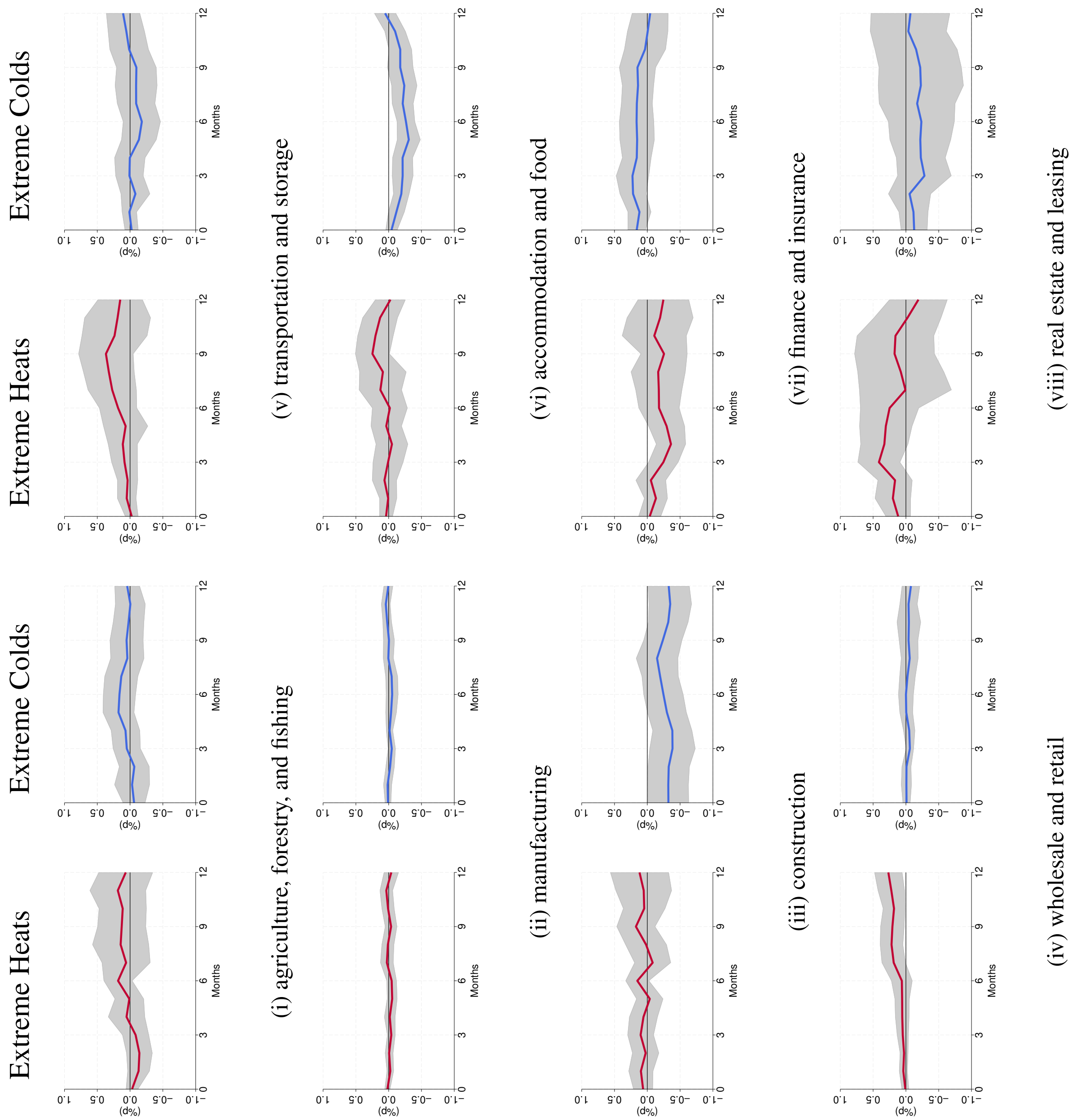

Figure D.1: Employment Response by Industry (January 2000–January 2009)

Notes: This figure plots the average impulse responses from equation (1) for the first 10 years, i.e., the period from January 2000 to January 2009. The red and blue lines represent the responses to extreme high and low temperature shocks, respectively. The shaded areas correspond to 95% confidence intervals.

D.2 February 2015–February 2024

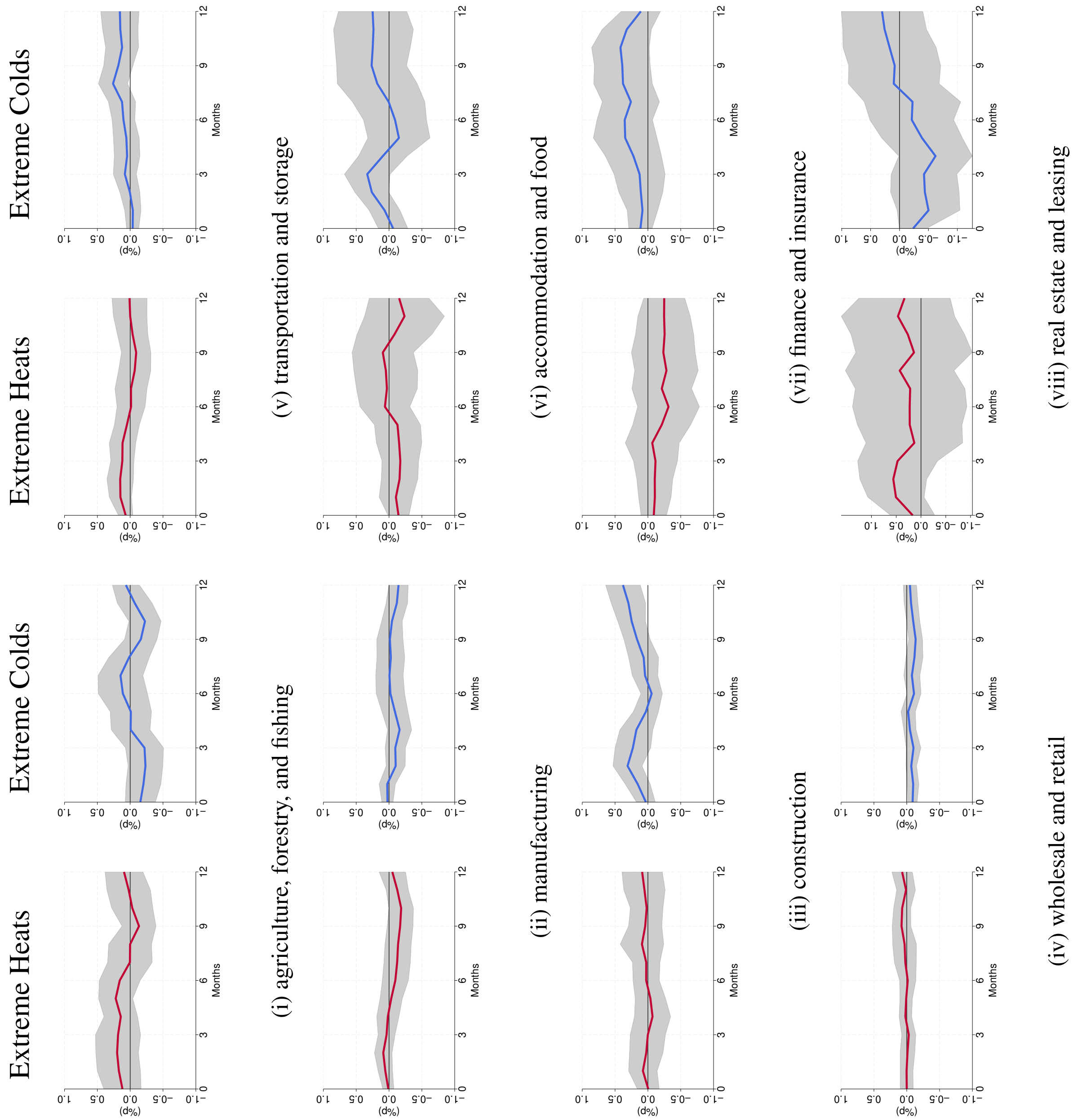

Figure D.2: Employment Response by Industry (February 2015–February 2024)

Notes: This figure plots the average impulse responses from equation (1) for the last 10 years, i.e., the period from February 2015 to February 2024. The red and blue lines represent the responses to extreme high and low temperature shocks, respectively. The shaded areas correspond to 95% confidence intervals.

D.3 Seasonal Effects by Industry (Full Sample)

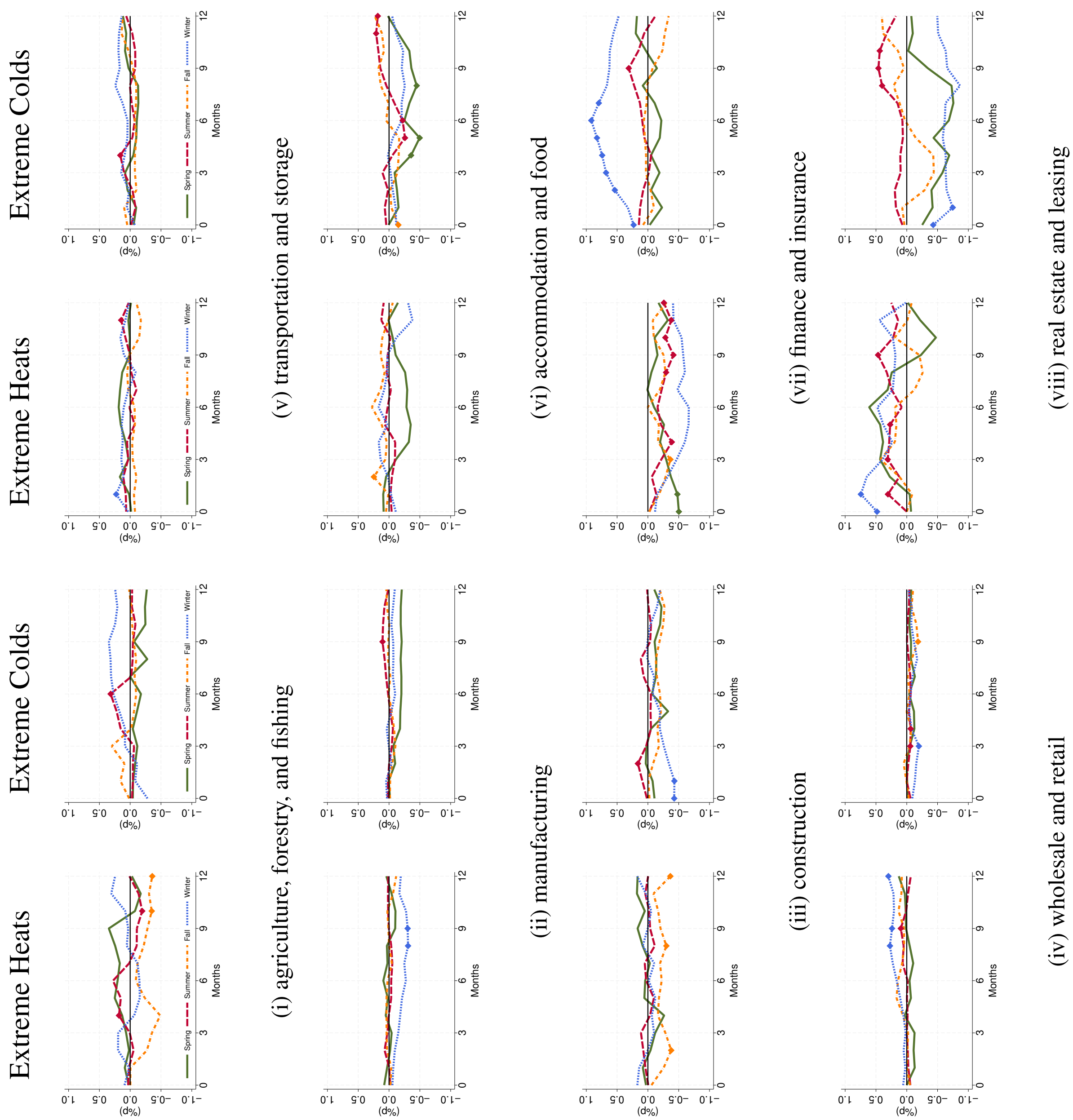

Figure D.3: Seasonal Employment Response by Industry (Full Sample)

Notes: This figure plots the responses of the number of workers by industry from equation (2) for the full sample (January 2000 – February 2024). The green solid, red dashed, yellow dash-dotted and blue dotted lines represent the responses of spring, summer, fall and winter, respectively. Diamond Markers denote statistical significance at the 95% confidence level.

D.4 Seasonal Effects by Industry (January 2000–January 2009)

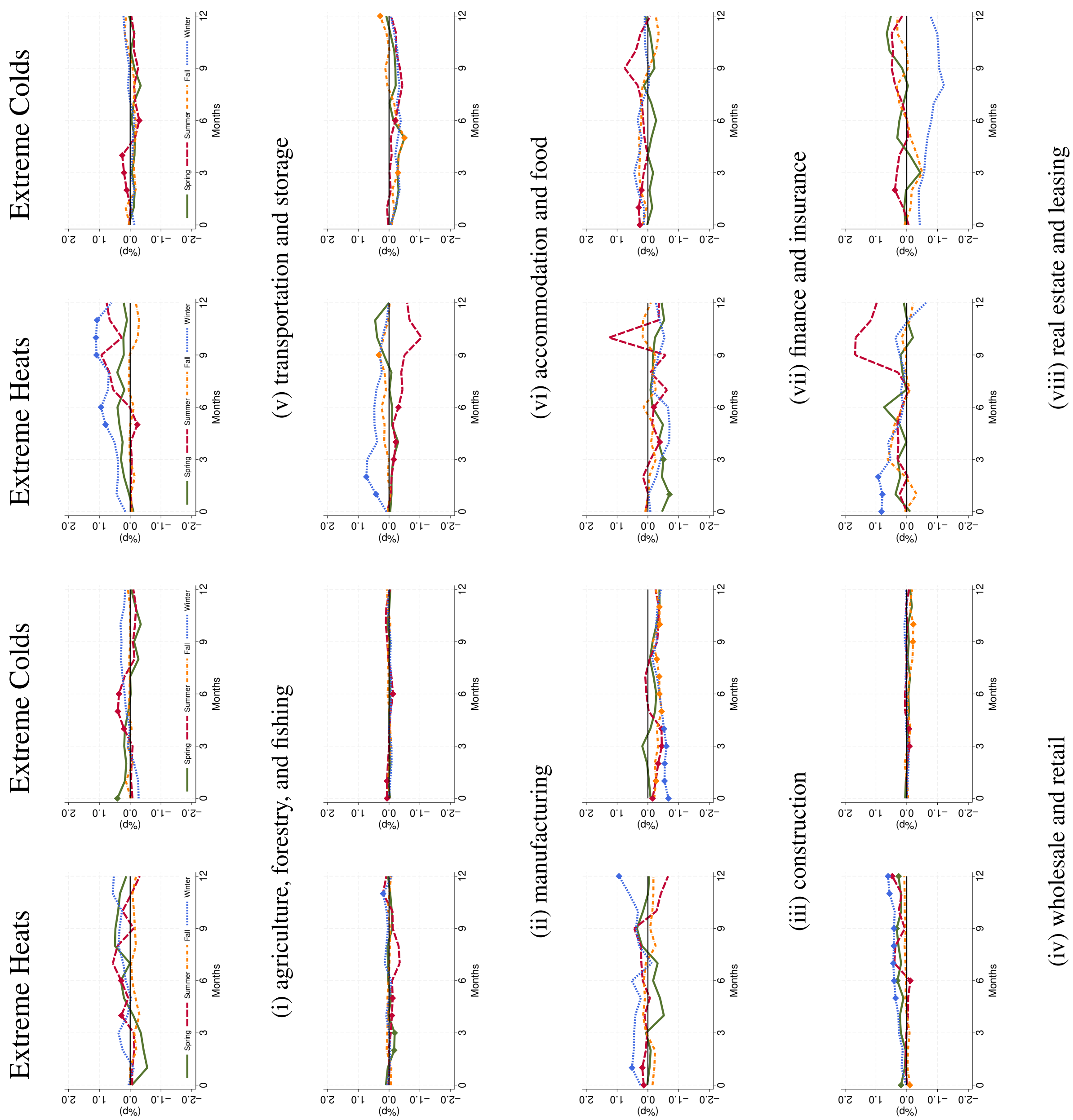

Figure D.4: Seasonal Employment Response by Industry (January 2000–January 2009)

Notes: This figure plots the responses of the number of workers by industry from equation (2) for the first 10 years (January 2000 – January 2009). The green solid, red dashed, yellow dash-dotted and blue dotted lines represent the responses of spring, summer, fall and winter, respectively. Diamond Markers denote statistical significance at the 95% confidence level.